Plant Archives Vol. 20, Supplement 2, 2020 pp. 1574-1583 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

CHARACTERIZATION AND CLASSIFICATION OF SALT-AFFECTED SOILS OF KAPURTHALA DISTRICT IN PUNJAB, NORTH-WEST, INDIA

Jaihoon Rafie and Raj-Kumar*
School of Agriculture, Department of Soil Science and Agriculture Chemistry, Lovely Professional University, Phagwara (Punjab) India
*Corresponding author Email: raj.18340@lpu.co.in

Abstract

An investigation was carried out in the Kapurthala district of Punjab, NW-India, the Kapurthala district lies between the latitudes of 31º07′30″ and 31º 39′30″ N and the longitudes of 75º 43′ 55″ and 75º 54′ 60″E, it's the smallest district of Punjab. The aim of the study was to evaluate the macro morphological, physical and chemical characteristics of salt affected soil 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 theses soils were alkaline, these soils have a pH of greater than 8.5. The electrical conductivity (EC) of these soils was below 1 dS m^{-1}. Organic carbon of these soils was low too high in epipedon ranged from 0.11 per cent to 0.93 per cent, where in subsurface horizons the soils were low to medium in organic carbon. Calcium carbonate of these soils in epipedon ranged from 0.2 per cent to 0.8 per cent. The available nitrogen, phosphorus and potassium of these soils ranged from 112.8 kg/ha to 677.3 kg/ha, 42.5 kg/ha to 107.5 kg/ha, and 313.6 kg/ha to 364.0 kg/ha respectively in the epipedon. CEC in these soils ranged from 5.70 $coml_c$/kg to 11.72 $coml_c$/kg. Accordingly exchangeable cations (Ca, Mg, Na and K) were evaluated in $coml_c$/kg of soil. Exchangeable sodium percentage of these soils was ranged between 18.9 and 70.4. Saturation percentage of these soils ranged from 33.05 to 42.50 in epipedon. Accordingly, salt affected soils of Kapurthala district were extracted with the help of vacuum pump and the composition of soil saturation paste such as pH_s, EC_e, Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, CO_3^{--}, Cl^- and SO_4^{--} were examined. Soil texture of these soils was sandy clay loam, loam, silty loam, silty clay loam and clay loam respectively. Moreover, salt affected soils of Kapurthala district classified as per Soil Taxonomy (2015) up to family level. Domeli, Jagjitpur, Khairanwali and Randhirpur series were classified in to the fine loam, mixed hyperthermic, family of Fluventic Haplustepts and Fajewal series classified in to the coarse loamy, mixed, hyperthermic, family of Typic Ustifluvent.

***Keyword*:** Salt affected soils, Soil characterization, Soil classification.

1. Introduction

Soils are crucial life supporting natural resource since they produce food, fiber and fodder which are basic for our very existence. They link the earth's rock core to all forms of life on the earth (Sehgal *et al.,* 1992). Since 1974, soil survey programs had been taken up in many states of India for various purposes with the establishment of National Land Resource Commission and State Land Use Boards, it become necessary to have soil resource map for developing national land use plans. The 1980s became the decade of awareness, as the productivity of agricultural soils world-wide was in general on the decline. Per capita food grain production decreased significantly. This decline was attributed to periodic droughts, poor management and exploitative agriculture coupled with degradation process Richard (1954). 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 (Sehgal *et al.,* 1992). 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". 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 (Sharma *et al.,* 1982).

The present study was conducted to characterize and classify the salt affected soils of Kapurthala district. As such it was highest importance that these soils were studied in the field, characterized in the laboratory and classified as per Soil Taxonomy (2015). The experimental results can be interpreted in a rational manner for effective transfer of technology to the farmers.

2. Materials and Methods

An investigation was carried in salt affected sols of Kapurthala district in Punjab, NW-India. It involved the study of macro morphological characteristics of five profiles in the field and collection of horizon wise samples. All soil samples were analysed for their physical and chemical characteristics in the laboratory and the soils were classified as per Soil Taxonomy (2015). The location of all the pedons was recorded with the help of global positioning system (GPS).

2.1 General description of the area

The Kapurthala district falls in Punjab state which lies between the latitudes of 31º 07′30″ and 31º 39′ 30″ N and the longitudes of 75º 43′ 55″ and 75º 54′ 60″ E, and forms a sort of the Bist Doab in central Punjab. It covers an area of 1670 sq. km. it is bounded by Beas River in the southwest, part of Hoshiarpur and Jullundur districts in northeast, and Jullundur and Firozpur districts in the south and southwest. The district comprises two units, namely Kapurthala and Phagwara which are separated by a part of the Jullundur district. The Kapurthala unit occupies a major part of the district. There are three tehsils, vis. Kapurthala, Sultanpur Lodhi and Phagwara and 566 inhabited villages in the district.

2.2 Climate and rainfall

Climatically, the area designated as semi-arid, the annual average maximum and minimum temperature ranges from 29 to 32°C in summer and 15 to 17°C during winter. There are four seasons in a year namely the cold season from November to March, the hot season from April to June, monsoon season from last week of June to the middle of September followed by post-monsoon season till the beginning of November. During the cold season, a series of western disturbances affect the climate during the summer months i.e. from April to June, weather is very hot, dry and uncomfortable. The weather becomes humid and cloudy from July to September due to the penetration of moist air of oceanic origin into the atmosphere. The normal annual rainfall of the district is 779 mm, which is distributed over 33 days in a year. The southwest monsoon which contributes 75 per cent of rainfall sets in the last week of June continues till the middle of September, July and August receive maximum rainfall. Rest 25 per cent of the annual rainfall occurs in the non-monsoon months in the wake of western disturbances and thunderstorms.

2.3 Soil sampling and soil analysis

The survey was carried out by the standard soil survey procedure as described in the Soil Survey Manual (USDA, 2015). 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. Samples were analysed for pH, EC using soil: water 1:2 (Jackson, 1967 and Bates, 1954). Organic carbon was determined by wet digestion method of Walkley and Black (1965). Calcium carbonate was determined by Puri, (1930). Available nitrogen was estimated by Subbiah and Asija, (1965). Available phosphorus was determined by using the procedure of extracting the sample with 0.05 M sodium bicarbonate (Olsen *et al.,* 1954). For available potassium samples were extracted with 1N ammonium acetate (Merwin *et al.,* 1950). CEC of these soils determined by using the method described by (Jackson, 1967), exchangeable cations were determined as per procedure described in practical soil science and agriculture chemistry manual Tolanur, (2018), and particle size distribution was analysed as per Sing *et al.,* (2013) manual. Saturation paste was prepared according to the procedure outlined by the Rhoades, (1982). Na, K were determined by using flame photometer, calcium and magnesium were analysed on flame photometer. CO_3, HCO_3, Cl and SO_4 estimated as per the procedure outlined by the Jackson (1958). pH_s and EC_e of saturation extract were also measured. For simultaneous extraction of available zinc, iron, manganese and copper in soil commonly DTPA method was used as per the procedure described by Lindsay *et al.,* (1978).

2.4 Place the sample were collected from

Soil profile observations have been taken from the five village of Kapurthala district, which are Domeli, Jagjitpur, Khairanwali, Randhirpur, and Fajewal respectively.

Table 1: Location of the profiles

Profiles	Location
Domeli	Village of Domeli, Phagwara tehsil, Kapurthala district
Jagjitpur	On the left side of Phagwara-Hoshiarpur road, Jagjitpur village, Phagwara tehsil, Kapurthala district
Khairanwali	On Taran-taran road near power house, about 1 km from Khairanwali village, Kapurthala district
Randhirpur	About 1 km before Khairanwali village lift side of Taran-taran road in Kapurthala district
Fajewal	About 1.2 km south east of Mansurwal Dona village, Kapurthala tehsil

Table 2: Site characteristics of the studied soil profiles

No	Series	Depth Cm	GPS Reading		Elevation (M)	Erosion	Vegetation	Slop %	Drainage
			Longitude	Latitude					
1	Domili	108	31°20.33.654	075° 47.39.276'	222	ei	Wheat	1-2	PD
2	Jagjit Pur	135	31°19 16.706	075° 48 14.706'	220	ei	eucalyptus, Dalbegia, wheat	1-2	MWD
3	Khairanwali	145	31°23.413’	075° 15 .472'	210	ei	wheat, paddy	1-2	WD
4	Randihrpur	138	31°23.117’	075° 17 .821'	209	ei	wheat, Maize, paddy, Sugar can	1	MWD
5	Fajewal	148	31°21.283’	075° 24 .226'	216	ei	Watermelon, melon	1	MWD

3. Result 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 salt affected 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 showed a great variation within each soil pedon among horizons and between the representative soil pedons. Accordingly, as tallied with Munsell Soil Color Chart, in salt affected soils of Kapurthala, the epipedon soil color (dry) varied from grayish brown in Domeli and Khairanwali (Table 3.1.1 and 3.1.3), light brownish gray in Jagjitpur and Fajewal series (Table 3.1.2 and 3.1.5) and brown in Randhirpur series (Table 3.1.4). Soil color (moist) in the subsurface horizons of all the pedons was dark gray brown, gray brown, brown, dark yellowish brown, yellowish brown and light yellowish brown. The variations in color observed within a pedon and among all the pedons could probably be attributed to differences with depth and topographic position in clay and organic matter content, parent material and drainage conditions. Dengiz *et al.* (2012) also indicated that soil color could be related to organic matter, waterlogging, carbonate accumulation and redoximrphic features.

There was a significant variation in grade and size of the structure characteristics with in each pedon among horizons and among soils pedons. The shape of structure in all the horizon of the pedons recorded as sub angular blocky structure except BC horizon of Domeli (Table 3.1.1) and Jagjitpur series where recorded massive structure (Table 3.1.2). Accordingly, the structure in the epipedon and subsurface horizon of the pedons varied from weak fine sub angular blocky in Fajewal series to weak and moderate medium sub angular blocky in Domeli, Jagjitpur, Khairanwali and Randhirpur series. The finding is in consent with the statement of Ashenafi *et al.* (2010) who reported that higher clay content could be a reason for better development of soils structure.

Considering soil consistence, characteristic outcomes in the epipedon layers varied from extremely hard (dry), loose (moist) sticky (wet) in Domeli series, hard (dry), friable (moist), sticky (wet) in Jagjitpur series, extremely hard (dry), friable (moist), slightly sticky and slightly plastic (wet) in Khairanwali, Randhirpur and Fajewal series respectively. Consistence varied from loose to friable (dry) and sticky and plastic to slightly sticky and slightly plastic among the horizons within the pedon and among the pedon. The observed differences in soil consistence among horizons within a pedon and among pedons could probably be explained by the observed differences in particle size distribution, particularly clay content and also nature of the clay particles. According to Foth, (1990), consistence of a soil is affected by clay content and type.

Table 3.1.1 : Macro-morphological characteristics of Domeli series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-18	10YR 6/4	l	2m sbk	dvh	mfi	ws	es	ds
AB	18-35	10YR 5/4	l	2m sbk	dvh	mfi	wp	ev	gs
B1	35-55	10YR 5/4	l	2c sbk	dvh	mfi	ws,wp	ev	gs
B21	55-70	10YR 5/6	l	2c sbk		mfi	ws,wp	ev	gs
B22	70-95	10YR 5/2	l	2m sbk		mfr	ws,wp	e	gs
BC	95-108	10YR 5/2	l	massive		mfr	ws,wp	e	-

Table 3.1.2 : Macro-morphological characteristics of Jagjitpur

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-30	10YR 4/1	scl	2m sbk	dh	mfr	ws	ev	ds
AB	30-52	10YR 5/3	l	2m sbk	dsh	mfr	wp	es	gs
B21	52-79	10YR 5/6	cl	2m sbk	dsh	mfr	ws,wp	e	gs
B22	79-100	10YR 5/4	cl	2m sbk		mfi	ws,wp	e	gs
B23	100-125	10YR 4/6	cl	2m sbk		mfi	ws,wp	e	gs
BC	125-135	10YR 5/6	cl	massive		mfi	ws,wp	e	-

Table 3.1.3 : Macro-morphological characteristics of Khairanwali series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			Dry	Moist	Wet		
Ap	0- 23	10YR 4/2	l	1m sbk	dsh	mfr	wss,wsp	ev	cs
AB	23-50	10YR 4/4	l	1m sbk		mfr	wss,wsp	es	ds
B21	50-82	10YR 5/4	l	2m sbk		mfr	wss,wsp	es	ds
B22	82-111	10YR 5/4	l	2m sbk		mfr	wss,wsp	ev	gs
B23	111-145	10YR 4/3	cl	2m sbk		mfi	wss,wsp	e	

Table 3.1.4 : Macro-morphological characteristics of Randhirpur series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-26	10YR 5/2	l	1m sbk	dsh	mfr	wss,wsp	ev	cs
AB	26-48	10YR 5/4	sicl	2m sbk	dh	mfr	wss,wsp	es	ds
B1	48-76	10YR 4/4	cl	2m sbk		mfr	wss,ssp	es	ds
B21	76-95	10YR 5/4	cl	2m sbk		mfr	wss,wsp	ev	gs
B22	95-118	10YR 5/4	sicl	2c sbk		mfi	ws,wp	e	-
B23	118-138	10YR 4/6	cl	2c sbk		mfi	ws,wp	-	-

Table 3.1.5 : Macro-morphological characteristics of Fajewal series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-24	10YR 5/2	cl	1w sbk	dsh	mfr	ws,wp	0	cs
AB	23-55	10YR 5/4	l	1w sbk		mfr	ws,wp	0	ds
B11	55-85	10YR 5/6	l	1w sbk		mfr	ws,wp	0	ds
B12	85-113	10YR 5/4	sil	1w sbk		mfr	ws,wp	0	gs
B13	113-148	10YR 4/4	sil	1w sbk		mfi	ws,wp	0	gs

Key: m-medium, c- course, sbk- sub angular blocky, mfr- weakly coherent, mfi- non coherent, ws- sticky, wp- plastic

3.2 Physical and chemical characteristics of the pedons

Texture: The particle size analysis of soils showed that the texture classes of the pedons varied from loam in Domeli series, sandy clay loam, loam and clay loam in Jagjitpur series, loam and clay loam in Khairanwali series, loam, silty clay loam and clay loam in Randhirpur series, and loam, silty loam and clay loam in Fajewal series respectively (Table 3.2.1 to 3.2.5).

Particle size distribution: The percentage of clay content is high in all the profiles and did not follow regular pattern. The clay content of the pedons ranged from 18.9 per cent in Domeli series (Table 3.2.1) to 30.4 per cent in Fajewal series in the epipedon horizons (Table 3.2.5). Clay content of the pedons in the subsurface horizons ranged from 19.5 per cent in B21 horizon of Domeli to 35.0 per cent in BC horizon of Jagjitpur and B21 horizon of Randhirpur series respectively. The mean clay content in all the horizons of all profiles is 26.96 per cent. The higher clay content of soils may be due to illuviation and process (Sharu *et al.,* 2013). Silt content was generally high in all the pedons. Silt content in the epipedon of the profiles ranged from 19.6 per cent in Jagjitpur series to 37.1 per cent in Fajewal series. The subsurface silt content of the pedons ranged from 22.2 per cent in B3 horizon of Khairanwali series to 49.5 per cent in AB horizon of Fajewal series. The mean silt content was 36.0 per cent. The sand value in the epipedon of these soils ranged from 32.5 per cent in Fajewal series to 52.2 per cent in Jagjitpur series. Sand content of subsurface horizons ranged from 18.9 per cent in B22 to 48.6 per cent in in AB horizon of Randhirpur series respectively. The mean sand content in all the profiles was 37.15 per cent.

Soil reaction, EC, OC, $CaCO_3$: Soil reaction (pH) and electrical conductivity (EC) of all the profiles were determined in a 1:2 soil to water ratio suspension. Salt affected soils of Kapurthala district are alkaline in nature. The epipedon soil pH ranged from 8.8 in Fajewal series to 10.3 in Domeli series. The pH of subsurface horizons of all the pedons ranged from 8.6 to 10.2. The highest pH range in subsurface horizons (10.2) was recorded B21 horizon of Domeli series and the lowest pH range (8.6) was recorded in BC horizon of Domeli series respectively. The mean of pH values for all the profiles was 9.4. The high pH may be due to their calcareous nature and the accumulation bases in the solum as soils were poorly leached (Satyanarayana and Biswas, 1970). The pH in Domeli series is high at the surface and then decreased with depth; this may be attributed to high base status of these. In all the profiles except Domeli the pH irregularly increased with depth. This increase in soil reaction could be due to leaching of bases from higher topography and getting deposited at lower elevations (Sitanggang *et al.,* 2006). The electrical conductivity (EC) values of the salt affected soils of Kapurthala district were below 1 dS m^{-1}. The electrical conductivity obtained in epipedon ranged from 0.18 dS m^{-1} in Domeli series to 0.55 dS m^{-1} in Khairanwali series. The electrical conductivity of salt affected soil in the sub surface horizons ranged from 0.06 dS m^{-1} in B1 horizon of Domeli and B23 horizon of Randhirpur series respectively to 0.62 dS m^{-1} in AB horizon of Khairanwali series. The mean value of EC of these soils was 0.24 dS m^{-1}.

The organic carbon content ranged from low too high in the epipedon and low to medium in the subsurface horizons. The epipedon organic carbon content ranged from 0.11 per cent in Fajewal series (Table 3.2.5) to 0.93 per cent in Khairanwali series (Table 3.2.3). The organic carbon in the subsurface horizon ranged from 0.12 per cent in AB horizon of Fajewal series to 0.47 in B22 horizon of Randhirpur series. The low organic carbon in all the horizon of Fajewal series may be due to high rate of mineralization and can be a cause of poor soil structure and low supply of compost, organic matter and farm yard manure (Karuma *et al.,* 2015). The organic carbon content of surface soils were greater than subsurface soil in all the series except Fajewal series, may be due to high amount of litter and crop residues at the surface and this was attributed to the addition of farmyard manure and plant residues to surface horizons which resulted in higher organic carbon content in surface horizons than subsurface horizons. These observations are in accordance with results of (Basavaraju *et al.,* 2005) in soils of Chandragiri Mandal of Chittor district of Andhra Pradesh.

Content of calcium carbonate in epipedon of all the series ranged from 0.2 per cent in Fajewal series to 0.8 per cent in Jagjitpur series. In subsurface horizons calcium carbonate ranged from 0.2 per cent in AB horizons of and Domeli series and B23, and BC horizons of Jagjitpur series respectively to 0.6 per cent in B22 horizon of Domeli, AB and B22 horizons of Randhirpur series respectively. Content of calcium carbonate in all the horizons were recorded below 1 per cent. According to FAO (1983), soils having more than 2 per cent calcium carbonate in their subsurface horizons show the presence of calcareous soil material. Calcium carbonate percentage is equal or more than to 2 per cent in all the horizons of all series. Therefore, most of these soils are calcareous in nature. The calcium carbonate mean for all the series is 0.39 per cent.

Available nitrogen, phosphorus and potassium

The available nitrogen content of the epipedon of pedons varied from 112.8 kg/ha to 677.3 kg/ha. The highest content of available nitrogen was recorded in epipedon of Jagjitpur series and the lowest available nitrogen content was recorded in epipedon of Fajewal series. The available nitrogen in subsurface horizons of series ranged from 37.6 kg/ha in B11 horizon of Fajewal series (Table 3.2.5) to 514 kg/ha in AB horizon of Jagjitpur series (Table 3.2.2). The mean available nitrogen is 269.21 kg/ha in the salt affected soils of Kapurthala district. Available nitrogen content was recorded in medium in the epipedon horizons of all the profiles except Jagjitpur series which recorded high. It could be due to lots of root residue and use of nitrogen fertilizers, under intensive cultivation. The available nitrogen content was recorded low in BC horizons of Domeli and Jagjitpur series. This reveals that available nitrogen is found limiting plant nutrients in the study area due to low level of soil organic matter content and the limited use of plant residues and animal manure (Adhanom and Toshome, 2016). The available phosphorus content in the epipedon of the pedons ranged from 42.5 kg/ha in Domeli series to 107.5 kg/ha in Fajewal series. High available phosphorus in the epipedon of soils may be due to the application of animal manure, compost, household wastes like ashes and DAP fertilizer for soil fertility management (Awdenegest *et al.,* 2013). The available phosphorus content in the subsurface horizons ranged from 42.5 kg/ha in the B21 and B22 horizons of Domeli series to 110 kg/ha in B23 horizon of Jagjitpur series. The mean available phosphorus content for all the pedons was 77.1 kg/ha. Available potassium observed in all pedons was high. The available potassium content of salt affected soils of Kapurthala district in the epipedon horizons ranged from 313.6 kg/ha in Domeli and Fajewal series to 364.0 kg/ha in Jagjitpur series. The available potassium content in the subsurface horizons of all the profiles ranged from 184.8 kg/ha to 420.0 kg/ha. The highest available potassium content was recorded in B1 horizon of Randhirpur series and lowest available potassium content was recorded in B21 and B22 horizons of Khairanwali series. The mean available potassium content of all the profiles of salt affected soils of Kapurthala district was 270.4 kg/ha.

CEC, exchangeable cations, and ESP

The cation exchange capacity (CEC) of the soil in the epipedon ranged from 5.70 $cmol_c$/kg of soil in Jagjitpur series (Table 3.2.2) to 11.72 $cmol_c$/kg of soil in Randhirpur series (Table 5.2.4). The CEC of the salt affected soil of Kapurthala district in the subsurface horizons ranged from 3.51 $cmol_c$/kg of soil in B1 horizon of Domeli village to 11.64 $cmol_c$/kg of soil in B1 horizon of Randhirpur series. Cation exchange capacity of salt affected soils of Kapurthala district is generally low according to Esu (1991) rating <6 $cmol_c$/kg low, 6-12 $cmol_c$/kg medium and >12 $cmol_c$/kg high, in the surface horizons of all the series except surface horizons of Khairanwali series and Randhirpur series. The low CEC of the soils could be attributed to low organic carbon and illite nature of clay minerals (Sharu *et al.,* 2013). The mean CEC of these soils was 7.06 $cmol_c$/kg of soil.

The exchangeable calcium content in the epipedon ranged from 1.8 $cmol_c$/kg in Jagjitpur series to 3.4 $cmol_c$/kg in Domeli series and Khairanwali series. The exchangeable calcium content in the subsurface horizons ranged from 0.4 $cmol_c$/kg in BC horizon of Domeli series to 5.0 $cmol_c$/kg in B22 horizon of Jagjitpur series. Exchangeable magnesium and sodium in the epipedon horizons of the pedons ranged from 0.2 $cmol_c$/kg in Fajewal series and 1.21 $cmol_c$/kg in Khairanwali series to 1.2 $cmol_c$/kg in Khairanwali series and 8.26 $cmol_c$/kg in Randhirpur series respectively. The exchangeable magnesium in subsurface horizon ranged from 0.6 $cmol_c$/kg in B23 horizons of Jagjitpur and Randhirpur series to 4.2 $cmol_c$/kg in BC horizon of Domeli series. The exchangeable sodium content in the subsurface horizon ranged from 1.13 $cmol_c$/kg in BC horizon of Domeli series to 7.39 $cmol_c$/kg in AB horizon of Randhirpur series. The exchangeable potassium content in all the horizons of salt affected soils of Kapurthala district in North-West Punjab ranged from 0.30 $cmol_c$/kg to 0.97 $cmol_c$/kg. The highest value of exchangeable potassium was recorded in B21 horizon of Jagjitpur series and the lowest exchangeable potassium was recorded in B3, B23 and B13 horizons of Khairanwali, Randhirpur and Fajewal series respectively.

The exchangeable sodium percentage (ESP) in the epipedon of all the series ranged from 18.9 per cent in Khairanwali series to70.4 per cent in Randhirpur series. The ESP in the subsurface horizons ranged from 18.2 per cent in BC horizon of Domeli series to 65.3 per cent in AB horizon of Randhirpur series. The exchangeable sodium percentage of the salt affected soils of Kapurthala district recorded more than 15 per cent in the all horizons of the profiles except B21, B22 and B3 horizons of Rawalpindi series. This indicates that there is sodicity problem in theses soils. According to Brady and Weli (2002), (Adhanom and Toshome, 2016) ESP of 15 per cent is considered as critical for most crops.

Saturation paste and saturation extract

Saturation percentage of salt affected soils of Kapurthala district in epipedon ranged from 33.05 per cent to 42.50 per cent. Highest value of saturation percentage was recorded in Randhirpur series (Table 3.2.4), and the lowest saturation percentage was recorded in Jagjitpur series (Table 3.2.2). In the subsurface horizon the saturation percentage of these soils ranged from 25.95 per cent in B12 horizon of Fajewal series to 45.45 per cent in B21 horizon of Khairanwali series.

Salt affected soils of Kapurthala district were extracted with the help of vacuum pump and the composition of soil saturation paste such as pH_s, EC_e, Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, CO_3^{--}, Cl^- and SO_4^{--} were examined (Table 3.2.1 to Table 3.2.5). The pH_s in saturation paste of salt affected soils ranged from 7.6 to 10.4. The highest value of pH_s was recorded in the epipedon horizon of Fajewal series and the lowest value was recorded in the BC horizon of Jagjitpur series. The EC_e of these soils ranged from 0.19me/l in B22 horizon of Domeli series to 2.90 me/l in the surface horizon of Khairanwali series.

Micronutrients

The results of available micronutrients of salt affected soils in Kapurthala district is presented in table 3.2.6. The availability of zinc content in the epipedon of salt affected soils of Kapurthala district ranged from 0.28 mg/kg of soil in Jagjitpur series to 2.58 mg/kg of soil in Randhirpur series. The availability of zinc in the subsurface horizons of all the series were ranged from 0.12 mg/kg of soil in B13 horizon of Fajewal series to 0.84 mg/kg of soil in B21 horizon of Jagjitpur series. According to nutrient critical value suggested by FAO (1983), the zinc content of salt affected soils in Kapurthala district is below the critical limits in all the subsurface horizons of all the pedons except B1 horizon of Rawalpindi and B21 horizon of Jagjitpur series individually. The availability of zinc was high in epipedon horizons of all series, and it decreased with depth and followed specific trend. The result of the studied area is similar (Jones, 2013) who also showed low zinc content in all the subsurface horizons of the profiles; it could be due to pH and soil type. (Barghouthi *et al.,* 2012).

The availability of iron in the all soil pedons ranged from 3.36 mg/kg of soil to 24.14 mg/kg of soil. The highest value 24.14 mg/kg of soil was recorded in epipedon of Khairanwali series and the lowest value 3.36 mg/kg of soil was recorded in BC horizon of Jagjitpur series. According to nutrient critical value levels by FAO (1983) the studied iron is above the respective critical level in the epipedon of all the series. Accordingly, the result showed that availability of iron is sufficient in all the horizons of all the series except BC horizon of Jagjitpur series, B21 horizon of Khairanwali series and B23 horizon of Randhirpur series respectively. The availability of iron in Fajewal series is above the respective critical level >4.5 mg/kg of soil in all the horizons of Fajewal series. The availability of manganese content in all soil series ranged from 2.48 mg/kg of soil in B23 horizon of Randhirpur series to 9.40 mg/kg of soil in epipedon of Randhirpur series. The result of manganese content in the studied area showed that it is sufficient in all the horizons of all the series except

B23 horizon of Randhirpur series. The concentration of extractable copper in epipedon of the studied pedons ranged from 0.38 mg/kg of soil in Fajewal series to 2.16 mg/kg of soil in Randhirpur series. The availability of copper in subsurface horizons of all the series ranged from 0.20 mg/kg of soil in BC horizon of Jagjitpur series to 2.16 mg/kg of soil in B3 horizon of Khairanwali series. The depth wise distribution of Cu in Domeli, Jagjitpur, and Randhirpur series, decreased with soil depth. The distribution of Cu is high in B3 horizon of Khairanwali series. The distribution of available copper decreased consistently from the surface to subsurface horizons may be due to its strong correlation with soil organic matter content, which decreased significantly with depth.

Table 3.2.1 : Physical and chemical characteristics of Domeli 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	0-18	10.3	0.18	0.79	0.8	476.6	42.5	313.6
AB	18-35	10.1	0.21	0.42	0.2	489.21	71.6	212.8
B1	35-55	10.1	0.06	0.39	0.4	439.0	47.0	212.8
B21	55-70	10.2	0.15	0.45	0.3	388.8	42.5	263.2
B22	70-95	10.1	0.07	0.33	0.6	301.5	42.5	240.8
BC	95-108	8.6	0.08	0.36	0.3	213.2	58.2	263.2

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	
0-18	5.77	3.4	0.4	1.56	0.41	27.0	44.8	36.6	18.9	1
18-35	3.53	0.8	0.8	1.47	0.46	41.2	45.1	33.8	21.1	1
35-55	3.51	0.6	1.2	1.30	0.41	37.0	41.7	36.0	22.3	1
55-70	3.70	0.6	1.2	1.39	0.51	37.5	38.4	42.1	19.5	1
70-95	4.17	1.0	1.4	1.21	0.56	29.0	36.2	41.0	22.8	1
95-108	6.19	0.4	4.2	1.13	0.46	18.2	37.3	38.2	24.5	1

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^{--}
0-18	36.60	8.9	0.94	8.3	7.40	0.46	1.6	4.4	5.6	1.25
18-35	37.65	8.8	1.13	4.1	9.65	0.26	2.8	5.4	4.4	1.29
35-55	38.00	8.9	1.08	3.6	8.34	0.21	2.4	7.0	1.0	1.56
55-70	30.55	8.7	0.38	3.7	0.48	0.21	Nil	4.2	1.2	1.10
70-95	30.90	8.7	0.19	5.2	0.43	0.26	Nil	5.4	1.6	1.80
95-108	28.15	8.5	1.05	5.3	1.91	0.36	0.8	4.8	1.4	2.05

Table 3.2.2 : Physical and chemical characteristics of Jagjitpur 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	0-30	9.0	0.46	0.52	0.6	677.3	44.8	364.0
AB	30-52	9.1	0.41	0.45	0.3	514.3	51.5	212.8
B21	52-79	8.9	0.31	0.40	0.3	464.1	47.0	263.2
B22	79-100	9.1	0.16	0.25	0.3	413.9	109.7	263.2
B23	100-125	8.9	0.19	0.35	0.2	338.6	110.2	240.8
BC	125-135	9.2	0.15	0.37	0.2	175.6	101.2	240.8

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	
0-30	5.70	1.8	1.0	2.34	0.56	41.0	52.2	19.6	28.4	scl
30-52	4.87	1.2	0.8	2.26	0.61	46.4	44.7	30.4	24.9	1
52-79	8.94	4.4	1.4	2.17	0.97	24.2	36.7	29.4	33.9	cl
79-100	8.19	5.0	1.0	1.73	0.46	21.1	33.8	31.4	34.8	cl
100-125	7.72	4.8	0.6	1.91	0.41	24.7	28.3	40.2	31.5	cl
125-135	8.68	4.6	1.6	1.82	0.60	20.7	32.5	32.5	35.0	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^{--}
0-30	33.05	9.1	2.33	14.0	12.35	0.64	0.0	10.2	15.0	1.97
30-52	34.70	9.3	1.10	12.6	11.22	0.48	0.0	9.4	14.3	1.98
52-79	37.45	9.3	1.01	11.4	10.13	0.54	0.0	8.2	14.3	1.98
79-100	39.20	8.5	1.98	11.8	10.53	0.43	0.0	8.8	12.1	1.98
100-125	41.35	8.9	1.82	10.6	9.64	0.23	0.0	8.4	11.6	1.97
125-135	40.65	7.6	1.71	9.9	7.26	0.48	0.0	6.8	11.0	1.95

Table 3.2.3 : Physical and chemical characteristics of Khairanwali 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	9.2	0.55	0.93	0.4	526.8	99.68	336.0
AB	23-50	9.9	0.62	0.30	0.5	112.8	108.8	291.2
B21	50-82	9.8	0.34	0.28	0.5	87.8	105.2	184.8
B22	82-111	9.9	0.17	0.33	0.3	200.7	108.4	184.8
B3	111-145	9.8	0.24	0.39	0.3	250.8	88.8	201.6

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	
0-23	6.37	3.4	1.2	1.21	0.56	18.9	43.2	31.4	25.6	l
23-50	6.37	2.2	1.4	2.26	0.51	35.4	27.8	47.6	24.8	l
50-82	5.49	1.8	1.0	2.34	0.35	42.6	41.0	35.5	23.5	l
82-111	7.60	3.2	0.8	3.04	0.56	40.0	42.1	32.8	25.1	l
111-145	8.29	3.6	1.0	3.39	0.30	40.8	43.1	22.2	34.7	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^{--}
0-23	39.15	9.3	2.90	6.9	26.40	0.86	4.8	13.6	2.80	0.73
23-50	40.15	9.0	2.32	5.0	23.04	0.55	3.2	12.4	10.2	0.72
50-82	45.45	7.7	2.37	5.3	16.30	0.54	2.4	11.6	14.8	1.34
82-111	37.20	8.2	1.71	4.7	15.06	0.54	1.6	10.4	11.6	0.76
111-145	38.90	8.1	0.91	3.5	10.00	0.52	1.6	4.8	5.80	0.67

Table 3.2.4 : Physical and chemical characteristics of Randhirpur 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	0-26	9.5	0.24	0.80	0.5	301.0	85.3	336.0
AB	26-48	9.8	0.20	0.41	0.6	163.0	80.6	313.6
B1	48-76	9.9	0.20	0.33	0.3	137.9	80.8	420.0
B21	76-95	10.0	0.18	0.41	0.4	125.4	69.4	313.6
B22	95-118	9.9	0.13	0.47	0.6	50.1	49.0	336.0
B23	118-138	10.0	0.06	0.42	0.4	75.2	46.5	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	
0-26	11.72	2.2	0.6	8.26	0.66	70.4	46.5	29.6	23.9	l
26-48	11.30	2.4	0.8	7.39	0.71	65.3	48.6	27.3	24.1	sicl
48-76	11.64	2.2	1.6	7.13	0.71	61.2	38.9	26.2	34.9	cl
76-95	10.64	1.8	1.8	6.43	0.61	60.4	32.7	32.3	35.0	cl
95-118	7.10	2.6	0.8	3.04	0.66	42.8	18.9	47.8	33.5	sicl
118-138	5.43	2.8	0.6	1.73	0.30	31.8	30.8	37.9	31.6	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^{--}
0-26	42.5	9.5	1.01	10.7	1.17	0.39	0.0	7.8	6.8	1.21
26-48	43.4	8.9	0.86	4.8	1.52	0.33	0.0	5.4	5.6	1.29
48-76	34.3	8.4	0.73	3.9	1.48	0.43	0.0	4.9	4.2	1.56
76-95	33.5	8.0	0.79	4.4	1.44	0.54	0.0	3.2	4.0	1.50
95-118	37.7	8.0	0.61	5.0	1.36	0.63	0.0	5.2	3.2	1.46
118-138	35.9	8.7	0.55	5.4	1.18	0.64	0.0	4.8	2.2	1.57

Table 3.2.5 : Physical and chemical characteristics of Fajewal 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	8.8	0.34	0.11	0.2	112.8	107.5	313.6
AB	23-55	9.08	0.36	0.12	0.3	87.8	88.9	268.8
B11	55-85	8.9	0.24	0.15	0.4	37.6	90.2	212.8
B12	85-113	8.7	0.23	0.15	0.4	175.6	87.8	240.8
B13	113-148	8.75	0.21	0.21	0.4	200.7	95.8	240.8

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	5.83	3.0	0.2	2.17	0.46	37.2	32.5	37.1	30.4	cl
23-55	7.49	3.2	1.8	2.08	0.41	27.7	28.1	49.5	22.0	l
55-85	7.29	2.8	1.6	2.43	0.46	33.3	37.3	47.8	21.9	l
85-113	7.75	4.3	0.8	2.60	0.35	33.5	24.5	49.2	24.1	sil
113-148	6.95	4.2	0.8	1.65	0.30	23.7	32.6	45.2	22.2	sil

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	35.20	10.4	1.10	9.7	1.53	1.02	0.0	2.4	7.8	0.94
23-55	29.85	9.6	1.08	8.3	1.21	0.48	0.0	2.5	7.2	0.87
55-85	27.15	9.5	0.63	8.4	1.10	0.39	0.0	1.6	5.0	0.86
85-113	25.95	9.2	0.71	10.1	1.10	0.43	0.0	1.6	3.4	0.82
113-148	26.35	8.3	0.35	7.9	1.70	0.55	0.0	0.8	2.8	0.60

Table 3.2.6 : Available micronutrients content of salt affected soils of Kapurthala district

Horizon	Depth (cm)	Zinc (mg/kg soil)	Iron (mg/kg soil)	Manganese (mg/kg soil)	Copper (mg/kg soil)
Domeli series					
Ap	0-18	1.62	20.04	8.68	1.22
B21	55-70	0.36	6.16	5.24	0.76
BC	95-108	0.26	5.40	3.98	0.90
Jagjitpur series					
Ap	0-30	0.28	6.02	4.14	1.02
B21	52-79	0.84	8.24	6.50	0.90
BC	125-135	0.30	3.36	4.58	0.20
Khairanwali series					
Ap	0-23	2.20	24.14	6.86	1.58
B21	50-82	0.26	3.94	3.68	0.50
B3	111-145	0.16	8.06	6.68	2.16
Randhirpur series					
Ap	0-26	2.58	22.50	9.40	2.16
B21	76-95	0.24	6.66	3.72	0.64
B23	118-138	0.18	3.62	2.48	0.28
Fajewal series					
Ap	0-24	1.84	21.46	6.70	0.38
B11	55-85	0.14	8.04	4.00	0.32
B13	113-148	0.12	8.38	6.44	0.38

3.3 Soil classification

Filed investigation and laboratory analysis of physical and chemical characteristics of the soils were used to identify the dominant soil type of salt affected soils of Kapurthala district based on Soil Taxonomy (2015). These soils are classified up to family level. The morphological, physical and chemical characteristics of these soils indicated that salt affected soils of Kapurthala district are entisols and Inceptisols (Table 3.3.1). The discussions related to the classification of thesis soils are available in (Rafie, 2020) PhD thesis.

Table 3.3.1 : Soil Taxonomy of salt affected soils of Kapurthala district

Series	Order	Suborder	Great group	Subgroup	Family
Salt-affected Soils					
Rawalpindi Domeli Jagjitpur Khairanwali Randhirpur	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Fine loamy, mixed, hyperthermic
Fajewal	Entisols	Fluvent	Ustifluvent	Typic Ustifluvent	Coarse loamy, mixed, hyperthermic

Conclusion

A study was under taken to characterize and classify the salt affected soils of Kapurthala district in Punjab. Profile samples were collected from five villages in Kapurthala district such as Domeli, Jagjitpur, Randhirpur, Khairanwali, and Fajewal series respectively. Sandy clay loam, loam, silty clay loam and clay loam texture classes were found in these soils. These soils have a pH of alkaline, electrical conductivity of these soils were below 1 dS m^{-1}. The ESP of these soils is greater than 15. The most limiting factors in these soils are little organic matter, presence of salt content such as sodium carbonate and crust, poor to moderate drainage, and weak and massive structure in some of the pedons respectively. Accordingly, salt affected soils of Kapurthala district required appropriate management such as usually drainage, suitable irrigation, and maintenance of organic matter along with the application of organic manure.

References

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.

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.

Ashenafi, A.; Abayneh, E. and Sheleme, B. (2010). Characterizing soils of DelboWegene watershed, Wolaita zone, Southern Ethiopia for planning appropriate land management, Journal of Soil Science and Environmental Management, 1(8): 184-199.

Barghouthi, Z.; Sameer, A.; Natsheh, A. and Salman, M. (2012). Analysis of Macro and Micronutrients in Soils from Palestine Using Ion Exchange Membrane Technology. Open Journal of Soil Science, 2: 44-49.

Brady, N.C. and Weil, R.R. (2008). The nature and properties of soils, 14th ed. Pearson Prentice hall, Upper Saddle River, New Jersey Columbus, Ohia, USA, 965.

Basavaraju, D.; Naidu, M.V.S.; Ramavatharam, N.; Venkaiah, K.; Rama, R.G. and Reddy, K.S. (2005). Characterization, classification and evaluation of soils in Chandragiri mandal of Chittoor district, Andhra Pradesh. Journal of Agropedology, 15: 55–62.

Dengiz, O.; Mustafa, S.; Esra, F.S. and Atasoy, C. (2012). Morphological and physicochemical characteristics and classification of vertisol developed on Deltaic plain, Turkey. Open Journal of Soil Science, 2: 20-27.

Esu, I.E (1991) Detailed Soil Survey of NIHORT Farmat Bunkure, Kano State, Nigeria, Institute for Agricultural Research, Ahmadu Bello University, Zaria.

Foth, H.D. (1990). Fundamentals of soil science, 12th ed. John Willey and Sons, New York.

FAO (Food and Agriculture Organization) (1983) Micronutrients, Fertilizer and Plant Nutrition Bulletin No. 7, FAO, Rome.

Jones, J.B. (2013). Agronomic Handbook, Management of crops, soils and their fertility. CRC Press LLC, Boca Raton, Florida, USA.

Jackson, M.L. (1967). Soil Chemical Analysis, Asia publ. House, Delhi Pp.3856

Jackson, M.L. (1958). Soil Chemical Analysis, Asia Publ. House, Delhi.

Karuma, A.; Gachene, C.; Msanya, B.; Mtakwa, P.; Amuri, N. and Gicheru, P. (2015). Soil Morphology, Physico - Chemical Properties and Classification of Typical Soils of Mwala District, Kenya, International Journal of Plant & Soil Science, 4(2): 156–170.

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.

Mervin, H.D. and Peech, M. (1950). Exchangeability of soils potassium in the sand, silt and clay fractions as influenced by the nature of the complementary exchangeable cations. Soil Sci. Soc. Amer. Pro., 15: 125- 28.

Olsen, S.R.; Cole, C.Y.; Watanabe, F.S. and Dean (1954). Estimation of phosphorus by extraction with sodium bicarbonate, U.S.D.A. Circular 939-19.

Puri, A.N. (1930). A new method of estimating total carbonates in soils. Imp. Agr. Pusa Bull. 206, pp.7

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.

Richards, L.A. (1954). Diagnosis and Improvement of Saline Alkali Soils, Agricultural Handbook 60, USDA and IBH Publishing Co. Ltd., New Delhi, India, Pp: 98-99. http://naldr.nal.usda.gov/NALWeb/Agricola_Link.asp? Accessed on 27/03/2018.

Rafie, J. (2020). Effect of intensive farming on the characteristics and classification of soils of Kapurthala in Punjab, NW-India, Department of Soil Science and Agriculture chemistry, School of Agriculture, Lovely Professional University, Phagwara, Punjab.

Soil, T. (2015) Illustrated Guide to Soil Taxonomy, version 2, U.S Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska.

Singh, K.; Manchanda, J.S. and Sadana, U.S. (2013). Experiential Learning on Evaluating Soil Health and Irrigation Water. Kuwait Printers. Sant Nagar. Opp. Govt. College for Boys. Civil Lines, Ludhiana.

Sharu, M.B.; Yakubu, M.; Noma, S.S. and Tsafe, A.I. (2013). Characterization and Classification of Soils on an

Agricultural landscape in Dingyadi District, Sokoto State, Nigeria. Nigerian Journal of Basic and Applied Science, 21(2): 137–147.

Sitanggang, M.; Rao, Y.S.; Nayan, A. and Mahapatra, S.K. (2006). Characterization and classification of soils in watershed area of Shikohpur, Gurgaon district, Haryana, Journal of Indian Soc. Soil Sci., 54: 106–110.

Sehgal, J.; Bajwa, M.S. and Sharma, P.K. (1992). Soil of Punjab, research Bulletin, NBSS Publ, 31. Nagpur, India

Sharma, P.K.; Charanjit, S.; Jawahar, L.S. and Kanwal, H.S. (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.

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.

Subbiah, B.V. and Asija, H.L. (1965). A rapid procedure for the estimation of the available nitrogen in soil, current Journal of Sci., 25: 259-60.

Tolanur, S. (2018). Second edition practical soil science and agriculture chemistry. CbS publishers and distributors Pvt. Ltd. New Delhi, India.

Walkley, A. and Black, C.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Journal of Soil Sci., 37: 27-38.