# EFFECT OF INTENSIVE FARMING ON THE CHARACTERISTICS AND CLASSIFICATION OF SOILS OF DISTRICT KAPURTHALA IN PUNJAB, NORTH-WEST, INDIA

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

**(Ph.D.)**

**DOCTOR OF PHILOSOPHY**

**in**

**(Soil Science and Agriculture Chemistry)**

**By**


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**Supervised By** **Professor/Dr. Raj Kumar**

**Co-Supervised by** **Dr. Nitin Baban Misal**


Transforming Education Transforming India

**LOVELY PROFESSIONAL UNIVERSITY**

**PUNJAB**

**Jun/2020**

# DECLARATION

I hereby declare that this Ph.D. thesis entitled "Effect of intensive farming on the characteristics and classification of soils of district Kapurthala in Punjab, North-West, India" was carried out by me for the degree of Doctor of Philosophy in Soil Science and Agriculture chemistry under the guidance and supervision of Dr. Raj Kumar, Professor and HOD- Department of Soil Science and Agriculture chemistry, School of Agriculture, Lovely Professional University, Punjab, India.

The interpretations put forth are based on my reading and understanding of the original texts and they are not published anywhere in the form of books, monographs or articles. The other books, articles and websites, which I have made use of are acknowledged at the respective place in text.

For the present thesis, which I am submitting to the university, no degree or diploma or distinction has been conferred on me before, ether in this or in any other University.

Place: Lovely Professional University **Jaihoon Rafie**

**Date**: -------/------/--------- **(Registration No. 11700566)**

I certified that the above statement made by the scholar is correct to the base of my knowledge and belief.

**Date**: ----/------/------ **Dr. Raj Kumar (HOD)**

Department of Soil science and Agriculture chemistry

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**Certificate-I**

This is to certify that the thesis entitled **"Effect of intensive farming on the characteristics and classification of soils of district Kapurthala in Punjab, North-West, India"** that is being submitted by Mr. Jaihoon Rafie (Registration No. 11700566), in partial fulfillment for the award of Ph.D. in (Soil science and Agriculture chemistry) to the Lovely Professional University is a record of bonafide work carried out by him under my guidance and supervision.

The results embodied in thesis have not been submitted to any other University or institute for the award of any degree or diploma.

| | |
|---|---|
| ----------------------------- | ------------------------------ |
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**Lovely Professional University**

**Date -------/--------/-------**

# Dedication

My humble effort I dedicated to my parents

Mr. Abobaker Rafie

Mrs. Bibi Parween Rafie

Whose affection, love, encouragement and prays of day and nights made me able to get such success and honor.

این اثر را تقدیم میکنم به دو گوهر نایاب و چراغ راه زندگیم:

پدرم بزرگوارم: دگر جنرال ابوبکر "رفیعی" و مادر مهربانم: بی بی پروین "رفیعی"

بی تردید هرچه آموختم در مکتب عشق شما آموختم و هرچه بکوشم قطره ای از دریای بی کران مهربانی تان را سپاس نتوانم بگویم

گران سنگ تر از این ارزان نداشتم تا به خاک پایتان نثار کنم، باشد که حاصل تلاشم نسیم گونه غبار خستگی تان را بزداید

جیحون "رفیعی"

دکتور علوم خاکشناستی و شیمی زراعت

## *Abstract*

*Soil resources of Kapurthala district in Punjab, North-West, India were studied. The Kapurthala district lies between the latitudes of 31°07'30" and 31° 39' 30" N and the longitudes of 75° 43' 55" and 75° 54' 60"E. Most of the studies on characteristics of soils of Kapurthala district have been done in the initial years of green revolution/intensive farming. Since then lots of change in the cropping pattern and soil characteristics have taken place because of the implementation of reclamation of salt-affected soils, scrapping of sandy layers and introduction of intensive farming practices. Now after forty-five years of intensive cultivation it was high time to revisit these soils. The investigation involved the study of macro-morphological characteristics of sixteen pedons from sixteen villages in the field. Horizon wise samples were collected. Location of all the pedons was recorded with the help of global positioning system (GPS). Physical and chemical characteristics of the soil samples were analysed in the laboratory. Soils were classified in the light of changed characteristics of the soils as per Soil Taxonomy (USDA 1999) up to family level.*

*As per macro morphological, physical and chemical characteristics, these soils grouped under salt-affected soils and normal soils. After, effects of intensive farming were studied by comparing the present data with the already established data. Comparison graphs of different parameters of soils of each series were plotted. The graphs of salt-affected soils showed that soil pH decreased in all the pedons except Domeli series in 2019 as compare to 1982. EC and calcium carbonate decreased while organic carbon percentage increased in salt-affected soils. The CEC decreased in most of series and exchangeable cations showed variation in salt-affected soils. The* $pH_s$ *and* $EC_e$ *graphs showed a decrease in all soil series except Fajewal series and* $Ca^{++}+Mg^{++}$ *in soil saturation extract showed variation. The* $Na^{+}$ *in soil saturation extract of salt-affected soils showed a decrease in all the soil series.*

*The actual productivity and potential productivity of these soils were evaluated by the Riquier Index model. So that experimental results can be interpreted in a rational manner for effective transfer of this beneficial technology to the farmers. Salt-affected soils of Kapurthala district were identified into three different classes in*

*terms of actual productivity. The maximum riquier index rating was obtained 65.40 (excellent) in Khairanwali series and the minimum value obtained 32.70 (average) in Domeli series. Salt affected soils of Kapurthala district were rated excellent class in terms of potential productivity. The maximum riquier rating obtained 82.67 in Khairanwali and the minimum 65.59 in Jagjitpur series.*

*In normal soils of Kapurthala the pH increased in all the series except Ap horizon of Nathupur series in 2019. The EC slightly increased in Bhanra, Kanjili, and Fatehpur series and slightly decreased in Nathupur, not changed or almost same in other normal soil series. Organic carbon increased in all the normal soils except Kanjili series, CEC slightly changed or almost same in all the series. The graphs for ESP content of these soil shows a slightly increase in most of these soils in 2019 and a slightly decrease in Kanjili series. Comparing graphs also were plotted for parameters such as* $pH_s$, $EC_e$ *and* $Na^+$ *of soil saturation extract.*

*In terms of actual productivity, normal soils of Kapurthala district were identified into three different classes. The minimum require index rating obtained 16.5 (poor class) in Mund series and maximum 55.23 (good class) in Dhoda series. Accordingly, In terms of potential productivity three classes were identified in normal soils of Kapurthala district. The maximum riquier index value obtained (79.04) in Dhoda series and the minimum value obtained 32.03 (average III) in Mund series respectively.*

## Acknowledgement

*In the name of Allah the most Merciful and Beneficent First and Foremost praise is to ALLAH, the Almighty, the greatest of all, on whom ultimately we depend for sustenance and guidance. I would like to thank* **Almighty Allah** *for giving me opportunity, determination and strength to do my research. His continuous grace and mercy was with me throughout my life and ever more during the tenure of my research.*

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*I owe a special word to my family members whom I kept awaiting during all these years and who faced so many difficulties during my long period of absence. This work would not have been possible without the support of my sincere and generous father '****General Abobaker Rafie'*** *and my loving mother '****Bibi Parween Rafie****. My older brother* ***Abonaser Rafie*** *who's not with us anymore and my younger brother* ***Shaheen Rafie*** *who's helped me and our family during my absence. I take this precious moment to express my heartfelt thanks to my family members whose association has always been a boost to me. A special thanks to (Mrs)* ***Aqlema Alokozay*** *who helped me many times during visa process. I love you all.*

*My special words of thanks should also go to (Miss.)* ***Maryam Sepehr*** *for her precious time spent, constructive criticisms, encouragement, support and prayers.*

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*On a different note, many people have been a part of my education and I offer my regards to all of those who supported me in any respect during the completion of the study.*

***Place: LPU, Phagwara, Punjab, India***

***Jaihoon Rafie***

***Signature -------------------------***

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**CHAPTER-I**

**Effect of intensive farming on the characteristics and classification of soils of district Kapurthala in Punjab, North-West, India**

## Introduction

Agriculture is being practised for more than ten thousand years. Since, then it has experienced substantial developments from the time of the initial cultivation. Agricultural development occurred independently in New Guinea, Africa's Sahel, northern and southern China, and several area of the Americas (Brothwell, 1975). The first commercial petrol-powered tractor was used in 1901 by Dan Albone successfully and in 1923 the International Harvester Farmall tractor changed the agriculture transition from horse to the machine. Since, then automatic mechanical harvesters, combines, transplanters, planters and other equipment have been developed. Such innovations brought speed and scale on farming tasks which were impossible previously, causing modern farms to more yield of high-quality produce per land unit (Jules, 2013).

The discovery of nitrogen and phosphorus as essential factors in plant growth directed to the manufacture of artificial fertilizers, making possible more intensive types of agriculture. The identification of vitamins and their role in livestock nutrition, in the first two decades of the $20^{th}$ century, led to the discovery of vitamin supplements, which in the 1920s allowed farm animals to be raised indoor, thus decreasing their exposure to deleterious natural elements (Brothwell, 1975).

Motivated by swift advances in the sciences, significant public investments and, policy support for agriculture during the $20^{th}$ century, Green Revolution transformed the global agriculture. The story of English wheat is an example of this global agricultural transformation. It took nearly thousand years for wheat yields to increase from 0.5 to 2 tons per hectare, but then wheat yields increased to over 7 tons per ha during the $20^{th}$ century. These advances occurred due to modern plant breeding, improved agronomy, and the development of synthetic fertilizers and pesticides. Most industrial countries had reached sustained food surpluses after 1950s and ended the threat of food shortages (Hazell, 2009).

The Green Revolution was a continuing method of change rather than a single event, and even today, management practices, continuous improvements of cereal crops helped and supported to attain the high levels of productivity. Although most of the Asian Green Revolution happened during the period 1965–1990, it had several technology and policy antecedents in the rice revolution that initiated in the latter part of the 19$^{th}$ century in Japan and transferred to Taiwan and Korea during the late 1920s and 1930s (Jirström, 2005).

Asia had invested heavily in irrigation before the Green Revolution and almost 25 per cent of the agricultural land was irrigated by 1970 (Appendix-VII). During the Green Revolution substantial investment were made across Asia, and the irrigated area increased to 33 per cent from 25 per cent of the agricultural area between 1970 and 1995 (Appendix-VII).

The last decade of the twentieth century was generally unfavourable for world food and agriculture. Global crop and livestock production was very low, only 1.1 per cent in 1998 in Japan. Similarly, the agricultural production in developing countries increased only by 2.6 per cent, lower than the already trivial rate of 2.9 per cent in 1997, although from 1993 to 1996 the slowdown increased at the high rate of 4 to 5 per cent. In 2000, 32 countries faced food scarcity as compared to 38 in 1991 (FAO 2000).

Agriculture is the backbone of the Indian economy. The geographical position of India has been very friendly for agricultural activities. The physical factors existing in India such as climate, soil, and relief became very helpful in the cultivation of so many crops. So from long past, the Indians had taken agriculture as their basic means of livelihood (Qadri, 2018). Over a period of 190 years, there was hardly any change in the form of technology in India from 1757 to 1947. For most of the farmers, agriculture was a means of existence; nearly 70 per cent of the total population derived their livelihood from agriculture itself. The villagers were self-sufficient to barter their products with each other, grain was the standard value. There was a natural economy and the money economy was rear. There was a rapid change in the structure of the rural economy when money entered the market through the process of commercialization of agriculture in the middle of the 19$^{th}$ century. The commercialization of agriculture was more pronounced when the British become the major ruling power in India (Gadgil, 1933). However, since the beginning of 19$^{th}$-century, agriculture did not contribute significantly in the economic growth of India. Before the initiation of the planning era in 1951, the progress of India's agriculture was quite deplorable. For the long period of 47 years from 1900 to 1947, the trend growth rate in the agriculture sector had stagnated at about 0.2 per annum while, from 1950-51 to 1985-86 India agriculture had grown annually at a compound rate of 2.66 per cent (Joshi *et al.*, 2006).

Then from mid-1960 onwards the traditional agriculture practices were continuously replaced by modern technology and farm practices in India. The Green Revolution started in India during the 1960s to elevated the food production and feed the millions of people across the country. It was also credited with increase in agricultural yields in many places where the technology was accepted (Sebby, 2010).

The Green Revolution started with the aid of the Rockefeller Foundation- a United States-based organisation and was centred on high-yielding varieties of wheat, rice, and other grains which were developed in Mexico and in the Philippines. In the early years of 1960 the area under the high yielding varieties program was only 1.9 million hectares which increased to nearly 15.4 million hectares, 43.1 million hectares and 63.9 million hectares in the first years of 1970, 1980 and 1990 respectively. Between 1965 and the early 1980s, northern and north-western states of India experienced the most benefits of this revolution. The program led to a significant increase in the production of food grains, mainly wheat and rice. High yielding varieties of wheat were sown about 75 per cent of the total cropped area in 1980s (Heitzman and Worden, 1995).

Growth in agricultural GDP showed high instability since the beginning of economic reforms in 1991. It varied from 4.8 per cent per annum in 1992-96 to a low of 2.4 per cent during 2002-06 before rising to 4.1 per cent in 2007-12. In 2013-14, the area and production under wheat increased to 30.47 million hectares and 95.85 million tonnes in comparison to 27.99 million hectares and 75.81 million tonnes in 2006-07 (Government of India, 2016).

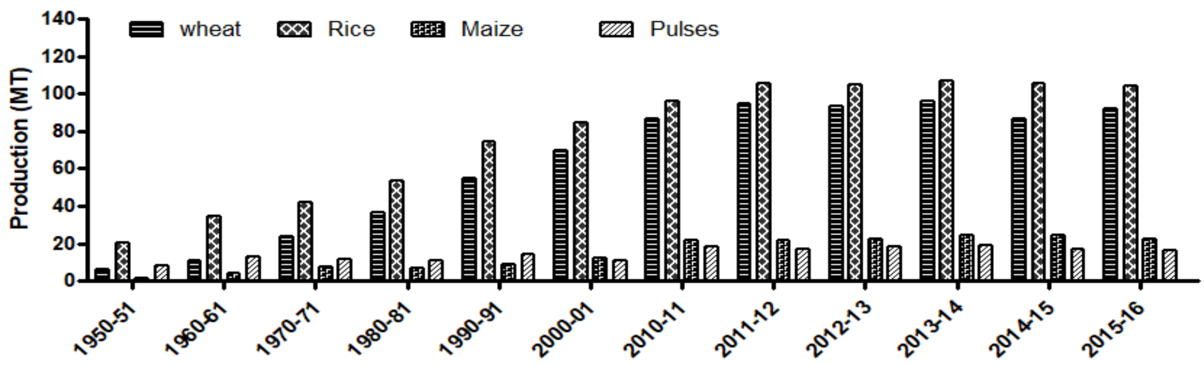
Area, production, and yield of major crops in India are shown in figure 1.1,1.2, and 1.3 respectively. In 1950-51 wheat covered 9.75 million hectares which increased to 330.42 million hectares in 2015-16, rice increased from 30.81 million hectares in

1950-51 to 43.50 million hectares in 2015-16. The area under maize and pulses in 1950-51 were 3.16 and 19.9 million hectares in India which were increased to 8.81 and 24.91 million hectares in 2015-16 respectively. The production of wheat and rice was 6.46 and 20.58 million tons which increased to 92.22 and 104.41 million ton respectively, while the yield of wheat in 1950-51 was 663 kg/ha and it's increased to 3034 kg/ha in 2015-16. The yield of rice increased from 668 in 1950-51 kg/ha to 2400 kg/ha in 2015-16. The yield of maize increased from 547 kg/ha in 1950-51 to 2563 kg/ha in 2015-16. The yield of pulses increased from 441 kg/ha in 1950-51 to 789 kg /ha in 2012-13 and in 2015-16 again it decreased to 656 kg/ha.

**Figure 1.1 Area under major crops in India (1950-2016)**

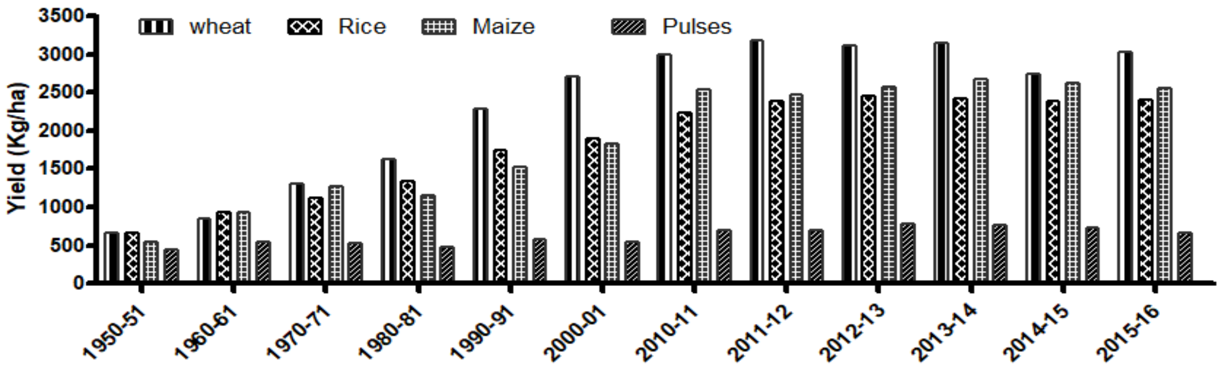

Source: Government of India, 2017

**Figure 1.2 Production of major crops in India (1950-2016)**




Source: Government of India, 2017

**Figure 1.3 Yield of major crops in India (1950-2016)**



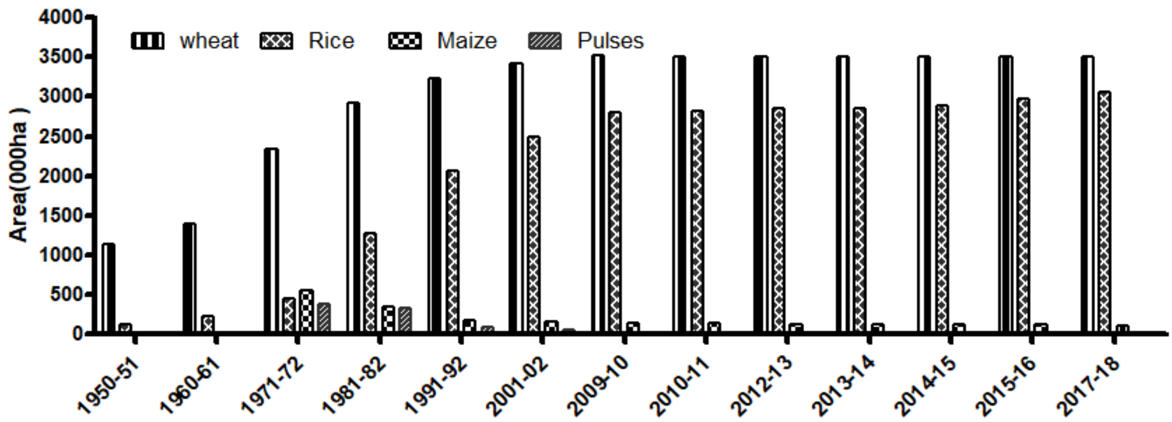

Source: Government of India, 2017

Land application designs, somatic topographies of the land, the country cultural unity and the colonial regime before independence were the factors that affected agriculture in India. The state of Punjab was made up of sandbar, alluvial plains, and an arid dry western region. The sandbar covered about 20 per cent of the total area of the state and it occupied by 20 per cent of its population (Bhalla, 1995). Punjab was the last state which was occupied by British in 1849, and at that time the only sources of water for irrigation and human consumption were rainfall and wells. Production in Punjab agriculture started while the British made huge investments in irrigation canals in the state in the late nineteenth and early twentieth centuries. Capital cost on useful irrigation channels in Punjab was forty per cent of the total made by the British government in India up to 1919-20. Thus, the segment of irrigated lands in Punjab was 50 per cent of the total for agriculture acreage (Hirashima, 1978). Punjab Agri-Horticulture society was created in 1851 by the British which was an important development in the agriculture policy. During the 20 years period from 1851 to 1871, the society tried to improve the agriculture products of Punjab (Kerr, 1976). Punjab Agriculture College was established at Lyallpur in 1909. Other agriculture canters were stated at Gurdaspur in 1909 and at Jullundur in 1912-13 to exhibit the techniques of dry farming to the farmers (Bhalla, 1995). The production of cereals and saleable crops increased with the creation of channels during the first half of the twentieth century. The yield of wheat, maize, sugarcane, and cotton increased from 0.87 million tonnes, 0.28 million tonnes, 124,000 tons, 70,000 bales in 1904-05 to 1.17 million tonnes, 0.03 million tonnes, 279,000 tons, 296,000 bales in 1944-45 respectively (Ministry of Agriculture, 1976).

The partition of the India and Punjab in 1947 resulted in a big setback to the Punjab agriculture, as a large part of productive and irrigated lands went to West Punjab in Pakistan and also led to the pull-up and migration of a good-sized part of the population across the border (Singh, 2001). Since the beginning of planning in 1950-51, Punjab recorded a very high rate of agricultural growth. Through the various land reforms and public investments during 1950s basic institutional and economic infrastructures were created in Punjab (Bahlla *et al.,* 1990). The agricultural and economic growth in Punjab was associated with the Green revolution. The increase in wheat production of Punjab from 1.9 in 1965 to 5.6 in 1972 and equally strong rice production corroborates the previous statement as reported by Singh and Kohli, (2005). After adoption of new agriculture technology made up of hybrid seeds, chemical fertilizer, insect repellent, and new agriculture practices in mid-1960 Punjab made wonderful progress and in a few years, the state established itself as a heartland of India's successful green revolution policy (Sidhu, 2005). The annual rate of increase in production of food grains during the period 1961-62 to 1985-86 for the state was more than double then that of the country as a whole. In 1974 the percentage of high yielding varieties of seed in the total area under food grains in Punjab was as high as 73 per cent while all India it was 31 per cent, which reached to 95 per cent in 1983-85, while it was 54 per cent in all India (Jodhka, 2006).

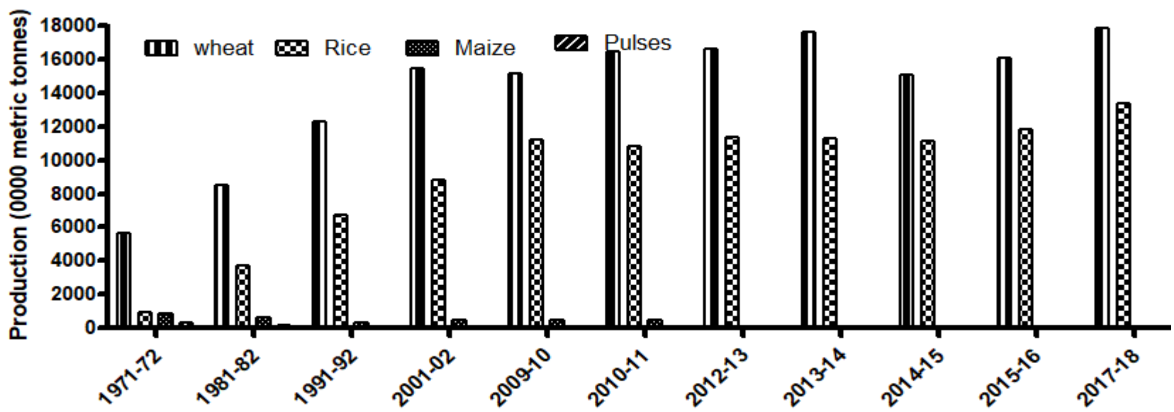
Area, production, and yield of major crops in Punjab are shown in figure 1.4, 1.5, and 1.6 respectively. The area under wheat and rice in 1950-51 was 1,137,000 ha and 120,000 ha which increased to 3,512,000 ha and 3,065,000 ha in 2017-18 respectively. The yield of wheat increased from 1,024 kg/ha in 1950-51 to 5,777 kg/ha in 2017-18 and the yield of rice increased from 892 kg/ha to 4,366 kg/ha in the same period. In 1971-72 the production of wheat was 5,618,000 tons which increased to 17,830,000 tons in 2017-18. Furthermore, the production of rice in Punjab during 1970-71 was 920,000 tons while it was 13,382,000 tons in 2017-18. The area under maize cultivation in Punjab in 1970-71 was 580,000 ha which decreased to 114,000 ha in 2017-18, the yield of maize increased from 1,564 kg/ha in 1970-71 to 3,706 kg/ha in 2017-18. Pulses covered 384,000 ha in 1971-72 which decreased to 20,000 ha in 2010-11. The production of pulses in 1970-71 was 302,000 tons in 1970-71 which decreased to 17,000 tons in 2010-11 and 9,000 tons in 2017-18 respectively.

**Fig 1.4 Area under major crops in Punjab (1950-2017)**




Source: Government of Punjab (Punjab at a Glance)-2018, Source 2: State agriculture Profile- Punjab, 2012

**Fig 1.5 Production of major crops in Punjab (1950-2017)**




Source: Government of Punjab (Punjab at a Glance), 2018, Source 2: State agriculture Profile- Punjab, 2019

**Fig 1.6 Yield of major crops in Punjab (1950-2017)**


Source: Government of Punjab (Punjab at a Glance), 2018, Source 2: State agriculture Profile- Punjab, 2019

The Kapurthala district located in the North West of Punjab in India, it lies between $31^0$39' 30" N and the longitudes of $74^0$ 54' 60" E. It covers an area of 1,670 sq km and is the smallest of all districts in Punjab. It is bounded by Beas River in the north-west, part of Hoshiarpur and Jullundur districts in north-east, and Jullundur and Firozpur districts in the south and south-west. The district comprises of two administrative units, namely Kapurthala and Phagwara which are separated by a part of the Jullundur district. The Kapurthala unit constitutes major part of the district. There are three tehsils, viz. Kapurthala, Sultanpur Lodhi and Phagwara and 556 inhabited villages in the district (Sharma *et al.*, 1982). There was a long belt of sand dunes in Kapurthala district, especially around Sultanpur Lodhi and Kapurthala Tehsils. These dunes were present as low or high ridges throughout the previous flood plain of Beas River. These regions were mostly used for cultivating oilseed, groundnut, and fodder crops under rainfed conditions because of the rolling topography and sandy texture. The epipedon sands were removed by the farmers to cultivate wheat and paddy. The major region of the previous flood plain among the sandbar and Beas flood plain was waterlogged because of flooding by Beas River before the construction of protection dams. The flooding and waterlogging caused the increased of sodicity in some of these regions. With the creation of various dams, the area was protected from the harms of floods and this, in turn, lowered the water table (Sharma *et al.,* 1982).

Total cropped area in Kapurthala district was 271,000 hectare in 1965-66, out of that 29.60 per cent was occupied by wheat and 7.49 per cent area was occupied by rice, 12.40 per cent and 13.8 per cent was occupied by maize and pulses respectively. The per cent area for wheat increased from 29.60 per cent in 1965-60 to 40.22 per cent in 1985-86. Per cent area for rice increased to 16.26 per cent and for pulses it decreased to 1.40 per cent in 1985-86. Furthermore, the per cent area under rice cultivation increased to 39.85 per cent in 2005-06 and area for maize and pulsed decreased to 1.11 and 0.04 per cent respectively.

The nature, properties, and extent of distribution of different soils occurring in Kapurthala district have been grouped in 16 soil series with 3-5 phases within each series. The suitability of soils for major crops grown in the area has been evaluated. The study revealed that 69 per cent of the total area of 1.67 million hectares in the district has been suffering from various kinds of soil problems, such as soil salinity, sodicity, sand dune formation and flooding. The salt-affected soils have comparatively low salt content and the underground water is of good quality (Sharma *et al*, 1982)

The Kapurthala district is covered with the Indo-Gangetic alluvium. The major part of this area is located in the river tract falling between the Beas and Black Bein and is called 'Bet'. In the south of the Black Bein an area known as 'Dona' (combination of sand and clay) is located. Sirowal, Dhak and Manjki tracts are present in the North-East, middle and South-East part of Phagwara. Sirowal has the characteristics of the 'Bet. The numerous hill streams coming down from Hoshiarpur District keep the soil moist all the year-round. Some of these streams are silt-laden and at first deposit fertile soil though their later deposits are more and more sandy. Due to the existence of these drainage channels patches and strata of hard clay are also found (Angurala, 2013).

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 became necessary to have soil resource maps for developing national land-use plans. An investigation was conducted in the Kapurthala region to classify, characterize, map and to find the problems (kind and degree) the soils of dist. Kapurthala (Sharma *et al.,* 1982). These soils have been grouped into sixteen soil series (including six series of the salt-affected members) depending upon the variations in texture, drainage, profile development, lime and salt contents. Salt affected soils occur in upper and lower terraces of Punjab and possibly Haryana and Uttra Pradesh. In Kapurthala district, they are mainly concentrated around East Bein in Phagwara tehsil, where they occupy an area of 13,045 ha representing 7.81 per cent of the total surveyed area (Sharma *et al.,* 1982). These very deep, calcareous, slightly to moderately saline-sodic soils dominance of bicarbonates and chlorides of sodium, having high (>40%) sodium on the exchange complex in the cambric horizon. Sharma *et al.,* (1982) have conducted the survey of their soils in 1987. Since then lot of change in the cropping pattern and soil characteristics has taken place due to adoption of reclamation of salt-affected soils, scrapping of sandy layers and introduction of intensive farming practices loading to Green Revolution. Most of the studies Uppal H.L (1957), Sharma *et al.,* (1982) and Sehgal (1992) on characteristics of soil have been done in the initial years of Green Revolution/intensive farming. After forty years of intensive cultivation, it is high time to revisit these soils and recharacterise and reclassify them again in the light of changed scenario. Accordingly, the present investigation was planned to understand the effect of more than four decades of intensive farming on the characteristics and classification of soils of dist. Kapurthala. As such, it was of highest importance that these soils are studied in the field, characterized in laboratory and reclassified in the light of new observation about soil characteristics so that experimental results can be interpreted in a rational manner for effective transfer of technology to the farmers.

Accordingly, the present investigation, to understand the effect of intensive farming on the characteristics and classification of soils of district Kapurthala in Punjab, NW-India, was undertaken with the following objectives:

1- To examine the macro morphological characteristics of the dominant soils of dist. Kapurthala in the field and their physical and chemical characteristics in the laboratory
2- To comparing the effect of pre and post green revolution/intensive farming era on the soil characteristics and their classification
3- To evaluate the actual and potential productivity of the soils of Kapurthala district

**CHAPTER-II**

## Review of literature

Literature related to the current investigation: Effect of intensive farming on characterization and classification of soil of district Kapurthala in Punjab, NW-India; has been reviewed and reported here under the following headings:

**2.0 World agriculture**

**2.1 World agriculture scenario from 1900-2000**

**2.2 State of agriculture in India**

**2.2.1 State of agriculture in India before 1947**

**2.2.2 State of agriculture in India from 1947-1970**

**2.2.3 State of agriculture in India from 1970-2019**

**2.3 State of agriculture in Punjab**

**2.3.1 State of agriculture in Punjab before 1947**

**2.3.2 State of agriculture in Punjab from 1947-1970**

**2.3.3 State of agriculture in Punjab from 1970-2019**

**2.4 Soil survey**

**2.4.1 Role of soil forming factors**

**2.4.2 Soil characteristics**

**2.4.2.1 Soil morphological characteristics**

**2.4.2.2 Soil physical-chemical characteristics**

**2.4.3 Soil classification**

**2.4.4 Soil mineralogy**

## 2.5 Salt affected soils

## 2.6 Soil productivity

## 2.0 World agriculture

## 2.1 World Agriculture Scenario from 1900-2000

The detailed evidences on agricultural production in the first half of the 19th century were reviewed by Federico, (2004). Author, estimated a yearly sequence of production for the main countries later 1870 and placed forward some theories on developments in the rest of the world. The study specified that agriculture production had increased more than population in the long term and growth had affected all landforms, even if it was decidedly faster in both the countries of Western Settlement and in Eastern Europe. Thus, in Asia or Western Europe agriculture growth was faster before 1st World War, an absolute excellent stage for world agriculture. In the interwar years the structure of production had changed with the increase in the share of livestock products.

Twentieth century witnessed dramatic changes in agriculture production in the United Kingdom and some part of Europe, also a visible increase in yield from 1945 to the end of century. These increase and changes were associated with modernization and increase in chemical application (Robinson and Sutherland, 2002).

A large number of mechanical advances led to the expansion of agriculture, which included plowing and cultivation using animal traction and irrigation technology including moving, lifting and storing of water as reported by David, (2007). In the early 19th century, mechanical advances such as the McCormick's reaper and the cotton gin, invented by Eli Whitney, were to profoundly affected agriculture and enabled the industrialization of agriculture. Farmall, a row-crop machine invented by International Harvester changed the agricultural transition from horse to machine in 1923. In the 1930s, manufacture of the power take-off permitted the tractor to be the basic farm machine able to power various other operations. The use of horse in US farms decreased from 26 million in 1919 to 4 million in 1955, and most of which were used for sports and entertainment only.

With the establishment of the Office of Special Studies green revolution began in 1943, which was a scheme collaborated between the Rockefeller Foundation and Manuel Avila Camacho, the President of Mexico (Brothwell, 1975). The scientists agreed that the Green Revolution will allow sufficient food production to fulfil the demand of growing world population. The Green Revolution had major effect on society and ecology along with millions dollar support from organizations including the Gates Foundation. Economic growth and industrial development were the major goals of the Mexican President. The Rockefeller Foundation spread the green revolution to many other countries with the increase in agricultural development. The Office of Special Studies in Mexico became an informal international research institution in 1959.

The demand for labour per hectare has not been significantly curtailed by the so called green revolution, Aggarwal (1971). This is so because increased use of farm machinery has also led to multiple cropping and more intensive agriculture. In fact, with green revolution it was the nature of demand of labour that has changed. For instance, more skilled labourers are required for round the year employment. At the peak periods, such as harvesting, labour demand becomes quite critical. This has resulted in high wages at the harvest times. The farmers consequently are seeking harvesting combines and other machines to replace expensive manual labour. It seems fairly clear that demand for labour will diminish as agriculture becomes more and more mechanized.

Green revolution research saved an estimated 18-27 million hectares from getting in to agriculture production as reported by Stevenson *et al.,* (2012). Increase in cereal yields, as a result of general adoption of improved crop germless have saved natural ecosystems from being converted to agriculture. Accordingly, the authors estimated that the total crop area in 2004 would have been 17.9 to 26.7 million hectares larger in a world that had not benefited from crop improvement since 1965, and displacing pastures and resulting in an estimated two million hectares of additional deforestation. However, the adverse effects of higher food prices on poverty and hunger under this setup would likely have dwarfed the wellbeing effects of agricultural expansion. Furthermore, authors mentioned that the relationship between adoption of new technologies and change in cover of land use was difficult. The study cleared that by increasing the productivity with new agricultural technologies, it's possible to increase the effectiveness of agriculture in comparison with alternative land use, from forest to agricultural.

The Schuman Declaration on 9 May 1950 started the European integration which proposed the establishment of the European Coal and Steel Community (Heidea *et al.*, 2011). As agriculture was an important part of the economy, it became involved in European and global integration processes. The Treaty of Rome laid the foundation of the European Economic Community (EEC), which eventually became the European Union. This treaty founded the primary role for the economic community, such as increase of the internal market and the basic agricultural policy. In other hand, a different chapter of the EEC Treaty identified in its first article that agriculture and trade in agricultural products should be part of the local market.

Since 1961, total agricultural production had expanded by approximately 170 per cent worldwide, on average of 2.2 per cent per annum (Wik *et al*., 2008). Most of these growths were created in developed countries but several of the under-developed countries, especially in sub-Saharan Africa, experienced decrease in agricultural productivity, increase in food scarcity and high levels of starvation and poverty.

The cost of total agricultural output had almost trebled from 1961 to 2000, with mean increase of 2.3 per cent per annum, continuously worldwide population growth rates 1.7 per cent per year (FAO 2006). Much of this growth invented in developing countries (3.4 to 3.8 per cent p.a.). The latter's high growth, among other things, reflected the developments of some large countries, especially China. Except China the rest of developing countries grew at 2.8-3.0 per cent per a year. Agriculture total production decreased from 9 per cent in the early 1970s to 4 per cent in 2006.

Increasing food consumption per capita had significant increase in developing countries in 1970 from an average of 2100 Kcal/person/day to almost 2700 Kcal/person/day in 2001. The proportion of hungry people was reduced from 37 per cent to 17 per cent over the same period. But there are still more than 850 million undernourished people worldwide. In sub-Saharan Africa, the worst hit continent, over one third of the population is chronically hungry (Wik *et al.,* 2008).

From the nutrient poor sandy soils Dutch farmers worked a hard living. Many people earned their income from agriculture. Around 1900 there were about 2.8 million workers in agriculture, But at the starting of the $20^{th}$ century, the condition for farmers became more favourable and healthier (Ban et *al.,* 1988). A method of change started on the sandy soils in the direction of a type of agriculture where farmers got their income from the sale of animal products and produced arable crops to feed their animals. This process was enhanced with the introduction of fertilizer, which not only increased the yields also overcame the problems of lack of manure. Development of efficient system for input supply, processing, marketing, and credit mostly by cooperatives had an important influence on the livelihood of small farmers, especially in the regions with poor sandy soils.

Furthermore, genetic engineering of crops was a notable subject since 1971 when the first genetically modified organisms were developed (James and Krattiger, 1996).The first field trials of transgenic crops included herbicide resistance used as a marker gene in tobacco in the America and France in 1986. In the interim period, more than 3500 field trials of transgenic crops leaded on more than 15000 individual’s sites in thirty four countries with minimum fifty six crops, typically in Europe and North America. 91 per cent of these trials performed in commercial nations, one per cent in Russia and Europe and the rest 8 per cent in the rising countries

China was the main commercialized transgenic country in the initial year of 1990 with the introduction of virus tolerant tobacco and tomato species. USA was the country which approved for the first time commercial sale of transgenic product for food used in 1944. By the end of 1995, thirty five countries were permitted to grow nine genetically modified crops commercially (James and Krattiger, 1996).

The use of organic generally depended on the organizations and individuals around the world which promoted organic farming, and they had believed that it’s a more sustainable method of agriculture (Brothwell, 1975). Its history goes back to the first half of the 20th century, while new significant agricultural practices began to act. The actual movement of organic began in the initial years of 1900s to the reaction in the change toward artificial nitrogen fertilizers and pesticides in the early days of industrial agriculture. It had been dormant for years and was kept alive by a relatively small group of ecologically active farmers. These farmers came together in various associations: Demeter International of Germany, which encouraged biodynamic farming and began the first certification program, the Soil Association of the United Kingdom, and Rodale Press in the United States, along with others. All the above organization joined Federation of Organic Agriculture Movements in 1972.

## 2.2 State of agriculture in India

### 2.2.1 State of agriculture in India before 1947

The history of modern agriculture in India begins in 1757. In that historic year the Indians lost the war of Plessey to the East India Company of the British soldier-traders. As a result of the failure, the income rights of a district in Bengal, the 24-Paragannahs, had to be conceded to the company. The position was occupied by British in the civil and revenue admiration of India expanded quickly. By, 1765, large lands of India, especially in the provinces of Bengal, Bihar and Orissa was under the control of the company and agriculture in India had become subjected to the British administration and its modernising influences (Bajaj *et al.,* 2001).

Wheat, barley and jujube were domesticated in the Indian subcontinent by 9000 BC. After that sheep, goat and elephant were domesticated, barley and wheat cultivation along with the domestication of cattle, primarily sheep and goat was visible in Mehrgarh by 8000-6000 BC. By the 5th millennium BC agricultural societies became general in Kashmir (Zaheer, 1996). Moreover, the primary sing of cultivation of cotton had already developed and it was cultivated by the 4th and 5th millennium BC. The Indus cotton industry was well developed and some approaches used in cotton rotating and production continued to be practiced till the recent Industrialization of India.

Among the fruits mango and muskmelon are native to the Indian subcontinent and hemp also domesticated by Indians which they used for a number of applications such as making narcotics, fibre and oil. Peas, sesame and dates were grown by Indus Valley farmers. Sugarcane was basically from tropical South Asia and Southeast Asia. Different species possibly invented in different locations with Saccharum barberi originating in India and Saccharum edule and Saccharum officinarum coming from New Guinea. Wild Oryza rice appeared in the Belan and Ganges valley regions of northern India as early as 4530 BC and 5440 BC respectively. Agricultural movement throughout the second millennium BC included rice cultivation in the Kashmir and Harrappan regions. Mixed farming was the basis of the Indus valley economy (Murphy, 2007).

In 1857 few Indian commercial crops such as cotton, indigo, opium, and rice prepared to the global market under the Birtish Raj in India due to the construction of Rampur canal on Sutlej River as reported by Roy, (2006). The second half of the 19th century witnessed some increase in the cultivated land at a normal rate of approximately one per cent per year by the later 19th century. Punjab, Narmada valley, and Andhra Pradesh became centres of agricultural improvements due to wide irrigation by canal networks. The world war also influenced Indian agriculture system

From 1891 to 1946 the annual growth rate of all crop production was 0.4 per cent and food grain production was almost stagnant. There were important local and intercrop changes; however, non-food crops response was better than food crops. Among food crops the most significant source of stagnation was rice. Bengal had under average production rates in both food and non-food crop production, while Punjab and Madras were the smallest stagnant states. Population growth accelerated in the interwar period where food production slowed, most important declined the availability of food per head. The crisis was most serious in Bengal, where food production dropped at a yearly rate of nearby 0.7 per cent from 1921 to 1946, when population grew at a yearly rate of about 1 per cent (Roy, 2006).

Agriculture performance in the interwar period was depressing. Cotton, indigo, opium and rice were the profitable crops which reached the worldwide market under the British Raj in India. The yearly growth rate of all crop production was 0.4 per cent and food grain yield was stagnant from 1891-1946. There were major regional and intercrop differences, and non-food crops were doing well than food crops (Brothwell, 1975).

In the context of economic liberalisation during 1900s (Kurosaki, 1999), investigated the performance of agriculture in India and Pakistan, from historical and comparative perspectives. Based on a new data set that corresponds to the current border, the stagnant performance of agriculture in India and Pakistan throughout the foreign period was turned into a sustained development since 1947, with a stronger performance in India particularly in terms of each capita food invention. The author mentioned that the changes had significant effect on agriculture production in India and Pakistan. Farmers had responded to changes in establishments and strategies, regulating their crop mix and production technology.

Many significant improvement were seen in the agricultural statistics of India after the First World War (Nath, 2008). The Royal Commission of Agriculture was appointed in 1926 by Government of India to observe the situations of agricultural and rural economy and the reports were published in 1928. The Commission suggested the constitution of the Imperial Council of Agricultural Research which was renamed after independence as the Indian Council of Agricultural Research.

The economic history and the degree of development of Indian agriculture from 1891 to 1947 were studied by Blyn, (1966), which closely examined the output, area and yield for eighteen crops that reputed most of agriculture in India. Author combined the output and trade data to determined trends in the availability of crops. Also, these trends were compared with population statistic to designate changes in India’s prosperity. Close examination was given to variations of output, intensity of cultivation, agriculture technology and physical environment.

### 2.2.2 State of agriculture in India from 1947-1970

Institutional and infrastructural reforms were introduced in India since independence for the development of agriculture sector. From independence to mid-sixties, Indian agriculture witnessed incredible agricultural reforms, development of important irrigation project and supports for cooperative credit organization. In mid-1960 new agricultural strategy was introduced. In this period India became self-sufficient in food grains. Agricultural transformations during this period took back seat while research, price support, marketing, input supply, credit, extension, and spread of technology were the primary concern of agricultural strategist (Rao and Hanumantha, 2000).

When independence came to India, agriculture was crossing a bad period, especially in Bengal which had recently faced a major famine. The per capita food availability in 1946 was 417 g daily which was very low. Indebtedness in rural areas was almost doubled between 1929 and 1936. India was facing a serious shortage of food and commercial crops. Improvement of agriculture was an urgent demand at that period. A noticeable mode of action was focused on the improvement of irrigation system which was exhausted after partition. In addition of improving irrigation some steps were taken to bring the farmers back on the land and decrease rural indebtedness through land reform. The average irrigated agriculture land area increased to 20.2 million hectares from 18.9 only in three years between 1947 and1950 (Bajaj *et al.,* 2001).

At the time of independence in India agriculture was the major source of income and occupation (Tripathi and Parsad, 2010). Agriculture and associated activities funded about fifty per cent to India's gross income, approximately 72 per cent working population was engaged in agriculture, which confirmed the backward economy of India and agriculture based economy at the time of independence. After 1947 India made much progress in agriculture and India's agriculture increased at the rate of 2.6 per cent per year. After that the focus of increased land area under agriculture production decreased over the time and productivity became the primary source of growth in agriculture production. Another vital side of agriculture development in India was the eradication of its requirement on imported food grains.

All mentioned developments in India's agriculture were contributed by series of steps such as land reform, inauguration of agriculture, new agriculture strategy investment in research and etc., introduced by Government of India.

Food grins production in Indi increased from 55.0 million tonnes to 108.4 million between the years of 1951 to 1971, in an annual rate of 2.7 per cent which was slightly ahead from population growth. The development was still not smooth and there were fairly a few years especially 1966, 1967, and 1973 when the country experienced a severe food crisis. Throughout the period with the exception of the year of 1972 food grains had to be imported the maximum being 10 million tonnes in 1966 (Dantwala, 1976).

India terms of trade improved slightly between 1950 and 1967 and the index of export and import price rose by 73 and 67 per cent respectively. After 1967 India belonged to the large group of developing countries that had included import substitution as an important element of their strategy of economic development (Cohen, 1969).

The two successive severe droughts in 1965-66 and 1966-67 increased the international anxieties about India's ability to feed her large and rapidly growing population (Paddock *et al.,* 1968). During this period, the high yielding varieties of cereals became commercially accessible. India's policy maker went for it with alacrity. Dr. Norman E. Borlaug complimented the then Minister of Agriculture who recognized the significance of the new wheat strains and took the risk involved in importing 18,000 tonnes of dwarf wheat Mexican varieties.

The yield of food grains had doubled in India after the introduction of dwarf wheat seeds (Chakravarti, 1973). The high yielding variety seed program had contributed to serious interregional differences in agriculture. The surprising success of the dwarf Mexican wheat was the back bone of the green revolution. The trend had just started and affected only a small section of millions of farmers. India experienced more normal weather conditions and most high yielding varieties during 1967-68.

Dwarf wheat seeds were introduced to India in 1966-1967 and their commercial adoption had been rapid and successful (Cummings, 1970).

During 1966-1967 crop years only 4.66 million were seeded under the High Yielding Varity Program (HVP) and 2.2 per cent of the total areas were under paddy, wheat, maize, and bajra but in 1968-1969 the areas under HVP increased to 22.97 million acres while the target under the fourth plan was sixty million acres. For this purpose the government established the National Seeds Corporation to provide quality seeds, financing and guidance.

Farmers in India were conservative; most of them were ready to adopt the new methods under High Yielding Variety Program (HVP). The adoption of the HVP was facilitated by the Intensive Agricultural District Program (IADP), which was built into the existing community development organization. The major objective of this program was to increase the food grain production by indicating and encouraging the adoption of improved farm practices and by making available the needed services, seeds, fertilizers, pesticides and tools. Each farmer had been helped to improve a crop production plan for his land and the success of the new high yielding seeds in IADP districts had spurred rapid diffusion (Chakravarti, 1973).

After the partition of India and Pakistan in 1947, different challenges came to India. Even during good harvest years food imports remained high. A large group of people were poor (Rena, 2013). To mitigate these problems in the mid of 1960s India adopted new farming policy under the green revolution. The green revolution had contributed to the Indian agriculture extremely and transformed India from a hungry nation to a food exporter.

Oommen (1971) studied green revolution and agrarian conflict in India, and noticed that the factors such as understand the common differences in rural poor, a practical numerical asset of the agricultural labour force and their awareness of their political negotiating rule, a proper support structure provided by political parties, the growing aspiration of the rural masse, and the increasing lack of fit between the socio-political framework and the economic order were involved in agrarian conflict in India. In no time and in no part of the India was rural unrest general except when the rural have-nots were mobilized by a political party or movement. Usually, the economically poor’s in rural India were also under privileged and politically helpless, and their aspirations therefore remained frozen.

Owing to green revolution the impacat of intensive farming practices in India was favorable (Chuadary, 2017). Intensive farming owing green revolution initiated in Punjab, Haryana, Rajasthan and other states of India which later sepread to West Bengal. India became self-sufficient in food front as use of high yield variety seeds, irrigation water, synthetic fertilizers, agriculture machineries, pesticides and agricultural awareness of the rural brought a notable change in agriculture. This extraordinary change in farming was officially known as Green Revolution.

### 2.2.3 State of agriculture in India from 1970-2019

The adequate experience with the new agriculture strategy allowed to ask how green the Green Revolution was and whether it was a revolution or only a small palace revolt (Abel, 1970). The author examined the demand and sully situation for agriculture products in 1970. Accordingly specified that India would easily end or become infected as an importer of 10 million tonnes of cereal grains by 1980, if this level of imports were not achieved in the severe absence, the consequences of price increases would increase sharply.

The green revolution had changed the face of agriculture in India and India became independent in its food production (Shetty *et al.*, 2014). Because of these advanced ideas and policies the crop production in India raised to 108.46 million tons in 1970-71, to 129.6 million tons in 1982-81.

The area under wheat and rice cultivation were 23.02 per cent and 10.4 per cent in 1970-71 which increased to 23.18 per cent and 12.98 per cent in 1980-81; 23.0 per cent and 13.4 per cent in 1990-91 while the land under fibre decreased from 5.14 per cent in the year of 1970-71 to 5.08 in the year of 1980-81 and 0.22 in the year of 1990-91. Tobacco productions decreased in India after initiation of green revolution, which came down from 0.27 per cent in 1970-71 to 0.222 in 1990-91. Accordingly, it was understandable that commercial crop took the lead in term of area (Kannan *et al.*, 2011).

Reforms of agriculture in India were discussed by (Kannan *et al.*, 2011). The author reported that the cropping trend in India changed over time and shifted from the growing of food grain to cash crops. The elevation in crop yield since late 1960s was a key factor for accelerated crop production in India. The usage of new crop varieties, irrigation facilities and synthetic fertilisers were important factors that ensure greater growth in crop produce. However, technical and recognized help for some crops such as rice and wheat brought major modifications in crop area and production arrangement in some region. Furthermore, crop production growth indicated that the improved income, good irrigation services, good rainfall and better fertilizers helped to progress crop output in India.

The implementation of high yielding seeds especially improved variety of wheat and the increased use of chemical made wheat production to increase by nearly 150 per cent between the year of 1965-66 to1975-76 and India became independent in crop production by late 1970. Enhanced agricultural yield improved the income of India which eventually led to the decline of food prices thus affecting the poverty in India World Bank (2004).

The decline in the share of agricultural workers among all workers was slower as compared to the decrease in the share of agriculture in GDP noticed as major contradictions of the Indian economy (Dev, 2009). the total agriculture workers declined slightly from 75.9 per cent in 1961 to 59.6 per cent in 1999 and 56.7 in 2004-05. As compared to the 34 per cent decline in the share of agriculture in GDP, the decline in the share of agricultural employment was only 19 per cent. This ultimately led to the slight increase in the labour productivity in agriculture and rapid increase in non-agricultural workers. In 2004-05, there were about 259 million workers among which 42% were females.

Joshi *et al.,* (2006) reported during 1980 the national level technologies was the main reason for the increase in the crop income while upturn in costs and diversification proved to be the leading source of growth in agriculture throughout 1990. The shift to higher value crops like vegetables and fruits accounted 25 per cent and 31 per cent of crop income growth in the 1980s and 1990s respectively. Price increase was the one of the major source of growth in the northern and eastern regions throughout 1990s while in the western and southern regions crop revenue increase was run by diversification in to the higher value crops.

The form of diversification across India had been systematised and various causes of diversification had been deciphered (Singh *et al.,* 2006). The increase in diversification index signified towards non-food grain crops in Karnataka. The index had increased and the similar increase in area under food grain indicates changed from course to fine cereals. In the year of 2001-02, major portion of export earnings came from non-traditional substances, specifically rice, fruits, vegetables, and livestock, which showed improvement to diversification. Indian agriculture had watched diversification with remarkable enhancements in the stocks of livestock and fishery sectors in the over-all income from agriculture. Inside the crop area diversification had mostly been in support of non-food grains crop in most of states in India.

In rural areas the prices of cereals were about 11 per cent lower than the urban areas in 1972-73 which increased to 16 per cent in 1993-94 (Rao *and* Hanumantha, 2000). In India food grains demand was declined and some of this drop specified an increase in consumer welfare. The decline was sharper in the rural areas where growths in organization made other food items and non-food commodities available. However, cereal consumption was increased among the poorest 30 per cent of the population of India.

Indian agriculture sector performed under various restrictions in the last five decades. The standard performance during late sixties, mid-seventies and early eighties helped to overcome the problem of total food anxiety (Deshpande *et al.,* 2002). It was claimed that the annual growth of agriculture showed declined trend in the post improvement period. While it rose at a yearly rate of 3.4 per cent during 1980s, it registered only 1.8 per cent growth among 1997-98 and 200-02. Growth rate was 4.7 per cent among 1992-93 and 1997-98. Also, it was claimed that there was a decrease in area, production and productivity of all crops. Whereas, area under all crops showed a low increase in growth rate during 1990, production and yield showed a decrease trend. Nineties had positive growth rate in GDP in most of the years except few years, but while comparing the aggregate growth, analysts tend to conclude with a bad performance during nineties. Probably the top achieved at the end point in the period of eighties leads to such an inference. It was pretty clear that the act during eighties of the agriculture sector was quite helpful.

The agriculture growth rate recorded noticeable decreased in the post improvement period 1990-91 to 2003-04 as compared to the period of 1980-81 to 1990-91 (Rao, 2008). This declined and unproductivity of agricultural development was impact the income and job engagement of most of local people dependent on agriculture. Almost all the regions in India experienced decreasing agriculture growth. Dry land region and small and marginal farmers with limited resources were the most adverse effected.

Agriculture sector in India had a conventional long period record of enchanting the India out of serious food shortages in spite of swift population increase. This was achieved through a helpful interface of organisation, expertise, addition, and strategy support assisted by strong political resolve. Industrial expansion of production per unit of cropped area was the key source of long runs growth. This caused in boosting of food grain yields, and food grain production enlarged from 51 million tonnes in 1950–51 to 217 million tonnes in 2006–07. Production of cotton, oilseeds and sugarcane in were also increased to 23 million bales, 24 million tonnes and 355 million tons respectively (Government of India, 2009).

The area under irrigation increased by more than four million hectares from 2004-2005 until 2006-2007 which increased irrigated sown area from 40 per cent in 2003-04 to 43 per cent in 2006-07 reported by (Kapur, 2018).

Green revolution has allowed the economy to stand on its own feet in the case of food grains and transformed India from begging bowl to grain bowl (Thomas, 2018). Food cereals production increased from 52 MT in 1951-52 to 264.77 MT in 2013-14. India in 2013 raised second place in wheat and rice production and first in millet production. Accordingly, India became self-sufficient in seed production, yield improving by thirty per cent, providing of better remunerative price than before to farmers. Short maturity period of the high yielding variety seeds, as a major achievement of first green revolution and concentration of green revolution in the certain rich state like Punjab, inequalities among the farmers was an unwelcomed result of green revolution. Author suggested that India need a second green revolution by reporting the statement that India was one of the firmest growing economies in the world, and agriculture sector plays a major role in its journey headed for development by providing livelihood to the half of its work potency. But the share of primary sector in the GDP is much lower than its counterparts, which mean the expansion scheme including the green revolution tracked by the economy has failed to bring the agriculture into the main stream and we have to ensure sustainable development also.

Economic Survey showed that production per hectare of major crops such as paddy, pluses and wheat were low 2015-16 reported by Mugunthan, (2016). India's average wheat production in 2013 was 3075 kg/ha which was lower than the world 3257 kg/ha. All India state had paddy production below that of China even most of that had yields below that of Bangladesh. India's best state, Punjab's paddy production was near to 6000 kg/ha while China produced 6709 kg/ha.

Soil Health Card scheme is under application in India since 2015 to provide soil health care to all farmers in India. Through this scheme farmers would receive information on soil nutrient status of their soils and endorsement on right amount of nutrient application for improvement of soil fertility and soil chemical characteristics (Ministry of Agriculture, 2019).

## 2.3 State of agriculture in Punjab

### 2.3.1 State of agriculture in Punjab before 1947

British occupied Punjab in 1849, which was the last state occupied by them, at the time; rainfall and underground water through wells was the only source of irrigation. British made massive investments in the late nineteenth and early twentieth centuries in irrigation canals which caused the beginning of the agricultural production in Punjab. Capital cost on useful irrigation channels in the state was forty per cent of the total investments made by the British rule during the period of 1919-20 in India. Thus, the segment of irrigated lands in the state was fifty per cent of the total investment for agriculture area (Hirashima, 1978).

After the takeover of Punjab by the British, they paid superior attention in the direction of the process of familiarizing technological improvements in the agriculture sector of Punjab. Punjab Agri-Horticulture society was created in 1851 by the British which was an important development in the agriculture policy. During the 20 years period from 1851 to 1871, the society tried to advance the agriculture sector in the state. So far, it was unable to attain its goals but it provided course for strategies to be assumed for the growth of agriculture in Punjab on modern lines (Kerr, 1976).

Land application designs, somatic topographies of the land, the country cultural unity and to the colonial regime before independence were the factors that affected agriculture in India. The state of Punjab was made up of sandbars, alluvial plains, and an arid dry western region. The sandbars covered about one-fifth of the total area of the state and it occupied by twenty per cent of its population. Mean rainfall was 87.20 cm as tube wells were tough to make in hilly regions. Only sixty per cent of the cultivated areas were watered in this part in comparison to more than 90 per cent for entire state area. The central plains which covered more than half of the total area and inhabited more than 50 per cent of the entire state population was made of old and new alluvium. Above ninety per cent of the net refined areas were watered from three recurrent rivers, many canals and large number of underground wells. The mean rainfall for this part was 57.40 cm. This region of the state was more developed in agriculture in comparison to the other regions while the south-western part of the state was mostly sandy. Agriculture in this part was more developed than in other parts of the state and the south-western region of Punjab was sandy. Though, there were few floodplains (bet) along the river yet. Underground water was in poor condition for irrigation in most parts. More than 85 per cent of the region was watered typically from channels (Bhalla, 1995).

In 1909 the Punjab Agriculture College was established at Lyallpur with the purpose of ratifying agriculture studies, which offered a degree of B.Sc. in agriculture. Continuously other agriculture institutes were established at Gurdaspur in 1909 while another agricultural centre was established in Jullundur to exhibit the techniques of farming to farmers (Bhalla, 1995).

Furthermore, modern methods of cultivation such as better crop rotation, application of organic fertilizers and prevention of crop disease were initiated. Various research works were performed in experimental form at Lyallpur. The nitrogen assimilating crops were included in the rotation and the use of green manure was encouraged. Similarly, various rotations of crops were developed for the different types of land with the advances in irrigation.

The advance implement of promoting agricultural mission was enhanced through the Village Farmers Associations which was established in 1911-12. The farmers made the associations and assumed to follow the strategies of the agriculture centres in all substances linked with the agricultural enhancements. In the year 1920-21 these links were effective virtually in all districts of Punjab (Annual Reports of Punjab, 1921).

Siddiqi, (1984) studied the agricultural advancements in Punjab during the period of 1850-1900. In this era the agriculture production did not change despite the advances in irrigation. The British government was believed to the idea that every individual had the right to the unlimited possession of the land. If by land policy was doomed a comprehensive, will be planned for efficient, long term use of regional agriculture resources. It was reasonably argued that the colonial administration had none. A little concentration was given by the local government to control the use of arable lands which prevented overexpansion of survived agriculture.

Since, the construction of the channels in the first half of the 20$^{th}$ century, the yield of cereals and saleable crops increased. The yield of wheat, maize, sugarcane, and cotton increased from 0.87 million tonnes, 0.28 million tonnes, 124,000 tons, 70,000 bales in 1904-05 to 1.17 million tonnes, 0.03 million tonnes, 279,000 tons, 296,000 bales in 1944-45 respectively (Ministry of Agriculture, 1976).

Agricultural development in Punjab played an exceedingly significant portion in the situation of agricultural expansion in India. The rate of food grains production in Punjab along with Bombay made the decrease in rest of the country, the rate of increase of food grains yield at the national level was almost zero from 1891 to 1946. The growth rate of agriculture yield for all crops in Punjab was 1.570 per cent per annum; that of acreage to be 0.960 per cent per annum and of output per acre to be 0.620 per cent per annum (Blyn, 1961).

During the British period agriculture was the major source of livelihood for the most of the population and the government revenue in Punjab (Mandakini and Bath, 2016). Thus, it became one of the thrust areas that determined the British polices. It also attributed to the transformation of the economy in the state. Accordingly, during the start of British government in Punjab, the agricultural processes in use, the feature of seeds, animal farming, crop rotation process and promotion of agriculture output was virtually becoming stagnant and useless. The British rule in Punjab opened the way for the introduction of western science and technology in the province. Numerous technological development like better irrigation structure, better livestock, the new technique of crop growing and use of more compost initiated by the British. Modification in the method of production conveyed substantial change in socio-economic format in Punjab and their effects were progressive and long-term.

In the half of the nineteenth era, the fast political change and constant warfare were adverse for the rapid expansion of agriculture science and technology. In the state, the Lahore Darbar and the East India Company were busy in the postponement of their own kingdoms. As a result more pressure was given on the development of the traditional modes of cultivation and irrigation and moderately slight was done for the introduction of new technical innovations (Singh, 1982).

### 2.3.2 State of agriculture in Punjab from 1947-1970

The division of the India and partitioning of Punjab in 1947 allocated a big setback to the Punjab agriculture, as a large part of productive and irrigated lands went to west Punjab in Pakistan and also led to the pull up and migration of a good-sized part of the population across the border (Singh, 2001). This apart on the positive side, the rich experience of the migrant farmers from previous canal groups helped the conversion of fairly regressive agriculture in the Punjab. The programmers of land reforms and consolidation of holdings further supported the farmer proprietorship in land. Agricultural education and research got boost, with Punjab Agricultural University being established at Ludhiana in 1962. Administration also invested deeply in the formation of infrastructure such as construction and development of canal irrigation scheme, rural electrification, rural roads system and agriculture market, development of health and public organization and expansion of many institutions to additional agricultural development.

Since the beginning of planning in 1950-51, Punjab recorded a very high rate of agricultural growth. Through the various land reforms and public investments during 1950s basic institutional and economic infrastructures were created in Punjab (Bahlla *et al.*, 1990).

British invested in the field of irrigation, power, and research in agriculture along with market development led to the advances in agriculture in the state. Concurrently, regulations to reform lands were passed and brought into effect. Accordingly these land reforms were unsuccessful to bring any improvement in land ownership, but the policies were successful in removing the intermediaries and decreasing the occupancy. These reforms during at the beginning of independence years placed the foundations for swift growth and transformation of agriculture. The state of Punjab recorded high agricultural growth due to the huge investment in irrigation, rural organisation and improvement of institutional structure during the period of 1950-51 to 1964-65.

Technological changes expanded production by raising the efficiency of input used and elevated engagement by increasing the demand for labour. But the comparative growth proportions of output and employment were depended upon the kind of technical change. There was a close association between the level of technology, agricultural expansion and the design and amount of labour employment. In the Punjab state, agriculture has experienced a quick technological transformation in the system of seed, irrigation method, and fertilizer with the advent of Green revolution (Sidhu and Grewal, 1990).

Agriculture development in Punjab was highly related with the well-recognized of Green Revolution which led to the development and use of modern high yielding varieties of food crops especially wheat and rice. The inspiring agriculture improvement in Punjab was showed by the elevation in the conditions of wheat production that increased to 5.6 million tons in 1972 from 1.9 million tons during the year 1965. Similarly Singh and Kohli, (2005) reported massive growth in rice production.

After adoption of new agriculture technology made up of hybrid seeds, synthetic fertilizer, insect repellents, and new agriculture practices in mid-1960 the state made wonderful development and in just few years, the state established itself as a hub of India's successful green revolution policy (Sidhu, 2005). These modern technologies focused to achieve changes in the agriculture system. After initiation of modern technologies in 1966, Punjab witnessed huge development in agriculture system. The author mentioned that it was essential to recognize that the Punjab agricultural system would not be same as what it is today, if India did not pick in favour of new system of agriculture to resolve the lasting food scarcity which it suffered in late 1950 and early 1960.

Singh, (2011) reported that the conformity of different new agriculture methods had supported the role of agricultural sector in the economy progress and employment generation of Punjab. The cropping concentration in Punjab was the highest among the Indian states. The invention and output of main crops increased few times due to the beginning of green revolution, but it limited the state to produce only two crops such as wheat and paddy, which resulted in unhealthy soil, pest infected crops, damaged groundwater and water logging wages.

The Green Revolution brought a swift development in agriculture of developing countries because of modern mechanical and petrochemical efforts throughout 1960s and 1970s, which was the beginning of modern wealth intensive agriculture in India (Dutta, 2012). Punjab was chosen as the first state for the initiation of Green revolution in India, although it was relatively dry, there had been extensive development of irrigation system during the British rule. Additionally, Punjab was also home to large number of wealthy farmers who became the earliest receiver of the benefits of green revolution (Sebby, 2010).

Interdiction of seed and fertilizer technology in Punjab during the mid-1960 brought huge change which led to extraordinary growth of agriculture output, particularly for wheat and rice (Bhalla *et al.,* 1990). Due to close input, feeding linkage and yield swift agricultural improvement was achieved by even faster growth in the industrial sectors. Thus, total income of the state increased to 5.0 per cent during 1960-61.

Punjab experienced a remarkable agricultural growth which was the highest among all the other states during the period of 1960s to the mid-1980 (Datta, 2012). It helped to improve the social and economic condition of the farmers and hurled it to the status of being called the "grain bowl of India". After that agriculture production sector in Punjab became extremely capital intensive and mechanised. During the period of 1960s to mi-1980 the state reached 95 per cent irrigation coverage of net agricultural area and 98 per cent gain in high yielding seed varieties.

Use of agricultural machinery and inorganic fertilizers greatly declined the employment rate in the state, while technological parameters such as cultivated area, cropping intensity, higher use of inputs, etc. increased labour use (Singh and Singh, 2006). The back-and-forth of these factors resulted in net decline in the human labour requirements. The author pointed out that the total requirements of Punjab agriculture was 651 million man days which dropped to 638 million man days in 1970 to 1971.

**2.3.3 State of agriculture in Punjab from 1970-2019**

Punjab agriculture development rate was the highest among the other states of India during the 1960s until the middle of the 1980. The rate of agricultural yield income was almost double than the income of the rest of the nation during the period of 1961-62 to 1985-86. The use of high yielding varieties of crops in Punjab was 73 per cent where as it 31 per cent in India, which further was increased to 95 per cent I 1983-85, while it was 54 per cent in all India. Although Punjab had 17459 tractors per 100,000 holding tractor while in India it was only 714. It was not only to the new agricultural technologies and high yielding varieties of seeds that the accomplishment of the green revolution was endorsed. The hard work and innovation of the farmers of Punjab was also highly praised. Their adoration for acreage and the attachment of them to the self-cultivation were the key which made the green revolution a success story in the area much before it spread to other state of India (Jodhka, 2006)

Bhalla *et al.,* (1990), reported that the share of area under wheat cultivation in the net agriculture area increased from 26.9 per cent in 1950-51 to 44.1 per cent in 1984-85. The shear of rice increase to 23.4 per cent in 1985 from 5-6 per cent in 1965

. For other crops, the area under cultivation decreased after the green revolution. Accordingly, yield grew remarkably in rice and wheat as compared to rest of the crops. Wheat produce grew by 2.6 per cent per annum during 1967-68 to 1984-85. The increase in rice yield was very impressive as it increased to 5.7 per cent in the post 1967 years from 1.7 per cent per annum in the pre green revolution era. Wheat output increased from 2.4 million tons in 1964-65 to 10.2 million tons in 1984-85. The production of rice was increased to 5.10 million tons in 1984-85 from 0.5 million tons in 1969-70. During this period rice and wheat became the major crops for cultivation in the state and it was related to the huge proportion of total agriculture yield.

In the 1970s and 80’s a large number of small farms were unable to keep up with the competition. There were 1,375,382 landholdings in Punjab in 1971, and this number fell to 1,027,127 by 1981. This decline of nearly 25 per cent of the farms of Punjab led to a shift towards large farms. In 1984, 24 per cent of small farmers and 31 per cent of marginal farmers were living below the poverty line (Singh, 1984). From 1977-79 there was an increase in per hectare income while, the financial returns from farming were decreased in Punjab (Sebby, 2010).

There was a rapid increase in the productivity of wheat and paddy during the initial years of the green revolution in Punjab. This was because of the larger use of new efforts such as fertilizers, irrigation; high yielding varieties of seeds and greater mechanization. In spite of these high doses of these inputs, productivity growth became slower and in the case of wheat, it was nearly established (Kaur *et al.,* 1990). The slow growth in productivity was complemented by quick growth in costs leading to a fall in the returns. The net returns over active costs from wheat cultivation per hectare at 1970-71 prices dropped from Rs 328 in 1971-72 to RS 54 in 1981-82. With the failure in the rate of return, small holdings were no longer workable. In the early 1970s, the green revolution backed to the stability of small farmers but in the late 1970s the load of economic crisis became more severe and intolerable, this headed to the breakdown of small and marginal farmers. Accordingly, between 1970-71 and 1980-81 there was a decline in the number of marginal holdings by 61.9 per cent and that of small holdings by 23.3 per cent. There was an increase in the number of medium, large and extra-large assets respectively by 2.3 per cent, 8.6 per cent and 7.3 per cent respectively. The net result was, 25.3 per cent of total operational holdings, disappeared during the 70s.

Diversification of agriculture in Punjab started on November 8, 1985, while the government of Punjab selected an expert committee, headed by Dr. S.S. Johal. Committee made some recommendations and submitted its report in May 1986. Since the committee was selected to look into the opportunities of diversification of agriculture, its agenda was concerned mainly with agriculture. After investigative economies of numerous creativities and given attention to various possibilities, the committee concluded that the impact of diversification power will not be felt except at least 20 per cent of the area occupied by wheat and paddy crops were diverted to other crops (Government of Punjab, 1986)

Agricultural diversification was suggested as the future strategy to address the problems and challenges in Punjab agriculture. Chand, (1999) studied the range of agricultural diversification by examining several proportions of the recommended alternative. The author discussed the predictions of the diversification alternative and its allegation on employment, income, natural resources, and ecology. Also, a strategy for the agricultural and economic development of Punjab in the post green revolution was suggested by the author.

The period of the 1970s and the 1980s was the excellent era for the agricultural economy, when the production of important crops developed expressively, the income of farmer's improved, agricultural employment increased and the national food economy turned from being deficient to self-sufficient while the era of the 1990s was serious for the farming economy of Punjab (Sidhu *et al.*, 2005).

The area under cotton was harmfully affected after the mid-1990s because of harsh weather and insect attack, its share in gross crop area decreased to 5.97 per cent in 2000-01, but in 2007-08 it again began to increase and became 7.69 per cent due to introduction of Bt varieties. The areas under cultivation of sugarcane, potato did not changed, pulses and oilseeds decreased to 0.25 and 0.71 per cent in 2010-11 from 7.29 and 5.20 per cent in 1970-71(Singh *et al.*, 2012).

The contract farming program launched by the Punjab government in October 2002, was expected at taking away 10 lakh hectares from the wheat-paddy revolution over the next five years as part of the crop adjustment program (Singh and Kohli, 2005). In 2002, a total of 29,000 acres had been sustained by the Punjab Agro Foodgrains Corporation (PAFC) under the program, applied jointly by the Department of Agriculture, Punjab Agro Industries Corporation and private companies. The PAFC not only delivered seeds purchased from there believed seed companies but also promised to purchase back the whole yield at pre-decided prices through a 3rd party agreement.

Punjab occupies only 1.5 per cent land of the country but it contributing 40–50 per cent rice and 60–65 per cent wheat to the central pool for the last 30 years. The agricultural land under food grains reached to 634,00 sq km from 39,200 sq km and the production rice and wheat reached to 0.32 from 0.18 kg/$m^2$ and 0.43 kg/$m^2$ from 0.22 respectively (Aggarwal *et al.,* 2009). This modification in agricultural system improved the need of irrigation water and the watered land reached to 95 per cent from 71 per cent in Punjab. Thus, there was a dire need to change at least 5 to 10 per cent of land under paddy cultivation, adoption of effective water management system and underground water supplementation technology on large scale for sustainable agriculture.

Punjab was a symbol of India's grain over supplies, giving India a much-needed food security but after 1985-86, green revolution started slowing and growth in Punjab agriculture decreased to 3 per cent per annum over the period of 1985-86 to 2004-05, virtually same as achieved at all India level (Gulati *et al.,* 2017). During 2004-05 to 2014-15 Punjab faced a real challenge, while its growth slowed down to just 1.6 per cent per annum, which was less than half of the all India Agri-GDP growth of 3.5 per cent over the same period. Providing food security to the country and reducing its own poverty to lowest levels within all India context, were the most admirable achievements of Punjab. Then, recently Punjab lost its well-known position of being the state with the highest per capita income in India, a title it carried since its beginning in 1966 till 2002-03. In 2014 Punjab stood at 7th position in per capita income amongst 21 major states of India.

Soils of Punjab were developed on alluvium at the initial to the medium stage of profile development. They were generally very deep, porous, sandy loam in texture, and showed weak to moderately developed soil structures with good soil, air, and water relationship. With intensive agriculture surface crusts, subsoil compaction, soil erosion, development of hardpan, development of fine-textured, sodic soils, pollution from agrochemicals, nutrient imbalance decline in quality and quantity of soil biomass and slow rate of decomposition of crop residues were the major problems being faced by the Punjab soils. In 2010-11, about 31,000 ha of land were reclaimed in Punjab through the application of 20 thousand tons of gypsum. And a total of 5.91 lakh ha of land was reclaimed through gypsum application in Punjab so far (Singh *et al*., 2012).

The total food grains production in Punjab increased to 290.92 lac metric tonnes in 2011-12, showing an increase of about four times. Wheat and rice played a major role in increasing agricultural production significantly in Punjab. The production of rice increased from 6.88 lac metric tonnes in 1970-71 to 105.42 lac metric tonnes in 2011-12, which shows a very significant hike of over 15 times. Similarly, the production of wheat has increased from 51.45 lac metric tons in 1970-71 to 179.82 lac metric tonnes during 2011-12 registering an increase of over 3 times. During 2010-11, the total cropped area of Punjab was 7882 thousand hectares; about 92.76 per cent was under 17 major crops in all districts of the state (Punjab Government, 2019).

Sustainability of resource use in Punjab was studied by (Taneja *et al.,* 2018). The indexes were based on three components namely land, water, and air. The data were deployed on five indicators pertaining to these components from 1970 to 2015. The overall index showed a decline in resource sustainability in the entire Punjab. Majority districts in the central and south-western regions became highly unsustainable overtime. Thus, a regular assessment of the sustainability of resource-use was required and this index could be useful for effective policy decision making. The overall index highlights the nature of resource sustainability. It raised awareness and understanding of district-level differences in sustainability. It aimed to trigger interventions leading to sustainable solutions in agriculture for Punjab.

Punjab witnessed a total annual wage of farmers from Government Procurement of Foodgrains was increased to Rs 1.24 Lakh Crore since April 2017 which was a rise of about Rs. 30,000 Crore over the earnings in the consistent procurement seasons of the previous Government and formers profits through the selling of food grains increased by 32 per cent. Overall Production of Cereals was increased from 30.75 Million Tons in 2016-17 to 31.7 Million Tons in 2017-18. Despite heavy rains and inclement weather, the production in 2018-19 was 31.50 Million Tons. The Agriculture Produce Markets act was modified to ensure agricultural marketing reforms and greater use of technology. Punjab State Council for Agricultural Education was established in Punjab to promote agricultural education in 2017. Accordingly, The Gross State Domestic Product had raised about 23 per cent from Rs 4.28 lakh crore in 2017- 18 to Rs. 5.18 lakh crore in 2018-19 (Punjab Government, 2019).

## 2.4 Soil Survey

### 2.4.1 Role of soil-forming factors

It has been generally recognized that soil is the ultimate product resulting from the integrated effects of living matter and climate acting upon parent material, as conditioned by relief over a period of time (Sehgal, 1974). In Punjab, some of the soil-forming factors like parent material (alluvium), vegetation (which is scanty), topography (monotonous plain), and time were quite comparable. The variations in climatic conditions, however, seemed to be greatly responsible for the development of differences in soil profiles. The influence of topography and time, however, was of local nature.

The soils of south-eastern part of sub-mountain tract of Punjab were studied in relation to topography by remote sensing followed by ground survey and laboratory analysis by Sawhney *et al.*, 2000). The study demonstrated a well-marked soil-physiographic relationship in the area having typical soil on each landform unit. The soils on relatively unstable landforms indicated young and immature A-C profile whereas, those from stable landforms showed distinct profile development having A-Bw-C and A-Bt-C horizons sequences. Topography and parent material were found to be the major factors governing the soil characteristics, especially on unstable surfaces whereas, time as an additional factor on stable surfaces.

In the Indo-Gangetic plain (India), a sequence of soils, developed under different climatic conditions was investigated micro-morphologically to study the evolution of the pedogenic calcite formations (Sehgal and Stoops, 1972). The climate of the plain grades from arid and hot to semi-arid and hot to less hot, and the soils, respectively, from Camborthids, through Calciorthids and Ustochrepts, to Haplustalfs. Nine different forms of calcite accumulations from microcrystalline calcite to coarsely recrystallize were distinguished and described. They may form combinations which were characteristic for specific soil conditions. An evolution pattern of different forms could be determined, not only within profiles but also among different soil types of the sequence; the highest complexity was found in the calcic horizons. Specific forms were observed in the saline and waterlogged soils. The origin of the different calcareous accumulations was discussed and the authigenic character of the calcitic nodules was propounded. In the scope of these findings, the use of the suffix Ca in horizon designation was discussed.

The main factors affecting the soils formed in the mountains of south-western Alberta were climate (principally water balance), parent material (texture, porosity and chemical composition), vegetation (especially on avalanche slopes), topography (aspect and slope angle) and time (Howell and Harris, 1978). Important local factors were fires and avalanches. The least well studied factor was undoubtedly that of time, but this could be overcome by more sedimentological studies, carefully differentiating the properties due to parent material, to a degree of weathering and to soil formation in situ.

The soils developed on alluvium covered major portion of Punjab, India. The alluvial plain between Beas and Sutlej Rivers in the central of Punjab was popularly known as Bist Doab which exhibited interesting landforms viz., flat plains; terraces; sand dune complexes; channels; flood plains and piedmont areas. The localized areas within the flat plains were salt-affected. The parent material of these soils was derived from the Himalayan mountains by river of Indus system during Pleistocene and recent times (Wadia, 1966).

The soils exhibited varying degrees of pedogenesis ranging from undifferentiated sediments in the flood plains and sand dunes to the soil showing argillic/Natric/Cambic horizons in planned areas away from the rivers (Sehgal, 1974).

Moreover, the differential degree of pedogenic development between the flood plain, channels, and upper terrace soils was due to topography and time, however, the differences within the upper terrace soils were probably due to rainfall.

Four dominant soils representing different physiographic units were investigated for their pedogenesis (Sharma *et al.,* 1979). According to the study the Samana soils (from sand dune complexes) permitting easy percolation of water were well drained, Dhoda and Jagjitpur soils (developed in flat plains) showed the presence of Fe-Mn concretions of mottles below surface horizon were imperfectly drained and Jatwan soils (developed in channels), showed characteristics associated with wetness (reduced colour accompanied by mottles and Fe-Mn concretion below 32 cm) were poorly drained. Samana soils showed the leaching of carbonates from the column and other soil showed the variable amount of free carbonates in the control section. In Jagjitpur and Jatwan soils, the carbonates had also been precipitated in the form of lime nodules but none of these soils showed the development of calcic horizon. The irregular distribution of soil separated as also of sand silt ratios suggested lithologic discontinuities in all the pedons, indicating stratified parent material. The specific difference between the soils developed on different geomorphic zones was explained in the light of different soil-forming factors affecting this area.

In the semi-arid region of Punjab in North-west India _annual rainfall 700–1320 mm, Alfisols occur on the concave surfaces within the landscape. These Alfisols were neutral to alkaline in reaction. Heavy monsoon rains following hot and dry summers promoted dispersion of clay particles upon wetting. Concavity of the landscape resulted in the accumulation of runoff water from the adjoining areas. The rainfall distribution pattern and topography interacted to facilitate lessivage leading to formation of Alfisols in association with Inceptisols (Sharma et al., 1998)

An investigation on soil formation of Hissar by Singh *et al.,* (1974), revealed that the parent material of soil was older alluvium and wind-blown sand and loess through the cyclonic storms from the adjacent area of Rajasthan deserts and physical weathering was more dominant over chemical weathering. Biota had no significance due to its scarcity. The day temperature was very high and the difference between day and night was quite appreciable along with scanty rainfall, more evaporation in comparison to precipitation was caused. External topography was flat or undulating but as a whole, the area was a part of closed drained basin. Furthermore, due to the combination of climate and topography factors, all the soluble based (K, Na, Ca, Mg) were not drained out to get concentrated in the soil as salt. Because of higher rates of evaporation Na salt moved to the surface through capillary movement and saline-alkaline conditions were created because of Na-salts.

### 2.4.2 Soil characteristics

#### 2.4.2.1 Soil morphological characteristics

Rubber growing soils of Kerela in India were studied by (Chandrakala *et al.,* 2018). The study revealed that, the soils were very deep to very shallow. Well drained to somewhat poorly drained, brown, dark brown, reddish brown, dark reddish brown, dark yellowish brown, yellowish brown, dark gray, yellowish red and red in colour. Moreover, soils were non-gravelly to gravelly. In sub surface soils iron concretions and mottles were observed. Generally surface structure was weak and fine to medium with sub-angular blocky whereas, sub surface was moderate, medium with sub-angular blocky. Consistency was friable, sticky and plastic. The clay content was 11.37 to 41.60 per cent in the surface soil and ranged from 8.95 to 63.52 per cent in the sub soil.

Six soil profiles (two each from vegetables, paddy and maize growing areas) from Balh Valley District Mandi, Himachal Pradesh (India) lying in North West Himalayas were studied for their morphological, physical and chemical properties (Mahajan *et al.,* 2007)The results shows that soils were deep, well drained, silty loam to silty clay loam with dark brown to brownish yellow in colour. No gravels were noticed up to 0.6 m depth and the soil consistency was firm to loose. Few too many black brown concretions were observed only in rice growing soils. Silty loam was the dominant texture of the soils irrespective of soil depth. Coarse sand fraction was more in all soil profiles. In none of the soils except Dhangu, illuviation of clay had been observed. The values of bulk density, particle density and porosity were variable depending upon organic carbon and other soil characteristics.

Eighteen typical soil pedons from Kavalur-1 micro watershed of Koppal district in Karnataka were identified and examined for their morphological characteristics, which represented the black and red soil areas (Prathibha *et al.,* 2018). The results revealed that the pedons were deep (100 - 150 cm) to very deep (>180) and varied in colour from reddish brown (2.5 YR 4/4) to dark reddish brown (5 YR 3/4) in case of red soils and dark greyish brown (10 YR 4/2)) to brown (10 YR 5/3) in case of black soils. Soil texture varied from sandy clay loam to clay and showed weak to moderate sub-angular structure. Consistence of soil pedons varied from slightly hard to very hard when dry, very friable to firm when moist, slightly sticky to very sticky and slightly plastic to very plastic when wet.

Morphological, physical and chemical characteristics of soils developed on three physiographic units such as sand dunes, interdunal areas, and alluvial terraces in the arid zone of Punjab in Northwest India were investigated. The morphological features revealed that in general the soils had 10 YR hues throughout the profile depth. The soil of alluvial terraces was comparatively darker in color in B horizon (value 4) than those of the sand dunes, which had higher value (5). Sand dune soils had sand to loamy sand texture in A horizon and loamy sand textures below. These soils did not show any gradation or stratification with depth. There was no structure development; the soils invariably were single-grained due to coarse texture. In soils of interdunal areas, texture was generally loamy sand in the surface horizons, sandy loam in B horizons, and sandy loam to loam in C horizons. Alluvial terrace soils were sandy loam in A horizons, loam in B horizons, and loam to clay loam in C horizons. The B horizon of interdunal soils had weak fine sub angular blocky structure, while the alluvial terrace soils had comparatively better developed weak fine sub angular blocky to weak medium sub angular blocky structure (Sidhu and Sharma, 1990)

A soil profile representative of typical soils of Mwala District, Kenya, was dug to study the morphological and physico-chemical characteristics of soil (Karuma *et al.,* 2015) Soil morphological observations revealed that the pedon was well drained and very deep with dark brown to dark yellowish brown topsoil overlying brown to strong brown sandy clay loam to sandy clay subsoil. "Clay eluviation's - illuviation is a dominant process influencing soil formation in the study area as indicated by the clay gradient between the eluvial and illuvial horizons and the presence of clay cutans in the subsoil. The soil was characterized by weak fine sub angular blocky throughout its pedon depth".

Soils in the Prakasam district of Andhra Pradesh were moderate deep to very deep along with moderately well drained conditions. According, the colour of the soil profiles ranged among 2.5YR to 10YR. Texture of the soils in this district was found to be loamy sand to clay, single grain, angular blocky and sub-angular blocky soil structure. The consistence of these soils showed variation among horizons of pedon and among pedons (Sekhar *et al.*, 2019).

In Bathinda district, the soils showed various morphological and physico-chemical properties like dunes, alluvial terrace and interdunal areas (Singh and Sharma, 2013). The soils present in the dunes were coarser in soil texture, lacked subsurface diagnostic horizons and do not showed structural development. Soils developed on interdunal terraces had yellowish brown colour in epipedon and dark yellowish brown in lower horizons and were relatively fine along with development of a structural B horizon. The alluvial terrace soils were fine, dark yellowish brown in colour throughout the profile and soil structure varies from weak fine sub- angular blocky to massive.

Thangasamy *et al.*, (2005) studied the soil characteristics in Sivagiri of Chitoor district in Andhra Pradesh. The study revealed that the soils were mostly deep and inappropriately drained. Soil colour was also varied from yellowish brown to dark grayish brown, along with crumb, sub-angular blocky, angular blocky and single grain structure. Consistency was hvs (dry), mfr (moist) and wss, wsp when wet depending on the clay content. Furthermore, Slight to effected with dilute HCL was observed in all the pedons.

The Davangere district of Karnataka in India had a combination of moderately shallow or shallow and deep or moderately deep soils (Vikas *et al.*, 2018). In all soil pedon hue was 2.5YR and 5YR, due to ascendancy of sesquioxides completed silica. The colour was darker in surface horizon than the sub surface horizons of profiles and the subsurface horizons had comparatively brighter colour chroma. The structure was sub angular blocky in epipedon and subsurface horizons. The consistency was recorded moderate to hard when dry and friable to firm when moist.

The colour of the soils in Garakahalli watershed in Karnataka varied from red to reddish brown in upland and reddish brown to grayish brown in the lowland Pillai *et al.,* (2004). The strong brown colour in the surface horizons was due to high organic matter content whereas in deeper layers the dark colour may be influenced by the parent material or ferrous iron oxide. The soils located on gently sloping topography showed yellowish brown to dark red while the soils found on nearly level topography showed light yellowish brown to very dark grayish brown.

The soils in upper slopes of Chhotanagpur plateau were yellowish red in epipedon and dark red in the lower layers, while the soils lower slope of the top sequence were light brownish gray to light gray in surface horizon and gray in the lower layers (Sarkar *et al.* 2001).

Seven soils series in Rajkot district of central Kathiawar region of Gujarat state were studied by Sharma *et al,*. (2001). Soil was widely different in their morphological, chemical and physical properties. Major variations were observed in soil drainage, colour, structure and depth in relation to top sequence. Soils were low to moderate in deep, somewhat extremely well in drainage, clay loam to clay in texture and reddish brown to dark brown in colour in surface, whereas in sub surface the soils were deep to vary deep, moderately well drained to poorly drained, clay in texture and grayish brown to dark grayish brown in colour.

Soil compaction is one of the main problems facing modern agriculture. Soil compaction in cropping system was reviewed by Hamza and Anderson, (2005). Overrate of machinery, intensive agriculture, short crop variations, severe grazing and unsuitable soil management are the factors that leads to compaction, also they reported that soil compaction occurs in a extensive kind of soils and climates and intensified by low 'organic matter content in soil and use of digging or rasping at high soil moisture content. Authors that soil compaction positively affect soil strength and negatively affect soil physical fertility through decreasing storage and supply of water and nutrients, which cause too much fertilizer requirement and higher production cost.

**2.4.2.2 Soil physical and chemical characteristics**

Soil and ground water of Kapurthala district was studied by Uppal H.l (1957). An area of about 136,217 ha, comprising of the tehsils of Kapurthala, Sultanpur Lodi, Bhallath and Phagwara was surveyed for soil and ground water. Of the 1,230 profiles studied in connection with the quality of soil, 630 pertained to the former there tehsils, were on the basis of a 242 ha grid, whilst 600 profile were related to the tehsils of

Phagwara, were on the basis of a 161 ha grid. The profiles extended to a depth of 10ft. The area, comprising of the entire district of Kapurthala was divided in to three category on the basis of reconnaissance and survey, area under high salt, high alkalinity and damaged structure covered 48,724 ha, excessively sandy, but normal with respect to salt content and alkalinity covered 11,331 ha, and good in all respects covered 64,749 ha respectively.

Sub humid soils of different districts of Kashmir region were studied by Mahapatra *et al.,* (2000). The physical and chemical characteristics and well recognized soils physiographic relation exists in this hilly region. The soil texture varied from sandy and loamy skeletal to fine loamy and fine, the soil pH recorded acidic to slightly alkaline and the content of organic matter was generally high. Soils of the study area were classified under the orders of Entisols, Inceptisols, Alfisols and Mollisols respectively.

Macro morphological, physical and chemical properties of forest soils in North Karnataka were investigated by Shamsudheen *et al.*, (2005). Accordingly, soil texture varied from sandy loam to clay in the study area. Coarse fragments and sand fraction were recorded in a high amount. The soils were acidic in nature; the pH ranged 5.1 to 5.9, rich in OC content and CEC was reported low. Based on the characteristics, these forest soils were classified as Dystrypt Haplustepts, Kanhaplic Haplustalfs, and Ustic Haplohumults.

Thangasamy *et al.,* (2005) studied the soils of Sivagiri Micro-watershed in Andhra Pradesh and reported acidic and to slight alkaline soils, low ECE with low organic carbon percentage, with huge variation in soil texture. Available NPK were reported low to medium and sulphur in the study area was high. The authors reported that these soils were deficient in Fe, deficient to sufficient in available Zn and sufficient in available Cu and Mn.

Soil pH of Shikohpur watershed in Gurgoan district of Haryana was somewhat acidic to alkaline with and ranged from 6.11 to 8.57 (Sitanggang *et al.,* 2006). The rise in soil pH down the slope might be attributed to leaching of bases from higher topography and receiving stored lower elevations and also high concentration of calcium carbonate in the lower areas. Further, the KCl-pH values were lower than the water pH standards and the change among KCl-pH and $H_2O$pH values with huge negative value ‘more than -0.5’ specified a high negative epipedon charge density in these soils.

Some preliminary results from analyses of the soil samples and data were argued by Kelly *et al.*, (2010) in Iraq and Afghanistan. According to the study soils at the epipedon and subsurface were different based on texture, spectral and chemical properties. Remote sensing technology was used to identify the soils in Afghanistan ad Iraq. Regular arrangement of soils characteristics existed in the arid soils in both countries.

Soils advanced on different physiographic unite (sand dunes, interdental areas and alluvial terrace) in Bathinda district in the arid zone of Punjab were studied by Singh & Sharma, (2013). Soil of sand mounds were coarse in soil texture, silt percentage were ranged from 2.0 to 16.01 per cent while the clay percentage varied from 2.9 to 8.9 per cent. These soils do not have subsurface diagnostic horizons and do not show structural development. The alluvial terrace soils were fine textured, soil bulk density ranged from 1.40 to 1.61 Mg $m^{-3}$ in sand dune, 1.42 to 1.66 Mg $m^{-3}$ in interdunal and 1.49 to 1.72 Mg/$m^3$ in alluvial terrace soils. Available volumetric water content varied from 9.3 to 15.7 per cent in sand dune soil, 10.60 to 16.20 per cent in interdunal area soils and 16.09 to 26.3 per cent in alluvial terrace soils. The fine texture alluvial terrace had the highest cation exchange capacity with mean of 8.44Cmol $kg^{-1}$, followed by interdunal 6.41Cmol $kg^{-1}$, and sand dunal soils 4.97 Cmol $kg^{-1}$, respectively.

Soils of hill forest at Chittagong collage of Bangladesh were studied for their physical and chemical characteristics. Four profile soil samples were collected based on the depth of soil horizon. Soils of all the pedons were categorised by coarse texture 38 per cent to 73 per cent sand portion, great bulk density, low OC percentage ranged from 0.26 per cent to 1.73 per cent, and acidic soil reaction varied from 4.40 to 5.50. Furthermore, soils were poor in exchangeable cation and cation extract. The CEC ranged from (9.12 $cmolckg^{-1}$ to14.5 $cmolckg^{-1}$), the exchangeable aluminum concentration ranged from 0.41 to 0.66 $cmolckg^{-1}$.(Akhtaruzzaman *et al.*, 2014).

The effects of plant covers on soil of Jilani Park Lahore were studied by Shoukat *et al.*, (2018). Soil pH of selected sites varied from 7.7 to 8.5 but under canopy and grass patches ranged from 9.8 to 10.3. Most of soil samples were non-saline but soil under plant cover was moderately saline. The analyses revealed that the soil contained increased proportion of accessible and low quantity of nitrogen. Moreover, the Jilani's Park soil also contained a significant amount of organic matter.

Physico-chemical properties of soils in Rahim Yar Khan District of Punjab province, Pakistan, were investigated by Aamer *et al.,* (2015). Sandy loam to loam texture was reported about 52 per cent of the electrical conductivity values within the normal range. The pH values of 92 per cent the study area ranged from 7.50 to 8.50 and 7.0 per cent soils had pH more than 8.50. About 93 per cent soils had low organic matter and 7 per cent soil samples had acceptable content of organic matter. About 47.0 per cent soils had low available phosphorus, 33 per cent samples had acceptable level of Av. phosphorus and 20 per cent samples had satisfactory level of available phosphorus contents. The K status of most of soils was suitable.

Different part of soils in Prakasam district of Andhra Pradesh in India were characterized by Sekhar *et al.,* (2019). Seven typical pedons samples were collected from Prakasam district. Soils were somewhat alkaline to alkali; the pH is ranged from 7.2 to 10.3 in reaction. Soils had ustic soil moisture regime and isohyperthermic temperature regime. Texture of the profiles ranged from loamy sand to clay. Organic carbon ranged low to medium and CEC ranged from 8.65 to 51.48 cmol $(+)kg^{-1}$, respectively. These soils were low in available nitrogen, low too high in available phosphorus and medium in available potassium. Moreover, these soils were deficient in DTPA extractable Zn except in the surface horizons of pedon 3, sufficient in Fe except in the Bw1 horizon of pedon 1, sufficient in Cu except in A3 horizon of pedon 7 and sufficient in Mn.

### 2.4.3 Soil classification

Soils of Punjab were characterized and classified by Sehgal, (1974). Based on the contribution of various climatic elements six climatic classes and three main soil moisture regimes have been discussed and soils were classified in to five orders such as Aridisols, Entisols, Inceptisols, Alfisols and Mollisols. Also he noticed 9 suborder, 17 great groups and more than 25 subgroups in the soils of Punjab. Accordingly a generalized soil map was prepared; showing the distribution of the major kind of soil.

The study revealed that a major part of Punjab was occupied by the Inceptisols and Aridisols followed by Alfisols and Entisols. Only a small fraction of the area was occupied by Mollisols.

The soils of Kapurthala were investigated by Sharma et al., (1982). The soil of Kapurthala district had been grouped in sixteen soil series including six series of the salt affected members. The soils of Kapurthala district were classified in 3 order (Aridisol, Inceptisol, Entisol), 4 suborder (Orthids, Ochrepts, Fluvents, Psamments) and 4 great groups (Cambothids, Ustochrepts, Ustifluvents, Ustipsamments). According to the study statistics, it was estimated that about 53,858 ha (32.25 per cent) was salt affected out of which about 68 per cent was severally to moderately affected.

Sawhney *et al.,* (2000) studied the topography of soils in south-eastern region of Punjab. The soils present in unstable landforms had young and immature A-C profile and the soil in stable landforms indicated distinct profile development having A-Bw-C and A-Bt-C horizon sequence. The soils on upper piedmont plain were classified as Typic Ustorthents, 'choe' beds as Typic Ustipsamments, recent flood plain as Aquic Ustifluvents, lower piedmont as Typic Haplustepts and old alluvial plain as Typic Haplustalfs.

Characterization and classification of four Vertisols located in Maharashtra plateau of Ahmed Nagar and Akola districts were studied by Challa *et al.,* (2000). Amalnar and Valpisoils had more calcium carbonate content than the soils in other places in the plateau. The study also reported the increase of sodium adsorption ratios in all the pedons and the maximum sodium adsorption ratio was found in slickenside zone. The soil environment was generally found to be dominated by sulphates, chlorides and bicarbonates. Zone of slickenside was found in all the pedons. On the basis of these characteristics the soils of the Khondwad and Amalnar region were classified as Halic Haplusterts and the soils of the remaining areas were classified as soils are grouped under sodic Haplusterts.

Tripathi *et al.,* (2006) classified the soil of Kiar-Nagali micro watershed. The soils were neutral to slightly alkaline, rich in various minerals, medium to very deep and have high temperature and water table is below wilting point for three months.

Texture varied from salty loam to loam, OC (4.5-23 g per kg of soil), CEC (9.8-14.8 Cmol/kg) and base saturation (56.6 to 74.8 per cent) respectively. On the basis of these characteristics the soils were classified as Typic Udorthents, Dystic Eutrudepts and Typic Dystrudepts.

Soils of Orissa were divided in to four orders namely Alfisols, Inceptisols, Entisols and Vertisoils. Inceptisols were most extensive occupying 49 per cent area followed by Alfsols 35 per cent, Entisols 10 per cent and Vertisols 6 per cent (Mishra, 2007).

Fourteen soil profiles were studied in northern transition zone of Karnataka for their morphological, physico-chemical properties (Pulakeshi *et al.* 2014). Texture of these soils varied from silty clay to clay, and the content of clay increased in subsurface horizons. These soils were sodic in soil reaction and electrical conductivity of these soils ranged 0.10 to 2.30 dS/m. OC and $CaCO_3$ content were found to decrease and increase with depth respectively. Ca and Mg were dominant cations in these soils followed by Na and K. As Per Soil Taxonomy (1999), soils of Mantagani village belonged to the order Vertisols, Entisols, Alfisols and Inceptisols.

Soils of experimental farm of Sokoine University of Agriculture in Tanzania were studied by Adamu et al., (2015). Four soil pedon were dug to represent the mapping units of the experimental area. The study revealed that, these soils were belonging Oxisols and Alfisols soil orders and comes under Ustox and Ustalfs suborder.

Typical soils of Mwala district, Kenya were classified by Karuma *et al.,* (2015). A soil profile representative of typical soils was excavated to analyse its morphological, physical and chemical properties and classified them using internationally known soil classification systems. According to the morphological and physico-chemical characteristics, the soil pedon was classified to the subgroup level of the USDA Soil Taxonomy as Typic Haplustults and Tier-2 of WRB as Haplic Cutanic Acrisols.

Soil of sub watershed in West Ethiopia was classified by Adhanom and Toshome, (2016). Three pedon along top sequence were studied. The soils were classified according to the procedure of 'World Reference Base for Soil Resources', these soils of the study area was classified under Mollic Nitisol. The control of such harmful effects would require proper soil conservation policies such as proper land leveling, afforestation, crop alternation, plowing, and presence of restorative crops in cropping systems on these lands.

Seven profiles were collected from the soils of Aboba area in western Ethiopia by Yitbarek *et al.,* (2016). The results exposed changes in macro-morphological, physico-chemical characteristics of the soil. Four soil types based on World Reference Base such as, Haplic Cambisols, Vertic Luvisols, Mollic Leptosols and Mollic Vertisols were identified

Lufega and Msanya, (2017) studied the soil of Morogoro District in Tanzania. Study exposed that soils were formed from in situ weathering of granitic rocks under Ustic moisture and Isohyperthermic temperature. Soil of Kiziwa were classified under order of Ultisols suborder of Ustults, great group of Haplustults, very deep almost flat, clayey, slight acid isohyperthermic family of Typic Haplustults , while soil of Mkambarani and Fulwe came under order of Inceptisols, suborder of Ustepts, great group of Dystrustepts.

'Profile samples were collected from five research sites of Wolkite University in Ethiopia, such as Wabe (RS1), Geche (RS2), Yefereze (RS3), Kotergedar (RS4) and Keratemo (RS5). The soil of Wolkite university research sites was classified on the bases of World Reference Base for soil resources. Pedon RS1 was classified as Haplic Vertisols with USDA corresponding of Typic Haplusterts. Pedon RS2 and RS3 were classified as Vertic Alisols (Hyperdysric), which was correlated with Ultisols (Typic Haplustults) in USDA classification. Pedon RS4 AND RS5 classified as Vertic Luvisols (Hypereutric), which was interrelated with Alfasols (Vertic Haplustalfs) in USDA classification (Yitbarek *et al.,* 2018)'.

### 2.4.4 Soil mineralogy

Mineralogical distribution of soils of Hissar, with the help of six representative profiles was studied by Singh *et al.,* (1974). The mineralogy of the sand fraction in all the profiles showed quartz, feldspars and muscovite as light minerals, and amphiboles biotite, chlorite, epidote, tourmaline: zircon, garnet, apatite, iron ores, sphene, kyanite and stauroite, as the heavy mineral assemblage. The study of the light and heavy minerals revealed that these were the admixture of sorted and unsorted grains. On the one hand it showed all sorts of angularity especially in smaller grains, denoting less transportation and mainly mechanical attrition. And on the other hand bigger grains were rounded to sub rounded with overgrowth showing long transportation, hence better source of the grains, over growths explaining diagenesis under sedimentary environments, second cycle of sedimentation. These bigger grains were again showing modifications due to mechanical attrition leaving broken overgrowth edges and irregular scratch or etching marks.

Murali *et al.,* (1974) studied the mineral composition of different soil in gneissic rocks of Mysore in South India. The soil fractions were found to be Kaolinitic and had high amount of amorphous material. The role of weathering was found in the transformation of parent materials and mineral along with their mechanisms.

Mineralogical composition of clay, silt and fine sand fractions of some Indian soils occurring under different climatic zones, were determined by Datta and Das, (1974). The study suggested that weathering of orthoclase and plagioclase feldspars was an important factor in the formation of clay minerals, partial hydrolytic decomposition of feldspars might lead to the formation of mica in the fine sand and also in silt with resultant illite or expanding lattice minerals in soil clays, whereas under intense weathering conditions complete hydrolytic decomposition brought about the formation of kaolinite in silt and clay.

Dinesh *et al.,* (2017) investigated the mineral content of soils in NE-part of Haryana. Study revealed that these soils were acidic to strongly basic. Quartz was the most abundant mineral in fine sand followed by other minerals like sphene, zircon and iron ores. Quartz was also the most abundant mineral in silt fraction followed by other minerals like vermiculite, chlorite and mica. The further analysis revealed that illite was the single most abundant mineral in clay fraction of theses soils.

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Two different clay samples from soil of Guruharsahai and Ferozepur region of Punjab, India were studied by Naithaini and Singh, (2013). The samples were analysed by using XRD to identify different minerals. Kaolinite, smectite, montmorillonite, illite, chlorite etc. were analyzed by XRD which were confirmed by FTIR. It was concluded that illite was present in both the clay samples because illite did not interfere with other clay minerals so its presence was confirmed by XRD, FTIR. Kaolinite was confirmed by XRD after heat treatment and was found in both the clay samples. Expanding clay smectite was present in both the clay samples which were confirmed by ethylene glycol treatment by XRD and FTIR. The presence of chlorite was confirmed by HCl treatment but XRD of clay obtained was not clear by the available XRD diffraction pattern. It was confirmed that chlorite was only present in clay of Guruharsahai and absent in clay of Ferozepur.

Mineral content and micromorphology of salt crusts located in the Punjab region of Pakistan was studied using XRDA together with thin section microscopy/EPMA (Shahid and Jenkins, 1994). Out of 25 samples collected between 1985-87, all qualified as saline or strongly saline, with pH ranging from 9.4-10+. According to XRDA analysis the mineralogy was dominated by thenardite in 13 crusts, by mirabilite in 8 and by halite in 4. Accompanying these minerals in smaller, variable amounts were calcite, nahcolite, thermonatrite, trona, burkeite, and gaylussite, together with occasional traces of sylvite, hexahydrite and natron. Variations were shown within and between sites and with season, year and depth. For the more common minerals, all combinations seem possible other than that of mirabilite with nahcolite or gaylussite. In thin section halite, thenardite and calcite were observed in a variety of habits and crystallisation sequences as well as in a range of microfabrics. Using also EPMA, bassanite, trona and possibly nahcolite, glauberite and thermonatrite were also recorded. The heterogeneity of salt mineralogy within these samples had implications for root environment and thus for management.

The mineral content of four soils developed on the Indo-Gangetic alluvium in NW-India was studied by using various sophisticated techniques. Quartz was the most abundant mineral in the sand and silt fractions. These fractions also had other minerals such as feldspar, biotite, muscovite and chlorite. In the clay fraction of each soils Illite, chlorite, and kaolinite were identified. The mineralogy of all the soils was very similar and no change in the mineralogical make-up with depth in a particular pedon was observed (Sidhu and Gilkes, 1977).

Salt affected soils covered about seven million hectares in the Indo-Gangetic plains, of which 0.7 million hectares were in the state of Punjab alone. Clay mineral content of some salt affected soils of south west in Punjab, particularly Dagru silt loam, Kaonia sandy loam, Sango Dhoan silt loam and Udaikaran silt loam were determined by X-ray diffraction and chemical techniques (Singh and Sawhney, 2006). The abundant mineral in clay fraction of all the four groups of the soils was Mica followed by kaolinite. Other minerals such as vermiculite, calcite and anatase were also found in these soils. Despite the evidence of high degree of pedogenesis, the study showed all the clay minerals were part of same parent materials with very little in situ alteration under existing conditions.

### 2.5 Salt-effected soils

A study was conducted on application of Geoinformatics for measuring salt affected soils in Gohana, Haryana using soil practices (Bhat *et al*., 2017). As geoinformatics is the use of information technology for study and earth resource management, the authors designed the map and examined the salt affected soils of Gohana by using photographic clarification of IRS-P6 satellite false colour combined image with ground survey and laboratory examination. A total of 72 samples were collected by them based on the quality of groundwater used for irrigation. Normal and salt affected soils had sandy clay loam to loamy sand texture, along with a variation of CEC, Ex. Na (%), OC (%), and $CaCO_3$ in both normal and salt affected soils. Furthermore, these soils had a strong correlation between EC and pH, Na, Ca, Mg, Cl, $SO_4$, ESP, SAR, CEC and clay and saturation percentage and clay. It was observed that out of 2.41 per cent salt affected area in block 1.13 and 1.28 per cent was affected by salt in the range of moderate and strong respectively.

The salt affected soil : their reclamation, carbon dynamic and biochar was reviewed by Amini *et al.,* (2016). The purpose of the review was to know the physical, biological and chemical problems of salt-affected soil, along with various methods applied to for reclamation and recovering of these soils. Application of biochar was the only method which not only increases carbon stock in these lands but also improved soil characteristics. The authors suggested reclamation of salt affected soils was possible with the application of organic manure and plant residues along with the application of biochar.

An investigation was carried out on the San Joaquin Vally of California to understand the specific management methods for development and reclamation of salt affected soil (Horney *et al.,* 2005). The sustainability of watered agricultural production policy in arid and semi-arid regions needs attention with saline and sodic conations. Accordingly, study discussed that for designing the GIS map of salinity zones on which site specific organic fertilizer application can be created, the author applied a site soil management on which initial measurements of soil EC added by directed soil sampling. The main objective was to improve a field practicable methodology for site specific soil management application and the purpose of the study on the production of cotton but it could be also used to other crops.

Pakistan's agricultural system is usually irrigated, which consumed 90 per cent of fresh water resources and given 80 per cent to the national production. It was caustic that the irrigated areas were the ones that are suffering most by the twin menaces of waterlogging and salinity. Climate change was expected to exacerbate this soil degradation process by way of heavy rainfalls and by increased evaporation, respectively. Finding of soil salinity was usually done by laborious soil sampling. A study to define surface soil salinity in the prime rice-wheat cropping area of Pakistan was conducted by Aamer *et al*., (2015) Remote sensing data in combination with geographic information system were used in this study; furthermore the effectiveness of different satellite imagery indicators was examined. Their results showed that 19 per cent of the rice wheat cropping area of Gujranwala distric in Rachna Doab of central Punjab province of Pakistan was salt affected.

Two major land degradation processes in agriculture land which harmfully affect the crop yield are soil salinity and soil alkalinity. Parent material, mineralogy, topography and human activities are the factors which influenced the genesis of salt affected soil (Kaledhonkar *et al.*, 2019). Furthermore useless irrigation water management counting canal network losses leads to the waterlogging and soil salinity while use of poor quality water for crop production without due attention to its chemical composition and leaching requirement of soil is responsible for soil salinization and alkalization in semi-arid and arid regions. Management of such soils includes reclamation through chemical amendment; salt leaching; improved agronomic, irrigation water and nutrient practices; alternate land uses; and use of salt-tolerant varieties. Solute transport in case of alkalinity is reactive and hence addition of chemical amendment is an important requirement for its reclamation. Similarly, solute transport in saline soils is non-reactive and leaching of soil mass by good quality water is sufficient for reclamation. In case of waterlogged saline soils, leaching along with water table control in root zone is a necessity.

Computerized database on salt affected soils was developed using Geographic Information System (GIS) (Mandal et al., 2010). These maps on 1:250,000 scales were geo-referenced and digitized. A relational database was developed in GIS linking polygons of salt affected soils and soil characteristics. State-wise estimate of salt affected soils were prepared from State maps for fourteen states and one Union territory. A total area of 6.7 Mha of salt affected soils was estimated at the country scale. Salt affected soils were variable in nature and distributed in nine physiographic units (*A*, B, C, D, F, G and H). Fifteen categories of soils were identified. These were merged to two categories i.e. saline and sadie for management purposes. Out of 6.7 Mha, saline and sadie soils covered 2.9 Mha and 3.7 Mha, respectively. The spatial distribution of sadie soils showed common occurrence in the arid and semiarid regions and the saline soils in the coastal region intercepted by the frequent ingression of saline sea water. Significant area of Sadie soils were distributed in the Gangetic plain in Uttar Pradesh, Punjab, Haryana and Bihar, the arid plain of Gujarat and Rajasthan and the peninsular plain of Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka. Saline soils were distributed in the coastal and deltaie plains and mangrove regions of Gujarat, Maharashtra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and the Andaman and Nicobar Islands. The inland saline soils were predominantly found in Gujarat and Rajasthan. The regional databases were prepared for agro-climatic zones. These databases also allowed superimposition of related datasets such as climate and geology, useful for reclamation and management.

The extent of salt-affected soils in Punjab based on the 1984 Landsat-MSS data (FCC) was investigated. The area of salt-affected soils was decreased from 0.699 million ha in 1972 to 0.488 million ha in 1984. The 1972 extent of salt-affected soils was based on the available maps and interpretation of ERTS pictures. The morphological, physical, chemical and mineralogical characteristics of salt-affected soils in Punjab were described. These soils were characterized by high pH, ESP and EC but lack columnar or prismatic structure. The highest salt accumulation was observed at the surface and decreases with depth. The only sodium containing silicate mineral identified in these soils was albite. The development of salt-affected soils in Punjab was intimately connected with fluctuation of ground water. These soils were formed by a combination of topographic, climatic, hydrological and geochemical conditions conducive for the accumulation of brackish waters at or near soil surface *(Sidhu et al.,* 1991).

### 2.6 Soil productivity and potentiality evaluation

A study was conducted to assess the soil degradation and resilience at northeast Nile Delta Egypt and evaluated their impact on soil productivity (Abdel Kawy and Ali, 2012). Landsat ETM+ images and digital elevation models were processed using ENVI 4.7 software to identify the main physiographic units in the area. The recognized units comprised; lacustrine, marine, and alluvial deposits. Twelve soil profiles were collected to represent the different mapped units, the locations of the soil profiles were selected to be the same sites previously studied by the Research Institute of Soils and Water in 1976. Changes in soil properties and productivity index during the last 35 years (1976–2011) were identified. The status of soil degradation was evaluated. It was found that the soil productivity index reflects the balance between soil degradation and resilience. The soil degradation processes overcome the soil resilience in most of the study area where the soil productivity index was decreased by 45.82 per cent of the total area.

A new system of soil appraisal in terms of actual and potential productivity was developed by Riquier *et al.,* (1970). Land utilization based on the fertility of the soil in its natural state and after improvement, and on the work needed to improve the soil.

A soil map of Nigeria, a map of the present productivity of the soil, and a map of the soil potentialities were included. Accordingly, nine factors were considered as determining soil productivity such as moisture (H), drainage (D), effective depth (P), texture/structure (T), bas saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity/nature of clay (A), and mineral reserves (M) therefore the formula for productivity and potentiality described as below:

$$\text{Productivity} = A \times D \times P \times T \times \overset{N}{\underset{S}{\text{or}}} \times O \times A \times M$$

$$\text{Potentiality} = A \times D \times P \times T \times \overset{N}{\underset{S}{\text{or}}} \times O \times A \times M+10$$

A study was conducted to evaluate the productivity of soils in Makurdi Southern Guinea of Nigeria using Riquier index by Agber and Ali, (2012). The factors used in this model included moisture duration, drainage, effective soil depths, texture, organic matter and CEC of clay. Comparisons were made of RI values obtained for the selected sites. Results from the research work revealed significantly higher average seed yield, plant height and leaf area index in the Teaching and Research Farm than the SIWES Farm of the University of Agriculture Makurdi. This coincided with the study location with a higher calculated Riquier index (RI). The significant correlations which existed between seed yield and RI evaluated showed that this index can actually explain yield variations.

The PI (Productivity Index) model developed by Kiniry in 1983 used an integrated approach to describe the relationship between plant productivity and soil properties. The main purpose to the PI model was the crops horizontal root spreading is controlled genetically and expressed under optimum soil of site conditions. If a root growth in soils affect by soil properties in which the root distribution will reduce. Accordingly it affects the surface biomass and decreased site quality. The *PI* model was:

$$\text{PI} = \sum_{I=1}^{r} (A \times B \times C \times D \times E \times RI)_i$$

Where *A* is the sufficiency of available water capacity, *B* the sufficiency of aeration, *C* the sufficiency of bulk density, *D* the sufficiency of the pH, and *E* the electrical conductivity. These terms were standardized to range from 0.0 to 1.0 and connected their sufficiency to the levels of soil properties, of which a value of 0 specified an unconditionally limiting level of soil property and a value of 1.0 indicated the optimum level (Kiniry *et al.,* 1983).

Another investigation was carried out at the Teachnig and Research Farm and SIWES farm of the Agriculture University of Makurdi in 2007 and 2088, to understand the effectiveness of soil productivity (PI) (Agber and Anjembe, 2012). PI model is used to evaluate the actual productivity and potential productivity of soils. Available water, soil reaction, BD, slope, clay and OC content along with depth of root zone were the main factors which are used in PI model to calculate soil productivity. As per the comparative study of PI model value seed yield, plant height and leaf area index in the Teaching and Research Farm was found higher than the SIWES Farm. This agreed with the study location with a higher calculated productivity index (PI). The substantial associations which occurred between seed yield and PI evaluated showed that this index can actually explain yield variations.

Amara et al., (2016) studied the actual productivity and potential productivity of soils of Singhanlli-Bogur miro watershed in Karnataka, India by using Riquier index model. The authors reported that there was no ‘excellent-I’ class in term of actual and potential productivity, more than 50 per cent of the area (396.30 ha) was poor in productivity, 42.60 ha was came under ‘extremely poor’, 161.60 ha ‘average’ and 144.0 ha was ‘good’ it term of actual productivity. In other hand in term of potential productivity 360.70 ha, 135.90 ha, and 242.90 were average, good and poor classes respectively.

In China, there is a growing argument on the role of cultivated land transformation on food security. Deng *et al.,* (2006) used satellite images to examine the changes in the area of cultivated land and its potential agricultural productivity in China. Authors found that between 1986 and 2000 China recorded a huge increase of cultivated land (+1.90%), which almost balance the decline in normal potential productivity, or bio productivity (-2.2%). Therefore, the study revealed that the conversion of cultivated land has not hurt China’s national food security. Accordingly argue that more recent change in the cultivated area likely had a little adverse effect on food security.

(Gale *et al.*, 1991) determined that the PI model could be used to estimate site quality for white spruce plantations and compared the use of PI vs. site index in equations describing changes in aboveground biomass with age. Their results indicated that site index and PI were not significantly correlated. However, PI was more highly correlated with aboveground stand biomass and mean annual biomass increment than was site index. The site index was more highly correlated with biomass estimates in older plantations (35-43 yr), whereas PI was more highly correlated to biomass estimates in younger plantations (19-34 yr). To further assess the relationships between estimates of biomass and site quality, adjusted for age, a Schumacher-type equation was used.

# CHAPTER-III

## Hypothesis of research

H0 ≠ Intensive farming has no effect on the characteristics and classification of soils of Kapurthala district in Punjab

H1= Intensive farming has an effect on the characteristics and classification of soils of Kapurthala district in Punjab

**CHAPTER-IV**

# Materials and Methods

This chapter concerns the experimental aspect of the investigation on the effect of intensive farming on the characteristics and classification of soils of district Kapurthala in Punjab, North-West, India; it involved the study of macro morphological characteristics of 16 pedons in the field and collection of horizon wise sample. All soil samples were analysed for their physical and chemical characteristics in the laboratory and the soils of district Kapurthala were classified in the light of changed characteristics of the soils. Accordingly, the present investigation includes the evaluation of the effect of intensive farming practices by comparing the effect of pre and post green revolution on the soil characteristics and their classification and actual productivity and potentiality productivity of the soils of district Kapurthala were evaluated. The location of all the pedons was recorded with the help of global positioning system (GPS).

## 4.1 General description of the area

The Kapurthala district falls in Punjab state which lies between the latitudes of 31°07′30″ and 31° 39′ 30″ N and the longitudes of 75° 43′ 55″ and 75° 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.

## 4.2 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.

**Table 4.1 Maximum and minimum temperature of Kapurthala during the year of 2018**

| No | Mount | Maximum °C | Minimum °C |
|---|---|---|---|
| 1 | January | 22 | 2 |
| 2 | February | 27 | 5 |
| 3 | March | 34 | 10 |
| 4 | April | 41 | 13 |
| 5 | May | 44 | 20 |
| 6 | Jun | 44 | 23 |
| 7 | July | 38 | 22 |
| 8 | August | 36 | 24 |
| 9 | September | 36 | 19 |
| 10 | October | 33 | 14 |
| 11 | November | 29 | 8 |
| 12 | December | 25 | 0 |

(https://www.timeanddate.com/weather/india/kapurthala/historic?month=12&year=2018)

### 4.3 Natural vegetation and land use

The important crop, vegetables, fruits and trees of the Kapurthala district in Punjab, India, which were recorded during macro morphological studies of the area, are listed in tables.

**Table 4.2 Major trees, shrubs and fruits of the area**

| NO | Tree | Botanical Name | Fruit | Botanical Name |
|---|---|---|---|---|
| 1 | Poplar | *Populus* | Guava | *Psidium guajava* |
| 2 | Safeda | *Eucalyptus* | Pears | *Pyrus* |
| 3 | Kikar | *Acacia nilotica* | Kinoow | *Citrus sp* |
| 4 | Daik | *Melia azadisachta* | Strawberry | *Fragazia x ananassa* |
| 5 | Black pine | *Pinus nigra* | Water melon | *Citrullus lanatus* |
| 6 | Rosewood | *Dalbergia sissoo* | Melon | *Cacumis melo* |
| 7 | Blue gum | *Eucalyptus* | | |

**Table 4.3 Major vegetable and crops of the area**

| NO | Vegetable | Botanical Name | Major crops | botanical Name |
|---|---|---|---|---|
| **2** | Okra | *Abelmoschus esculentus* | Rice | *Oriza sativa* |
| **3** | Tomato | *Solanum lycopersicum* | Wheat | *Triticum* |
| **4** | Onion | *Allium cepa* | Corn, Maize | *Zea mays* |
| **5** | Squash | *Cucurbita* | Sugar cane | *Saccharum officinarum* |

### 4.4 Soil sample collection

Soil profile observations have been taken from the already established series as reported by Uppal (1957) Sharma *et al.*, (1982) and Sehgal *et al.*, (1992). Profile samples were collected from the following villages.

**Table 4.4: Place the samples were collected from**

| No | Village | Location |
|---|---|---|
| 1 | Rawalpindi | On the north side of West Bein about 45 km to Rawal pindi, Phagwara Tehsil, district Kapurthala |
| 2 | Domeli | Village of Domeli, Phagwara tehsil, Kapurthala district |
| 3 | Jagjitpur | On the left side of Phagwara-Hoshiarpur road, Jagjitpur village, Phagwara tehsil, Kapurthala district |
| 4 | Khairanwali | On Taran-taran road near power house, about 1 km from Khairanwali village, Kapurthala district |
| 5 | Randhirpur | About 1 km before Khairanwali village lift side of Taran-taran road in Kapurthala district |
| 6 | Fajewal | About 1.2 km south east of Mansurwal Dona village, Kapurthala tehsil |
| 7 | Dhoda | About 600 m near north east of Jagjitpur village outside of Phagwara-Hoshiarpur road, Phagwara tehsil, Kapurthala district |
| 8 | Tulewal | Modhapur road, 650 m south of Modhapur village, Phagwara tehsil, Kapurthala district |
| 9 | Samana | More than one km north of Dakh Darweshpind on Phagwara-Jadiala road, Phagwara tehsil, Kapurthala district |
| 10 | Ucha | Near to Ucha Pind, in the village of Ucha, Kapurthala district |
| 11 | Fattudhinga | 300 m south of Nadal-Bholath road, Bolath village |
| 12 | Nathupur | In the old bed of beas river- Nangal Labana village, Kapurthala tehsil, Kapurthala district |
| 13 | Mund | Mund village, next to Beas river in Mund village, Kapurthala tehsil |
| 14 | Bahanra | About 100 m north east of the village Fatehjalal, about 500 m from Kapurthala district |
| 15 | Kanjili | About 200 m near to Kanjili bridge and boat club, Kanjili village |
| 16 | Fatehpur | Muradpur Dona village opposite of Rampur village, Sultanpur Lodhi tehsil, Kapurthala district |

### 4.5 Preparation of soil samples

Soil 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.

### 4.6 Method of soil analysis

**4.6.1 Soil reaction:** The soil pH was determined in 1:2 soils: water suspension with glass electrode using pH meter. Firstly take soil and weight 20 gr of soil then put it into 100 ml beaker then add 40 ml of water. Then satire the suspension at least 4 times in a period of half an hour and measure pH with the help of pH meter (Jackson 1967).

**4.6.2 Electrical conductivity:** The electrical conductivity of soil was measured with EC meter. Weight 20 gr of soil in a 100 ml beaker and add 40ml of distilled water to it. Stirred it 4-5 times and leave it all night then at the endpoint measured EC with EC meter (Jackson 1967 and Richards 1954).

**4.6.3 Organic carbon:** The organic carbon content in soils was measured with Walkley and Black method. Take 2g of soil in a 250 ml conical flask, then add 10 ml of 1N $K_2Cr_2$ $O_7$ solution, then mixed it properly. In the second step added 20 ml concentrated $H_2So_4$. Leave the flask for 30 minutes so that it remained cools. After that added 2g of sodium fluoride powder, 100ml distilled water and shacked vigorously. Then Added 10 drops of diphenylamine indicator which gave violet color to suspension. Then titrated the content with ferrous ammonium sulphate solution until the color of titrating changed from violet to light green than it was the endpoint. Then, I noted down the volume of ferrous ammonium sulphate solution (Black,1965 and Jackson 1967).

**4.6.4 Calcium carbonate in soil:** calcium carbonate is determined by titration of the soil with 0.05 N $H_2SO_4$ in the presence of a mixture of indicator bromothymol blue and bromocresol green. First weight 10g of soil and transfer it to a 250 ml conical flask, then add approximately 100 ml of distilled water, 0.5g of powdered calcium sulphate, 10 ml of 0.1 N aluminium chloride solution and 10 drops of each indicator viz, bromothymol blue and bromocresol green, then put the flask on the hot plate and bring it is content to a boil and then remove it from the source of heat. If the above suspension turns green, calcium carbonate is present. If it turns golden yellow, calcium carbonate is absent. If the suspension turns green titrate it against 0.5N $H_2SO_4$ till it turns yellow, bring it back to a boil it will change back to green. Continue to add sulphuric acid and go on boiling till a permanent golden yellow color is obtained. This is the endpoint not the amount of acid used Piper (1950).

**4.6.5 Available nitrogen:** first weigh 5 gr of soil sample on a filter paper. Put it into a Kjeldahl distillation flask, then moisten the sample with 20 ml of 2.5% NaOH solution and quickly fit the cork. After this pipette out 10 ml of 0.02 N $H_2SO_4$ in a conical flask, add about 3 drops of methyl red indicator and dip the end of delivery tube into the conical flask. Switch on the heater/hot plate to distil ammonia gas. Collect 30 ml of the distillate in 0.02N $H_2SO_4$. At the last titration the excess of $H_2SO_4$ in the conical flask against 0.02N NaOH and note the volume of 0.02N NaOH used when color changes from pink to yellow (Subbiah *et al.,* 1956).

**4.6.6 Available phosphorus:** The available phosphorus in soil was determined by Olsen's method. For determination of available phosphorus weight one gram of soil and put into conical flask with a size of 150 ml. Then add a small amount of Darco-G 60 and 20 ml of 0.5 N $NaHCO_3$.Shaked the flask for 30 minutes on an electric shaker and filter suspension through Whatman No. 1 filter paper, and similarly prepared a blank solution, pipette out 5 ml of extract in a 25 ml volumetric flask. Add 5ml of 0.5 N $H_2SO_4$ and shake for a while until $CO_2$ evaluation disappears, then Added 4 ml of Ascorbic acid to it and added distilled water and mix contents of the flask by measuring the intensity of blue color development at 760 nm wavelengths in the spectrophotometer. (Olsen *et al.,* 1954).

**4.6.7 Available potassium:** The available potassium content in the soil can determine with flame photometer. Weigh 5g of soil put it into 150 ml conical flask. Add 25 ml of ammonium acetate solution on the conical flask and shake the suspension for five minutes. Filter the contents through Whatman No.1 filter paper. Pipette out 5 ml of the filtrate in a 25 ml volumetric flask make the volume. Feed the extract to flame photometer and take the readings with the solution (0, 5, 10, 15, 20 and 25 ppm) of K and note down readings (Merwin *et al.,* 1950).

**4.6.8 Saturation percentage of soil:** equals the weight of water required to saturate the pore space divided by the weight of the dry soil. It is useful for describing soil texture. Very sandy soils have SP content of less than 20 per cent; sandy loam to loam soils have SP values between 20 and 35 per cent; and silt loam, clay loam, and clay soils have SP values from 35 to over 50%. Also, salinity measured in saturated soil can be correlated to soil salinity at different soil-water contents measured in the field. As a general rule, the SP soil-water content is about two times higher than the soil-water content at field capacity. Therefore, the soil salinity in a saturation extract is about half of the actual concentration in the same soil at field capacity

**4.6.9 Estimation of micronutrients**: The available micronutrients in soil were determined by using atomic absorption spectrophotometer. Analysis of micronutrients involves two steps:

A) **Extraction of soil**: For simultaneous extraction of available Zn, Fe, Mn and Ca in soil commonly DTPA (diethylene triamine pentaacetic acid) method was used. In the first step, take 10 g of air-dried soil sample and transfer it to 100 ml narrow-mouth polyethylene bottle. Further include 20 ml DTPA solution and stopper the bottle. Shacked the suspension on the electrical shaker for 2 hours at $25^{o}C$ then filter the contents through Whatman no.1 filter paper. Also, take a blank without soil (Lindsay *et al.*, 1978).

B) **Estimation from soil extract**: The stock solution containing 1000 mg of the given micronutrient per litter can be prepared by dissolving the required quantity of their respective salts and making the final volume to 1 litter with deionized water. Respective salts were copper sulphate, zinc sulphate, ferrous sulphate and manganese sulphate. Pipette out 5 ml of 1000 g solution in 100 ml volumetric flasks from solution and make the volume with deionized water and 0.005 M DTPA extract. The concentration of the micronutrients in soil extract can be estimated after feeding it to the AAS and readings for absorbance and concentration were recorded (Lindsay *et al.*, 1978).

**4.6.10 Soil texture:**

Toke 20 g oven-dry soil, passed through a 2.0 mm sieve in a 600 ml beaker and add 20ml $H_2O_2$ and swirl the contents well, let the reaction precede for 5-10 minutes place the beaker over a laboratory hot plate continue assimilation, thrilling the contents all the time with a glass rod then cool the beaker and its content. After this wash the soil particles from the internal sides of the cup by rubbing with distilled water. Then added 25 ml 2N HCl and allow the content to react for an hour with intermittent shaking at intervals, then filter the content through Wathman No50 filter paper and wash the soil along with distilled water until the excess is free from chlorides, then transfer the filtered sample to a 600 ml beaker with the help of distilled water. Then added distilled water until the volume became 400-500 ml and dropped a few drop of phenolphthalein indicator. Then with the addition of 10/N sodium hydroxide make the suspension pink in colour and mix the suspension with an electrical hothead for 10 mins. Transfer the contents to a 70 mesh sieve placed over the funnel, which is held over the top of one litter cylinder and wash the soil particles on the sieve with a jet of distilled water till only the coarser particles are retained on the sieve then transfer these particles to a weighed 100 ml beaker, after this dry it at $105^0$ C in the oven to a constant weight and record this weight, then make up the volume of the suspension in the cylinder to one litter by adding more distilled water and place the cylinder in a temperature control chamber. Next day early in the morning note down the temperature of the content, find out the required time for sampling against the temperature for silt clay and clay alone from sedimentary time table, then stir the content with the plunger by moving it up and down and remove the plunger gently and note down time at which the plunger is taken out. This is the starting time for settling, then inserts the sampling pipette into the suspension and dips it to 10 cm depth from the surface suspension about 20 seconds before the sampling time. Pipette 25 ml of the suspension at each requisite time at a moderate speed, take out the pipette and transfer the sample collected to a weighed 100 ml beaker and dry the sample $105^o$ C to a constant weight after this weighs the beakers with silt+clay and clay samples up to milligram level and decant the remaining suspension by washing repeatedly with distilled water. In the end remove any particles left in the cylinder with a jet of distilled water into a weighed 100 ml beaker and dry the contents of the beaker in an over and weigh these. The weight of the soil particles in the beaker is the amount of fine sand in the total sample then compares the prescient fine sand thus obtained with that obtained by the difference method (Shiwany *et al.*, 2002)

#### 4.6.11Cation exchange capacity:

Cation exchange capacity was determined by the procedure of Belyayeva (1967) as modified by Jackson (1975) for calcareous and sodic soils. This method involves removal of soluble salts with 80 per cent methanol. Sum of the cations in this leachate is equal to cation exchange capacity.

**4.6.12 Saturation paste and saturation extract:**

Saturation paste was prepared according to the procedure outlined by the Rhoades (1982). Na, K were estimated by the help of flame photometer, calcium and magnesium were analyzed on …. $CO_3$, $HCO_3$, Cl, and $SO_4$ ions were estimated as per the procedures outlined by the Jackson (1958). $pH_s$ of soil paste and $EC_e$ of saturation extract were also measured.

**4.7 Soil productivity and potentiality**

Actual and potential productivity of the soils of Kapurthala district were evaluated by Requier Index model (Requier *et al.*, 1970).

Productivity employed in the sense of initial soil capability to produce a certain amount of crop per hectare per annum, and is expressed as a percentage of the optimum yield per hectare of that same crop grown on the best soil.

**4.7.1 Factor used in calculating the productivity index**

Nine factors are conceder as determining soil productivity vis Moisture (H), Drainage (D), Effective depth (P), Texture/structure (T), Base saturation (N), Soluble salt concentration (S), Organic matter content (O), Mineral exchange, capacity/nature of clay(A), Mineral reserves (M).

**Productivity** = $\mathbf{H \times D \times P \times T \times N \times O \times A \times M}$

Potentiality is that productivity of a soil when all possible improvements have been made, even the most difficult and costly

**4.7.2 Determination of the index of potentiality**

The index of potentiality is required to express potential productivity after soil management

**H** (Dryness) - requires irrigation

**D** (Poor drainage) – requires drainage

**P** (Poor texture or structure) – requires stone removal

**N** (Low nutrient content) – requires application of fertilizers

**S** (salinity) – requires desalting

**O** (low organic carbon) – requires application of organic matter

**Potentiality= H×P×T×N×O×A×M + 10%**

**Table 4.5: Classes of productivity (P) and potentiality (P1)**

| P | Classes | Rating | P1 |
|---|---|---|---|
| 1 | Excellent | 65-100 | I |
| 2 | Good | 35-64 | II |
| 3 | Average | 20-34 | III |
| 4 | Poor | 8-19 | IV |
| 5 | Extremely poor | 0-7 | V |

### 4.9 Soil type

Soils of Kapurthala district have been discussed under two categories, normal and salt affected soils. All type of soils which are not sodic or salt affected are studied under normal soils category.

### 4.8 Demonstration

**Sand removed from epipedon**

**Macro-morphological study of the pedon**

**Sample collections**

**Samples in the laboratory** **sieved samples in laboratory**


**Some random click of soils analysis and sample collection**

**CHAPTER-V**

# Result and Discussion

An investigation was carried out on the soil resources of Kapurthala district in Punjab, North-West, India. It involved the study of macro-morphological characteristics of sixteen pedons from sixteen villages in the field. Horizon wise samples were collected. Location of all the pedons was recorded with the help of global positioning system (GPS). All soil samples were analysed in laboratory for their physical and chemical characteristics. Soils were classified in the light of changed characteristics of the soil as per Soil Taxonomy (USDA, 1999) up to family level. After, effects of intensive farming were studied by comparing the present data with the already established data of Uppal H.L, (1957), Sharma *et al.*, (1982) and Sehgal *et al.*, (1992). Comparison graphs of different parameters of soil of each series were prepared. And the actual productivity and potential of these soils were evaluated.

The soils of Kapurthala district have been grouped into sixteen soil series, depending upon the variation in soil texture, drainage, profile development, salt content and other physico-chemical characteristics. Six series specifically Rawalpindi, Domeli, Jagjitpur, Khairanwali, Randhirpur and Fajewal series are discussed under salt affected soils and the remaining ten series namely Dhoda, Tulewal, Samana, Ucha, Fattu Dhinga, Nathupur, Mund, Bahanra, Kanjili and Fatehpur series are discussed under normal soils. The results obtained are presented and discussed in the subsequent paragraphs.

## 5.1 Characterization and classification of soils of Kapurthala district, NW-Punjab

### 5.1.1 Macro-morphological characteristics of salt affected soils in Kapurthala district

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 gray (10YR 6/1) in Rawalpindi (Table 5.1), grayish brown in Domeli and Khairanwali (Table 5.2 and 5.4), light brownish gray in Jagjitpur and Fajewal series (Table 5.3 and 5.6) and brown in Randhirpur series (Table 5.5). Soil color (moist) in the subsurface horizons of all the pedons was dark gray, 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 5.2) and Jagjitpur series where recorded massive structure (Table 5.3). 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 Rawalpindi, 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 hard (dry), friable (moist), sticky and plastic (wet) in Rawalpindi (Table 5.1), extremely hard (dry), loose (moist) sticky (wet) in Domeli series (Table5.2), hard (dry), friable (moist), sticky (wet) in Jagjitpur series (Table 5.3), extremely hard (dry), friable (moist), slightly sticky and slightly plastic (wet) in Khairanwali, Randhirpur and Fajewal series Table 5.4, 5.5 and 5.6 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. The results for macro-morphological are written in the tables below and the site characteristics of the pedons separately for salt and normal soils presented in Appendix-I.

**Table 5.1 Macro-morphological characteristics of Rawalpindi series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | Reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | Dry | Moist | Wet | | |
| **Ap** | 0-26 | 10YR 5/2 | cl | 2m sbk | dh | mfr | ws,wp | es | gs |
| **AB** | 26-42 | 10YR 4/4 | sicl | 2m sbk | dh | mfr | ws,wp | e | iw |
| **B1** | 42-58 | 10YR 4/4 | sicl | 2c sbk | dh | mfr | ws,wp | es | iw |
| **B21** | 58-74 | 10YR 5/4 | sicl | 2c sbk | dh | mfr | ws,wp | ev | gs |
| **B22** | 74-105 | 10YR 5/5 | sicl | 2c sbk | dh | mfr | ws,wp | ev | gs |
| **B3** | 105-130 | 10YR 6/4 | sic | 2c sbk | dh | mfr | ws,wp | ev | - |

**Table 5.2 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 5.3 Macro-morphological characteristics of Jagjitpur series**

| 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 5.4 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 5.5 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 5.6 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 |

**Figure 5.1.1 Attachment photos of pedons for salt-affected soils**

**Representative Rawalpindi series**

**Representative Domeli series**


**Representative Jagjitpur series**


**Representative Khairanwali series**

**Representative Randhirpur series**

**Representative Fajewal series**

### 5.1.2 Physical and chemical characteristics of salt affected soils in Kapurthala district

#### 5.1.2.1 Physical characteristics of salt affected soils

**Texture**

The particle size analysis of soils showed that the texture classes of the pedons varied from clay loam, silty clay loam and silty clay in Rawalpindi series (Table 5.7), loam in Domeli series (Table 5.8), sandy clay loam, loam and clay loam in Jagjitpur series (Table 5.9), loam and clay loam in Khairanwali series (Table 5.10), loam, silty clay loam and clay loam in Randhirpur series (Table 11), and loam silty loam and clay loam in Fajewal series (Table 5.12) respectively.

**Particle size distribution**

**Clay**

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 5.8) to 30.9 per cent in Rawalpindi series in the epipedon horizons (Table 5.7). Clay content of the pedons in the subsurface horizons ranged from 19.5 per cent in B21 horizon of Domeli to 45.1 per cent in B3 horizon of Rawalpindi series. The mean clay content in all the horizons of all profiles is 28.48 per cent. The higher clay content in Fajewal series was 30.4 per cent (Table 5.12) it decreased irregularly with depth. The higher clay content of soils may be due to illuviation and process (Sharu *et al.,* 2013).

**Silt**

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 (Table 5.9) 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 58.4 per cent in B1 horizon of Rawalpindi series. The highest silt content in Domeli series was recorded 42.1 per cent in B21 horizon and the lowest silt content was recorded 33.8 per cent respectively. The percentage of silt content increased in depth. The mean silt content in all the profiles of salt affected soils is 37.6 per cent.

**Sand**

The sand value in the epipedon of salt affected soils ranged from 32.5 per cent in Fajewal series to 52.2 per cent in Jagjitpur series (Table 5.12 and 5.9 respectively). Sand content of subsurface horizons ranged from 12.7 per cent to 48.6 per cent. The highest sand content in subsurface horizons was recorded in AB horizon of Randhirpur series and lowest was recorded in B1 horizon of Rawalpindi series. Sand content of Rawalpindi shows irregular decrease with depth. The sand content of Domeli series ranged from 36.2 per cent in B22 horizon to 45.1 per cent in AB horizon. Khairanwali series has the highest value of sand content (43.2 %) in AP horizon, and the lowest 27.8 per cent in AB horizon. The mean sand content in all the profiles of salt affected soils is 34.0 per cent.

**5.1.2.2 Chemical characteristics of salt affected soils**

**Electrical conductivity**

The (1:2 soil: water) 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 0.15 dS $m^{-1}$ in Rawalpindi 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 $m^{-1}$ to 0.62 dS $m^{-1}$. The highest value (0.62 dS $m^{-1}$) was recorded in AB horizon of Khairanwali series and the lowest value (0.06 dS $m^{-1}$) was recorded in B1 horizon of Domeli series and B23 horizon of Randhirpur series respectively. The electrical conductivity of Jagjitpur and Randhirpur series decreased regularly with depth. The electrical conductivity value of Rawalpindi series and Fajewal series increased with depth irregularly. The mean value of electrical conductivity in all the profiles of salt affected soils was 0.23 dS $m^{-1}$.

**Soil reaction**

The data on soil reaction (pH) determined in a 1:2 soil to water ratio suspension are presented in Tables. The epipedon soil pH ranged from 8.5 in Rawalpindi 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 AB horizon of Rawalpindi series and BC horizon of Domeli series respectively. The mean of pH values for all the profiles is 9.3. The highest mean value 9.9 was recorded in Domeli series and the lowest mean value 8.8 was recorded in Rawalpindi and Fajewal series respectively. The pH for all the series was strongly alkaline (Table 5.7 to Table 5.12). 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)

**Calcium carbonate**

Content of calcium carbonate in epipedon of all the series ranged from 0.2 per cent in Fajewal series (Table 5.12) to 0.9 per cent in Rawalpindi series (Table 5.7). In subsurface horizons calcium carbonate ranged from 0.2 per cent in AB horizons of Rawalpindi and Domeli series and B23, and BC horizons of Jagjitpur series respectively to 1.1 per cent in B22 horizon of Rawalpindi series. Content of calcium carbonate in all the horizons were recorded below 1 per cent except B21 and B22 horizons of Rawalpindi series. 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 0.4 per cent.

**Organic carbon**

The organic carbon content of salt affected soils of Kapurthala district ranged from low too high in the epipedon horizons except Fajewal series which is low. The epipedon organic carbon content ranged from 0.11 per cent in Fajewal series (Table

5.12) to 0.93 per cent in Khairanwali series (Table 5.10). The organic carbon content ranged from low to medium in the subsurface horizons. The highest organic carbon content 0.69 per cent was recorded in AB horizon of Rawalpindi series and the lowest 0.12 per cent was recorded in AB horizon of Fajewal series. The organic carbon content is low in all the horizons of Fajewal series it 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. Depth wise distribution of organic carbon content percentage in all the profile except Fajewal series followed decreasing trend with depth. It reflects the rapid rate of organic matter decomposition in these soils. Similar finding were reported by (Murthy *et al.,* 1977) in Vanivilas Command Area and in Malaprabha Command Area (Shadaksharappa *et al.*, 1995).

**Available nitrogen**

Most of the nitrogen present in soils is associated with organic compounds like proteins, amino acids and amino sugars. Soil nitrogen also occurs in inorganic forms like ammonium, nitrate, and nitrite. As the nitrogen in organic compound is not easily available, it has to be mineralized to ammoniacal and nitrate forms before plants can utilize it. So the soil available nitrogen which represents the fraction of total nitrogen that can be easily used by the plants comprises ammoniacal, nitrate and the easily oxidizable organic forms (Sawhney *et al.,* 2002). 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 5.12) to 514 kg/ha in AB horizon of Jagjitpur series (Table 5.9).

The mean available nitrogen is 255.84 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. Available nitrogen content was recorded low in all the horizons of Fajewal series and in subsurface horizons of Rawalpindi series, Khairanwali series and Randhirpur series. Furthermore, 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)

**Available phosphorus**

Phosphorus (P) occurs in soils both in organic and inorganic forms. Organic forms. Organic fraction is present in humus and other organic compounds like phytins and nucleic acid. Inorganic fraction occurs in combination with calcium, iron, aluminium and other elements. Plant absorbs P from the soil as $H_2PO_4^-$ and $HPO_4^{-2}$ ions (Sawheny *et al.,* 2002). The available phosphorus status in salt affected soils of Kapurthala district is determined by Olsen *et al.,* (1954) method was high to very high in all the epipedon horizons of the pedons. The available phosphorus content in the epipedon of the pedons ranged from 24.6 kg/ha in Rawalpindi 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). According to (Girma *et al.,* 2013) the high phosphorus in epipedon might be attributed to external phosphorus supply and phosphorus carried over from fertilization. The available phosphorus content in the subsurface horizons ranged from 42.5 kg/ha to 110 kg/ha. The highest value of available phosphorus was recorded in B23 horizon of Jagjitpur series and the lowest phosphorus content was recorded in the B21 and B22 horizons of Domeli series. The mean available phosphorus content for all the pedons was 71.90 kg/ha. The highest concentration of available phosphorus was recorded in B23 horizon of Jagjitpur series followed by 108.8 kg/ha in AB and B22 horizons of

Khairanwali series. Available phosphorus observed in all the epipedon horizons categorized as high to very high Table 5.7 to Table 5.12).

**Available potassium**

The readily available potassium constitutes about 1-2 per cent of total potassium in mineral soils. It consists of soil solution and exchangeable potassium adsorbed on soil colloidal surfaces. The neutral normal ammonium acetate solution, (Merwin *et al.,* 1950) which extracts both exchangeable and water soluble potassium is most commonly used for determination of available potassium. 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 (Table 5.8 and 5.12) to 453.6 kg/ha in Rawalpindi series (Table 5.9). 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 272.94 kg/ha.

**CEC, Exchangeable cations and ESP**

The cation exchange capacity (CEC) of the soil in the epipedon ranged from 3.82 $cmol_c$/kg of soil in Rawalpindi series (Table 5.7) to 11.72 $cmol_c$/kg of soil in Randhirpur series (Table 5.11). 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). Yakubu *et al.,* (2011) opined that organic matter content of soils which normally influences the CEC is generally low and therefore the CEC values may not be attributed to the amount of organic matter. The mean CEC of all the series of salt affected soils of Kapurthala district is 7.08 $cmol_c/kg$ of soil.

The exchangeable form of cations is the most important source of immediately available plant nutrients. It is by virtue of this property of soil colloids, that a soil is able to sustain crop growth by regulating plant nutrients supply. In a neutral soil, the major exchangeable cations are $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ (Singh, 2010). The exchangeable calcium content in the epipedon ranged from 0.4 $cmol_c/kg$ in Rawalpindi 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 $cmol_c/kg$ to 7.0 $cmol_c/kg$. The highest value of exchangeable calcium 7.0 $cmol_c/kg$ was recorded in B22 horizon of Rawalpindi series and the lowest value 0.4 $cmol_c/kg$ was recorded in BC horizon of Domeli series. The mean exchangeable calcium of all the series is 3.05 $cmol_c/kg$. 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 Rawalpindi and Khairanwali series to 1.6 $cmol_c/kg$ in Rawalpindi 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 mean exchangeable magnesium and sodium of all the pedons of salt affected soils in Kapurthala district is 1.31 $cmol_c/kg$ and 2.45 $cmol_c/kg$ respectively. 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 mean of exchangeable potassium of all the series is 0.52 $cmol_c/kg$.

The exchangeable sodium percentage (ESP) in the epipedon of all the series ranged from 18.9 per cent in Khairanwali series (Table 5.10) to70.4 per cent in Randhirpur series (Table 5.11). The ESP in the subsurface horizons of salt affected soils of Kapurthala district ranged from 12.6 per cent in B22 horizon of Rawalpindi 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 48.00 per cent. Highest value of saturation percentage was recorded in Rawalpindi series (Table 5.7), and the lowest saturation percentage was recorded in Jagjitpur series (Table 5.9). In the subsurface horizon the saturation percentage of these soils ranged from 25.95 per cent in B12 horizon of Fajewal series to 46.05 per cent in AB horizon of Rawalpindi series. The mean saturation percentage of all the profiles was 33.06 per cent.

Soil solution is the major source of plant nutrients, nutrient cycling in ecosystems, and pollutant transformation and transport in soil. 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 (Table5.7 to Table 5.12). 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. $Na^+$ and $K^+$ in saturation paste ranged from 0.43 me/l in B22 horizon of Domeli series to 26.40 me/l in epipedon horizon of Khairanwali series and 0.10 me/l in Ap horizon of Rawalpindi series to 1.02 me/l in Ap horizon of Fajiwal series respectively. $CO_3^{--}$ value was recoded nil in all the horizons of Rawalpindi, Jagjitpur, Randhirpur and Fajewal series and B21 and B22 horizons of Domeli series. Khairanwali was the only profile of salt affected soils in Kapurthala district which $CO_3^{--}$ was presented in all the horizons. $SO_4^{--}$ was ranged from 0.6 me/l in B13 horizon of Fajewal to 2.5 me/l in BC horizon of Domeli series. Therefore, it may be concluded that all the pedons still had some salts in various horizon.

**Micronutrients**

In today's intensive agriculture, deficiencies of micronutrients, particularly, Zn, Mn, Fe and Cu have become one of the important factors limiting yields of crops in many part of India. These deficiencies have emanated from the intensive cropping coupled with the use of high analysis macronutrient fertilizers and decline in the use of organic manure (Kuldip S *et al.,* 2013). The results of available micronutrients of salt affected soils in Kapurthala district is presented in table 5.13. 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 content of zinc was low B3 horizon of Rawalpindi series, B21 and BC horizons of Domeli series, BC horizon of Jagjitpur series, B21 and B3 horizons of Khairanwali series, B21 and B23 horizons of Randhirpur series and B11 and B13 horizons of Fajewal series respectively. In other hand 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 decreasd 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, when compared with the critical levels. The effect of pH on the availability of manganese was observed in the current study. Similar result was reported by (Nazila *et al.,* 2007).

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 Rawalpindi, 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 5.7 Physical and chemical characteristics of Rawalpindi 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 | 8.5 | 0.15 | 0.72 | 0.9 | 376.2 | 24.6 | 453.6 |
| AB | 26-42 | 8.6 | 0.26 | 0.69 | 0.2 | 263.4 | 103.0 | 240.8 |
| B1 | 42-58 | 8.7 | 0.23 | 0.63 | 0.3 | 213.2 | 60.4 | 263.2 |
| B21 | 58-74 | 8.8 | 0.30 | 0.33 | 1.0 | 170.0 | 82.8 | 263.2 |
| B22 | 74-105 | 9.0 | 0.18 | 0.36 | 1.1 | 62.72 | 62.7 | 240.8 |
| B3 | 105-130+ | 9.7 | 0.11 | 0.35 | 0.5 | 75.26 | 51.5 | 246.4 |

| 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 | 3.82 | 0.4 | 1.6 | 1.21 | 0.61 | 31.6 | 42.4 | 26.7 | 30.9 | cl |
| 26-42 | 10.67 | 6.2 | 2.0 | 1.91 | 0.56 | 17.9 | 14.6 | 45.7 | 39.7 | sicl |
| 42-58 | 8.56 | 4.2 | 2.2 | 1.47 | 0.71 | 17.1 | 12.7 | 58.4 | 28.9 | sicl |
| 58-74 | 10.47 | 6.4 | 1.8 | 1.56 | 0.71 | 14.8 | 19.1 | 49.5 | 31.4 | sicl |
| 74-105 | 11.63 | 7.0 | 2.4 | 1.47 | 0.16 | 12.6 | 15.3 | 47.0 | 37.7 | sicl |
| 105-130+ | 9.85 | 5.4 | 2.4 | 1.39 | 0.66 | 14.1 | 14.1 | 40.8 | 45.1 | sc |

| 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 | 48.00 | 8.1 | 0.66 | 5.9 | 1.88 | 0.10 | 0.0 | 6.4 | 3.0 | 0.89 |
| 26-42 | 46.40 | 7.7 | 0.80 | 7.5 | 1.95 | 0.39 | 0.0 | 8.4 | 2.7 | 1.11 |
| 42-58 | 45.05 | 8.1 | 0.70 | 8.1 | 2.09 | 0.36 | 0.0 | 11.2 | 2.4 | 0.86 |
| 58-74 | 41.15 | 7.8 | 0.50 | 6.5 | 1.79 | 0.23 | 0.0 | 6.8 | 1.6 | 0.98 |
| 74-105 | 38.00 | 8.2 | 0.79 | 5.4 | 1.71 | 0.33 | 0.0 | 5.6 | 2.4 | 0.98 |
| 105-130+ | 46.75 | 8.2 | 1.05 | 5.3 | 1.78 | 0.33 | 0.0 | 4.4 | 1.8 | 0.98 |

**Table 5.8 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 | l |
| 18-35 | 3.53 | 0.8 | 0.8 | 1.47 | 0.46 | 41.2 | 45.1 | 33.8 | 21.1 | l |
| 35-55 | 3.51 | 0.6 | 1.2 | 1.30 | 0.41 | 37.0 | 41.7 | 36.0 | 22.3 | l |
| 55-70 | 3.70 | 0.6 | 1.2 | 1.39 | 0.51 | 37.5 | 38.4 | 42.1 | 19.5 | l |
| 70-95 | 4.17 | 1.0 | 1.4 | 1.21 | 0.56 | 29.0 | 36.2 | 41.0 | 22.8 | l |
| 95-108 | 6.19 | 0.4 | 4.2 | 1.13 | 0.46 | 18.2 | 37.3 | 38.2 | 24.5 | l |

| Saturation paste and saturation extract analysis (me/l) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Depth(cm) | Sat (%) | $pH_s$ | $EC_e$ | $Ca^{++}+Mg^{++}$ | $Na^+$ | $K^+$ | $CO_3^{--}$ | $HCO_3^-$ | $Cl^-$ | $SO_4^{--}$ |
| 0-18 | 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 5.9 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 | l |
| 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 5.10 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 5.11 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 5.12 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 5.13 Available micronutrients content of salt affected soils of Kapurthala district**

| Rawalpindi series | | | | | |
|---|---|---|---|---|---|
| **Horizon** | **Depth (cm)** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| Ap | 0-26 | 1.74 | 14.48 | 8.90 | 1.22 |
| B1 | 42-58 | 0.78 | 8.04 | 7.58 | 1.20 |
| B3 | 105-130+ | 0.28 | 5.50 | 4.66 | 0.48 |
| **Domeli series** | | | | | |
| **Horizon** | **Depth (cm)** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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** | | | | | |
| **Horizon** | **Depth (cm)** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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** | | | | | |
| **Horizon** | **Depth (cm)** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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** | | | | | |
| **Horizon** | **Depth (cm)** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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** | | | | | |
| **Horizon** | **Depth (cm)** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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 |

### 5.1.3 Macro-morphological characteristics of normal soils in Kapurthala district

Soil color is one of the important properties, which helps in identifying the kinds of soils and recognize the successions of soil horizons or layers in soil profiles. It has long been used for soil identification and qualitative measurements of soil properties and is a helpful field soil property for characterizing soil type (Noshadi *et al.*, 2013). Soil color (dry) in the epipedon horizons of normal soils in Kapurthala district recorded in the following variations, gray in Dhoda, brown in Tulewal and Randhirpur, grayish brown in Samana, Ucha, Fattu Dhinga, Bhanra, Nathupur, Bhanra Kanjili and Fatehpur series, and light yellowish brown in Mund series respectively (Table 5.14 to 5.23). According to Wakene (2001), color is a function of pH, redox reaction and organic matter. A change in soil color from adjacent soil also indicates a difference in the soils mineral origin (parent material) or in soil development, 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 (Fisher and Binkley, 2000).

Soil structure (aggregation) is affected by cation effect, clay particle interaction, iron and aluminium colloids, organic matter and soil moisture conditions (Brady and Weil, 2008). Soil structure has a major influence on the ability of soil to support plant growth, cycle-C and nutrient, receive and store water and to resist soil erosion, and the dispersal of chemical of anthropogenic origin (Sumner, 2000). In normal soils of Kapurthala district there was a variation in grade and size of structure in each horizon of a pedon and among the pedon. The shape of structure in all the horizons of the pedons recorded as sub angular blocky structure except BC horizon of Dhoda (Table 5.14) and Tulewal (Table 5.15) series individually, where recorded massive structure and AC, C2, C3, C4 horizons of Nathupur (Table 5.19) and all horizons of Mund (Table 5.20) where the structure had no specific shape. Accordingly, 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 structure. Soil structural property variations could be due to organic matter content and textural characteristics (Mohammed *et al*., 2005). Soil structure is strongly affected by changes in climate, biological activities, soil management practices and physicochemical nature of the soil. The arrangement and placement of soil particles in to aggregates determines the response of soil to exogenous stresses such as tillage, traffic, and raindrop impact (Lal and Shukla, 2004). Extensive network of roots, soil micro-organisms and inorganic materials are among the major responsible factors for the formation of soil structure.

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 (Lal and Shukla, 2004). Most of time consistence is described for three moisture levels; wet, moist, and dry (Buol *et al*.,2003). It is a term used to describe the action of physical forces of cohesion and adhesion on the attributes of soil material at these moisture contents that determines the resistance of soil material to crushing or rupture and its ability to change the shape or to be moulded. Ashenafi *et al*., (2010) stated that friable consistency of soils indicates soils are workable at appropriate moisture content and lack of very sticky and very plastic consistency. Soil consistence characteristics in normal soils of Kapurthala district varied from hard to soft (dry), loos (moist), sticky and plastic (wet) in Dhoda, soft (dry) friable (moist), slightly sticky and slightly plastic (wet) in Tulewal, Samana, Ucha, Fattu Dhinga, Nathupur and Fatehpur series, also in Kanjili series except it is sticky and plastic when (wet), soft (dry), friable (moist), non-sticky and non-plastic (wet) in Mund series respectively. The results of macro morphology of the normal soils are presented below.

**Table 5.14 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 5.15 Macro-morphological characteristics of Tulewal series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | dry | moist | wet | | |
| **Ap** | 0-25 | 10YR 4/2 | scl | 2m sbk | dsh | mfr | wss,wsp | e | ds |
| **AB** | 25-41 | 10YR 6/4 | sl | 2m sbk | | mfr | wss,wsp | es | ds |
| **B1** | 41-62 | 10YR 5/4 | scl | 1c sbk | | mfr | wss,wsp | e | gs |
| **B2** | 62-90 | 10YR 6/6 | scl | 1c sbk | | mfr | wss,wsp | e | gs |
| **BC** | 90-123 | 10YR 6/6 | sl | Massive | | mfr | wss,wsp | e | - |

**Table 5.16 Macro-morphological characteristics of Samana series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | Reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | dry | moist | wet | | |
| **Ap** | 0-30 | 10YR 4/1 | cl | 2m sbk | dsh | mfr | wss,wsp | ev | cs |
| **AB** | 30-50 | 10YR 6/3 | sl | 2m sbk | | mfr | wss,wsp | es | gs |
| **B1** | 50-69 | 10YR 5/4 | sl | 2m sbk | | mfr | wss,wsp | es | gs |
| **B21** | 69-90 | 10YR 5/6 | sl | 2c sbk | | mfr | wss,wsp | e | gs |
| **B22** | 90-114 | 10YR 5/4 | sl | 2c sbk | | mfr | wss,wsp | e | gs |
| **B23** | 114-142 | 10YR 6/4 | sl | 2msbk | | mfr | wss,wsp | | |

**Table 5.17 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 | |

**Table 5.18 Macro-morphological characteristics of Fattu Dhinga series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | Reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | dry | moist | wet | | |
| **Ap** | 0-25 | 10YR 4/3 | sl | 1m sbk | dsh | mfr | wss,wsp | es | cs |
| **AB** | 25-56 | 10YR 5/4 | sl | 2m sbk | dsh | mfr | wss,wsp | es | ds |
| **B21** | 56-77 | 10YR 4/4 | sl | 2m sbk | dsh | mfr | wss,wsp | e | gs |
| **B22** | 77-107 | 10YR 5/4 | sl | 2m sbk | dsh | mfr | wss,wsp | - | gs |
| **B23** | 107-135 | 10YR 5/4 | ls | 1m sbk | dsh | mfi | wss,wsp | - | |

**Table 5.19 Macro-morphological characteristics of Nathupur series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | Reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | dry | moist | wet | | |
| **Ap** | 0-26 | 10YR 4/3 | ls | 1m sbk | dsh | Mfr | Wss,wsp | ev | ci |
| **AB** | 26-50 | 10YR 4/6 | sl | 1m sbk | | Mfr | Wss,wsp | es | ci |
| **AC** | 50-73 | 10YR 4/6 | s | 0 | | Mfr | Wss,wsp | es | ds |
| **C2** | 73-96 | 10YR 5/2 | s | o | | Mfr | Wss,wsp | e | ds |
| **C3** | 96-120 | 10YR 5/1 | s | o | | Mfi | Wss,wsp | e | ds |
| **C4** | 120+ | 10YR 5/2 | s | o | | | | e | - |

**Table 5.20 Macro-morphological characteristics of Mund series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | Reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | dry | moist | wet | | |
| **A1** | 0-28 | 10YR 4/3 | ls | o | dsh | mfr | wso,wso | ev | ci |
| **C1** | 25-50 | 10YR 4/6 | l | o | | mfr | wso,wso | es | ci |
| **C2** | 50-69+ | 10YR 6/1 | s | o | | mfr | wso,wso | 0 | - |

**Table 5.21 Macro-morphological characteristics of Bahanra series**

| Horizon | Depth (cm) | Color | Texture | Structure | Consistence | | | Reaction with HCl | Boundary |
|---|---|---|---|---|---|---|---|---|---|
| | | Moist | | | dry | moist | wet | | |
| **Ap** | 0-25 | 10YR 4/2 | ls | 1m sbk | dsh | mfr | wss,wpo | eo | cs |
| **AB** | 25-55 | 10YR 6/4 | ls | 1m sbk | dsh | mfr | wss,wpo | eo | gs |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **B1** | 55-79 | 10YR 5/6 | ls | 1m sbk | dsh | mfr | wso,wpo | eo | gs |
| **B2** | 79-120 | 10YR 4/6 | ls | 1m sbk | dsh | mfr | wso,wpo | eo | gs |
| **BC** | 120-140 | 10YR 5/6 | ls | 1m sbk | dsh | mfi | wso,wpo | eo | gs |

**Table 5.22 Macro-morphological characteristics of Kanjili series**

| **Horiz on** | **Depth (cm)** | **Color** | **Texture** | **Structure** | **Consistence** | | | **Reaction with HCl** | **Bound ary** |
|---|---|---|---|---|---|---|---|---|---|
| | | **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 |

**5.23 Macro-morphological characteristics of Fatehpur series**

| **Horiz on** | **Depth (cm)** | **Color** | **Texture** | **Structure** | **Consistence** | | | **Reaction with HCl** | **Bound ary** |
|---|---|---|---|---|---|---|---|---|---|
| | | **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 | c sbk | | mfi | wss,wsp | 0 | gs |

**Figure 5.1.2 Attachment photos of normal soils**

**Representative Dhoda series**

**Representative Tulewal series**

**Representative Samana series**

**Representative Ucha series**

**Representative Fattu Dhinga series** **Representative Nathupur series**

**Representative Mund series** **Representative Bhanra series**

**Representative Kanjili series** **Representative Fatehpur series**

### 5.1.4 Physical and chemical characteristics of normal soils in Kapurthala district

#### 5.1.4.1 Physical characteristics of normal soils of Kapurthala district

**Texture**

The particle size analysis of soils showed that the texture classes of the normal soils of Kapurthala district varied from clay loam in all the horizon of Dhoda series except B1 horizon which is sandy clay loam (Table 5.24), sandy clay loam and sandy loam in Tulewal series (Table 5.25), clay loam in the epipedon horizon of Samana and sandy loam in the subsurface horizons (Table 5.26), sandy loam and loam in Ucha (Table 5.27), sandy loam in Fattu Dhinga except loamy sand in B23 horizon (Table 5.28), loamy sand and sand in Nathupur series (Table 5.29), loamy sand, loam and sand in Mund series (Table 5.30), loamy sand in Bhanra series (Table 5.31), clay loam and sandy clay loam in Kanjili series (Table 5.32), sandy loam, loamy sand and sand in Fatehpur series (Table 5.33) respectively.

**Particle size distribution**

**Clay**

The percentage of clay contents is low in Ucha, Fattu Dhinga, Nathupur, and Bhanra series. The percentage of clay is low in all the horizons of Mund series except C1 horizon. In Samana and Fatehpur series percentage of clay contents are 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 4.7 per cent in Nathupur series (Table 5.29) to 35.4 per cent in Samana series (Table 5.26). The clay content in subsurface horizons ranged from 0.8 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 0.8 per cent was recorded in C3 horizon of Nathupur 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 to clay. As such the parent material controls the genesis of these soils. Low clay content could also be associated with young age of the soil as proposed by (Collins and Fenton, 1982) as an index for measuring soil development.

**Silt**

The percentage of silt content in normal soil of Kapurthala district in North-West Punjab in the epipedon ranged from 6.3 per cent in Fattu Dhinga series (Table 5.28) to 41.6 per cent in Dhoda series (Table 5.24). The percentage of silt content in the subsurface horizons of these soils ranged from 0.9 per cent to 41.3 per cent. The highest value of 41.3 per cent of silt content was recorded in BC horizon of Dhoda series and the lowest value of 0.9 per cent of silt content was recorded in C3 horizon of Natpur series. According to particle size distribution rating proposed by Hazelton and Murphy (2007), the silt content of normal soils of Kapurthala district characterized by very low to high. In the epipedon horizons, the silt content of all the series was recorded low except Dhoda series which was recorded high and Fattu Dhinga and Bhanra which recorded very low. The mean of silt content of normal soils of Kapurthala district was 18.41 per cent.

**Sand**

The sand value of normal soils in Kapurthala district 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 to 98.3 per cent. The highest value of 98.3 per cent was recorded in C3 horizon of Nathupur series and the lowest value of 23.1 per cent was recorded in BC horizon of Dhoda series. According to particle size distribution rating proposed by Hazelton and Murphy (2007), 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. The sand content of Dhoda series except BC horizon, Tulewal, Samana, Nathupur, Kanjili and Fatehpur series increased in subsurface horizons with depth. The mean of sand content for these soils was 65.00 per cent.

### 5.1.4.2 Chemical characteristics of normal soils in Kapurthala district

**Soil reaction (1:2)**

Soil reaction is commonly expressed in term of soil pH, which is the negative logarithm of the hydrogen ion activity. The data on soil reaction determined in a 1:2 soils to water ratio suspension. According to Tekalign, (1991) rating, the pH of normal soils of Kapurthala district characterized under strongly alkaline pH except epipedon of Bhanra series (Table 5.31) which was 7.5 moderately alkaline pH. The pH value of these soils in the epipedon ranged from 7.5 in Bhanra series to 9.9 in Fattu Dhinga series. The pH value of subsurface horizons ranged from 8.0 to 10.9. The highest value of pH was noted in B21 horizon of Fattu Dhinga series and the lowest pH of these soils were recorded in BC horizon of Bhanra series. The pH value in all the series increased with depth except B1 horizon of Tulewal series, B22 horizon of Samana series, C2 horizon of Nathupur series and C1 horizon of Mund series respectively. The pH is high in all the horizons of normal soils in Kapurthala district of Punjab, it might be due to their calcareous nature and the accumulation bases in the solum as soils were poorly leached (Satyanarayana *et al.,* 1970). Furthermore, the alkalinity in these soils may be due to over liming, also alkaline irrigation water may cause these soils and this is treatable. According to (Das, 1996) these soils have a great deal with sodium, calcium and magnesium.

**Electrical conductivity**

The electrical conductivity of normal soils of Kapurthala district was below 1dS $m^{-1}$. The electrical conductivity of these soils in the epipedon ranged from 0.06 dS $m^{-1}$ in Nathupur series (Table 5.29) to 0.53 dS $m^{-1}$ in Fatehpur series (Table 5.33). The electrical conductivity of normal soils in Kapurthala district in the subsurface horizons ranged from 0.02 dS $m^{-1}$ to 0.70 dS $m^{-1}$. The highest value of electrical conductivity was recorded in B22 horizon of Fatehpur series and the lowest value of electrical conductivity was recorded in AC horizon of Nathupur series. The electrical conductivity value in Samana, Mund, and Bahanra and Dhoda series except B22 horizon decreased with soil depth while in Kanjili series increased with depth but not followed regular pattern. The mean of electrical conductivity in all the series is 0.270 dS $m^{-1}$. Electrical conductivity values in normal soils of Kapurthala district were rated as very low, and it's below 0.8 dS $m^{-1}$, which shows normal condition and it is suitable for all crops. According to Havlin *et al*., (1999) this range is categorized as very low and implies that the soils are not salt affected.

**Organic carbon percentage**

In the normal soils of the study area, the organic carbon content in the epipedon ranged from 0.2 per cent in Kanjili series (Table 5.32) to 0.93 per cent in Dhoda series (Table 5.24), while in the subsurface horizon it ranged from 0.06 per cent to 0.54 per cent. The highest value of 0.54 per cent was recorded in B1 horizon of Samana series and the lowest value of 0.06 per cent was recorded in B3 horizon of Kanjili 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 was high in the epipedon horizons of Dhoda and Tulewal series, medium in the epipedon horizons of Samana, Ucha Fattu Dhinga, and Nathupur series and low in the epipedon horizons of Mund, Bahanra, Kanjili and Fatehpur series. 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 (Ojanuga, (1971). In most of the series the organic carbon content is higher in the surface horizon then subsurface horizon and decrease with soil depth. A similar observation had been made by Ojanuga, (1971). The mean organic carbon of all the series was 0.321 per cent.

### Calcium carbonate percentage

Calcium carbonate content of normal soils of Kapurthala district in the epipedon ranged from 0.1 per cent in Nathupur series to 0.5 per cent in Samana series, while in the subsurface horizon it ranged from nil to 0.5 per cent. The highest content of calcium carbonate 0.5 per cent was recorded in AB horizons of Tulewal and Samana series, B23 horizon of Fattu Dhinga series, C2 horizon of Nathupur series, and B21 horizon of Kanjili 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.

### Available nitrogen

Nitrogen is the most extensively limiting plant nutrient in crop production. Now about 50 per cent of human population riles on fertilizer N for food production and the world uses around 132 million tons of nitrogen fertilizers. The consumption of nitrogen fertilizer is steadily increasing in developing countries like India and China due to raising food demand growing population (Goswami *et al.*, 2009). 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 to 672.7 kg/ha. The highest value of available nitrogen content was recorded in B1 horizon of Kanjili series (Table 5.32) and the lowest value of available nitrogen content was recorded in the B23 horizon of Fattu Dhinga series (Table 5.28) and B22 horizon of Kanjili series (Table 5.32) respectively. The mean available nitrogen was 239.74 kg/ha. Available nitrogen in the epipedon of all the series of normal soils in Kapurthala district ranged from low to high. Dhoda and Tulewal 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 in the surface horizon. Accordingly B1 horizon of Kanjili series also had high level of available nitrogen. It could be due to of 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 (Adhonan *et al.,* 2016). Low available nitrogen in most of subsurface horizons of the series could be due to low amount of organic carbon percentage in these soils.

**Available phosphorus**

Phosphorus in soils is present in organic as well as inorganic forms. Plant takes phosphorus as $HPO_4$ and $H_2PO_4$ ions. The major source of these phosphate ions is the inorganic form. Iron phosphate and aluminium phosphate in acid soils and calcium phosphate in calcareous soils act as the source of inorganic forms of phosphorus. All these inorganic forms of phosphorus are in dynamic equilibrium with water soluble phosphorus in soils. So it is obvious that the method that is employed for the determination of available phosphorus in soil must include predominantly these inorganic forms, in addition to the water soluble phosphorus (Kuldip S *et al.,* 2013). The available phosphorus status in normal soil of Kapurthala district was determined by Olsent *et al.,* (1954) method. The available phosphorus in the epipedon of normal soils of the study area ranged from 33.8 kg/ha in Tulewal series (Table 5.25) to 107.9 kg/ha in Fatehpur series (Table 5.33), while in subsurface horizon ranged from 33.8 kg/ha in B21 horizon of Dhoda series (Table 5.24) to 122.3 kg/ha in B3 horizon of Ucha series (Table 5.27). The available phosphorus contents were high in surface horizons of all the series except Tulewal, Samana and 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 is 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. 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. The mean available phosphorus of all the series was 77.18 kg/ha.

**Available potassium**

The available potassium by definition is the sum of exchangeable and water soluble potassium. Both of these forms of potassium (constituting only about 1-2 per cent of total potassium in soil) are in equilibrium with the non-exchangeable potassium i.e. the potassium which is fixed by vermiculite, illite and other 1:2 type clay minerals in the soil. With the removal of exchangeable potassium by crops or through leaching some of the fixed potassium is released to maintain the equilibrium and thus becomes available. The contribution of potassium, present in the form of mineral like feldspars and mica to overall available potassium, in the soil, is also of significant importance. The most widely accepted (Kuldip S *et al.,* 2013). The method of determining available potassium was introduced by (Marwin and Peech, 1950). According to the method they have given available potassium observed in normal soils of Kapurthala district were high. The available potassium in the epipedon of normal soil ranged from 263.2 kg/ha in Dhoda series to 420.0 kg/ha in Nathupur series, while in the subsurface horizons ranged from 184.8 kg/ha in C3 and C4 horizons of Nathupur series. 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 water (Raju *et al.,* 2005) The similar results were reported by Hirekurabar *et al.,* (2000) in cotton based cropping system in Karnataka. The mean of available potassium of all the normal series was 295.5 kg/ha.

**CEC, exchangeable cation and ESP**

The cation exchange capacity of normal soils in Kapurthala district in epipedon ranged from 2.69 $cmol_c/kg$ in Nathupur series to 11.64 $cmol_c/kg$ in Fattu Dhinga series. In the subsurface horizon the CEC ranged from 2.03 $cmol_c/kg$ to 12.60 $cmol_c/kg$. The highest value of CEC was recorded in B1 horizon of Kanjili series and the lowest CEC was recorded in C3 horizon Nathupur series. CEC of these soils consistently decreased with soil depth in Dhoda, Ucha and Fattu Dhinga series and increased in Tulewal and Samana series. In the remaining series, it did not follow any consistent trend. The result could be strongly associated with the nature and amount of clay of the soils. Decreased in CEC with soil depth could be due the strong association between organic carbon and CEC. According to Brady and Weil (2002), CEC depends on the nature and amount of colloidal particles. The mean value of all the series was 6.95 $cmol_c$/kg. The highest mean value 11.9 $cmol_c$/kg was recorded in Kanjili series, followed by 9.08 $cmol_c$/kg and the lowest mean value was recorded in Nathupur series. Hazelton and Murphy, (2007), CEC values are rated < 6 $cmol_c$/kg as very low, 6 - 12 $cmol_c$/kg as low; 12 – 25 $cmol_c$/kg as medium, 25 – 40 $cmol_c$/kg as high and > 40 $cmol_c$/kg as very high. 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 $cmol_c$/kg and 13.16 $cmol_c$/kg respectively.

The exchangeable calcium in the epipedon of normal soil pedons in Kapurthala district ranged from 0.6 $cmol_c$/kg in Nathupur series to 8.2 $cmol_c$/kg in Fattu Dhinga series, while in subsurface horizons it ranged from 0.6 $cmol_c$/kg in C2 horizon of Nathupur series to 8.4 $cmol_c$/kg in BC horizon of Tulewal series. Exchangeable calcium increased with soil depth in Tulewal, Samana, Ucha, and Nathupur series, which might be due to the effect of washing away by soil erosion from the upper areas and adjacent slopes (Hailu *et al.*, 2015), and decreased in Dhoda, Fattu Dhinga, Mund, and Kanjili series respectively, but not followed regular trends. According to FAO, (2006) rating the exchangeable calcium contents were very low to medium in normal soils of Kapurthala district. The exchangeable manganese in epipedon soils ranged from 0.4 $cmol_c$/kg in Bahanra series to 2.2 $cmol_c$/kg in Fattu Dhinga series, while in the subsurface horizon it ranged from 0.2 $cmol_c$/kg in Dhoda series to 2.4 $cmol_c$/kg in Kanjili series. Exchangeable sodium percentage in the study area ranged from 0.52 $cmol_c$/kg in Bahanra series to 2.17 $cmol_c$/kg in Mund series in the epipedon. In the subsurface horizons ranged from 0.34 $cmol_c$/kg in BC horizon of Dhoda series and B11 horizon of Bhanra series respectively to 5.56 $cmol_c$/kg in B3 horizon of Kanjili series followed 3.82 $cmol_c$/kg in B22 horizon of Kanjili series. The mean exchangeable sodium of all the normal soil series was 0.97 $cmol_c$/kg. Accordingly, the exchangeable potassium content in the epipedon horizons of pedons were ranged from 0.35 $cmol_c$/kg in Ucha and Mund series to 0.61 $cmol_c$/kg in Tulewal and Samana series. In the subsurface ranged from 0.2 $cmol_c$/kg in B21 and B3 horizons of Kanjili series to 0.8 $cmol_c$/kg in B2 horizons of Tulewal series. The mean exchangeable potassium of all the normal soil series of Kapurthala district was 0.47 $cmol_c$/kg. According to FAO (2006) rating exchangeable manganese content were very low to medium, exchangeable sodium contents were medium to very high and exchangeable potassium content were medium to high except BC horizon of Bhanra and B21 and B3 horizon of Kanjili 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 28.9 per cent in Nathupur series and in the subsurface ranged from 5.5 in the BC horizon of Dhoda series to 66.0 per cent in Natpur series. The ESP of all the series in normal soils except Nathupur and Mund 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.

**Saturation past and saturation extract**

Saturation percentage of normal soils in Kapurthala district ranged from 28.10 per cent in Mund series (Table 5.30) to 44.40 per cent in Kanjili series (Table 5.32) 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 33.45 per cent. Highest mean value was recorded in Kanjili series 41.71 per cent and followed by 41.15 per cent in Dhoda series and the lowest mean value 27.24 per cent was recorded in Bahanra series.

Accordingly, the composition of soils saturation paste and saturation extract such as $pH_s$, $EC_e$, $Ca^{++}$,$Mg^{++}$, $Na^+$, $K^+$, $CO_3^{- -}$, $HCO_3^-$, $Cl^-$, and $SO_4^{- -}$ were determined in laboratory. The $pH_s$ 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 $EC_e$ of less than 4 except epipedon of Fatehpur series which indicate no salinity (Balpande *et al,,* 1996) And it ranged from 0.21 me/l in BC horizon of Tulewal series to 9.8 me/l in the epipedon horizon of Fatehpur followed by 1.58 me/l in B23 horizon of Samana series. Ca+Mg contend in saturation extract of normal soils of Kapurthala district ranged from 0.48 me/l in

Fatehpur series to 15.4 me/l in Dhoda series in epipedon horizons, while in subsurface horizons ranged from 1.5 me/l in BC horizon of Bahanra series to 11.8 me/l in C2 horizon of Nathupur series. Sodium content of the saturation paste of these soils in the epipedon horizons ranged from1.31 me/l in Mund series to 6.06 me/l in Tulewal series. In the subsurface ranged from 0.78 me/l in C4 horizon of Nathupur series and B3 horizon of Kanjili series. Sodium contents decreased with depth in all the series except Fattu Dhinga series which increased in B21 and B22 horizons. Potassium continent in soil solution ranged from 0.3 me/l in the surface horizon of Dhoda series to 1.30 me/l in Fatehpur series respectively, while in subsurface ranged from 0.14 me/l in B21 horizon of Dhoda series to 1.05 me/l in AC horizon of Nathupur series. Carbonate ($CO_3^{- -}$) is nil in all the horizons of Tulewal, Ucha, Randhirpur, Fattu Dhinga, Natpur, Bahanra, Kanjili and Fatehpur series. The highest value 3.2 me/l of carbonate was recorded in the surface horizon of Samana series. Bicarbonate in normal soils of Kapurthala district ranged from 1.2 me/l in B3 horizon of Kanjili series to 13.2 in the surface horizon of Mund series. Chloride concentrations contribute to the total soluble salt concentration. Due to the fact that chloride salts are quite soluble, they will readily leach from soils with good drainage. High levels will reduce biological activity. Accordingly, Cl in these soils ranged from 0.6 me/l in BC horizon of Dhoda series and AB horizon of Bahanra series respectively to 19.0 me/l in C1 horizon of Munds series followed by 7.8 me/l in surface horizon of Dhoda series. Sulphate contents in saturation extract of all the horizons of the study area were ranged from 0.32 me/l in AC horizon of Nathupur series to 2.87 me/l in the surface horizon of Kanjili series.

**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 5.34). Extractable zinc in the epipedon horizons of the study area ranged from 0.12 mg/kg of soil in Mund series to 1.70 mg/kg of soil in Fatehpur series, while in subsurface ranged from 0.04 mg/kg of soil in C2 horizon of Mund, BC horizon of Bhanra, and B22 horizon of Fatehpur series respectively to 0.32 mg/kg of soil in B1 horizon of Tulewal series. Available zinc content was low in the surface horizon of Dhoda, Ucha, Nathupur, and Mund series, and it ranged low in all the subsurface horizons of all the series of normal soils in Kapurthala district. Considering 0.6 mg/kg of soil as critical level (Lindsay and Norvell, 1978) for available zinc, these soils were classified as deficient in all the horizons of the series except epipedon horizons of Tulewal, Samana, Fattu Dhinga, Bhanra, Kanjili and Fatehpur series. Similar views were expressed by Venkatesu *et al.,* (2002) in soils of Nellore district of Andhra Pradesh.

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 (Lindsay and Norvell, 1978) as the critical limit for DTPA- extractable iron for normal plant growth, 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, B23 horizon of Fattu Dhinga series, C2 horizon of Mund series and B3 horizon of Kanjili series respectively. This could be attributed to the parent material and pH condition of the soils (Hailu and Hagos 2014).

The available manganese content of these soils ranged from 4.86 mg/kg of soil in Mund to 11.14 mg/kg of soil in Nathupur series in the epipedon. In the subsurface horizon it ranged from 0.88 mg/kg of soil in BC horizon of Dhoda series to 12.26 mg/kg of soil. The available manganese content was sufficient to high in all the horizons of series except B21 and BC horizons of Dhoda series and C2 and C4 horizons of Nathupur series, considering 3.5 mg/kg of soil (Lindasy and Norvell, 1978), as critical limit of manganese content.

The DTPA- extractable Cu in the epipedon horizons of normal soils in Kapurthala district ranged from 0.30 mg/kg of soil in Mund 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 1.94 mg/kg of soil in C1 horizon of Mund series. Considering 0.2 mg/kg of soil (Lindsay and Norvell, 1978) 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.

**Table 5.24 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 | 41.4 | 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(%) | $pH_s$ | $EC_e$ | $Ca^{++}+Mg^{++}$ | $Na^+$ | $K^+$ | $CO_3^{--}$ | $HCO_3^-$ | $Cl^-$ | $SO_4^{--}$ |
| 0-24 | 39.55 | 7.4 | 1.45 | 15.4 | 6.0 | 0.30 | Nil | 6.4 | 7.8 | 2.59 |
| 24-45 | 40.50 | 8.0 | 0.98 | 9.8 | 7.0 | 0.23 | 1.6 | 7.2 | 4.4 | 2.74 |
| 45-65 | 42.75 | 7.7 | 1.24 | 5.2 | 5.7 | 0.18 | 4.0 | 2.4 | 5.2 | 1.96 |
| 65-87 | 41.35 | 7.5 | 0.61 | 5.1 | 3.17 | 0.14 | 2.4 | 4.8 | 5.4 | 1.95 |
| 87-113 | 45.00 | 7.4 | 0.57 | 4.8 | 3.65 | 0.18 | 2.4 | 3.2 | 4.8 | 1.57 |
| 113-139 | 38.05 | 7.9 | 0.36 | 5.9 | 1.95 | 0.33 | Nil | 1.6 | 0.6 | 1.66 |

**Table 5.25 physico-chemical characteristics of Tulewal 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 | 8.8 | 0.09 | 0.92 | 0.3 | 551.9 | 33.8 | 280.0 |
| AB | 25-41 | 9.6 | 0.09 | 0.40 | 0.5 | 376.3 | 39.8 | 246.4 |
| B1 | 41-62 | 8.6 | 0.24 | 0.31 | 0.1 | 175.6 | 36.5 | 313.6 |
| B2 | 62-90 | 8.8 | 0.22 | 0.19 | 0.2 | 213.2 | 36.7 | 240.0 |
| BC | 90-123 | 8.9 | 0.16 | 0.40 | 0.1 | 150.5 | 37.1 | 206.88 |

| 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 | |
| 0-25 | 8.61 | 5.0 | 1.8 | 1.2 | 0.61 | 13.9 | 54.1 | 22.3 | 23.6 | scl |
| 25-41 | 8.65 | 5.6 | 1.4 | 1.4 | 0.70 | 16.1 | 54.9 | 30.4 | 14.7 | sl |
| 41-62 | 8.86 | 6.2 | 1.6 | 1.6 | 0.60 | 18.1 | 49.4 | 22.3 | 28.7 | scl |
| 62-90 | 8.31 | 5.8 | 1.2 | 1.2 | 0.80 | 14.4 | 51.9 | 19.7 | 28.4 | scl |
| 90-123 | 10.26 | 8.4 | 0.8 | 0.8 | 0.60 | 7.7 | 59.2 | 27.2 | 13.6 | sl |

| 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 | 35.0 | 8.0 | 1.47 | 9.2 | 6.06 | 0.43 | Nil | 8.8 | 5.2 | 1.66 |
| 25-41 | 31.9 | 8.1 | 1.16 | 6.2 | 3.17 | 0.46 | Nil | 9.6 | 4.0 | 1.68 |
| 41-62 | 33.5 | 8.6 | 0.72 | 5.4 | 2.91 | 0.31 | Nil | 7.6 | 3.8 | 1.7 |
| 62-90 | 34.4 | 8.5 | 0.60 | 5.2 | 2.17 | 0.39 | Nil | 3.4 | 4.2 | 1.25 |
| 90-123 | 37.7 | 8.5 | 0.21 | 5.1 | 2.69 | 0.33 | Nil | 4.4 | 1.8 | 1.64 |

**Table 5.26 physico-chemical characteristics of Samana 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 | 8.8 | 0.20 | 0.66 | 0.5 | 401.4 | 83.7 | 372.4 |
| AB | 30-50 | 9.1 | 0.16 | 0.43 | 0.5 | 338.6 | 37.6 | 291.2 |
| B1 | 50-69 | 9.8 | 0.13 | 0.54 | 0.4 | 426.4 | 93.4 | 268.8 |
| B21 | 69-90 | 9.6 | 0.11 | 0.34 | 0.4 | 150.5 | 104.8 | 291.2 |
| B22 | 90-114 | 8.7 | 0.08 | 0.38 | 0.4 | 175.6 | 104.1 | 246.4 |
| B23 | 114-142 | 9.6 | 0.06 | 0.24 | 0.2 | 200.7 | 79.0 | 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 | |
| 0-30 | 7.19 | 5.0 | 0.8 | 0.78 | 0.61 | 10.8 | 30.1 | 37.6 | 35.4 | cl |
| 30-50 | 8.54 | 6.2 | 1.0 | 0.78 | 0.56 | 9.1 | 68.8 | 16.4 | 14.8 | sl |
| 50-69 | 8.55 | 6.4 | 1.0 | 0.69 | 0.46 | 8.0 | 63.5 | 22.1 | 14.3 | sl |
| 69-90 | 8.91 | 7.2 | 0.6 | 0.6 | 0.51 | 6.7 | 63.7 | 25.1 | 11.2 | sl |
| 90-114 | 10.84 | 8.0 | 1.6 | 0.78 | 0.46 | 7.1 | 61.4 | 28.4 | 10.2 | sl |
| 114-142 | 10.5 | 8.2 | 1.2 | 0.69 | 0.41 | 6.5 | 54.0 | 33.9 | 12.1 | sl |

| 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 | 35.5 | 7.8 | 1.26 | 7.9 | 4.69 | 0.52 | 3.2 | 2.8 | 3.8 | 2.06 |
| 30-50 | 33.0 | 8.0 | 0.91 | 6.9 | 3.56 | 0.64 | 1.6 | 3.6 | 2.2 | 1.50 |
| 50-69 | 32.7 | 7.8 | 0.82 | 7.3 | 3.95 | 0.83 | Nil | 5.2 | 2.4 | 0.98 |
| 69-90 | 31.6 | 7.7 | 1.01 | 6.5 | 3.13 | 0.68 | Nil | 7.6 | 1.6 | 0.80 |
| 90-114 | 30.0 | 7.6 | 0.88 | 4.2 | 4.04 | 0.70 | 2.4 | 4.8 | 2.0 | 0.65 |
| 114-142 | 30.6 | 7.5 | 1.58 | 5.7 | 3.45 | 0.66 | Nil | 8.4 | 1.4 | 0.72 |

**Table 5.27 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 |

**Table 5.28 physico-chemical characteristics of Fattu Dhinga 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 | 9.9 | 0.29 | 0.71 | 0.3 | 338.6 | 82.2 | 364.0 |
| AB | 25-56 | 10.6 | 0.31 | 0.43 | 0.2 | 313.6 | 81.0 | 336.0 |
| B21 | 56-77 | 10.9 | 0.26 | 0.40 | 0.1 | 200.7 | 79.0 | 336.0 |
| B22 | 77-107 | 10.6 | 0.22 | 0.39 | 0.2 | 250.8 | 77.0 | 291.2 |
| B23 | 107-135 | 10.6 | 0.11 | 0.22 | 0.5 | 37.6 | 75.9 | 246.4 |

| 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 | |
| 0-25 | 11.64 | 8.2 | 2.2 | 0.78 | 0.51 | 6.7 | 79.1 | 6.3 | 14.5 | sl |
| 25-56 | 9.80 | 6.8 | 1.8 | 0.69 | 0.51 | 7.0 | 79.3 | 9.8 | 10.9 | sl |
| 56-77 | 7.96 | 5.2 | 1.6 | 0.60 | 0.56 | 7.5 | 74.6 | 1.2 | 13.2 | sl |
| 77-107 | 6.61 | 4.2 | 1.4 | 0.60 | 0.46 | 9.0 | 71.5 | 13.9 | 14.6 | sl |
| 107-135 | 6.33 | 3.2 | 2.2 | 0.52 | 0.41 | 8.2 | 78.2 | 17.3 | 4.7 | 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 | 31.00 | 8.1 | 1.20 | 11.9 | 1.83 | 0.64 | Nil | 8.0 | 5.8 | 1.46 |
| 25-56 | 35.05 | 8.3 | 0.30 | 5.1 | 1.78 | 0.52 | Nil | 3.6 | 5.2 | 1.17 |
| 56-77 | 34.10 | 8.3 | 0.29 | 5.2 | 2.04 | 0.48 | Nil | 4.4 | 5.0 | 2.05 |
| 77-107 | 32.25 | 8.6 | 0.86 | 5.2 | 2.13 | 0.39 | Nil | 7.2 | 4.4 | 1.95 |
| 107-135 | 31.40 | 8.0 | 0.59 | 5.2 | 1.67 | 0.36 | Nil | 4.8 | 4.2 | 1.39 |

**Table 5.29 physico-chemical characteristics of Nathupur 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 | 8.8 | 0.06 | 0.63 | 0.1 | 275.9 | 84.2 | 420.0 |
| AB | 26-50 | 8.9 | 0.04 | 0.34 | 0.4 | 175.6 | 77.9 | 364.0 |
| AC | 50-73 | 9.0 | 0.02 | 0.13 | 0.0 | 112.8 | 74.1 | 313.6 |
| C2 | 73-96 | 8.5 | 0.07 | 0.15 | 0.5 | 163.0 | 79.7 | 336.0 |
| C3 | 96-120 | 9.3 | 0.08 | 0.24 | 0.1 | 50.1 | 69.2 | 184.8 |
| C4 | 120+ | 9.2 | 0.07 | 0.12 | 0.2 | 75.2 | 84.8 | 184.8 |

| 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 | |
| 0-26 | 2.69 | 0.6 | 0.8 | 0.78 | 0.51 | 28.9 | 77.5 | 17.8 | 4.7 | ls |
| 26-50 | 2.65 | 0.8 | 0.6 | 0.69 | 0.56 | 66.0 | 80.3 | 10.3 | 9.4 | ls |
| 50-73 | 2.96 | 1.0 | 0.8 | 0.60 | 0.56 | 20.2 | 91.7 | 5.2 | 3.1 | s |
| 73-96 | 2.29 | 0.6 | 0.8 | 0.43 | 0.46 | 18.7 | 90.8 | 4.6 | 4.2 | s |
| 96-120 | 2.03 | 0.8 | 1.2 | 0.52 | 0.51 | 25.6 | 98.3 | 0.9 | 0.8 | s |
| 120+ | 2.85 | 1.0 | 0.6 | 0.69 | 0.56 | 24.2 | 88.9 | 9.8 | 1.4 | s |

| 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 | 37.50 | 7.7 | 0.50 | 4.2 | 2.09 | 1.19 | Nil | 8.4 | 5.2 | 1.46 |
| 26-50 | 30.05 | 7.9 | 0.95 | 10.1 | 1.65 | 0.52 | Nil | 7.6 | 3.6 | 0.98 |
| 50-73 | 28.70 | 8.0 | 0.62 | 6.8 | 1.19 | 1.05 | Nil | 7.2 | 3.0 | 0.32 |
| 73-96 | 30.90 | 8.3 | 0.62 | 11.8 | 1.14 | 0.86 | Nil | 3.2 | 2.4 | 0.64 |
| 96-120 | 29.65 | 8.2 | 0.44 | 6.7 | 0.91 | 0.64 | Nil | 2.8 | 1.6 | 0.62 |
| 120+ | 34.40 | 8.0 | 0.55 | 6.8 | 0.78 | 0.46 | Nil | 3.6 | 0.8 | 0.60 |

**Table 5.30 physico-chemical characteristics of Mund 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) |
|---|---|---|---|---|---|---|---|---|
| A1 | 0-28 | 9.2 | 0.41 | 0.39 | 0.4 | 401.4 | 89.8 | 364.0 |
| C1 | 25-50 | 9.0 | 0.13 | 0.47 | 0.4 | 426.4 | 79.2 | 336.0 |
| C2 | 50-69+ | 9.6 | 0.39 | 0.14 | nil | 75.2 | 77.5 | 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 | |
| 0-28 | 9.52 | 5.2 | 1.8 | 2.17 | 0.35 | 22.7 | 83.4 | 12.8 | 3.2 | ls |
| 25-50 | 2.51 | 0.8 | 0.6 | 0.86 | 0.25 | 34.2 | 43.8 | 29.4 | 26.7 | l |
| 50-69+ | 7.01 | 3.4 | 1.4 | 1.91 | 0.3 | 27.4 | 89.2 | 8.3 | 2.5 | s |

| Saturation paste and saturation extract analysis (me/l) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Depth (cm) | Sat (%) | $pH_s$ | $EC_e$ | $Ca^{++}+Mg^{++}$ | $Na^+$ | $K^+$ | $CO_3^{--}$ | $HCO_3^-$ | $Cl^-$ | $SO_4^{--}$ |
| 0-28 | 28.1 | 8.2 | 0.90 | 8.1 | 1.31 | 0.68 | Nil | 13.2 | 6.6 | 1.56 |
| 25-50 | 50.2 | 7.9 | 1.01 | 7.7 | 1.27 | 0.36 | 2.4 | 12.4 | 19.0 | 1.88 |
| 50-69+ | 26.8 | 7.4 | 0.81 | 6.9 | 1.22 | 0.38 | Nil | 8.8 | 4.4 | 1.34 |

**Table 5.31 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 |

**Table 5.32 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 |

**Table 5.33 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 |

**Table 5.34 Available micronutrients content of normal soils in Kapurthala district**

| Dhoda series | | | | |
|---|---|---|---|---|
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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 |
| **Tulewal series** | | | | |
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 0-25 | 1.32 | 16.48 | 5.80 | 1.10 |
| 41-62 | 0.32 | 6.32 | 8.34 | 0.42 |
| 90-123 | 0.24 | 4.74 | 9.24 | 0.28 |
| **Samana series** | | | | |
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 0-30 | 0.86 | 10.06 | 8.28 | 1.74 |
| 69-90 | 0.20 | 8.86 | 10.44 | 0.78 |
| 114-142 | 0.14 | 9.08 | 12.26 | 0.68 |
| **Ucha series** | | | | |
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 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 |
| **Fattu Dhinga series** | | | | |
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 0-25 | 0.98 | 20.40 | 8.04 | 1.26 |
| 56-77 | 0.12 | 5.16 | 5.50 | 0.34 |
| 107-135 | 0.10 | 4.04 | 6.58 | 0.28 |
| **Nathupur series** | | | | |
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 0-26 | 0.44 | 14.42 | 11.14 | 2.02 |
| 73-96 | 0.14 | 5.44 | 3.02 | 0.36 |
| 120+ | 0.10 | 4.68 | 1.88 | 0.22 |
| **Mund series** | | | | |
| **Horizon** | **Zinc (mg/kg soil)** | **Iron (mg/kg soil)** | **Manganese (mg/kg soil)** | **Copper (mg/kg soil)** |
| 0-28 | 0.12 | 7.22 | 4.86 | 0.30 |
| 25-50 | 0.10 | 8.08 | 7.16 | 1.94 |
| 50-69+ | 0.04 | 3.36 | 1.96 | 0.22 |

| Bhanra series | | | | |
|---|---|---|---|---|
| **Horizon** | **Zinc mg/kg soil** | **Iron mg/kg soil** | **Manganese mg/kg soil** | **Copper mg/kg soil** |
| 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** | | | | |
| **Horizon** | **Zinc mg/kg soil** | **Iron mg/kg soil** | **Manganese mg/kg soil** | **Copper mg/kg soil** |
| 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** | | | | |
| **Horizon** | **Zinc mg/kg soil** | **Iron mg/kg soil** | **Manganese mg/kg soil** | **Copper mg/kg soil** |
| 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 |

### 5.1.5 Soil classification of Kapurthala district in North-West Punjab

Filed investigation and laboratory analysis of physical and chemical characteristics of the soils were used to identify the dominant soil type of Kapurthala district based on Soil Taxonomy (2015). These soils are classified up to family level. The morphological, physical and chemical characteristics of soils of Kapurthala district indicate that these soils are entisols and Inceptisols (Table 5.35).

**5.1.5.1** Soils of Rawalpindi, Domeli, Jagjitpur, Khairanwali and Randhirpur series do not have andic soil properties in 60 per cent or more of the thickness between the soil surface and either a depth of 60 cm or a densic, lithic, or paralithic contact or duripan if shallower, also do not have a spodic horizon, an albic horizon in 50 percent or more of each pedon, and a cryic or pergelic soil temperature regime, do not have a mollic epipedon; or Both a surface horizon that meets all of the requirements for a mollic epipedon, except for thickness after the soil has been mixed to a depth of 18 cm, and a sub-horizon more than 7.5 cm thick, within the upper part of an argillic, kandic, or natric horizon, that meets the color, organic-carbon content, base saturation, and structure requirements for a mollic epipedon but is separated from the surface horizon by an albic horizon. Accordingly, unlike Entisols, Inceptisols have a cambic horizon with its upper boundary within 100 cm of the mineral soil surface and its lower boundary at a depth of 25 cm or more below the mineral soil surface. As such these soils are classified under the Inceptisols order of Soil Taxonomy (USDA 2015). These soils were mainly freely drained and have an ustic moisture regime. They receive dominantly summer precipitation, or they have a hyperthermic or warmer temperature regime, furthermore these soils do not have, in a layer above a densic, lithic, or paralithic contact or in a layer at a depth between 40 and 50 cm from the mineral soil surface as such these soils recognized under suborder of Ustepts. Do not have a duripan that has its upper boundary within 100 cm of the mineral soil surface, and do not have a calcic horizon with its upper boundary within 100 cm of the mineral soil surface or a petrocalcic horizon with its upper boundary within 150 cm of the mineral soil surface as such it recognized under Haplustepts great group. Also these soils have a slope of 1-2 per cent and An irregular decrease in organic-carbon content (Holocene age) between a depth of 25 cm and either a depth of 125 cm below the mineral soil surface or a densic, lithic, or paralithic contact, whichever is shallower as such come under Fluventic Haplustept. These soils formed in alluvium. Slopes are gentle, and coarse stratification is common. The native vegetation consisted mostly of grass and widely spaced trees. Most of these soils are used as cropland therefore these soils are classified fine loamy mixed hyperthermic family of Fluventic Haplustept. Accordingly, soils of Dhoda, Tulewal, Samana, Ucha, and Fattu Dhinga recognized under order of Inceptisols, sub order of Ustepts, great group of Haplustept and sub group of Fluventic Haplustepts, but because of sandy loam texture in most of their horizons qualify for coarse loamy class. Coarse fraction suite of these soils consists of feldspars, quart, biotite, muscovite and amphiboles. As such these soils are classified coarse loamy, mixed, hyperthermic, family of Fluventic Haplustept.

**5.1.5.2** Soils of Kanjil and Fatehpur series do not have andic soil properties in 60 percent or more of the thickness between the soil surfaces. Also these soils do not have organic soil material that meets overlie cindery, fragmental, or pumiceous materials. As such these soils have been classified under the Inceptisols order of Soil Taxonomy (USDA 2015). These soil have an ustic moisture regime and do not have an exchangeable sodium percentage of 15 or more or a sodium adsorption ratio of 13 or more, in half or more of the soil volume within 50 cm of the mineral soil surface, a decrease in exchangeable sodium percentage values with increasing depth below 50 cm and ground water within 100 cm of the mineral soil surface for some time during the year, also these soil have a temperature regime warmer than cryic. As such these soils recognised under the Ustepts sub order. The pedon do not have a calcic horizon with its upper boundary within 100 cm of the mineral soil surface and either free carbonates or a texture of loamy fine or coarser in all parts above the calcic or petro calcic horizon. As such these soils classified in to Haplustept great group. These soil do not have a lithic contact with 50 cm of the surface, and also do not have in any horizon within 75 cm of the mineral soil surface, redox depletions with chroma of 2 or less and also aquic conditions. These pedon have a base saturation by sum of cations of more the 60 percent in all horizons between either an Ap horizon or a depth of 25 cm from the mineral soil surface, whichever is deeper, and either a depth of 75 cm or a densic, lithic, or paralithic contact. Do not have a gypsic horizon that has its upper boundary within 100 cm of the mineral soil surface. As such these soils characterised under the Typic Haplustepts sub group. These soils have texture of clay loam and sandy clay loam in Kanjili and sandy loam loamy sand and sand in Fatehpur; as such qualify for fine, coarse loamy class. Clay fraction of these soil have a mineral suite of illite, mixed layer minerals kaolinite, chlorite, smectite, with illite being less than 35 percent. Coarse fraction suite of these soils consists of feldspars, quartz, biotite, muscovite, pyroxenes, and amphiboles, As such there have mixed mineralogy class. Therefor these soils are classified fine loamy, mixed, hyperthermic family of Typic Uplustepts in Kanjili and coarse loamy, mixed, hyperthermic, family of Typic Uplustepts in Fatehpur series respectively.

**5.1.5.3** Soil of Nathupur, Mund and Bahanra series do not have a layer 25 cm or thicker, with an upper boundary within 100 cm of the mineral soil surface, that has either slickensides close enough to intersect or wedge-shaped aggregates that have their long axes tilted 10 to 60 degrees from the horizontal; and do not have a weighted average of 30 per cent or more clay in the fine-earth fraction either between the mineral soil surface and a depth of 18 cm or in an Ap horizon, whichever is thicker, and 30 per cent or more clay in the fine-earth fraction of all horizons between a depth of 18 cm and either a depth of 50 cm or a densic, lithic, or paralithic contact, a duripan, or a petrocalcic horizon if shallower. As such these soils are classified under the Entisols order of Soil Taxonomy (USDA 2015). Do not have a densic, lithic, or paralithic contact within 25 cm of the mineral soil surface and have a slope of less than 25 per cent (1-2 %), more than 0.2 per cent organic carbon of Holocene age at a depth of 125 cm below the mineral soil surface or an irregular decrease in content of organic carbon from a depth of 25 cm to a depth of 125 cm or to a densic, lithic, or paralithic contact if shallower, so these soils recognized under Psamment sub order. These soils are loamy sand and sand in all the layers. Some formed in poorly graded (well sorted) sands on shifting or stabilized sand dunes, in cover sands, or in sandy parent materials that were sorted in an earlier geologic cycle. Some formed in sands that were sorted by water and are on outwash plains, lake plains, natural levees, or beaches. Also these soils have an ustic moisture regime and warmer temperature, as such recognized under Ustipsamment great group. Moreover these soils are fixed on sands that have deep ground water and thick regolith and do not have lamellae within 150 cm of the soils surface. Commonly the sands are a mixture of quartz and feldspars. These soils are freely drained sands. As such classify under Typic Ustipsamment. Soils of Natpur, Mund and Bhanra series have a texture of sand and loamy sand in the all horizon with sand percentage of 77.5 per cent in surface horizon of Nathupur, 83.4 per cent in Mund series and 86.9 per cent in Bhanra series respectively recognized under sandy, mixed, hyperthermic, family of Typic Ustipsamment.

**5.1.5.4** Soil of Fajewal series do not have a layer 25 cm or more thick, with an upper boundary within 100 cm of the mineral soil surface, that has either slickensides close enough to intersect or wedge shaped aggregates that have their long axes tiled 10 to 60 degrees from the horizontal. As such these soils are classified under the Entisols order of Soil Taxonomy (USDA 2015). do not have a densic, lithic, or paralithic contact within 25 cm of the mineral soil surface and have a slope of less than 25 per cent; and more than 0.2 per cent organic carbon of Holocene age at a depth of 125 cm below the mineral soil surface with an irregular decrease in content of organic carbon from a depth of 25 cm to a depth of 125 cm or to a densic, lithic, or paralithic contact if shallower. As such the soils of Fajewal series was recognised under Fluventic sub order. Accordingly, these soils have ustic moisture regime and a temperature regime warmer than cryic. These soils are on flood plains along rivers and streams in areas of middle or low latitudes. So these soils come under Ustifluvents great group. Moreover these soils do not have In any horizon within 50 cm of the mineral soil surface, redox depletions with chroma of 2 or less or aquic conditions and do not have anthraquic conditions. Also these soils have a texture of clay loam in the surface and loam and silty loam in the subsurface horizons, with a moderately well, as such recognised uncer Typic Ustifluvent sub group. Furthermore, the soils of Fajewal series do not have fine Particle size class and clay of swelling type in major part of the upper 125 cm. as such these soils qualify as coarse loamy, mixed, hyperthermic, family of Typic Ustifluvent.

**Table 5.35 Soil Taxonomy of Kapurthala district**

| Series | Order | Suborder | Great group | Subgroup | Family |
|---|---|---|---|---|---|
| **Salt-affected Soils** | | | | | |
| Rawalpindi<br>Domeli<br>Jagjitpur<br>Khairanwali<br>Randhirpur | Inceptisols | Ustepts | Haplustepts | Fluventic Haplustepts | Fine loamy, mixed, hyperthermic |
| Fajewal | Entisols | Fluvent | Ustifluvent | Typic Ustifluvent | Coarse loamy, mixed, hyperthermic |
| **Normal soils** | | | | | |
| Dhoda | Inceptisols | Ustepts | Haplustepts | Fluventic Haplustepts | Fine loamy, mixed calcareous hyperthermic |
| Tulewal<br>Samana<br>Ucha<br>Fattu Dhinga | Inceptisols | Ustepts | Haplustepts | Fluventic Haplustepts | Coarse loamy mixed hyperthermic family of Fluventic Haplustept |
| Kanjili | Inceptisols | Ustepts | Haplustepts | Typic Haplustepts | Fine loamy, mixed hyperthermic, family of Typic Haplustept |
| Fatehpur | Inceptisols | Ustepts | Haplustepts | Typic Haplustepts | Coarse loamy, mixed hyperthermic, family of Typic Haplustepts |
| Natpur<br>Mund<br>Bahanra | Entisols | Psamment | Ustipsamment | Typic Ustipsamment | sandy mixed hyperthermic family of Typic Ustipsamment |

## 5.2 Effect of intensive farming on the characteristics and classification of soils of Kapurthala district in Punjab

This study was conducted in the North Indian state of Punjab, district Kapurthala. It is the most intensively cultivated region in India with a cropping intensity of 189 per cent, predominantly of rice-wheat system. Due to high nutrient demand and its continuous cultivation, the cropping system is presumed to adversely affect soil properties (Annual Report of Punjab, 2011). However, this has been postulated without any real-time data analysis on a regional scale. Therefore, the effect of intensive farming was studied by comparing the present soil characteristic data with the already established data of Uppal H.L, (1957), Sharma *et al.,* (1982) and Sehgal *et al.,* (1992). Data for different parameters of soil and soil extract such as pH (1:2), EC (1:2), organic carbon, calcium carbonate, exchangeable cations, E.S.P, $pH_s$, $EC_e$, $Ca^{++}$+$Mg^{++}$, $Na^+$, and $CO_3^{--}$+$HCO3^-$ of each series are plotted in Fig 5.2.1 to 5.2.22, and discussed below separately for salt affected soils (5.2.1) and normal soils (5.2.2).

### 5.2.1 Salt-affected soils

Depending upon the variation in soil texture, drainage, profile development, salt content and other physical and chemical characteristics the soils in Rawalpindi, Domeli, Jagjitpur, Khairanwali, Randhirpur, and Fajewal series were known as salt-affected soils. The graphs for salt affected soils are plotted in figure 5.2.1 to 5.2.12. Accordingly, application of 37 years of intensive farming in the study area showed significant changes in physical and chemical characteristics of soils. This might be due to reclamation of salt-affected soils, continuous use of organic and inorganic fertilizers, scraping of sand layers from the surface soils and change in cropping pattern under intensive agriculture.

#### 5.2.1.1 Soil pH (1:2)

The pH values in salt-affected soils ranged from 8.4 in the epipedon of Rawalpindi to 10.5 in B1 horizon of the Jagjitpur series in 1982. The pH mean for all the salt-affected soils was 9.43 (Appendix II). While in 2019 the pH ranged from 8.5 in epipedon of Rawalpindi to 10.3 in epipedon of Domeli series. The pH mean for all the series was 9.3. The salt-affected soils of Kapurthala district are generally alkaline in pH. As per the comparison graphs, soil pH decreased in all the horizons of

Jagjitpur, Khairanwali, Randhirpur, and Fajewal series, along with all the horizons of Rawalpindi series except AB and BC horizons. While in Domeli series which is still unreclaimed, the pH showed an increase in all the horizons of the series (Figure 5.2.1). An increase in pH of Domeli series may be due to leaching of soluble salts under intensive farming resulting in high ESP and high pH (Raj Kumar *et al.*, 1995)

The decline in soil pH with 37 years cropping under intensive farming may be due to intensive irrigated agriculture and the use of urea form of fertilizer over the years. The decrease in pH is further magnified due to the build-up of soil organic matter. Organic matter has been reported to magnify the decrease in pH of sodic and calcareous soils, (Ponnamperuma, 1972). The decrease in pH has implications for the availability of phosphorus and micronutrients, the availability of micronutrients such as Zn, Cu, Fe, and Mn increases with a decrease in pH. The decline in soil pH shows that the problem of alkalinity that affected 8-10 per cent of the soils during the early 1980s in Punjab has virtually been ameliorated. This has generally been caused due to the reclamation of alkali soils through the application of gypsum along with keeping the soil flooded with water. Furthermore, long term intensive cultivation of rice and wheat cropping has resulted in a favourable pH environment by decreasing the pH of most of the study area, leading to increased nutrient availability in soils and reclamation of the salt-affected soils (Benbi and Brar, 2009).

**5.2.1.2 Electrical conductivity (EC)**

The electrical conductivity of salt-affected soils in 1982 ranged from 0.07 dS $m^{-1}$ in B22 and B23 horizon of Domeli series to 2.6 dS $m^{-1}$ in the epipedon of Randhirpur series. The mean for EC of all the series was 0.8 dS $m^{-1}$ in 1982 (Appendix II). In 2019 the EC of salt-affected soils was less than 1 dS $m^{-1}$, it ranged from 0.06 dS $m^{-1}$ in B1 horizon of Domeli and B23 horizon of Randhirpur to 0.62 dS $m^{-1}$ in AB horizon of Khairanwali. The mean for EC of these soils was 0.28 dS $m^{-1}$ in 2019.

The comparison graphs show that the EC after almost 37 years of intensive farming in the studied area decreased in all the pedons of salt-affected soils (Figure 5.2.2). Soil electrical conductivity as affected by cropping, irrigation, land use and application of fertilizer, manure, and compost. Irrigation of the soils with water low in salts, allows salts to leach down, decreasing EC (Trolier-McKinstry and Newnham, 2018).

### 5.2.1.3 Organic carbon percentage

Organic carbon content of salt-affected soils ranged from 0.02 per cent in B3 horizons of Fajewal series to 0.90 per cent in AB horizon of Domeli series in 1982 and the mean organic carbon of these soils was 0.19 per cent. In 2019 organic carbon content ranged from 0.11 per cent in Ap horizon of Fajewal series to 0.93 per cent in epipedon of Khairanwali series and the mean of organic carbon was recorded 0.41 per cent.

The graphs of organic carbon percentage for all the series such as Rawalpindi, Domeli, Jagjitpur, Khairanwali, Randhirpur, and Fajewal series shows that organic carbon content in salt-affected soils of Kapurthala district increased in all the series except AB horizon of Domeli series which showed a decrease in organic content percentage (Figure 5.2.3). This could be due to the cultivation of fertilized rice-wheat and application of amendments. (Benbi and Brar 2009) observed that the fertilized rice-wheat cropping being followed in the Punjab state had resulted in an improved soil organic carbon level. Results of long term experiments have also shown that with optimum application of inorganic fertilizers, the soil organic contents has either been maintained or slightly increased over the years (Biswas and Benbi, 1997). Furthermore, the farmers of the region leave much crop residues on the soils as well as they bring frequently of organic amendments such as organic manure, green manure, compost which increase the amount of organic carbon in soils.

### 5.2.1.4 Calcium carbonate percentage

Calcium carbonate content ranged from 0.0 per cent in epipedon of Jagjitpur series to 7.9 per cent in C horizon of Khairanwali series in 1982. The mean calcium carbonate of these soils was 2.08 per cent. In 2019 calcium carbonate percentage ranged from 0.2 per cent in AB horizon of Rawalpindi and Domeli, B23 and B3 horizon of Jagjitpur series and epipedon of Fajewal series respectively to 1.1 per cent in B22 horizon of Rawalpindi series. As per the graphs, calcium carbonate content in salt-affected soils of Kapurthala district decreased in Rawalpindi, Domeli, Khairanwali, Randhirpur, Fajewal and Jagjitpur series except for Ap and AB horizons (Figure 5.2.4). This could be due to use of acid farming fertilizers, increased of organic carbon percentage which case leaching solubilised carbonates under irrigated farming (Raj Kumar *et al.*, 1995).

### 5.2.1.5 Cation exchange capacity

CEC of salt-affected soils of Kapurthala district ranged from 3.8 $cmol_c$/kg of soil in C2 horizon of Domeli series to 12.8 $cmol_c$/kg of soil in B23 horizon of Jagjitpur series in 1982, the mean CEC of these soils was 9.10 $cmol_c$/kg of soil in 1982. While in 2019 CEC range from 3.51 $cmol_c$/kg of soil in B1 horizon of Domeli series to 11.72 $cmol_c$/kg of soil in epipedon of Randhirpur series with a total mean of 7.05 $cmol_c$/kg of soil. According to the graphs plotted the cation exchange capacity content decreased in Domeli, Jagjitpur, Khairanwali, Fajewal, Rawalpindi except for AB, B22, and B3 horizons and Randhirpur series in B22 and B23 horizons (Figure 5.2.5). The organic carbon content of the soils which normally influence the CEC is generally increased and therefore the CEC values may not be attributed to the amount of organic matter. Earlier the soils were highly calcareous and sodic which generally leads to overestimation of sodium and calcium leading to higher CEC. However, at present, the soils are non-sodic and relatively less calcareous which resulted in a better estimate of CEC. So the value of CEC is lower in most cases even though organic carbon has increased (Kumar, 1992). A similar observation was made by Yakubu *et al.*, (2011).

Cation exchange capacity gives an insight into the fertility and nutrient retention capacity of the soil. CEC is an important index of nutrient status because exchangeable cations are the most important source of immediately available plant nutrients. Over a course of time, CEC was found to increase, due to increases in the nutrient storage capacity of mine spoils (Matthews, 2014).

### 5.2.1.6 Exchangeable cations

Exchangeable calcium ranged from 1.0 $cmol_c$/kg of soil in the epipedon of Khairanwali to 6.6 $cmol_c$/kg in B1 horizon of the Rawalpindi series in 1982. While in 2019 ranged from 0.4 $cmol_c$/kg of soil in the epipedon of Rawalpindi series to 6.2 $cmol_c$/kg of soil in AB horizon of Rawalpindi series. Based on the comparison graphs of 1980 and 2019 it is obtained that exchangeable calcium decreased in the Rawalpindi series, not changed in Jagjitpur series, decreased in the Khairanwali series except epipedon and AB horizons and in the epipedon horizon of Fajewal series, in

Fajewal series it did not follow a regular trend (Figure 5.26). Accordingly, in Domeli series exchangeable calcium and magnesium decreased in all the horizons in 2019 as compared to 1982.

Exchangeable sodium content ranged from 0.6 $cmol_c$/kg of soil in C2 horizon of Domeli series to 7.4 $cmol_c$/kg in B23 horizon of Jagjitpur series in 1982. In 2019 ranged from 1.13 in BC horizon of Domeli series to 8.26 in epipedon of Randhirpur series. Comparison graphs of the data show that exchangeable sodium decreased in all the horizons of Rawalpindi, Domeli, Jagjitpur, Khairanwali and Fajewal series respectively, while it increased in Randhirpur series (Figure 5.2.6). The decrease in the exchangeable cations might be due to long-continued irrigated cropping, ideally including a low land rice crop along with the application of chemical soil amendments followed by leaching (Abrol *et al.*, 1988).

**5.2.1.7 Exchangeable sodium percentage (ESP)**

Exchangeable sodium percentage in 1982 ranged from 15.6 in B3 horizon of Rawalpindi to 80.0 in the epipedon of Jagjitpur series in 1982. The mean for ESP of all the salt-affected soil series was 47.15 in 1982. The ESP ranged from 12.6 in B22 horizon of Rawalpindi to 70.4 in the epipedon horizon of the Randhirpur series. The mean for ESP of all the series was 34.0. Exchangeable sodium percentage of salt-affected soil of Kapurthala district in 2019 decreased in all the horizons of Domeli, Jagjitpur, Khairanwali and Fajewal series along with all the subsurface horizons of Rawalpindi series, while the exchangeable sodium percentage increased in Randhirpur series except B22 and B23 horizons respectively (Figure 5.2.7). The change in ESP of salt-affected soils may be attributed to the change in pH of these soils due to application of organic manures and gypsum FAO, (1988).

**5.2.1.8 Saturation extract of salt-affected soils**

Comparison graphs were plotted for the parameters of saturation paste and saturation extract such as $pH_s$, $EC_e$, $Ca^{++}+Mg^{++}$, $Na^+$, and $HCO_3^-$ respectively (Figure 5.2.8 to 5.2.12). The $pH_s$ content of salt-affected soils in 1982 ranged from 8.1 in B3 horizon of Fajewal series to 10.2 in AB horizon of Jagjitpur series, while in 2019 ranged from 7.6 in BC horizon of Jagjitpur series to 10.4 in epipedon of Fajewal series. The mean for $pH_s$ of salt-affected soil series was 9.3 in 1982 and it is 8.6 in 2019 respectively. The $EC_e$ content of these soils ranged from 0.4 me/l in B31 and BC horizons of Domeli series to 9.2 me/l in the epipedon of Randhirpur series in 1982. While in 2019 it ranged from 0.19 me/l in B22 horizon of Domeli series to 2.90 me/l in epipedon of Khairanwali series. The mean for $EC_e$ content of these soils was 3.32 me/l in 1982 and 1.11 me/l in 2019 respectively. The $pH_s$ and $EC_e$ graphs showed a decrease in all the horizons of salt-affected soils except the Fajewal series which showed an increase figure 5.2.8 and 5.2.9 respectively.

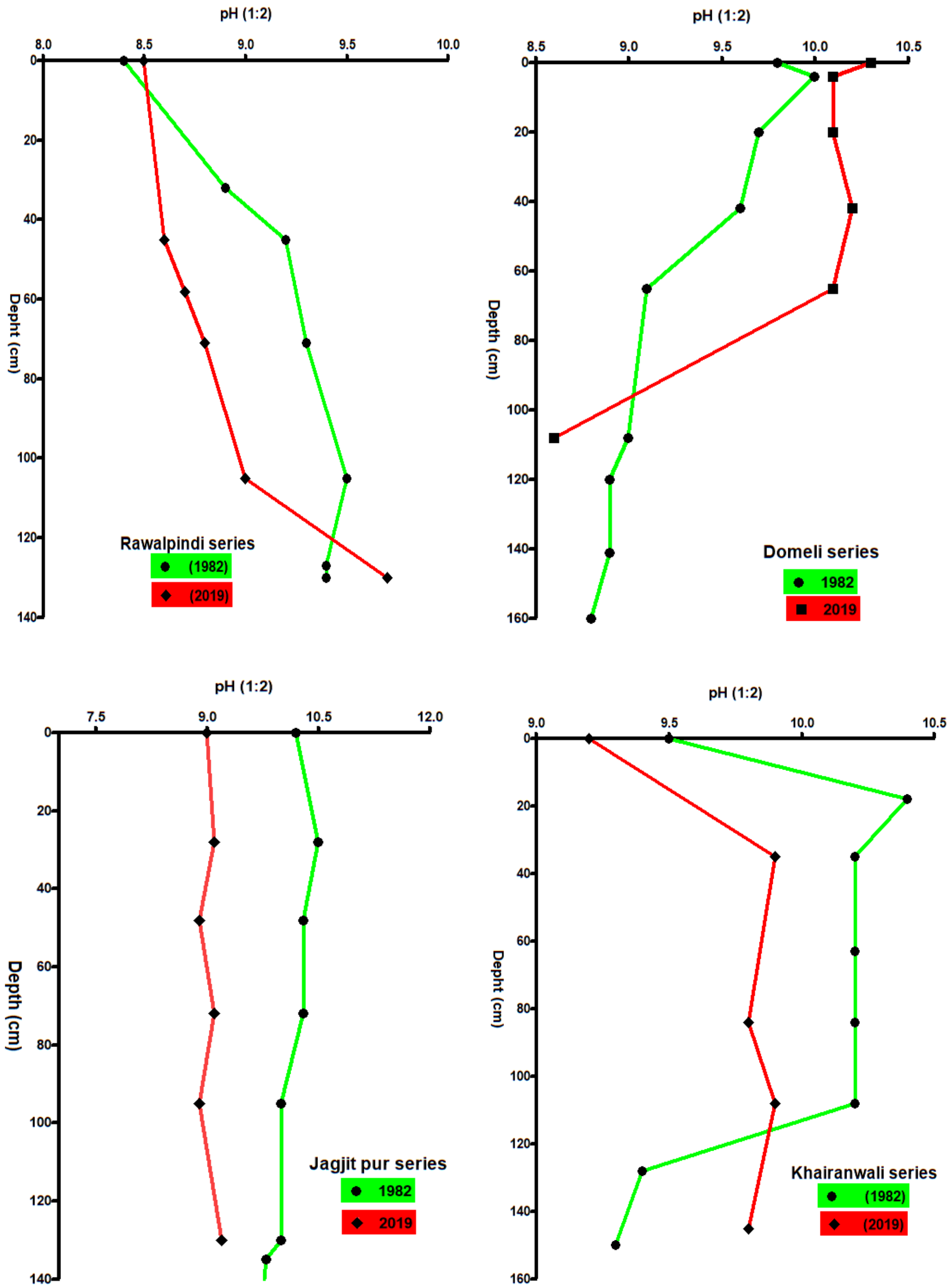
$Ca^{++}$+$Mg^{++}$ showed increased in Rawalpindi, Jagjitpur, Fajewal and Domeli series except for B22 and BC horizons individually. While it decreased in Randhirpur series along with the Khairanwali series except for B21, B23, and B3 horizon respectively (Figure 5.2.10).

$Na^+$ in saturation extract ranged from 1.7 me/l in C2 horizon of Domeli series to 82..5 me/l in Randhirpur series in 1982. In 2019 $Na^+$ in soil paste extract ranged from 0.23 in B22 horizon of Domeli series to 23.04 in AB horizon of Khairanwali series. The mean for $Na^+$ was 24.47 me/l in 1982 and 6.06 me/l in 2019. $Na^+$ in soil paste showed a decrease in all the horizons of all the series (Figure 5.2.11).

$Co_3$+$HCO_3$ ranged from 2.0 me/l in B3 horizon of Rawalpindi series to 51.2 me/l in B23 horizon of Randhirpur series in 1982. While in 2019 it ranged from 0.8 me/l in B13 horizon of Fajewal series to 18.4 me/l in epipedon of Khairanwali series.

The graphs of $HCO_3$+$CO_3$ showed a decrease in Domeli, Jagjitpur, Khairanwali, Randhirpur, and Fajewal series (Figure 5.2.12).

**Figure 5.2.1: Comparison graphs for pH (1:2) of salt affected soils of Kapurthala district**



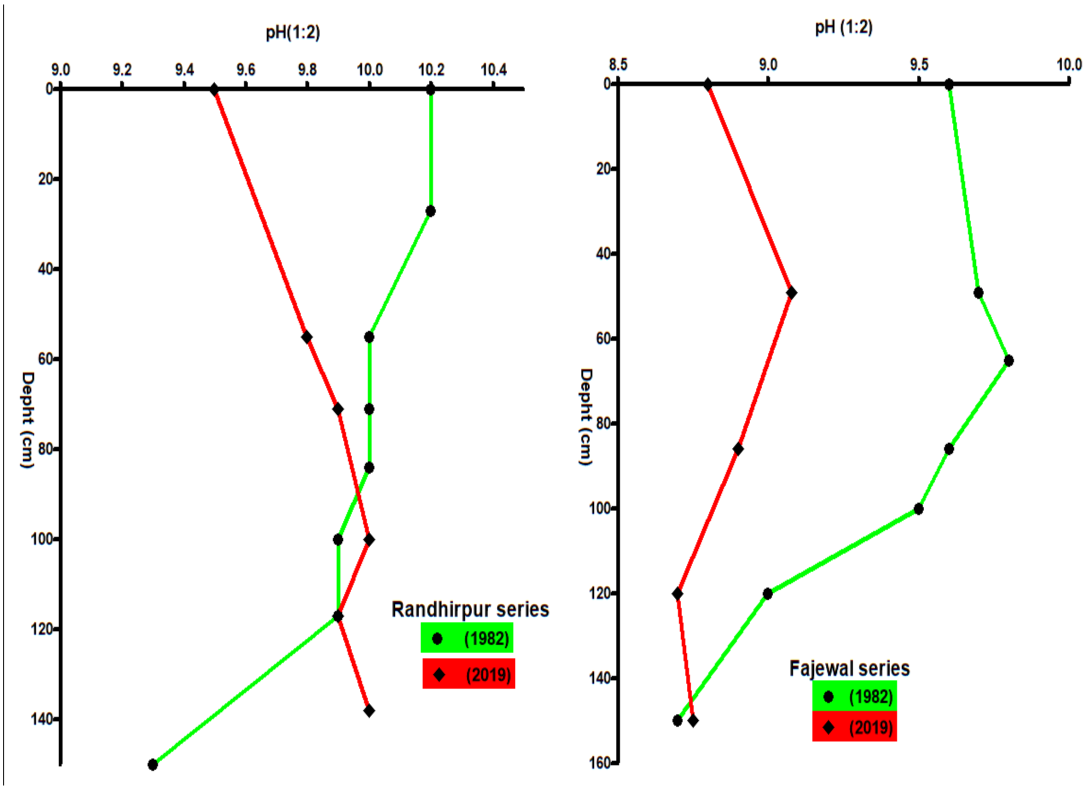
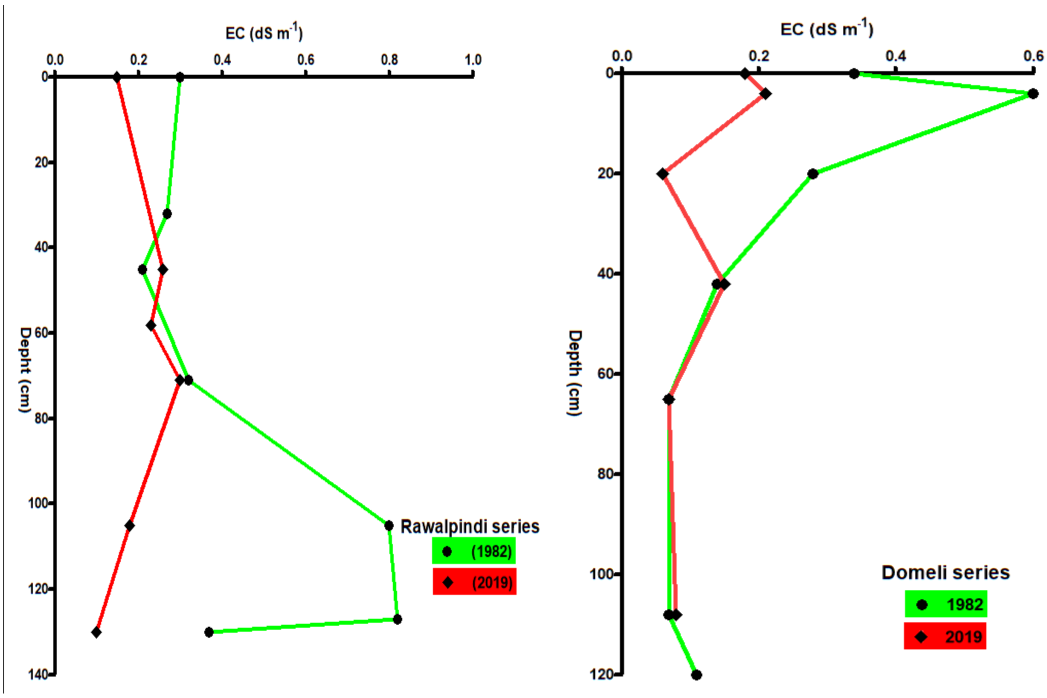
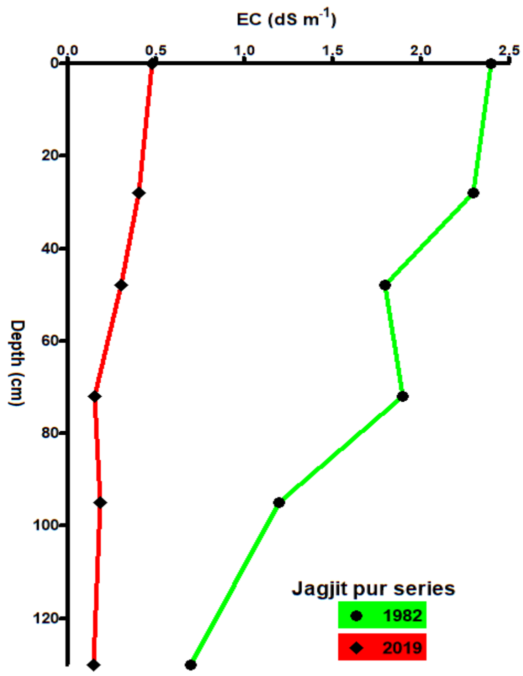
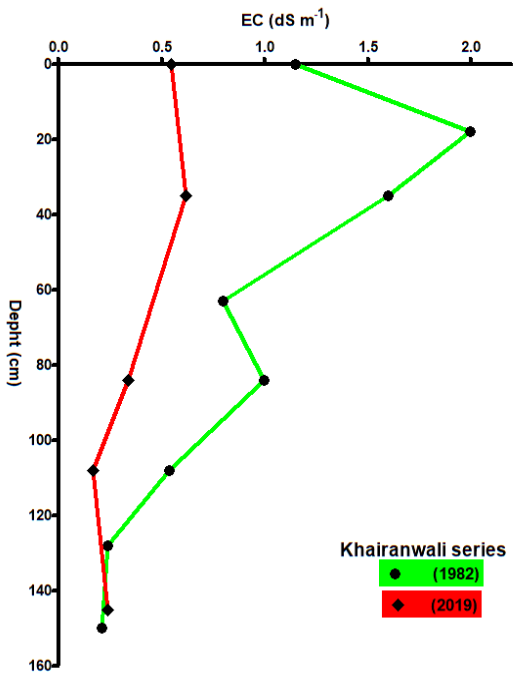
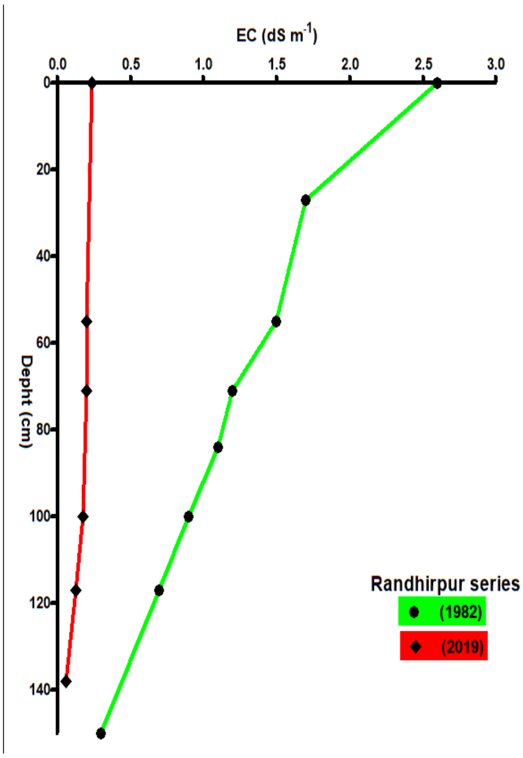



**Figure 5.2.2: Comparison graphs for EC (dS m$^{-1}$) of salt affected soils of Kapurthala district**




EC (dS m-1)
Depth (cm)
Jagjit pur series
1982
2019


EC (dS m-1)
Depht (cm)
Khairanwali series
(1982)
(2019)


EC (dS m-1)
Depht (cm)
Randhirpur series
(1982)
(2019)

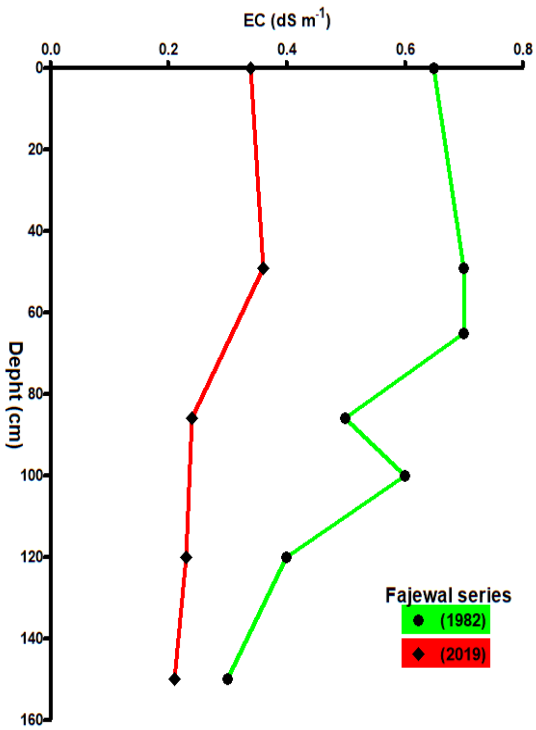
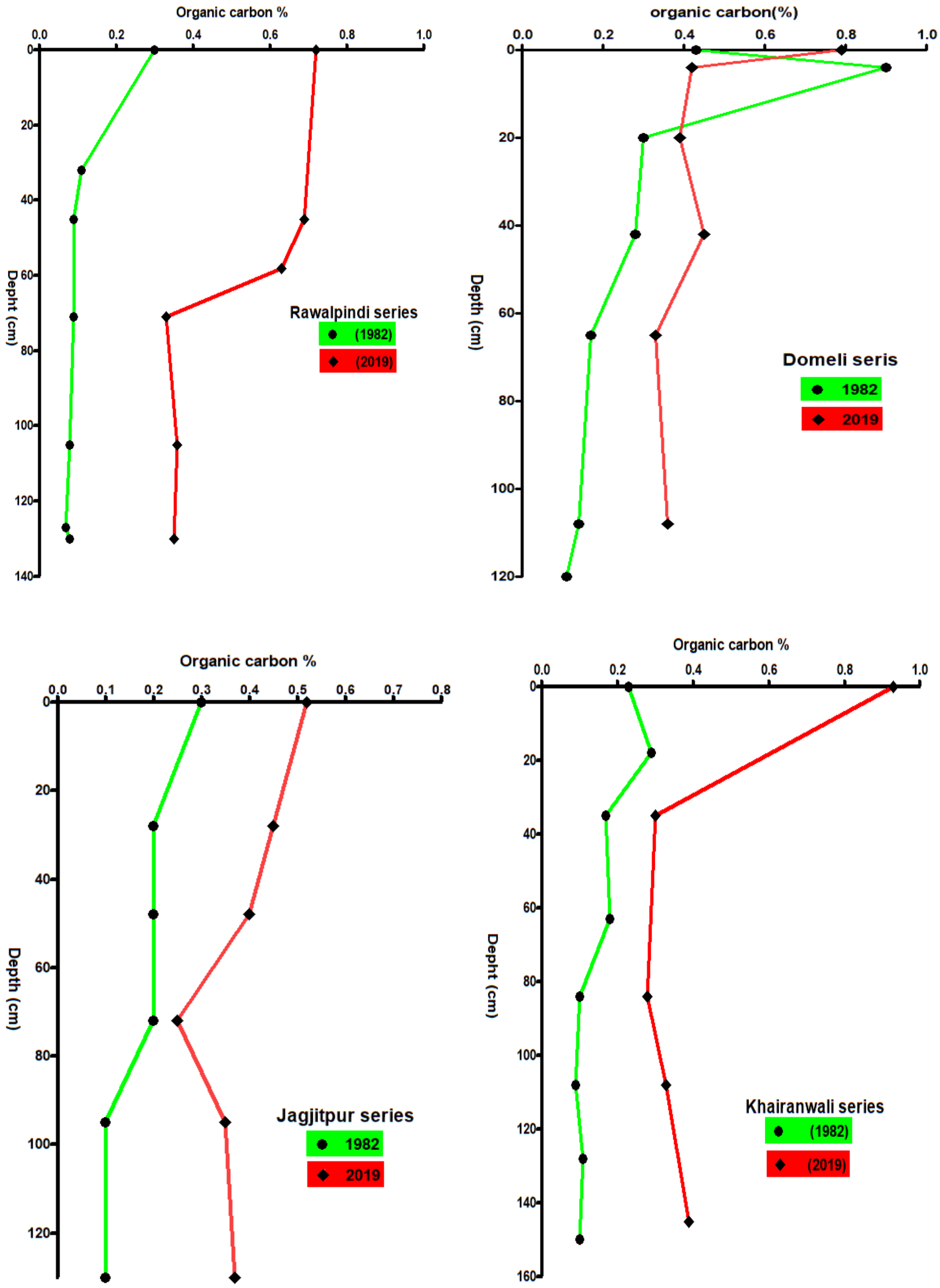

EC (dS m-1)
Depht (cm)
Fajewal series
(1982)
(2019)

**Figure 5.2.3: Comparison graphs for organic carbon percentage of salt affected soils of Kapurthala district**



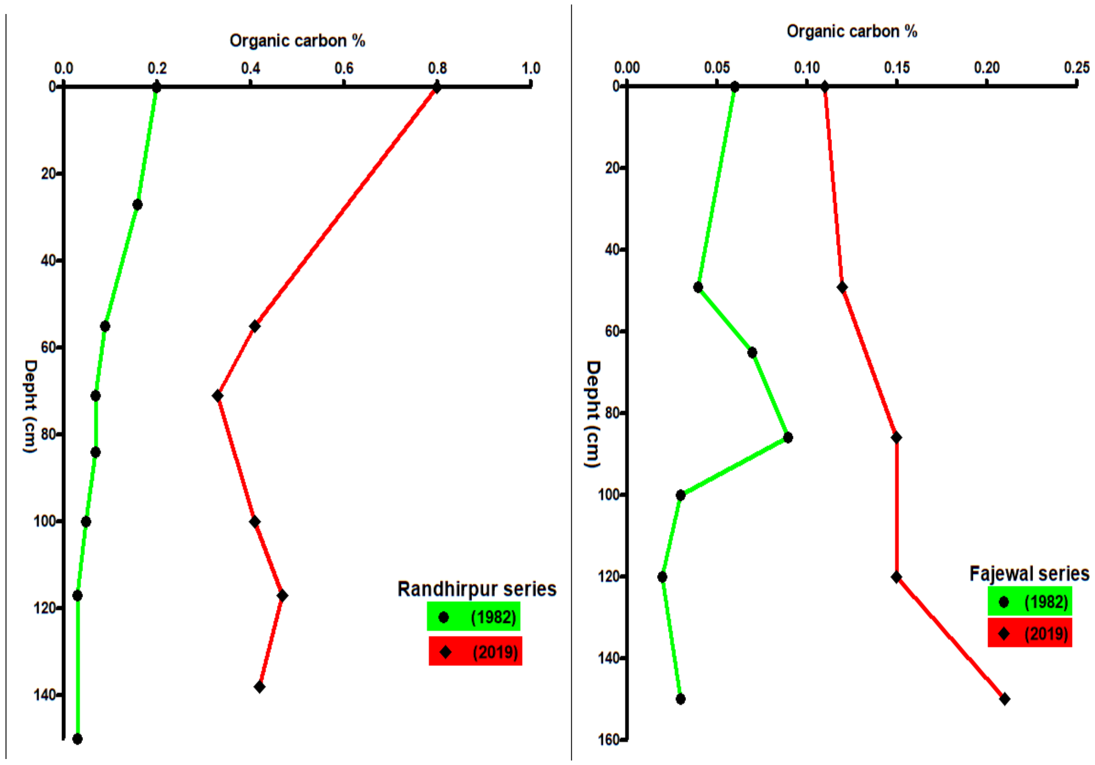
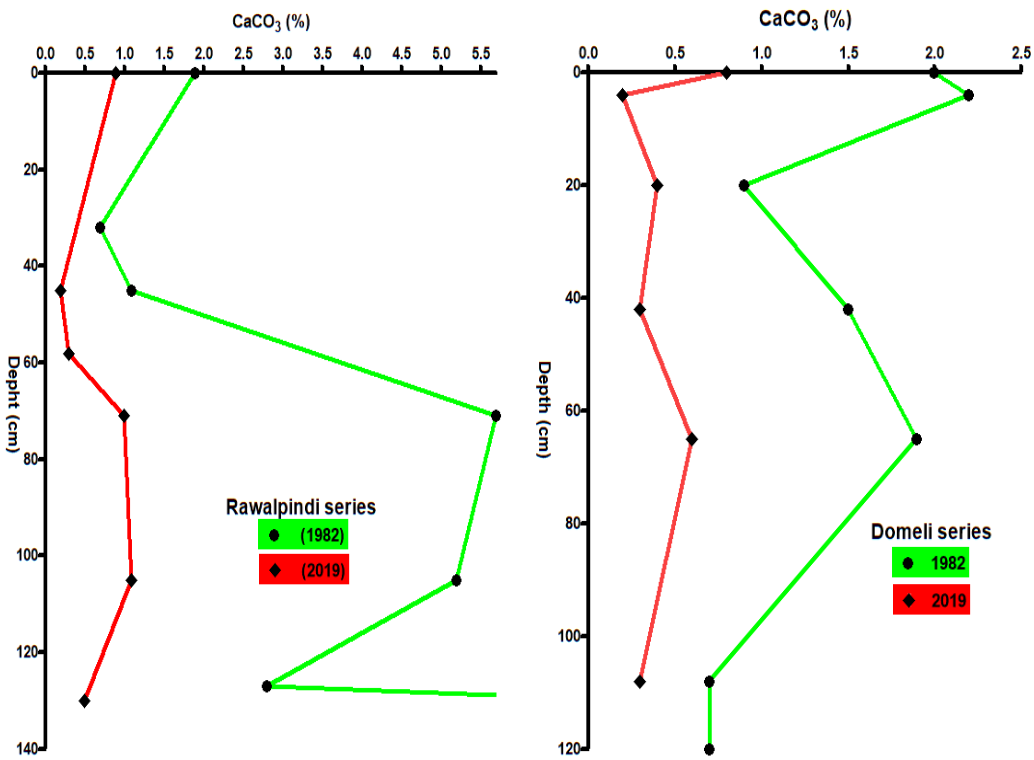



**Figure 5.2.4: Comparison graphs for calcium carbonate percentage of salt-affected soils of Kapurthala district**



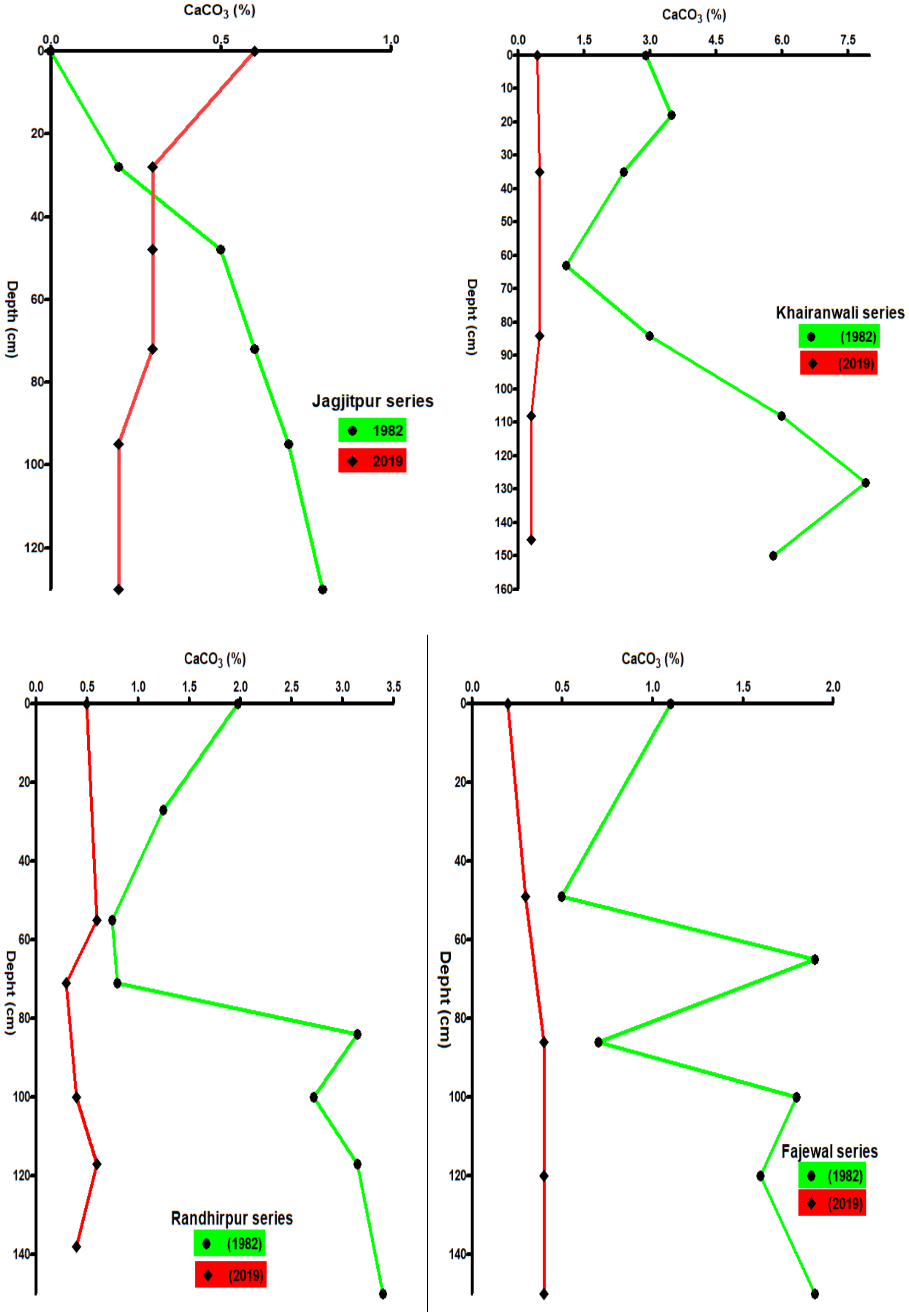
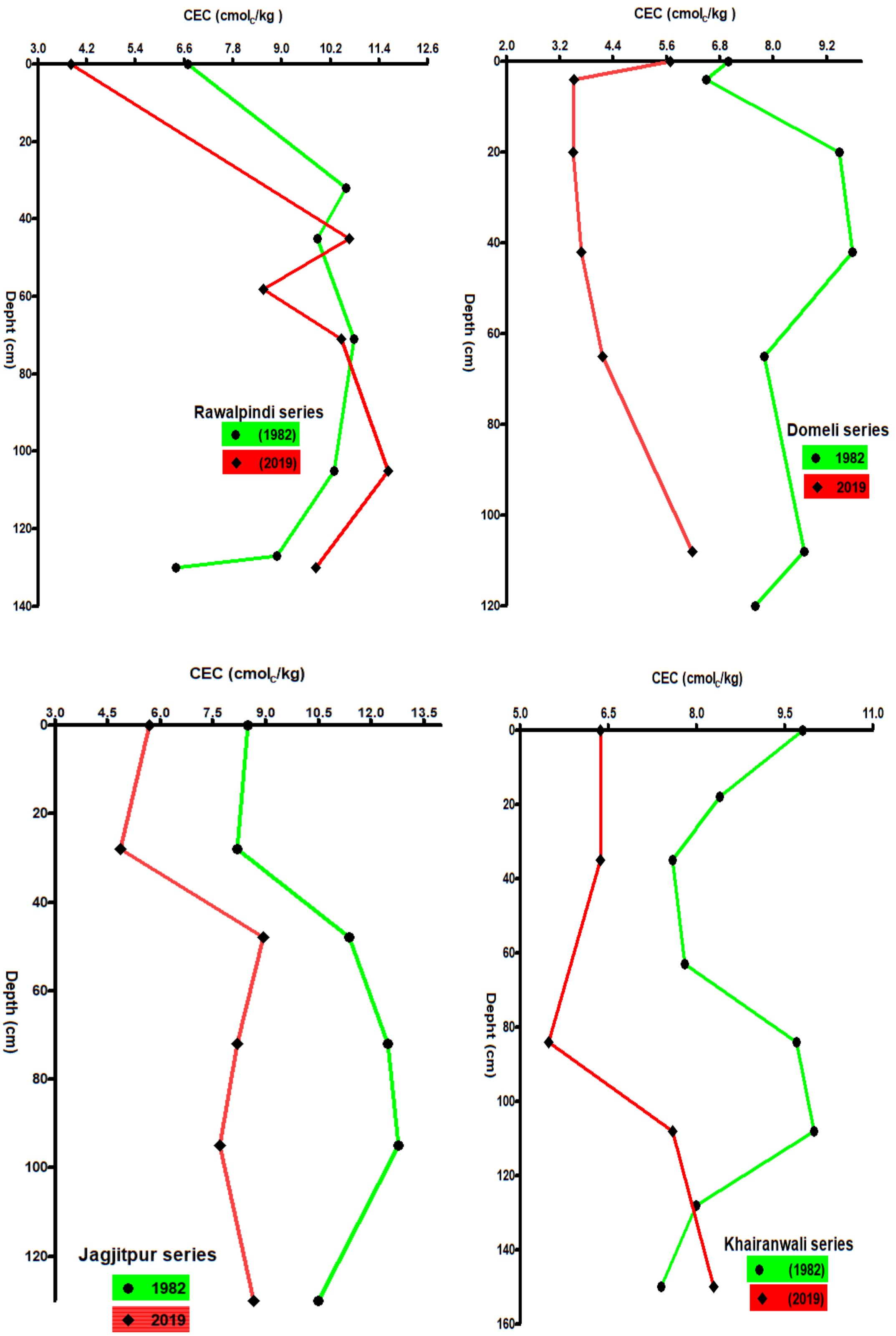

CaCO3 (%)
Depth (cm)
Jagjitpur series
1982
2019
CaCO3 (%)
Depht (cm)
Khairanwali series
(1982)
(2019)
CaCO3 (%)
Depht (cm)
Randhirpur series
(1982)
(2019)
CaCO3 (%)
Depht (cm)
Fajewal series
(1982)
(2019)

**Figure 5.2.5: Comparison graphs for CEC ($cmol_c$/kg) of salt-affected soils of Kapurthala district**



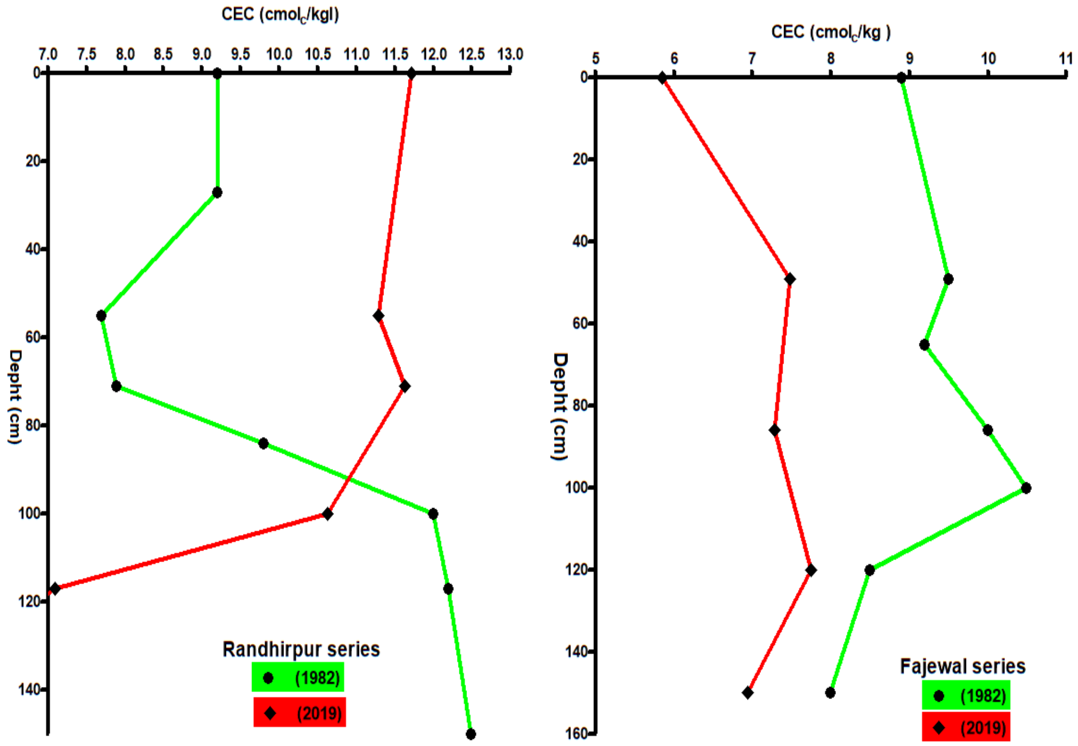
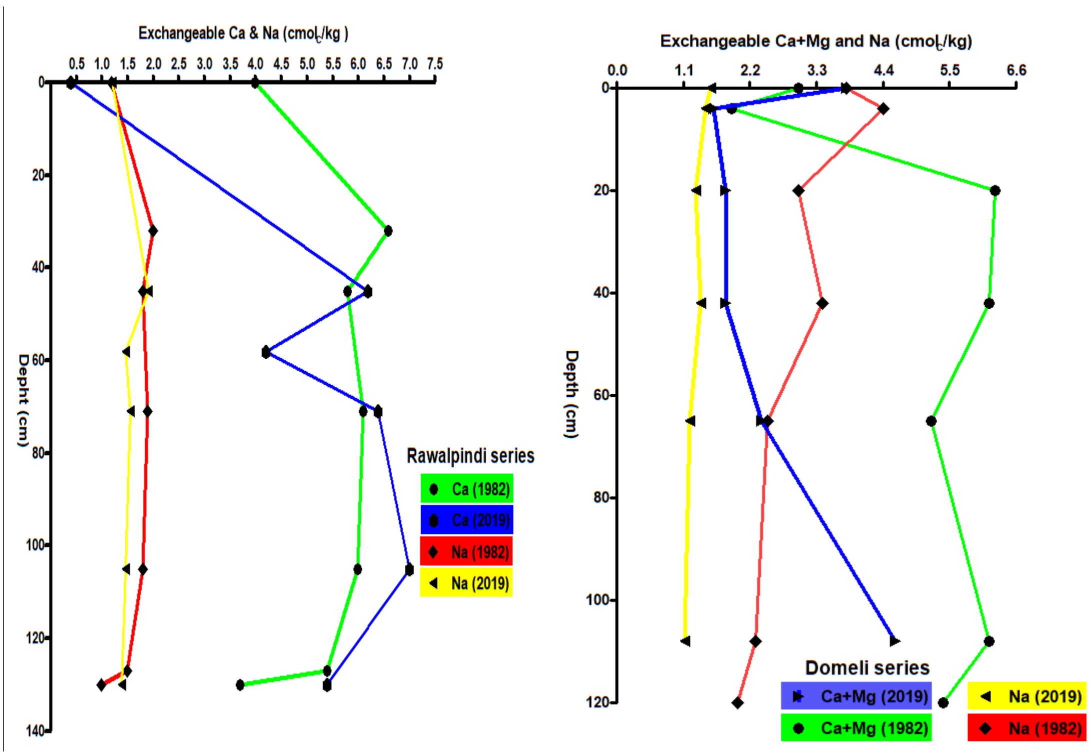



**Figure 5.2.6: Comparison graphs for Exchangeable $Ca^{++}$ and Na $^{++}$ ($cmol_c/kg$) of salt-affected soils of Kapurthala district**



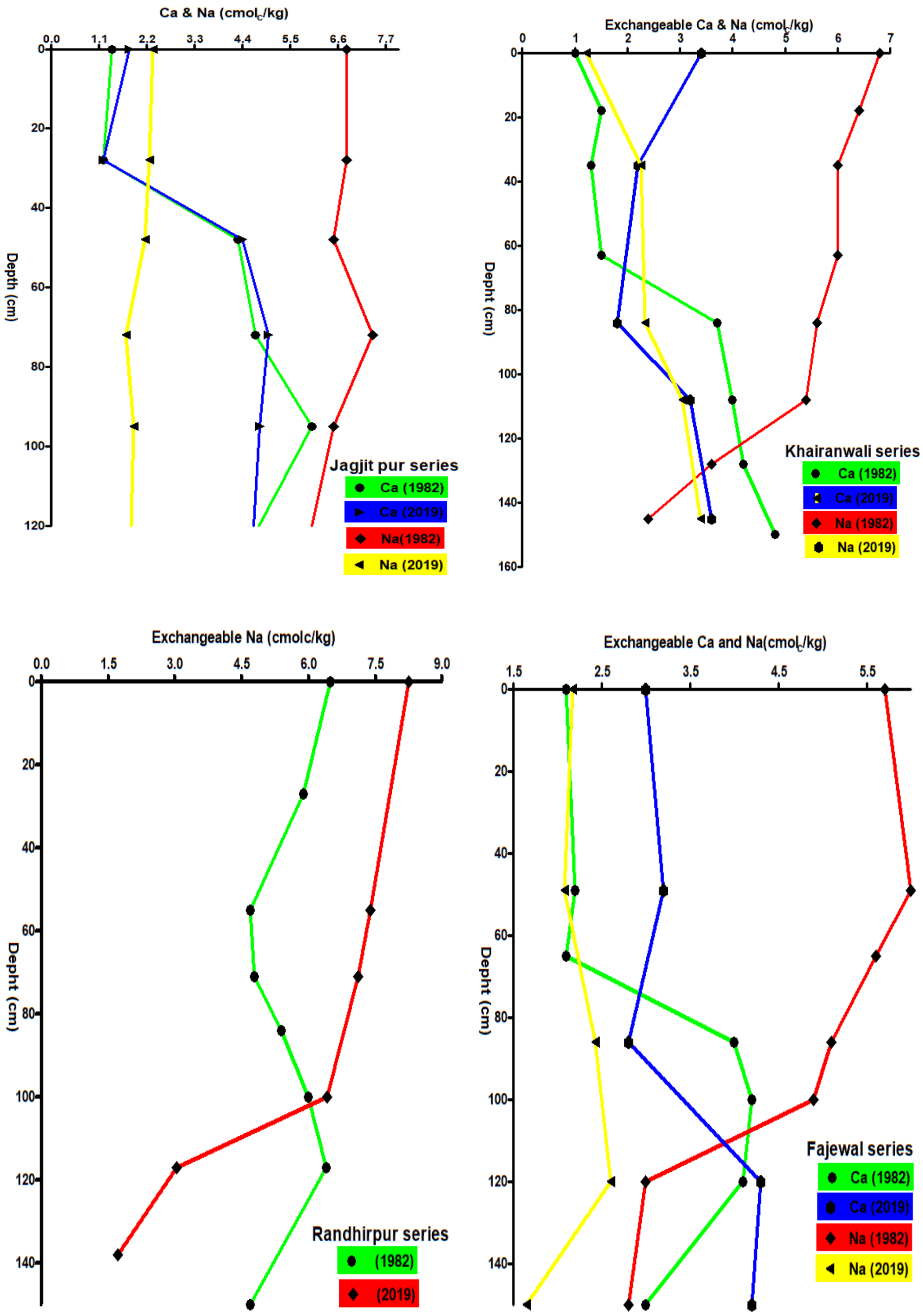
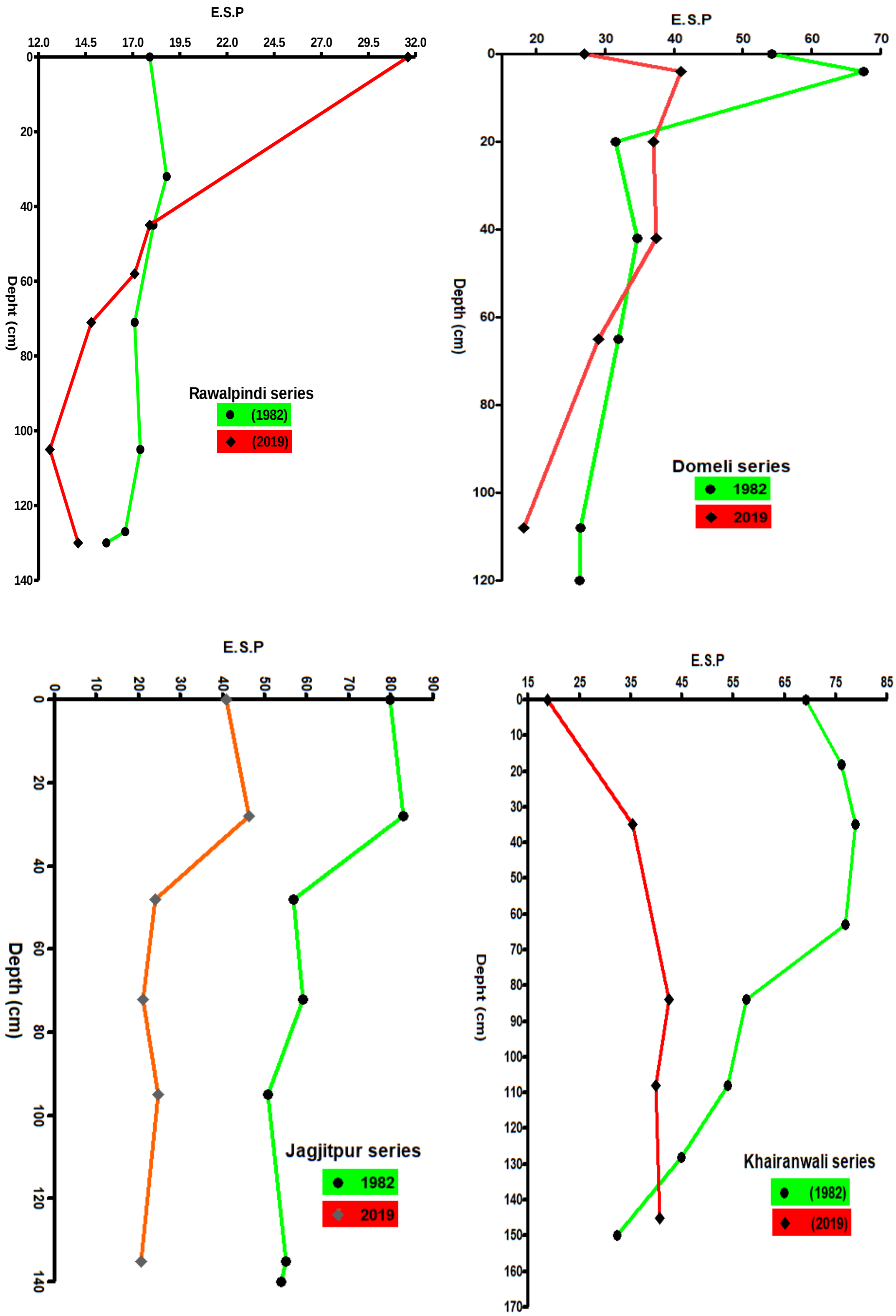

Ca & Na (cmolc/kg)
0.0
1.1
2.2
3.3
4.4
5.5
6.6
7.7
Depth (cm)
Jagjit pur series
Ca (1982)
Ca (2019)
Na(1982)
Na (2019)
Exchangeable Ca & Na (cmolc/kg)
Depht (cm)
Khairanwali series
Ca (1982)
Ca (2019)
Na (1982)
Na (2019)
Exchangeable Na (cmolc/kg)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
Depht (cm)
Randhirpur series
(1982)
(2019)
Exchangeable Ca and Na(cmolc/kg)
1.5
2.5
3.5
4.5
5.5
Depht (cm)
Fajewal series
Ca (1982)
Ca (2019)
Na (1982)
Na (2019)

**Figure 5.2.7: Comparison graphs for exchangeable sodium percentage of salt-affected soils of Kapurthala district**



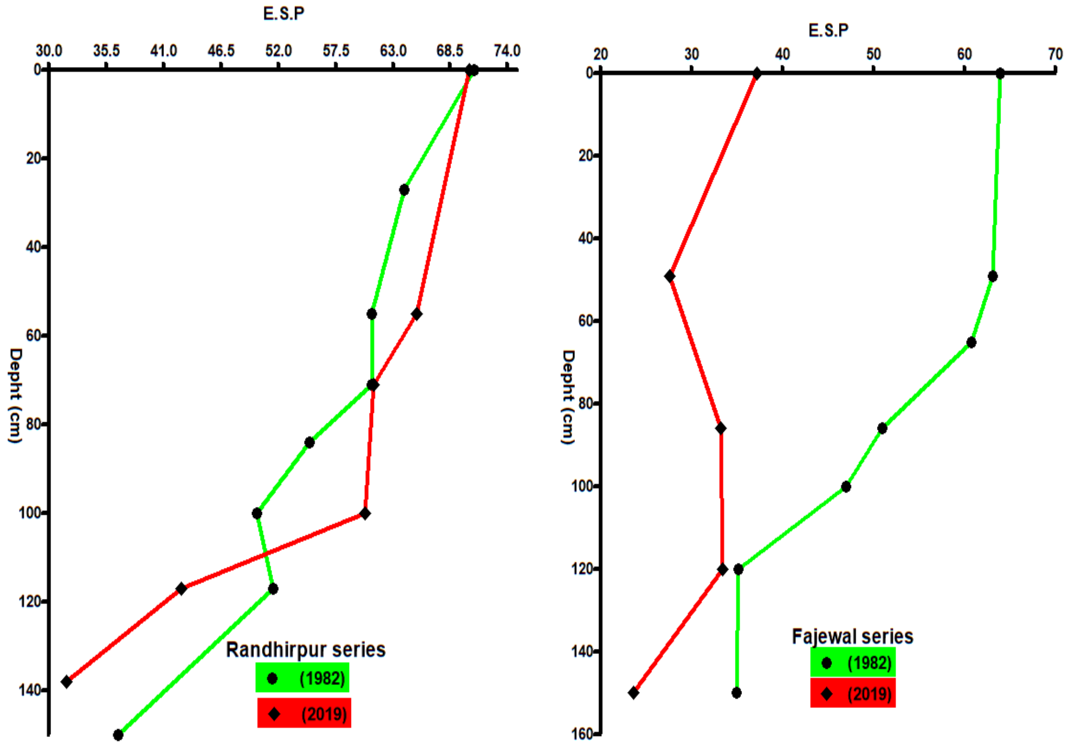
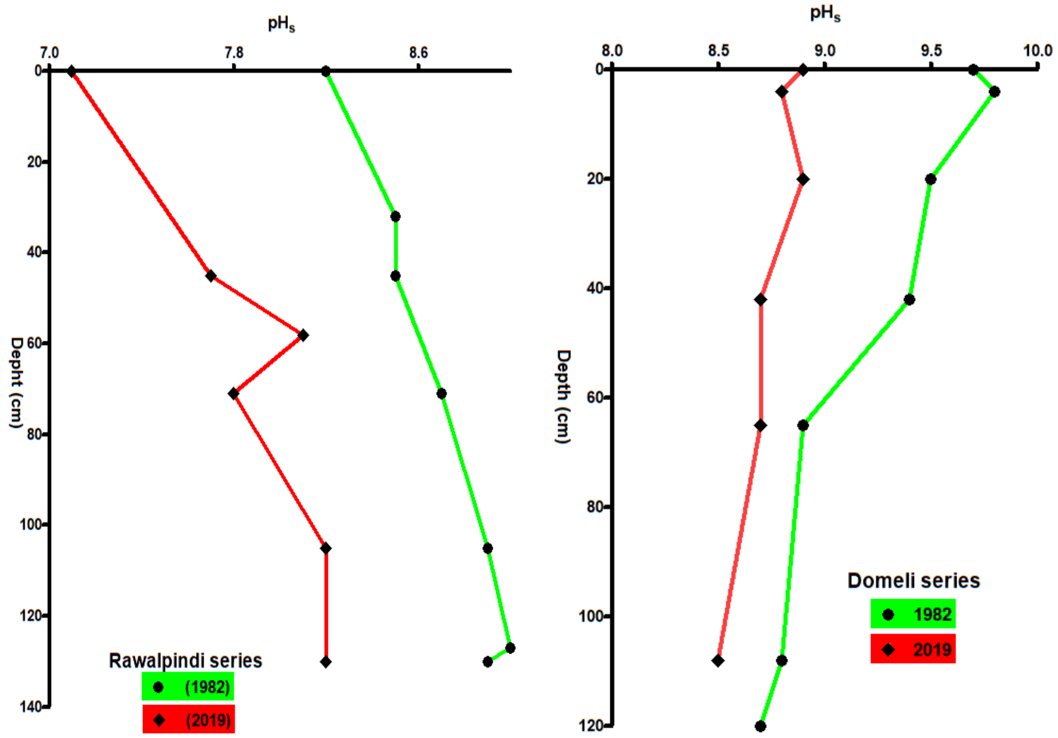
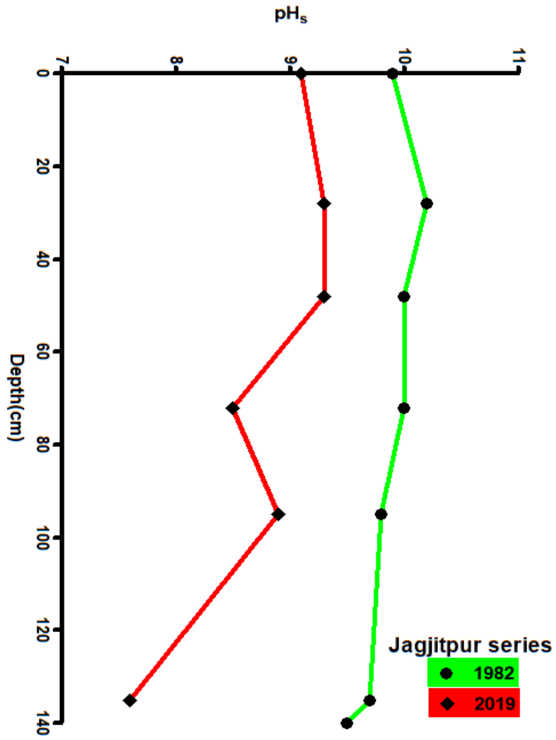
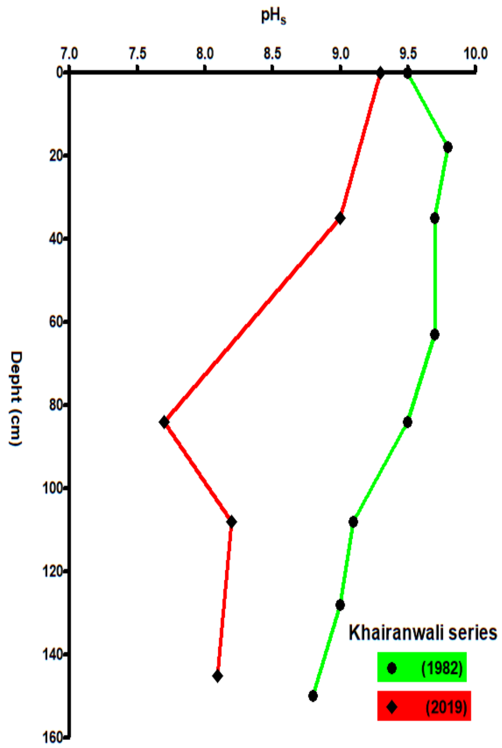
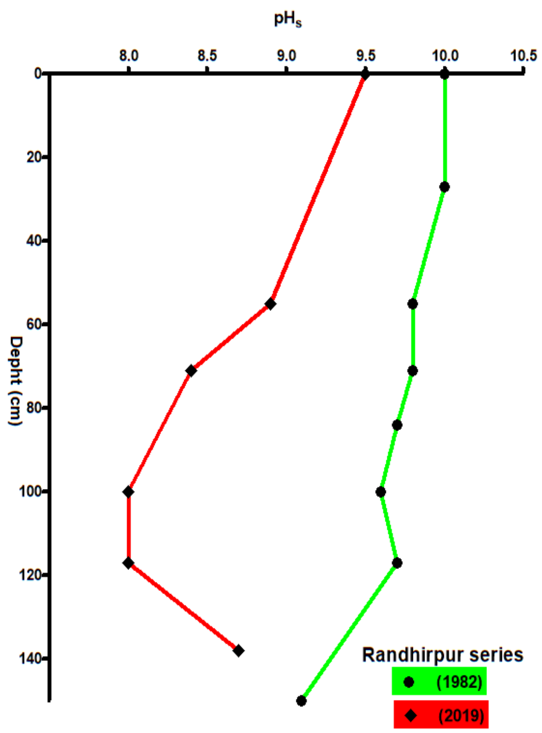



**Figure 5.2.8: Comparison graphs for $pH_s$ of salt-affected soils of Kapurthala district**




pHs
7
8
9
10
11
Depth(cm)
0
20
40
60
80
100
120
140
Jagjitpur series
1982
2019


pHs
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Depht (cm)
0
20
40
60
80
100
120
140
160
Khairanwali series
(1982)
(2019)


pHs
8.0
8.5
9.0
9.5
10.0
10.5
Depht (cm)
0
20
40
60
80
100
120
140
Randhirpur series
(1982)
(2019)

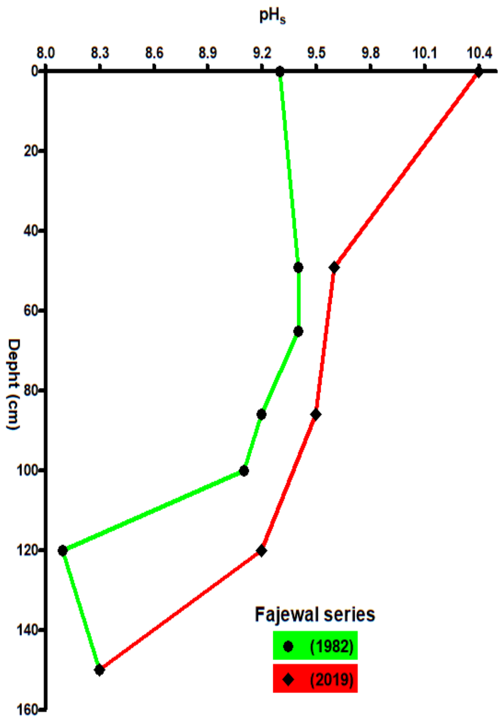
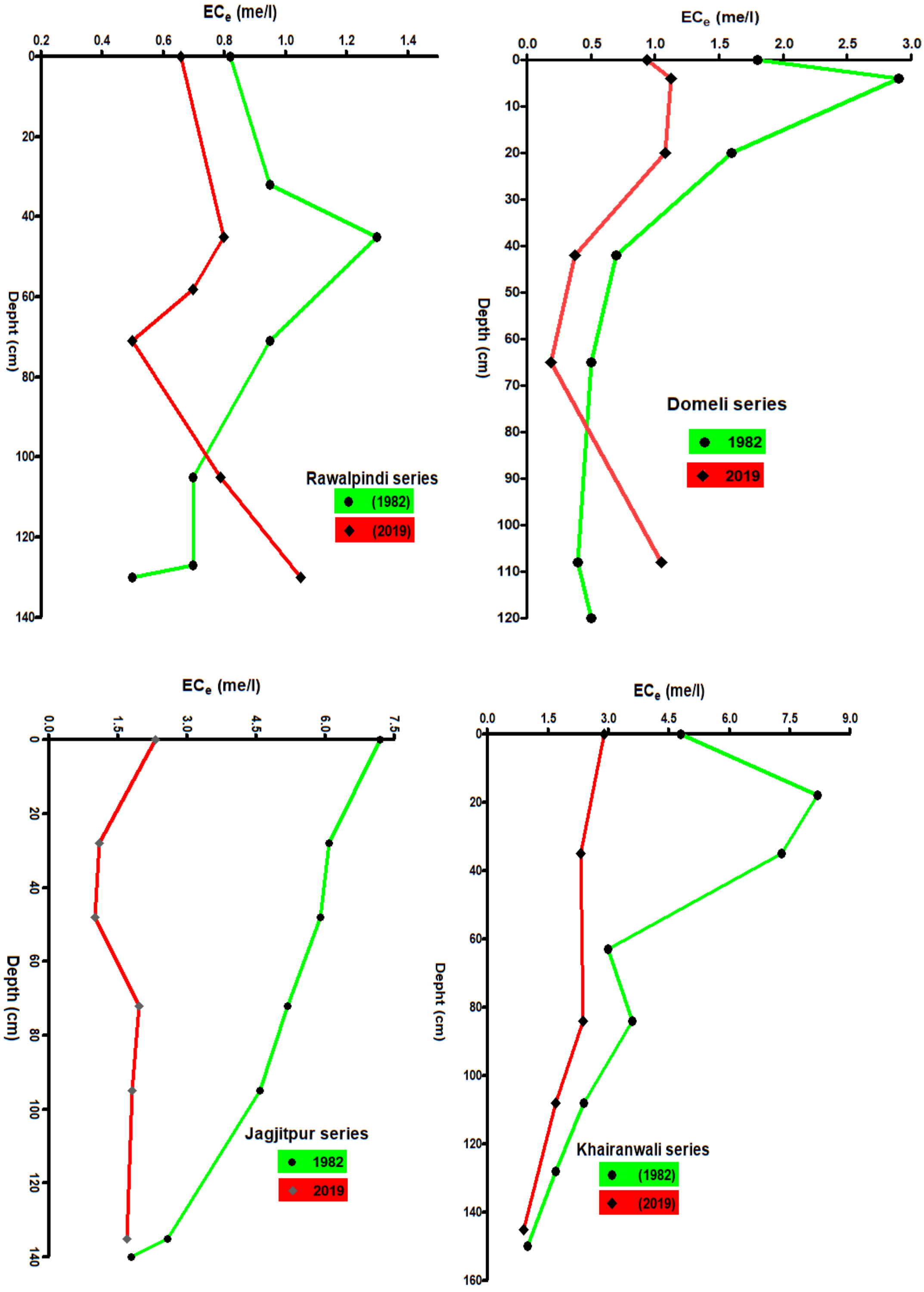

pHs
8.0
8.3
8.6
8.9
9.2
9.5
9.8
10.1
10.4
Depht (cm)
0
20
40
60
80
100
120
140
160
Fajewal series
(1982)
(2019)

**Figure 5.2.9: Comparison graphs for $EC_e$ of salt-affected soils of Kapurthala district**



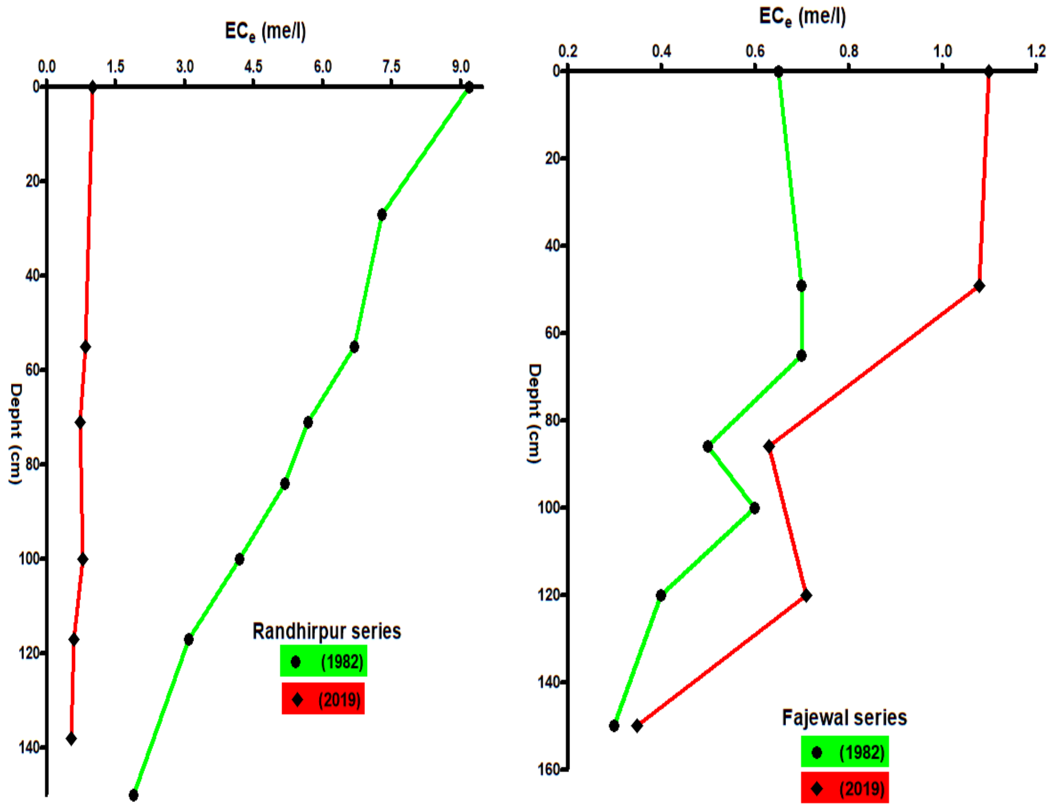
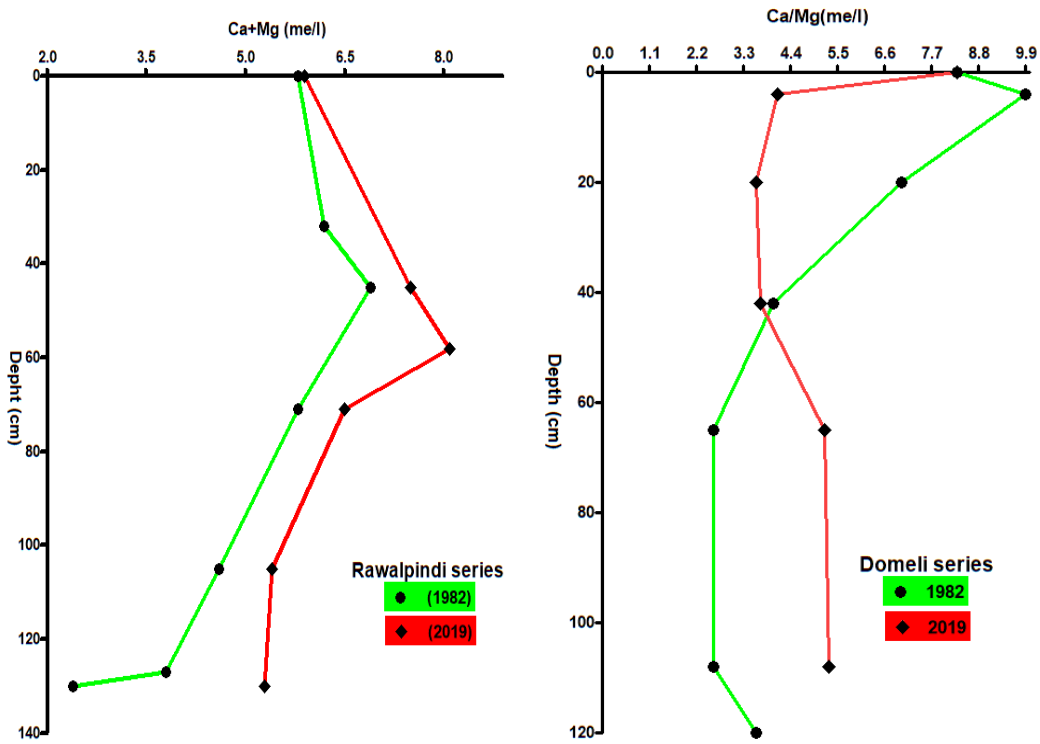
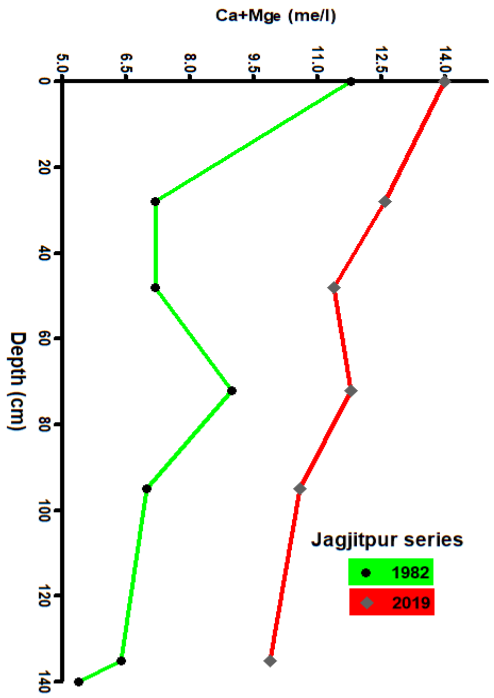
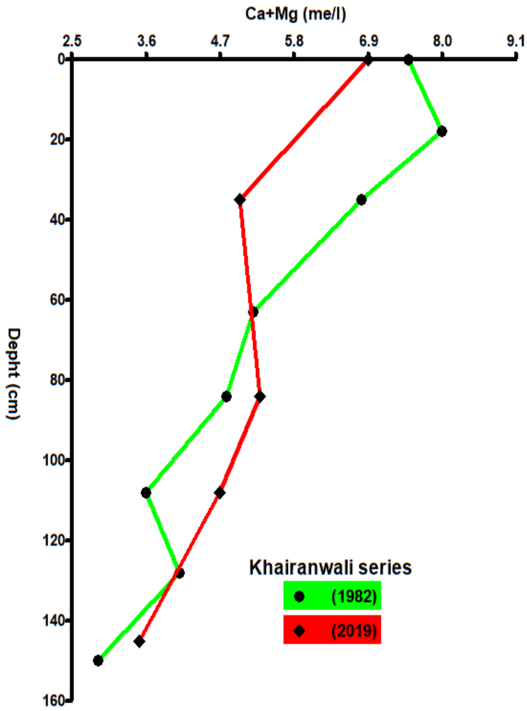



**Figure 5.2.10: Comparison graphs for Ca+Mg (me/l) of salt-affected soils of Kapurthala district**

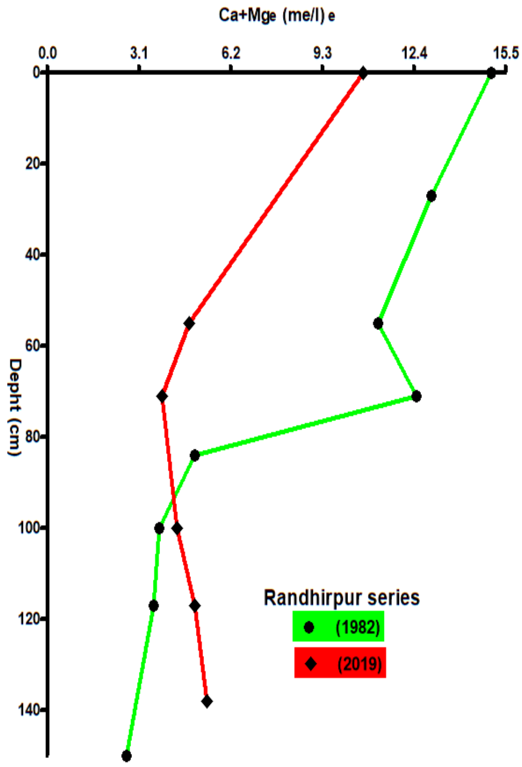




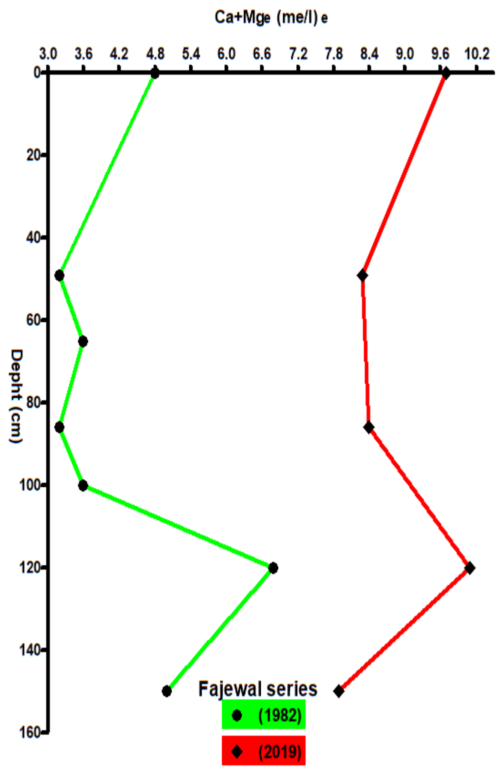
Ca+Mge (me/l)
5.0
6.5
8.0
9.5
11.0
12.5
14.0
Depth (cm)
0
20
40
60
80
100
120
140
Jagjitpur series
1982
2019

Ca+Mg (me/l)
2.5
3.6
4.7
5.8
6.9
8.0
9.1
Depht (cm)
0
20
40
60
80
100
120
140
160
Khairanwali series
(1982)
(2019)

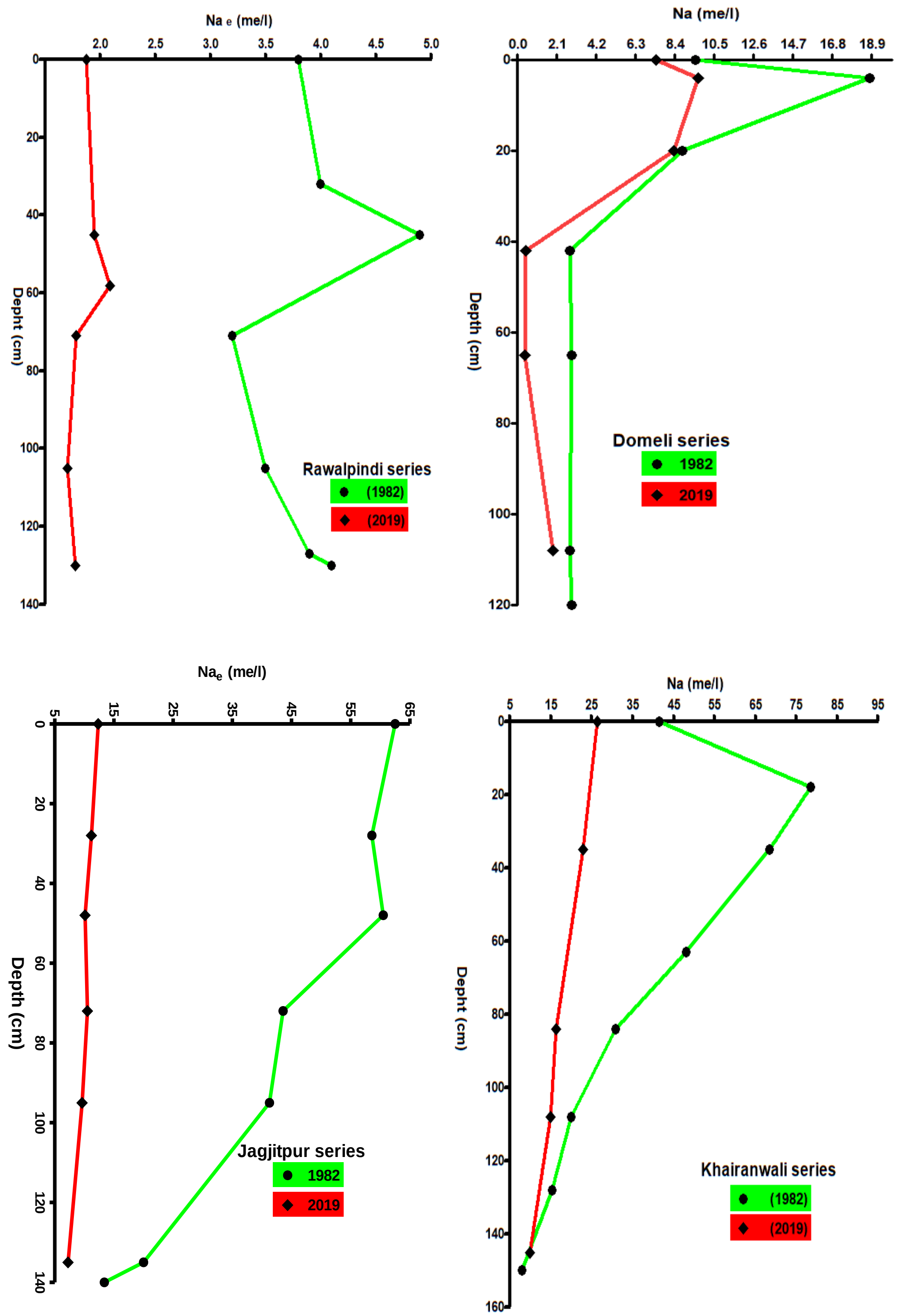



Ca+Mge (me/l) e
0.0
3.1
6.2
9.3
12.4
15.5
Depht (cm)
0
20
40
60
80
100
120
140
Randhirpur series
(1982)
(2019)

Ca+Mge (me/l) e
3.0
3.6
4.2
4.8
5.4
6.0
6.6
7.2
7.8
8.4
9.0
9.6
10.2
Depht (cm)
0
20
40
60
80
100
120
140
160
Fajewal series
(1982)
(2019)

**Figure 5.2.11: Comparison graphs for Na (me/l) of salt-affected soils of Kapurthala district**



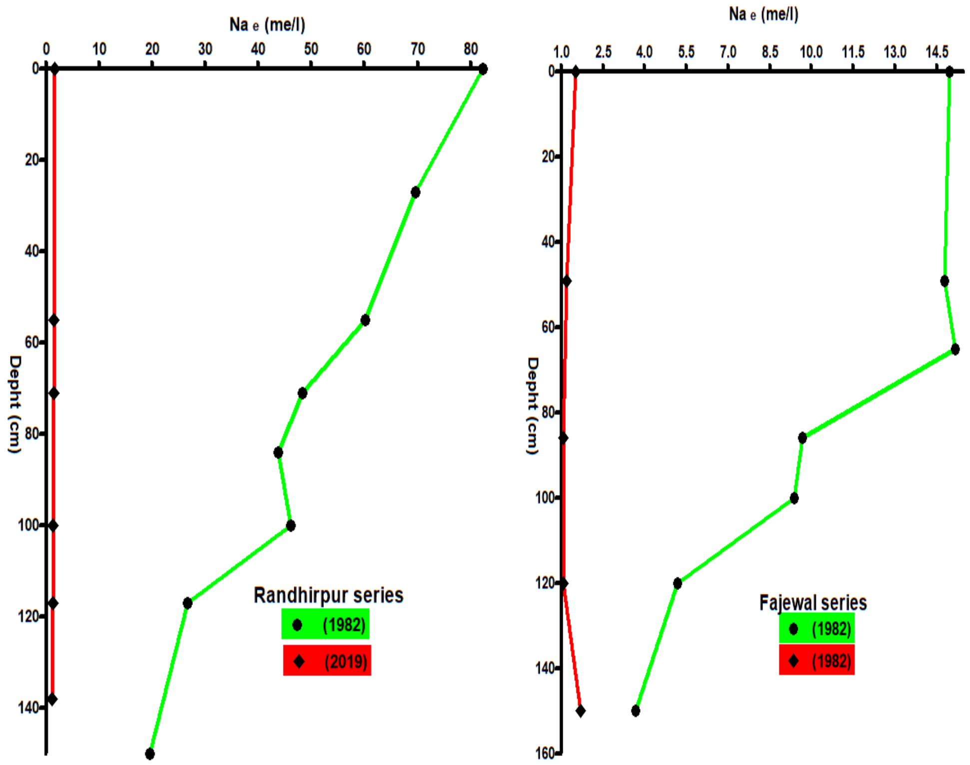
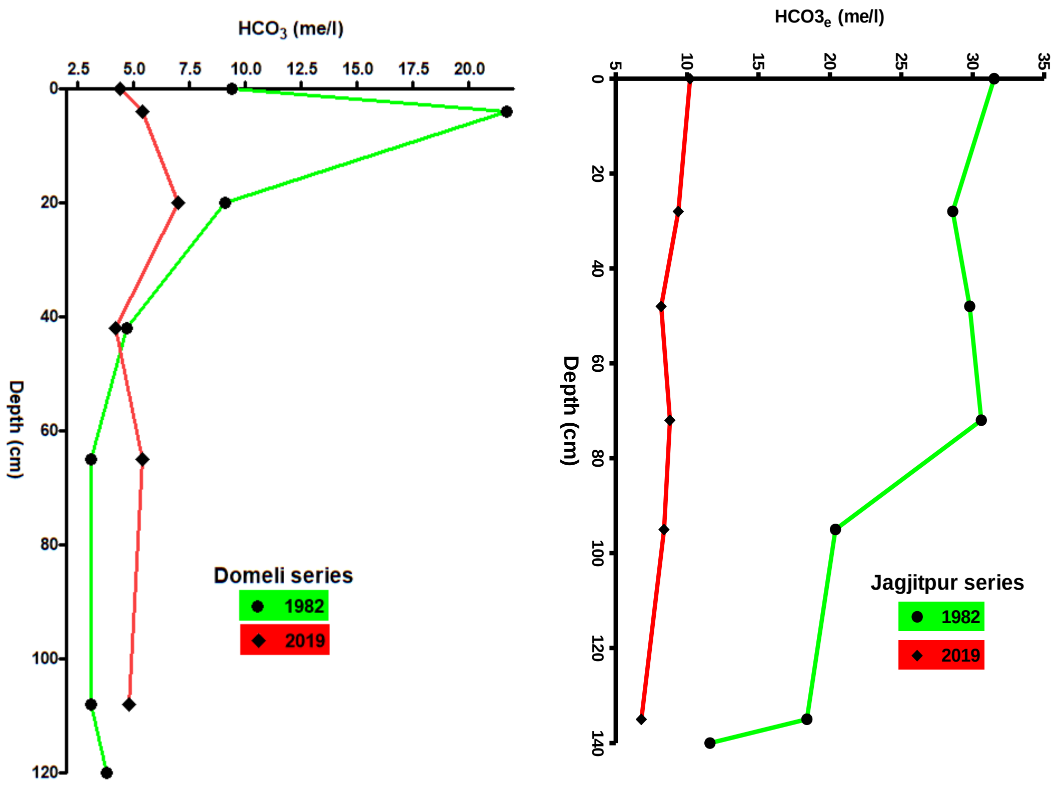
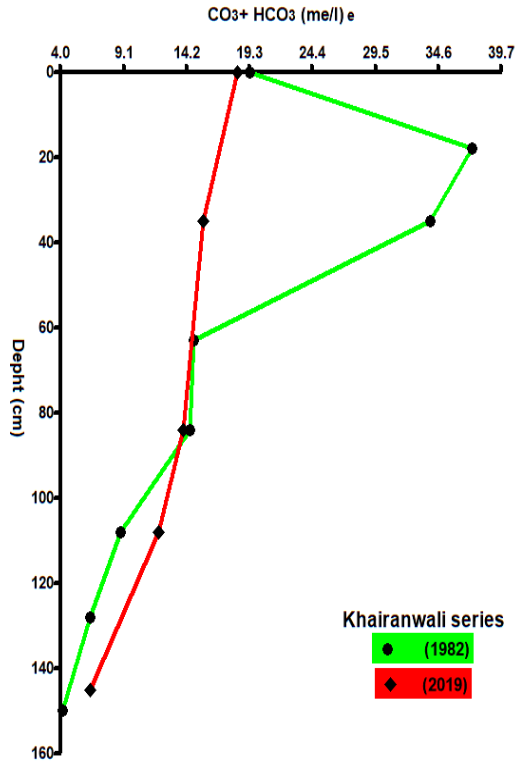
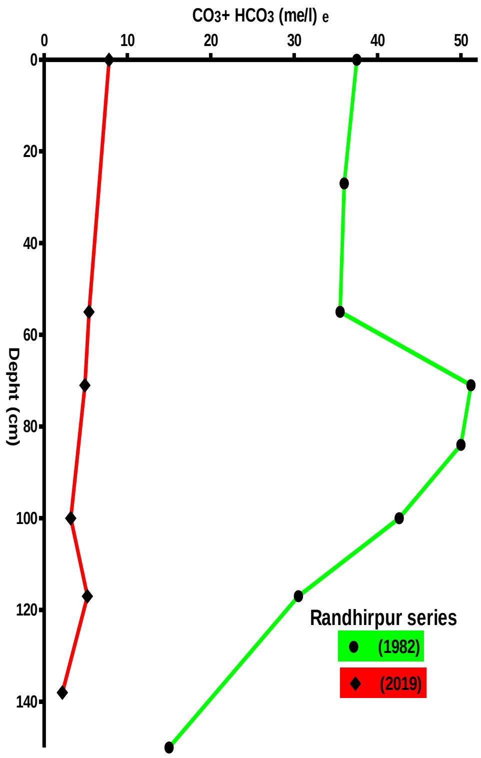
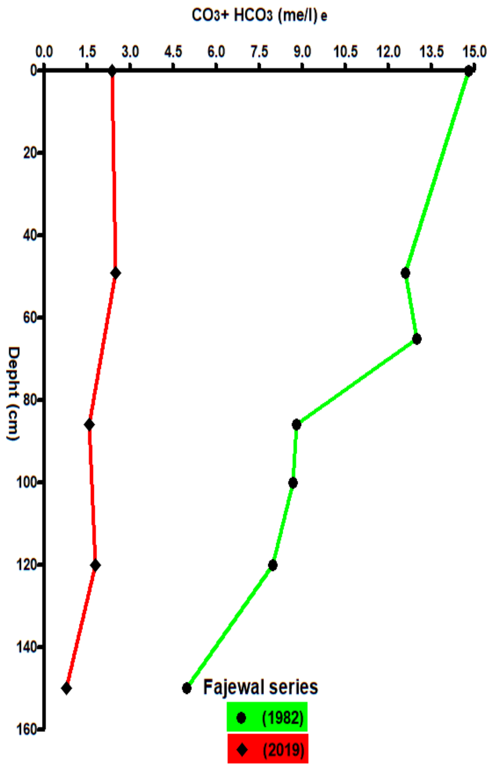



**Figure 5.2.12: Comparison graphs for $CO_3$+ $HCO_3$ (me/l) of salt-affected soils of Kapurthala district**




CO3+ HCO3 (me/l) e
4.0
9.1
14.2
19.3
24.4
29.5
34.6
39.7
Dephth (cm)
Khairanwali series
(1982)
(2019)


CO3+ HCO3 (me/l) e
Dephth (cm)
Randhirpur series
(1982)
(2019)


CO3+ HCO3 (me/l) e
Dephth (cm)
Fajewal series
(1982)
(2019)

### 5.2.2 Normal soils in Kapurthala

Depending upon the variation in soil texture, drainage, profile development, salt content and other physical and chemical characteristics the soils in Dhoda, Tulewal, Samana, Ucha, Fattu Dhinga, Nathupur, Mund, Bhanra, Kanjili and Fatehpur series are known as normal soils in Kapurthala district. The graphs are plotted in Figure 5.2.13 to 5.2.22 for different parameters of each series except Mund series. In Mund series the location where the profile sample was collected in 1982 was occupied by Beas River and the soils were disturbed. The changes in the characteristics of all normal soils are discussed below.

#### 5.2.2.1 pH (1:2)

The 1:2 soil: water pH of normal soils in Kapurthala district ranged from 7.1 in IIIC horizon of Bhanra series to 8.9 in the epipedon of Nathupur series and B21 horizon of Fattu Dhinga series (Appendix II). While in 2019 ranged from 7.5 in the epipedon of Bahanra series to 10.9 in B21 horizon of Fattu Dhinga series. The mean for pH of normal soils in Kapurthala district was 8.3 in 1982 and 9.2 in 2019 respectively. The pH of normal soils in Kapurthala district increased in all the horizons of all the series except Ap horizon of Nathupur series (Figure 5.2.13). The increase in pH value might be due to irrigation water and the direct addition of basic cations to the soil (Haliru and Japheth, 2019). Hailu *et al*., (2003) and Getaneh *et al*, (2007) reported significant change in pH of soils upon irrigation with different water sources.

#### 5.2.2.2 Electrical conductivity

Electrical conductivity of these soils ranged from 0.06 dS $m^{-1}$ in C horizon of Bahanra series to 0.42 dS $m^{-1}$ in B23 horizon of Fattu Dhinga series in 1982. The mean EC of normal soils in 1982 was 0.22 dS $m^{-1}$. The EC value ranged from 0.02 dS $m^{-1}$ in AC horizon of Nathupur series to 0.70 dS $m^{-1}$ in B22 horizon of Fatehpur series with mean of 0.27 dS $m^{-1}$ in 2019. The comparative plot of EC shows that electrical conductivity of normal soils in Kapurthala district in 37 years of intensive agriculture slightly increased in Bhanra, Kanjili and Fatehpur series. It may be due to scrapping of sand layers from the surface of Bhanra and Fatehpur series and use of chemical fertilizers. (Figure 5.2.14). While EC slightly decreased in Nathupur series, not changed or almost same in other normal soil series of Kapurthala district.

### 5.2.2.3 Organic carbon percentage

Organic carbon content of these soils ranged from 0.03 per cent in IV C horizon Fatehpur series along with epipedon and IIC horizon of Bahanra series in 1982 to 0.58 per cent in epipedon of Samana series, while in 2019 the content of organic carbon ranged from 0.06 per cent in B3 horizon of Kanjili series to 0.93 in epipedon horizon of Dhoda series. The mean for organic carbon content of normal soils in Kapurthala district was 0.19 per cent in 1982 and 0.23 per cent in 2019 respectively.

Organic carbon percentage increased in all the horizons of all the series respectively except Kanjili series (Figure 5.2.15). Benbi and Barar (2009) observed that the fertilized rice-wheat cropping being followed in the Punjab state had resulted in an improved soil organic carbon level. Results of long term experiments have also shown that with optimum application of inorganic fertilizers, the soil organic content has either been maintained or slightly increased over the years (Biswas and Benbi, 1997). Furthermore, our study not support the finding of (Kaur, 2014) which reported that organic carbon content was reduced to very low and poor levels in Punjab, because of very low or limited application of organic manures and non-recycling of crop residues. The decreased in organic carbon content of the soils in Kanjili series could be attributed to the use of lower layer water for irrigation purpose which has sodicity. This might be increased the pH of these soils and decreased the organic carbon percentage (Raj Kumar, 1992).

### 5.2.2.4 Calcium carbonate (%)

Calcium carbonate content ranged from 0.0 per cent in Dhoda, Samana, Bahanra and Fatehpur series respectively to 5.5 per cent in C3 horizon of Ucha series in 1982. In 2019 $CaCO_3$ percentage ranged from 0.0 per cent in AC horizon of Nathupur series and AB, B12 and BC horizons of Bahanra series respectively to 0.7 per cent in B21 horizon of Kanjili series. The men for calcium carbonate content of these soils were 2.08 per cent in 1982 and 0.3 per cent in 2019 respectively. Calcium carbonate content decreased in Ucha, Fattu Dhinga, and Kanjili series along with epipedon of Tulewal series while in the subsurface horizons of Tulewal calcium carbonate showed an increase in 2019 (Figure 5.2.16).

### 5.2.2.5 Cation exchange capacity (CEC)

CEC of these soils ranged from 0.7 $cmol_c$/kg of soil in VC horizon of Nathupur series to 14.0 $cmol_c$/kg of soil in B31 horizon of Dhoda series in 19882 (Appendix II). The cation exchange capacity of these soils ranged from 2.03 $cmol_c$/kg of soil in C3 horizon of Nathupur series to 13.16 $cmol_c$/kg of soil in B3 horizon of Kanjili series. The mean for CEC of these soils was 6.97 $cmol_c$/kg of soil in 1982 and 6.97 $cmol_c$/kg of soil in 2019 respectively, indicating no major change.

The content of CEC of normal soils in Kapurthala district slightly increase in Bhanra and Nathupur series, it could be due to the increase in the organic matter content resulting from continuous irrigation (Denef 2008). The CEC content slightly decreased in Fatehpur soil series, which might be due to scrapping of surface sand layers by farmers. As per the graphs the CEC content in Dhoda, Tulewal, Samana, Ucha, Fattu Dhinga, and Kanjili soil series are almost same or not changed.

### 5.2.2.6 Exchangeable cations

Exchangeable calcium of normal soils ranged from 0.3 $cmol_c$/kg of soil in IIIC, IV and VC horizons of Nathupur series to 10.4 $cmol_c$/kg of soil B31 horizon of Dhoda series in 1982. The exchangeable cation content in 2019 ranged from 0.6 $cmol_c$/kg of soil in C2 horizon of Nathupur series to 8.4 $cmol_c$/kg of soil in BC horizon of Tulewal series.

Based on the comparison graphs it obtained that exchangeable calcium was almost same or not changed in Dhoda, Tulewal, Samana, Fattu Dhinga, and Nathupur soil series. While it slightly increased in Bhanra and Fatehpur series, it could be due to scrapping of sand layers from the surface of these soils by farmers (Figure 5.2.18). While it slightly decreased in Ucha and Kanjili series except epipedon. The decrease in the availability of exchangeable cations might be due to long-continued irrigated cropping, ideally including a rice crop along with the application of chemical soil amendments followed by leaching (Abrol *et al.*, 1988).

The exchangeable sodium percentage ranged from 0.01 $cmol_c$/kg of soil in IIC and IIIC horizons of Bahanra series to 1.7 $cmol_c$/kg of soil in epipedon of Kanjili series in 1982, while in 2019 ranged from 0.34 $cmol_c$/kg of soil in BC horizon of Dhoda and B11 horizon of Bahanra series to 5.56 $cmol_c$/kg of soil in B3 horizon of Kanjili series. The content of exchangeable Na in 2019 as compared to 1982 increased

Nathupur, Bahanra, Fatehpur and Kanjili series except Ap horizon. It did not changed or very small change in Dhoda, Tulewal, Samana, Ucha and Fattu Dhinga series respectively (Figure 5.2.18).

### 5.2.2.7 Exchangeable sodium percentage (E.S.P)

Exchangeable sodium percentage of normal soils in Kapurthala district ranged from 0.4 per cent to IIIC horizon of Bahanra series to 15.4 in epipedon of Kanjili series in 1982. ESP ranged from 5.5 in BC horizon of Dhoda series to 66.0 per cent in AB horizon of Nathupur series. The mean for ESP of normal soils was 4.41 in 1982 and 14.4 in 2019 respectively.

Exchangeable sodium percentage of normal soils in Kapurthala district slightly increased in Tulewal, Samana, and Ucha except Ap horizon, increased in Nathupur, Bhanra, Fatehpur and Kanjili except Ap horizon. While ESP content is almost same or very small change in Dhoda and Fattu Dhinga series. Increase in ESP content of Bhanra and Fatehpur series is may be due to scrapping of sand layers from the surface of the soils by farmers. The change in ESP of soils is may be attributed with the change in pH of soils and the application of organic manures and gypsum FAO, (1988).

### 5.2.2.8 Saturation extract

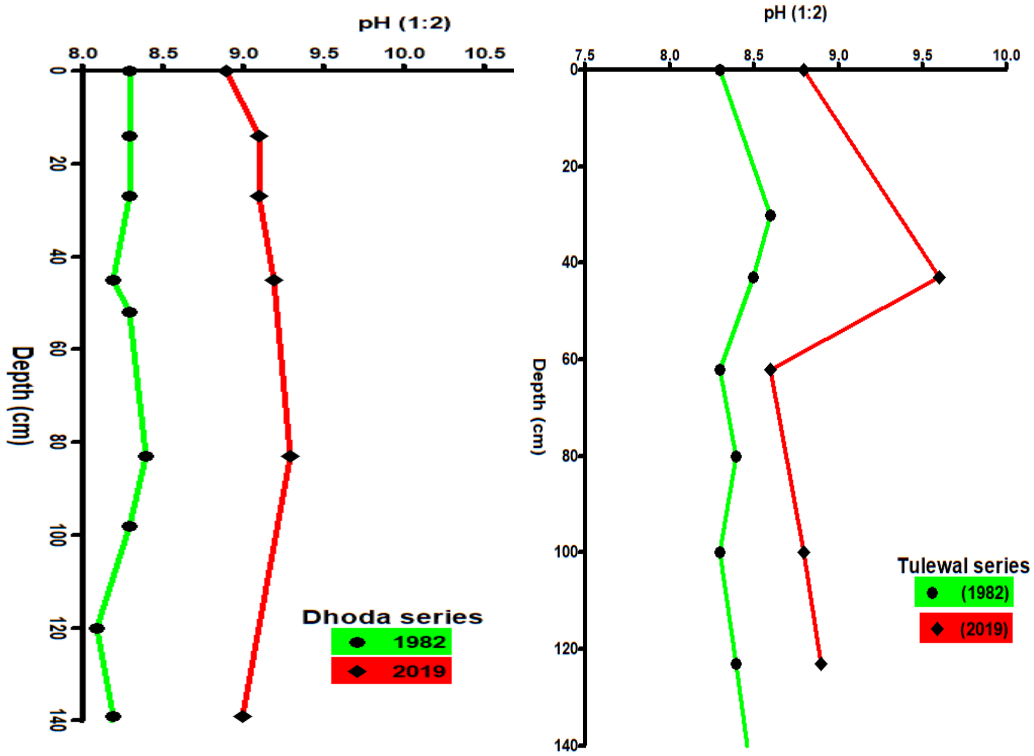
Comparison graphs were plotted for the parameters of $pH_s$, $EC_e$, and $Na^+$ of Soil saturation paste and saturation extract. The $pH_s$ ranged from 7.0 in IIC and IIIC horizons of Bahanra series to 8.5 in epipedon horizon of Kanjili series. While in 2019 it ranged from 7.2 in epipedon and AB horizon of Bahanra series to 9.8 epipedon horizon of Fatehpur series. The mean for $pH_s$ of these soils was 7.8 in 1982 and 8.19 in 2019 respectively. The pHs did not changed or almost same in Dhoda, Tulewal, Ucha, Fattu Dhinga and Bhanra series. It increased in Fatehpur series, this might be due to scrapping of sand layers from the surface of the soils by farmers. Slightly decrease in Samana Nathupur and Kanjili series (Figure 5.2.20).

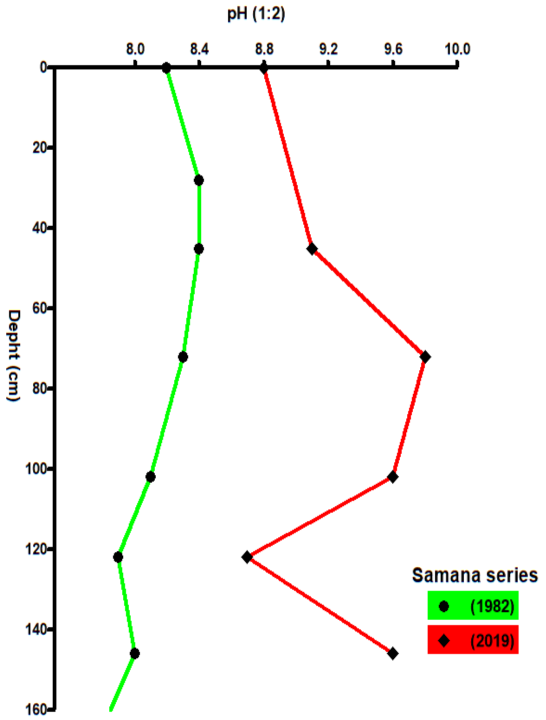
The $EC_e$ of normal soils ranged from 0.2 dS $m^{-1}$ in epipedon of Bhanra series to 1.4 dS $m^{-1}$ in epipedon horizon of Dhoda series in 1982. The $EC_e$ in 2019 ranged from 0.20 dS $m^{-1}$ B12 horizon of Bahanra series to 9.8 dS $m^{-1}$ in the epipedon horizon of Fatehpur series. The mean for ECe of these soils were 0.88 dS $m^{-1}$ in 1982 and 0.82

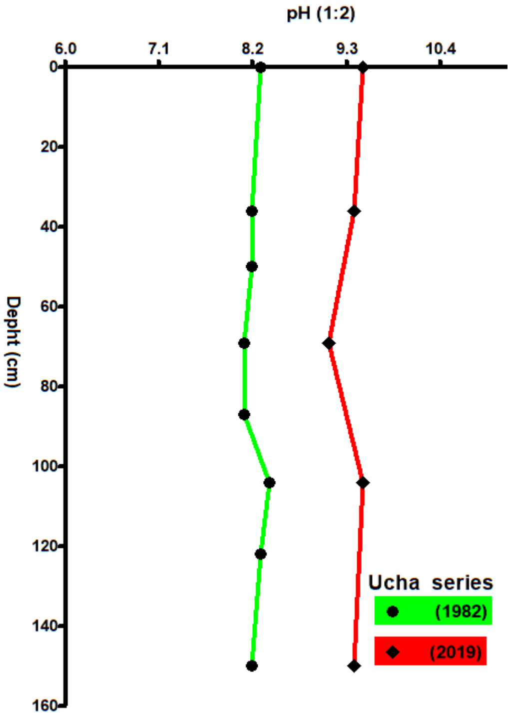
dS $m^{-1}$ in 2019 respectively. The $EC_e$ content did not changed or almost same in Dhoda, Tulewal, Samana, Ucha, Bhanra, and Nathupur series, while slightly (Figure 5.2.21).

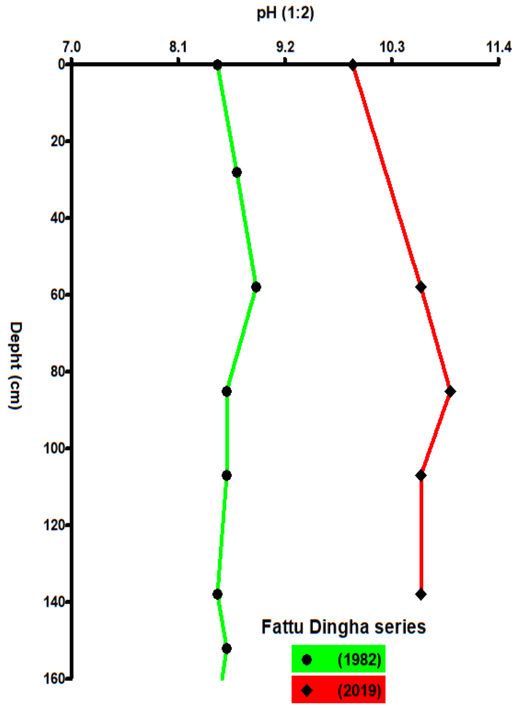
The $Na^+$ content in saturation extras of normal soils ranged from 0.9 me/l in VC Nathupur series to 9.8 me/l in IIC2 horizon of Fatehpur series in 1982. While in 2019 ranged from 0.48 me/l to 7.0 me/l in epipedon of Dhoda series. The mean of sodium in soil extract of normal soils was 2.26 me/l in 1982 to 2.70 in 2019 respectively. The data of $Na^+$ in soil extract showed that $Na^+$ content slightly increased in Dhoda, Tulewal, Samana, Ucha, Fattu Dhinga, and Nathupur series, it might be due to irrigation with sodic water. Furthermore, the content of $Na^+$ slightly decreased in Kanjili and Fatehpur series figure 5.2.22, which could be due to leaching and scrapping of sand layers in surface soils of Fatehpur series.

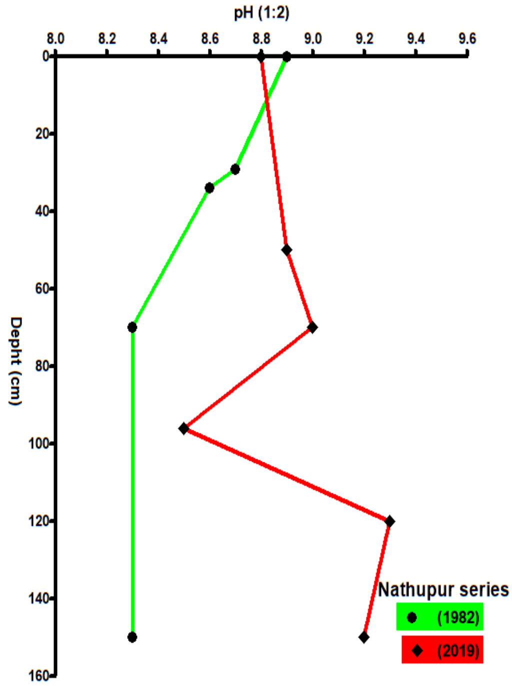
**Figure 5.2.13: Comparison graphs for pH (1:2) of normal soils of Kapurthala district**

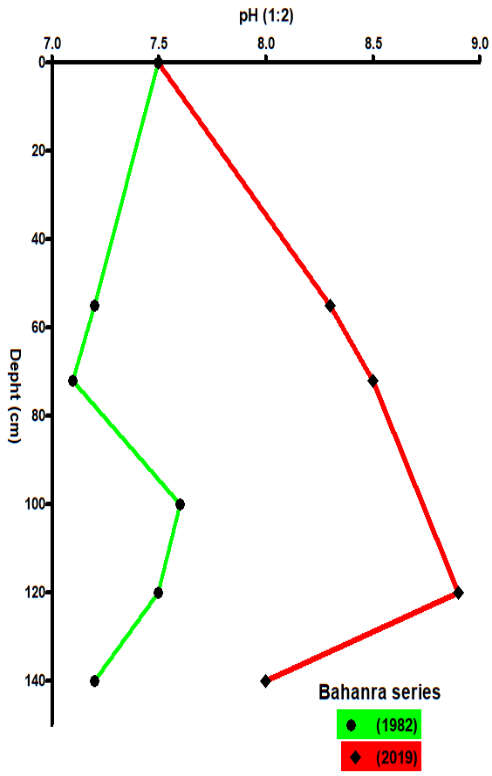


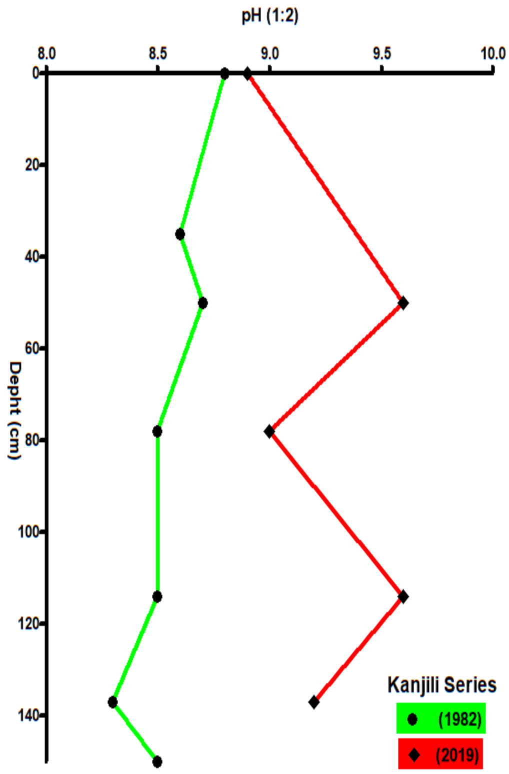

pH (1:2)
8.0
8.4
8.8
9.2
9.6
10.0
0
20
40
60
80
100
120
140
160
Depht (cm)
Samana series
(1982)
(2019)


pH (1:2)
6.0
7.1
8.2
9.3
10.4
0
20
40
60
80
100
120
140
160
Depht (cm)
Ucha series
(1982)
(2019)


pH (1:2)
7.0
8.1
9.2
10.3
11.4
0
20
40
60
80
100
120
140
160
Depht (cm)
Fattu Dingha series
(1982)
(2019)


pH (1:2)
8.0
8.2
8.4
8.6
8.8
9.0
9.2
9.4
9.6
0
20
40
60
80
100
120
140
160
Depht (cm)
Nathupur series
(1982)
(2019)


pH (1:2)
7.0
7.5
8.0
8.5
9.0
0
20
40
60
80
100
120
140
Depht (cm)
Bahanra series
(1982)
(2019)


pH (1:2)
8.0
8.5
9.0
9.5
10.0
0
20
40
60
80
100
120
140
Depht (cm)
Kanjili Series
(1982)
(2019)

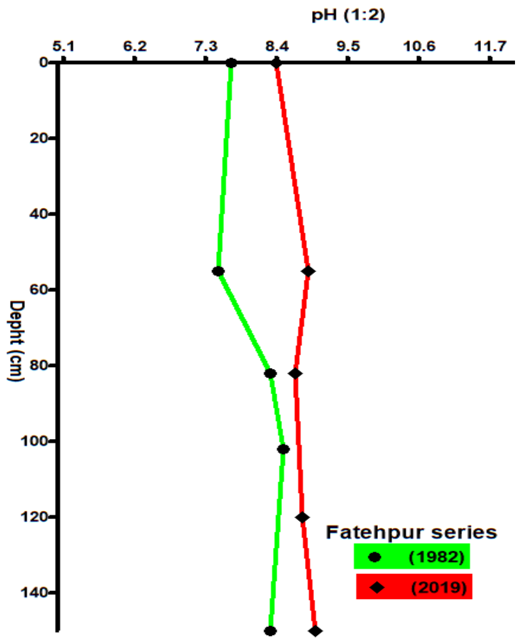
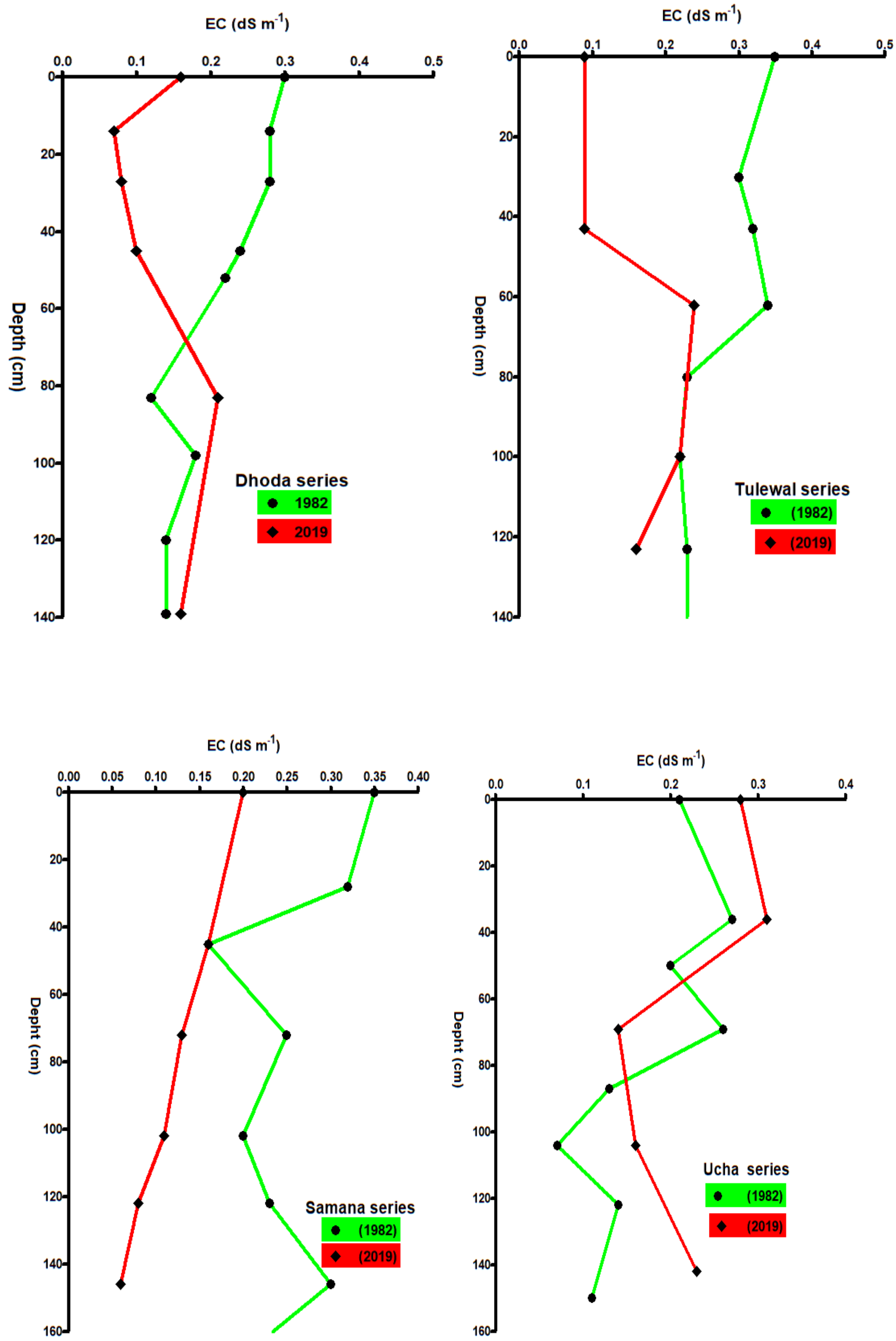
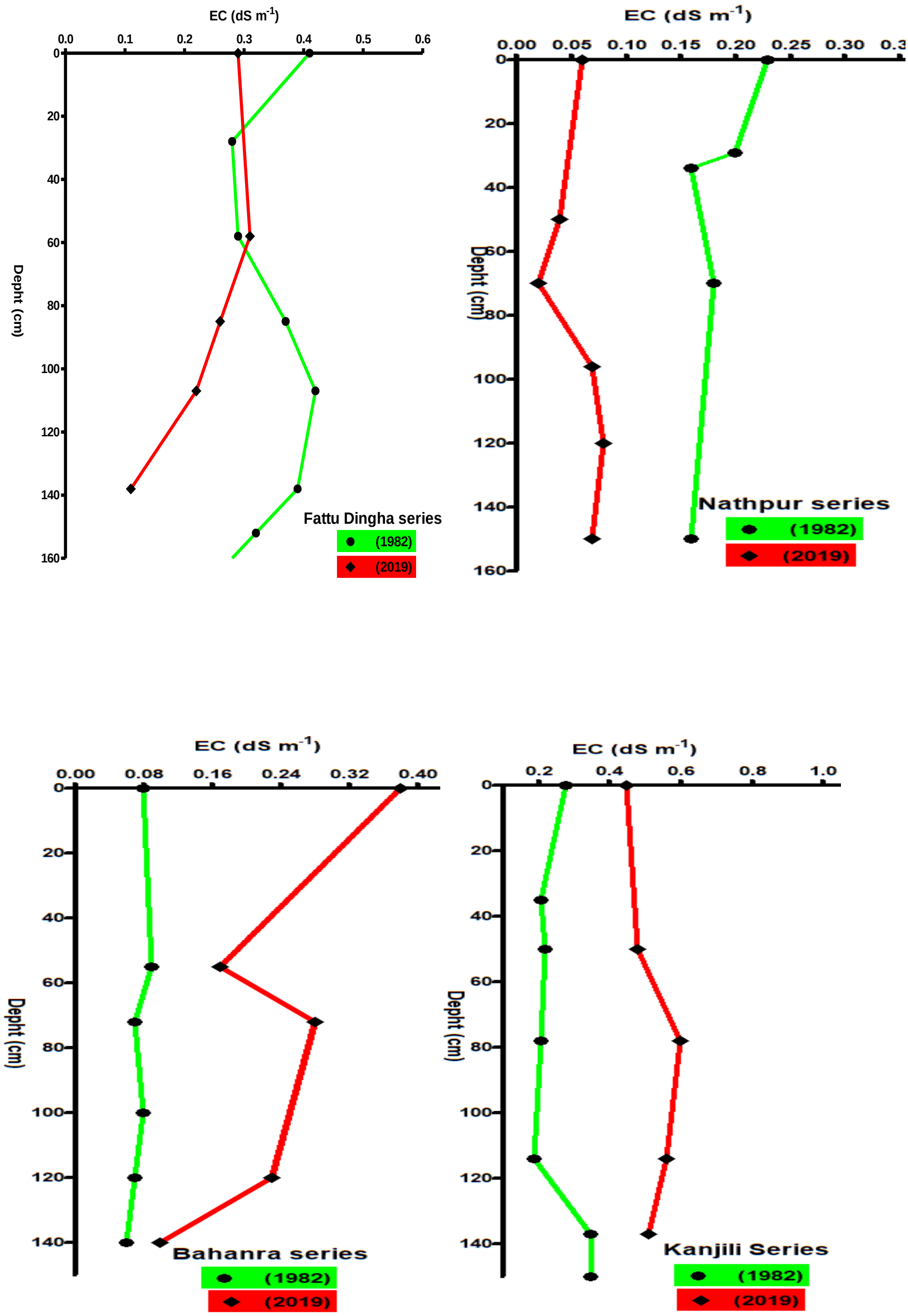

pH (1:2)
5.1
6.2
7.3
8.4
9.5
10.6
11.7
0
20
40
60
80
100
120
140
Depht (cm)
Fatehpur series
(1982)
(2019)

**Figure 5.2.14: Comparison graphs for EC (dS $m^{-1}$) of normal soils of Kapurthala district**




EC (dS m-1)
Depht (cm)
Fattu Dingha series
(1982)
(2019)
Nathpur series
(1982)
(2019)
Bahanra series
(1982)
(2019)
Kanjili Series
(1982)
(2019)

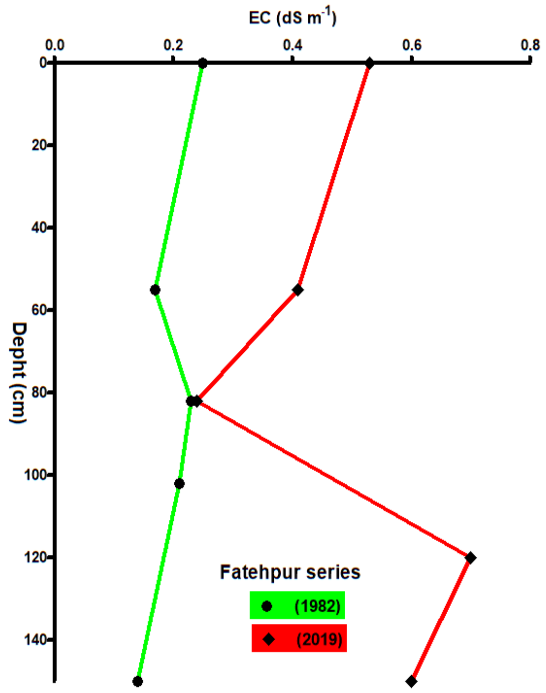
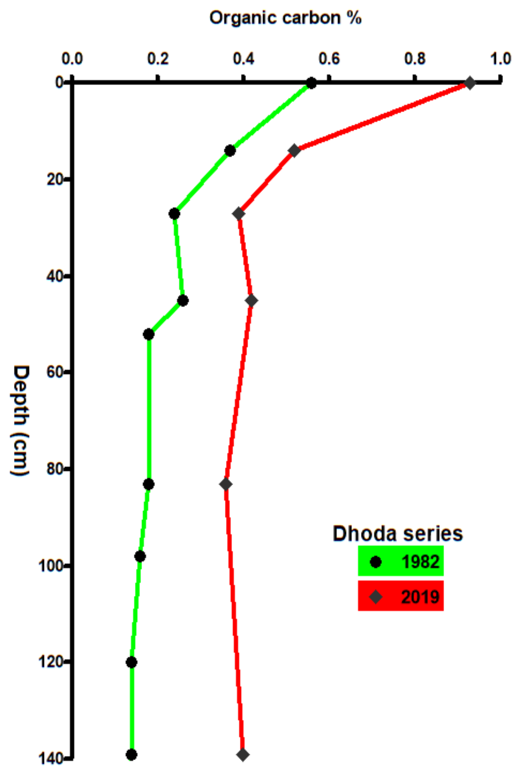
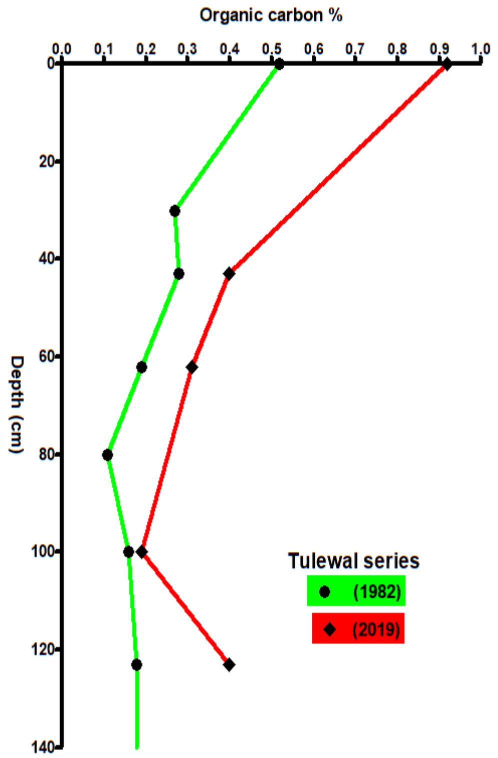
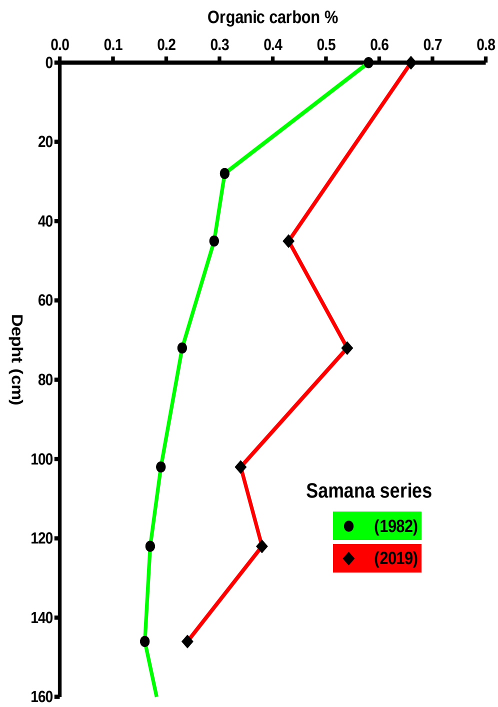
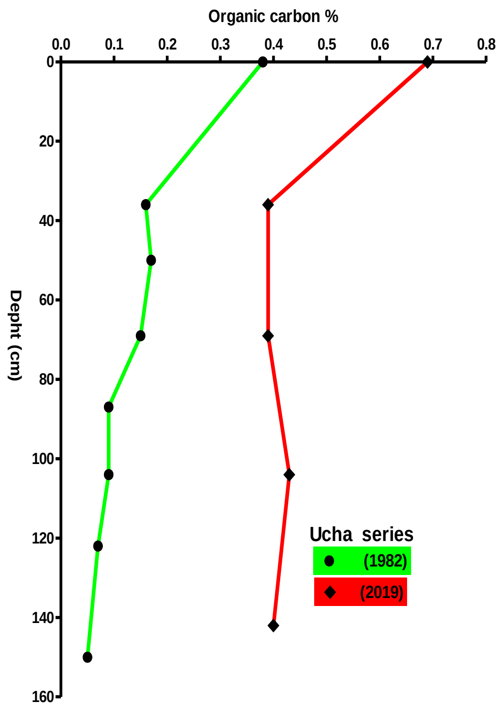


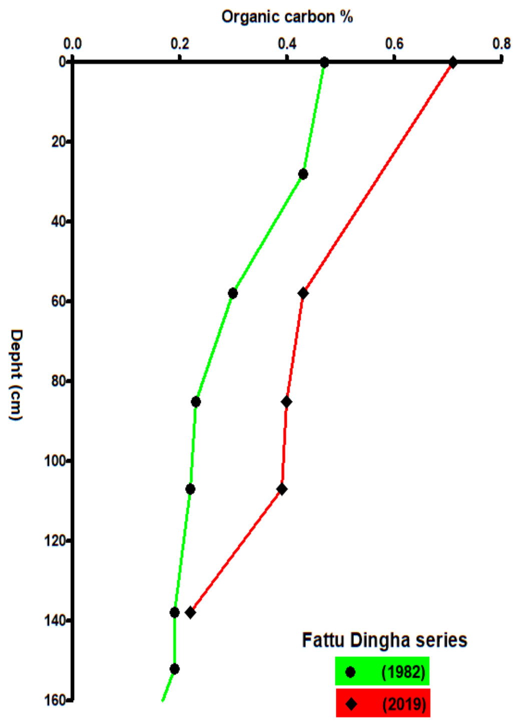

**Figure 5.2.15: Comparison graphs for organic carbon percentage of normal soils of Kapurthala district**

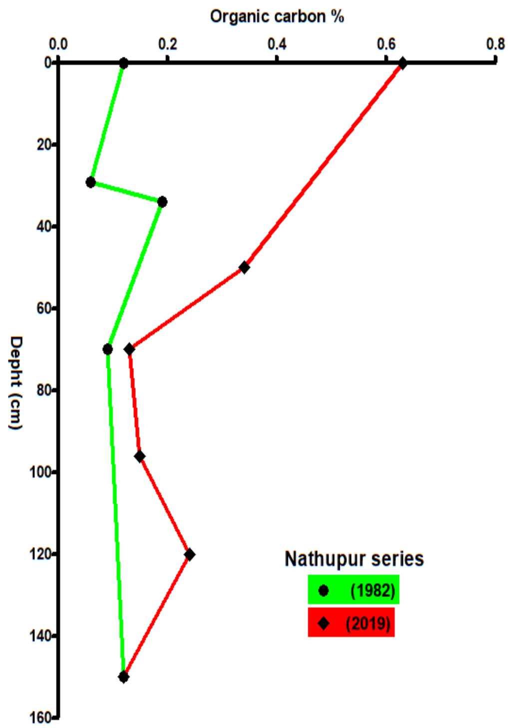


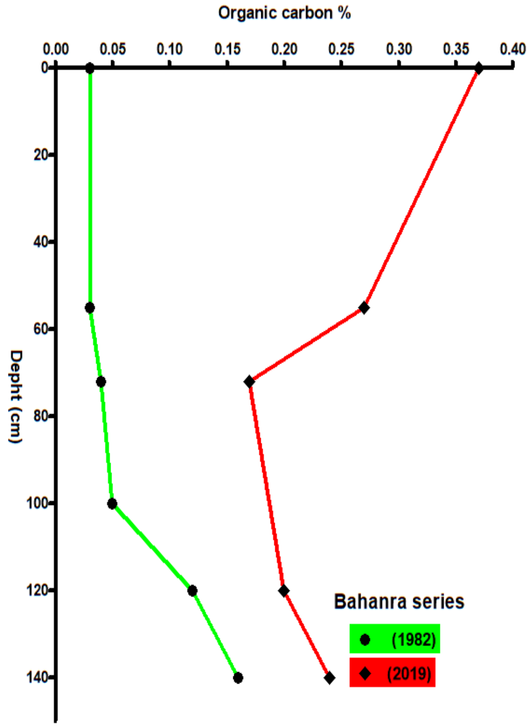



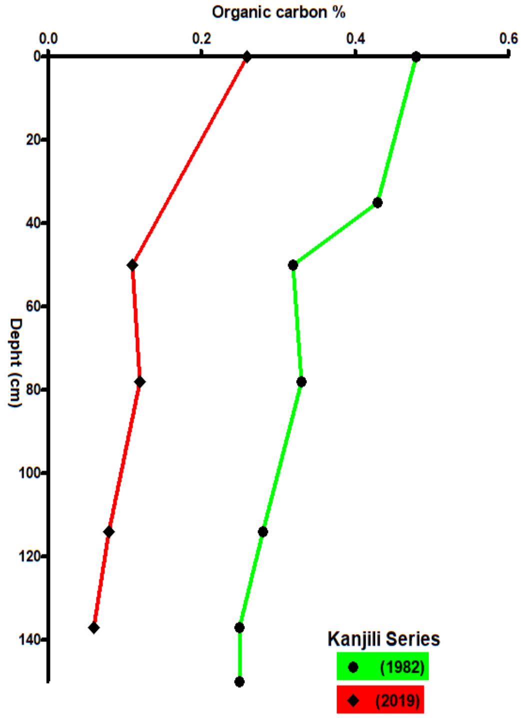

Organic carbon %
Depht (cm)
Samana series
(1982)
(2019)


Organic carbon %
Depht (cm)
Ucha series
(1982)
(2019)


Organic carbon %
Depht (cm)
Fattu Dingha series
(1982)
(2019)


Organic carbon %
Depht (cm)
Nathupur series
(1982)
(2019)


Organic carbon %
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0
20
40
60
80
100
120
140
Depht (cm)
Bahanra series
(1982)
(2019)


Organic carbon %
0.0
0.2
0.4
0.6
0
20
40
60
80
100
120
140
Depht (cm)
Kanjili Series
(1982)
(2019)

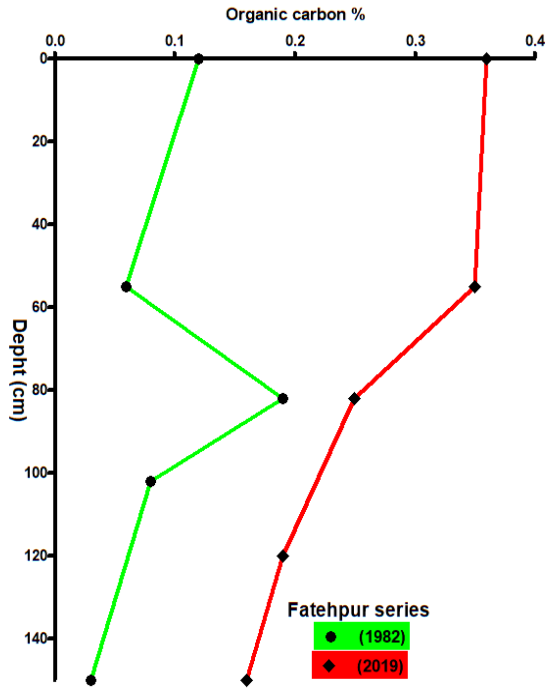
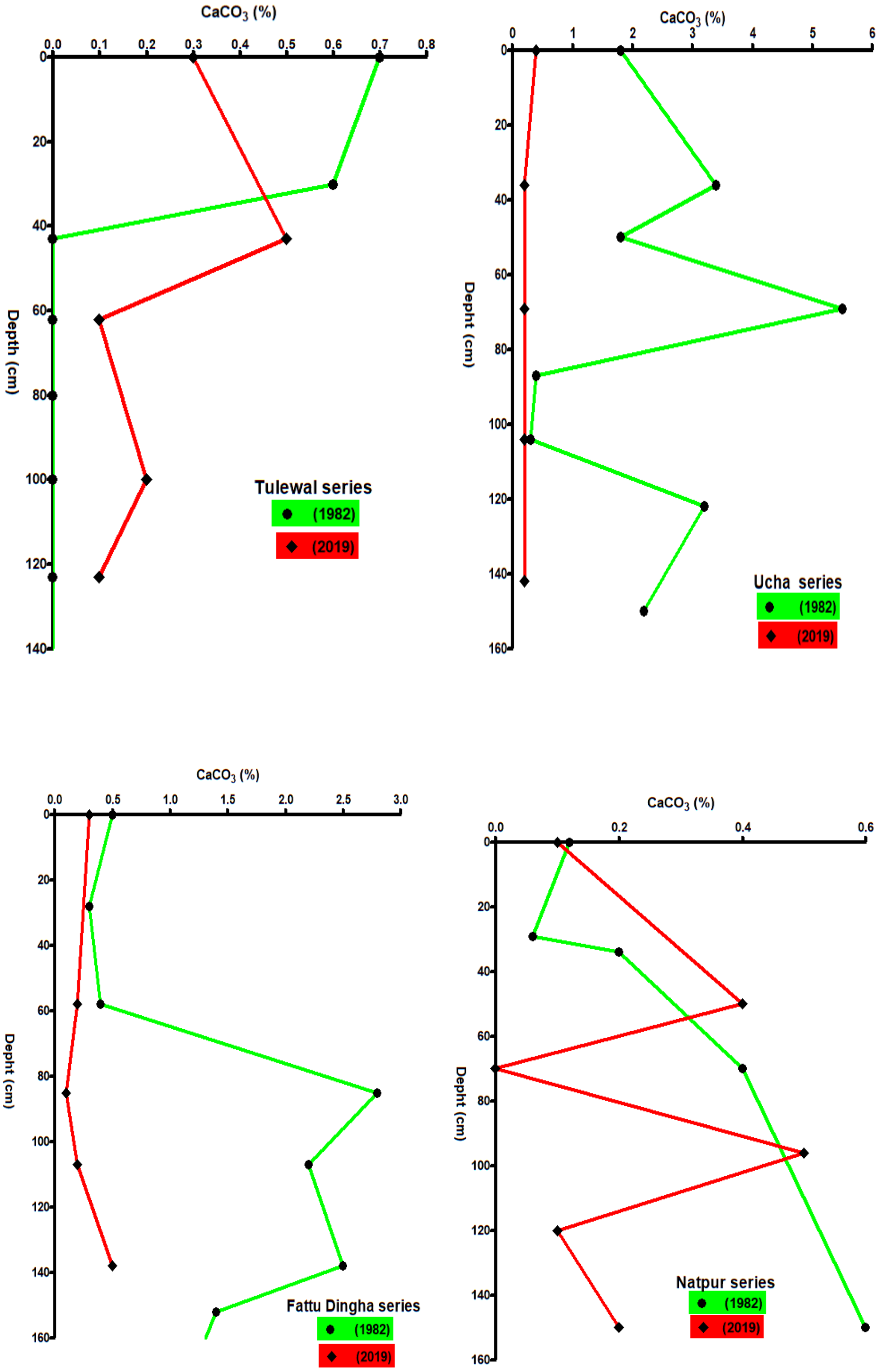

Organic carbon %
0.0
0.1
0.2
0.3
0.4
0
20
40
60
80
100
120
140
Depht (cm)
Fatehpur series
(1982)
(2019)

**Figure 5.2.16: Comparison graphs for calcium carbonate percentage of normal soils of Kapurthala district**



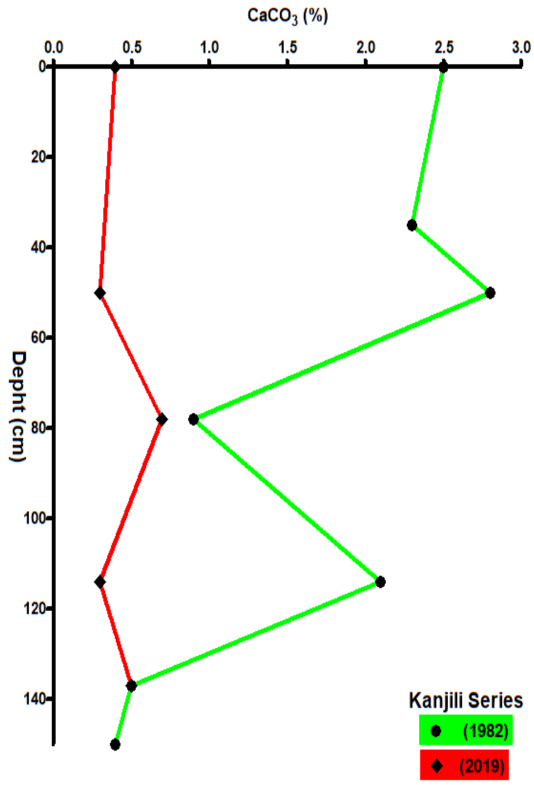
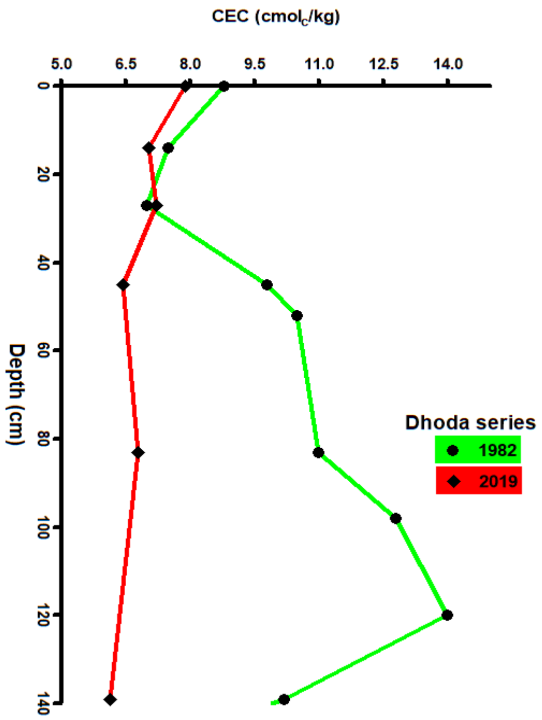
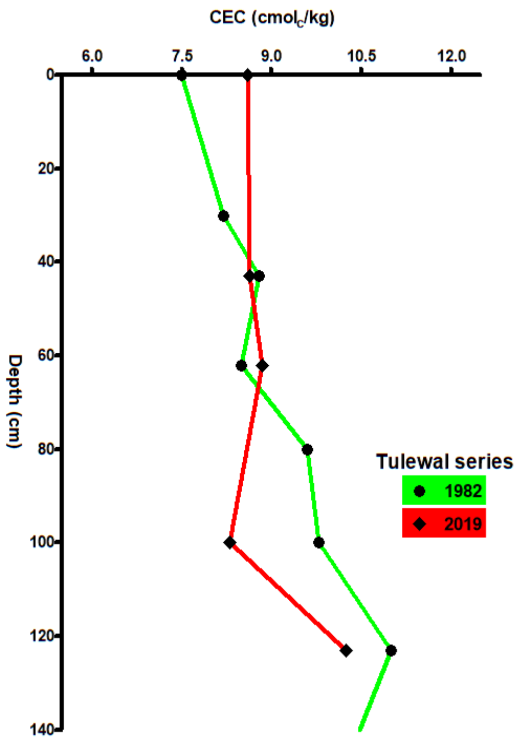
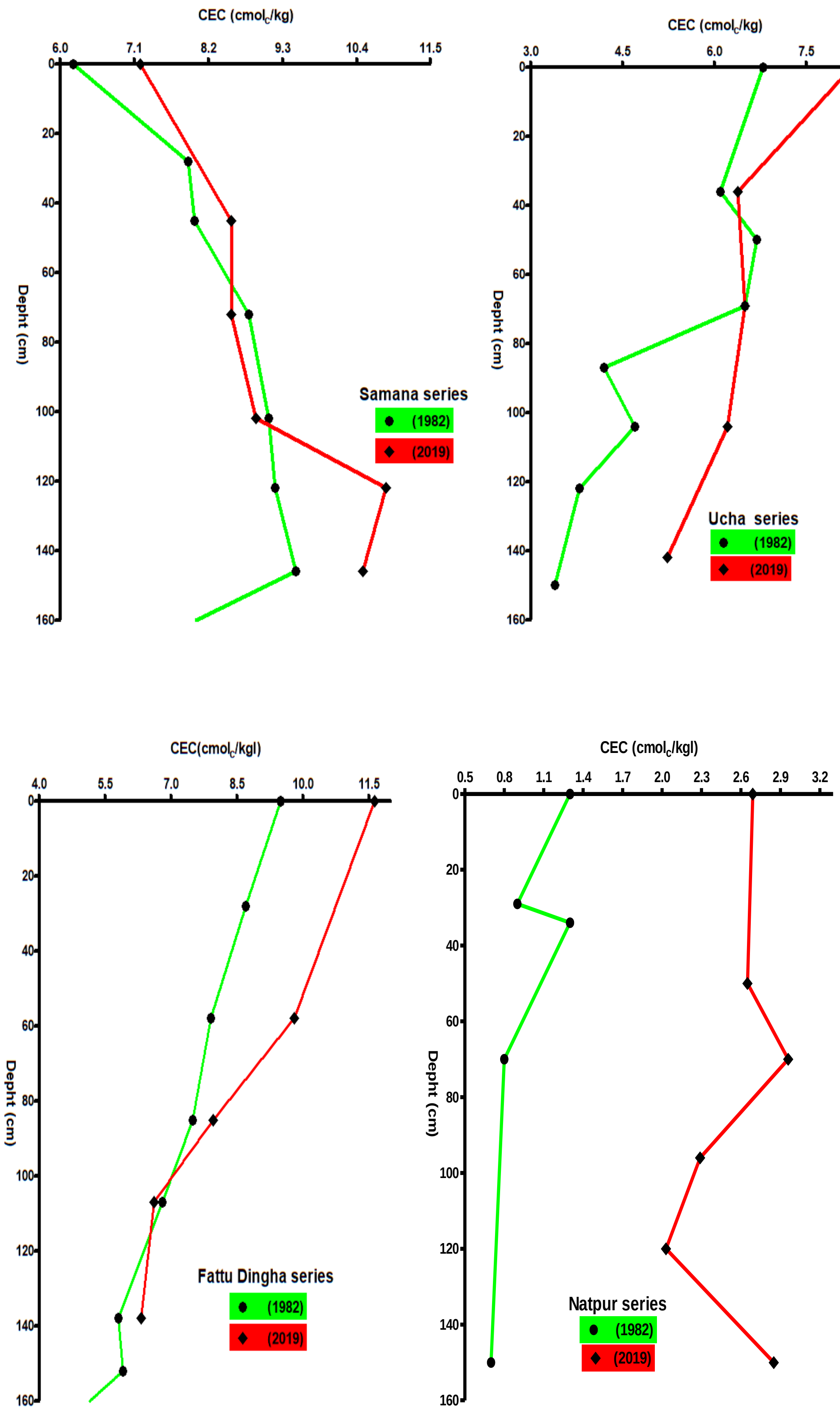
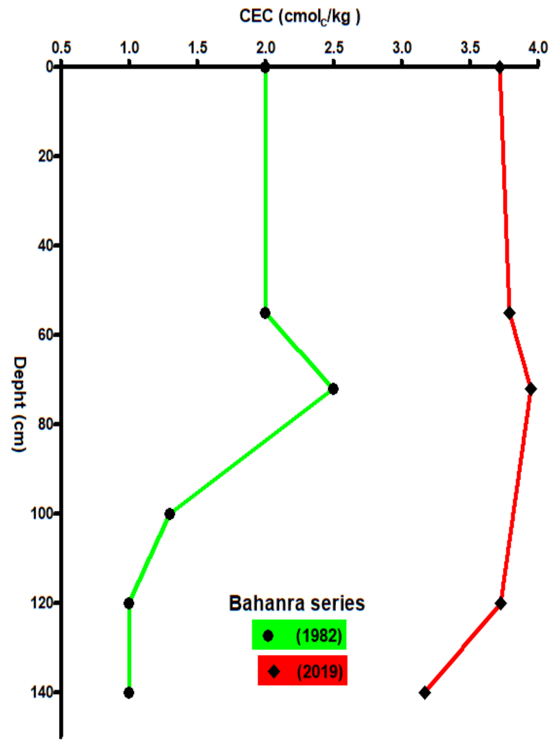


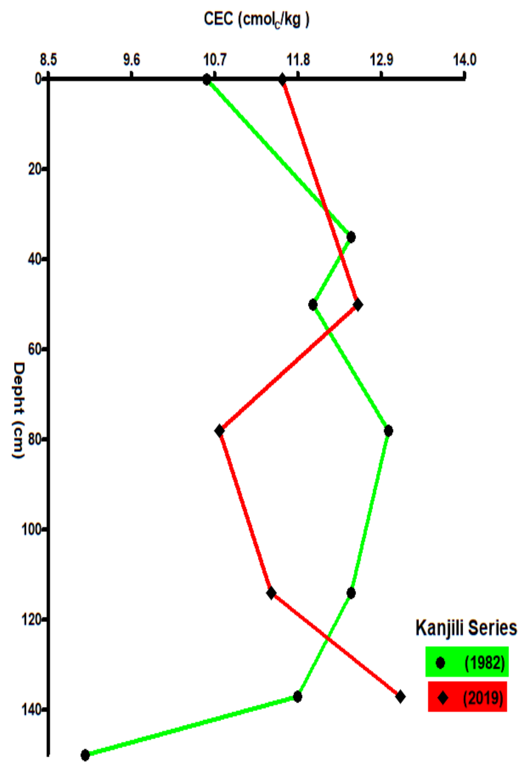

**Figure 5.2.17: Comparison graphs for CEC ($cmol_c$/kg) percentage of normal soils of Kapurthala district**




CEC (cmolc/kg)
6.0
7.1
8.2
9.3
10.4
11.5
Depht (cm)
0
20
40
60
80
100
120
140
160
Samana series
(1982)
(2019)
CEC (cmolc/kg)
3.0
4.5
6.0
7.5
9.0
Depht (cm)
Ucha series
(1982)
(2019)
CEC(cmolc/kgl)
4.0
5.5
7.0
8.5
10.0
11.5
Depht (cm)
Fattu Dingha series
(1982)
(2019)
CEC (cmolc/kgl)
0.5
0.8
1.1
1.4
1.7
2.0
2.3
2.6
2.9
3.2
Depht (cm)
Natpur series
(1982)
(2019)


CEC (cmolc/kg )
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
20
40
60
80
100
120
140
Depht (cm)
Bahanra series
(1982)
(2019)


CEC (cmolc/kg )
8.5
9.6
10.7
11.8
12.9
14.0
0
20
40
60
80
100
120
140
Depht (cm)
Kanjili Series
(1982)
(2019)

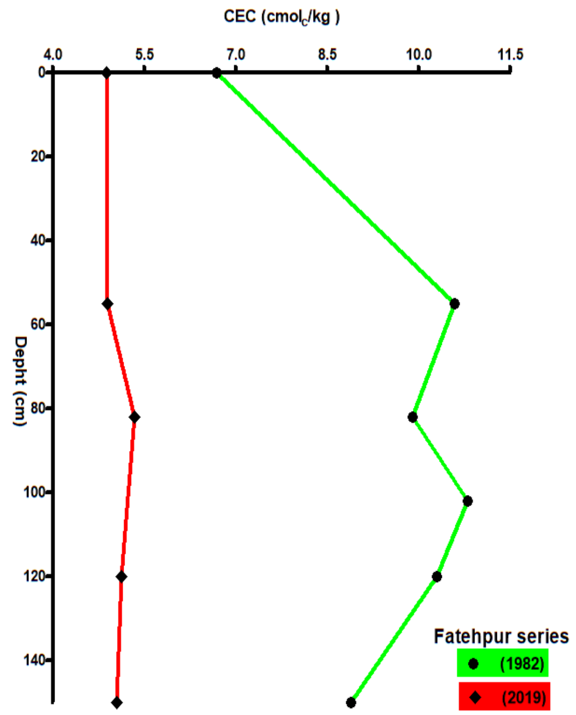
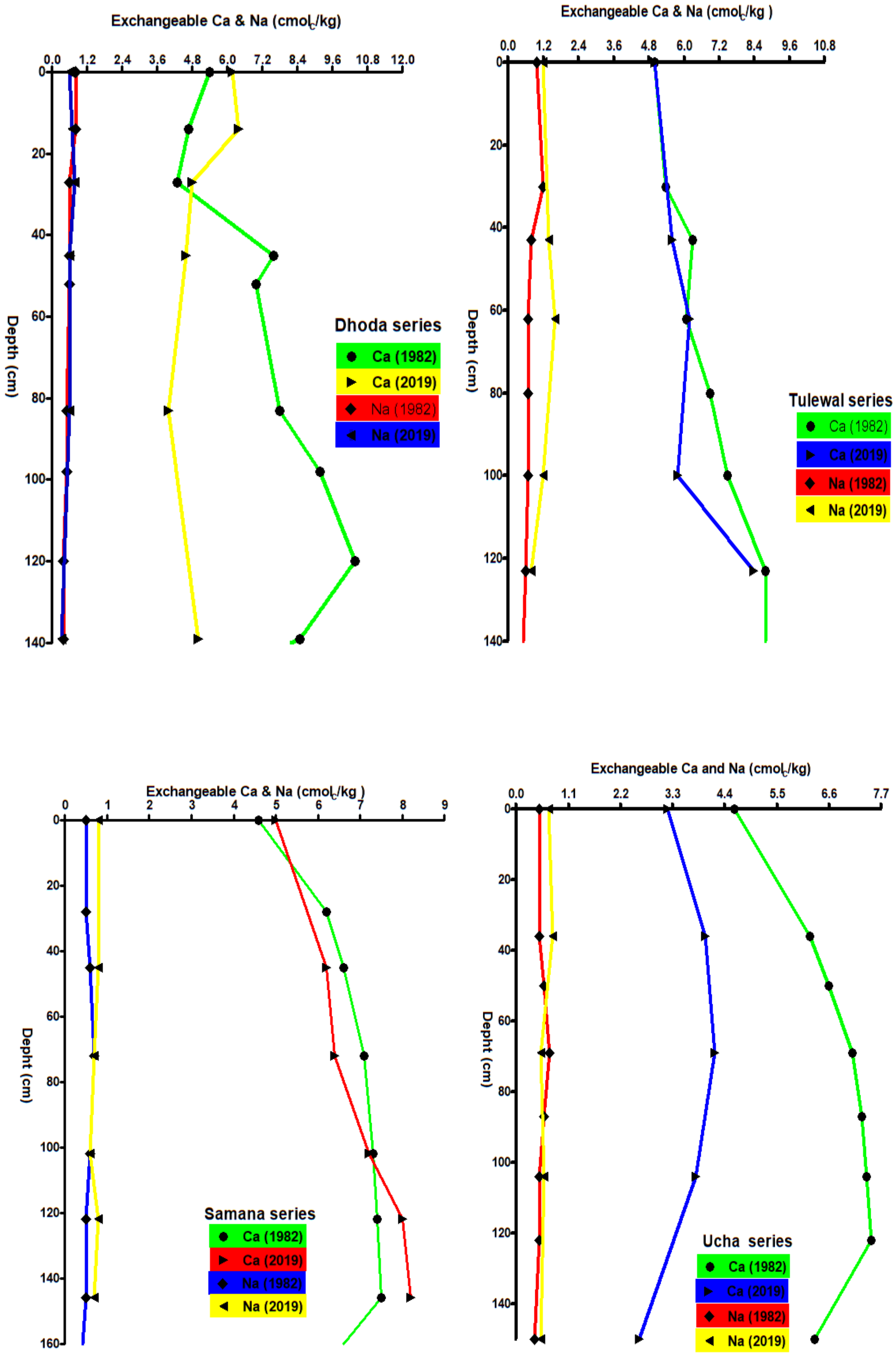
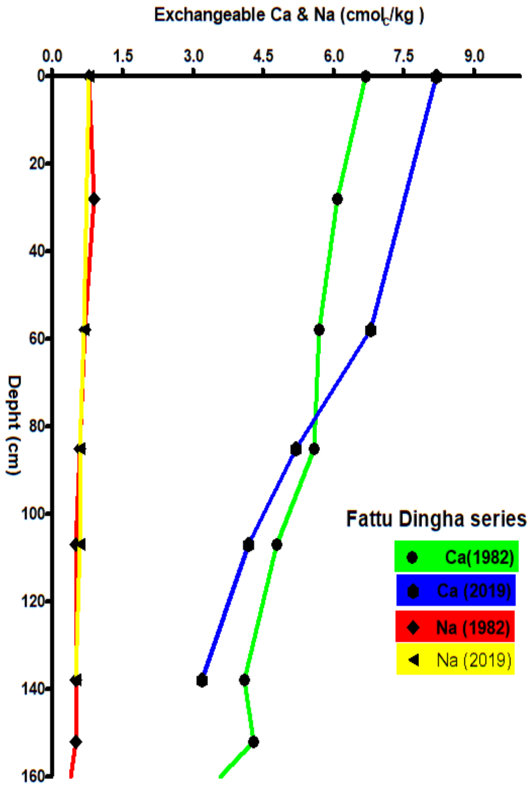
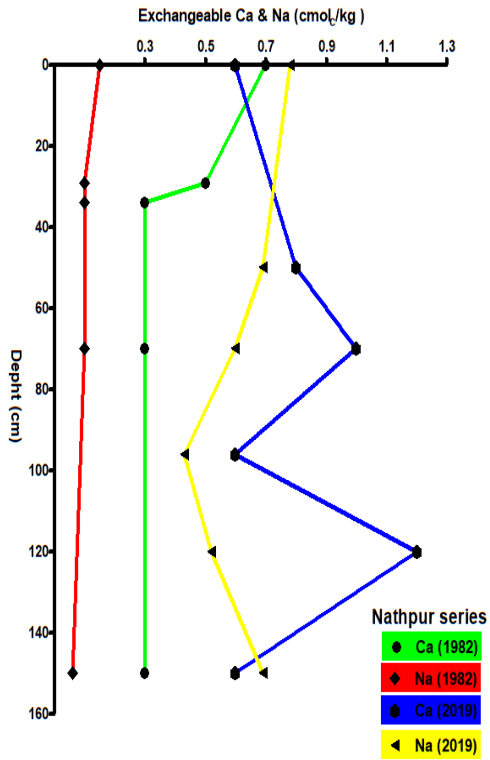
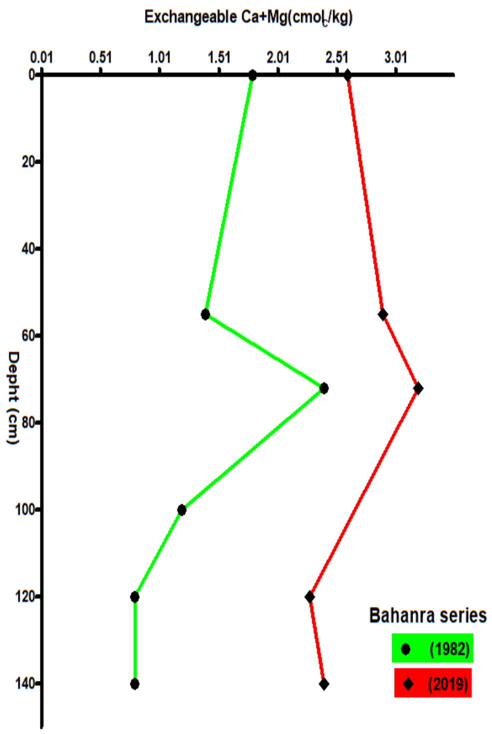

CEC (cmolc/kg )
4.0
5.5
7.0
8.5
10.0
11.5
0
20
40
60
80
100
120
140
Depht (cm)
Fatehpur series
(1982)
(2019)

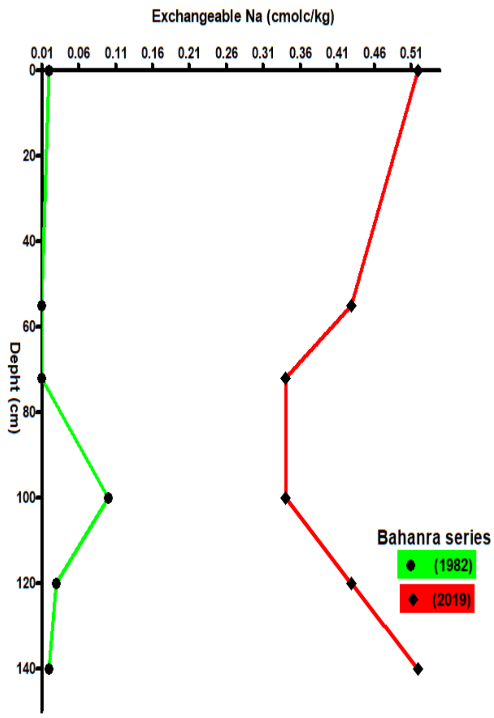
**Figure 5.2.18: Comparison graphs for exchangeable Ca and Na (cmol$_c$/kg) of normal soils of Kapurthala district**




Exchangeable Ca & Na (cmolc/kg )
Depht (cm)
Fattu Dingha series
Ca(1982)
Ca (2019)
Na (1982)
Na (2019)


Exchangeable Ca & Na (cmolc/kg )
Depht (cm)
Nathpur series
Ca (1982)
Na (1982)
Ca (2019)
Na (2019)


Exchangeable Ca+Mg(cmolc/kg)
Depht (cm)
Bahanra series
(1982)
(2019)


Exchangeable Na (cmolc/kg)
Depht (cm)
Bahanra series
(1982)
(2019)

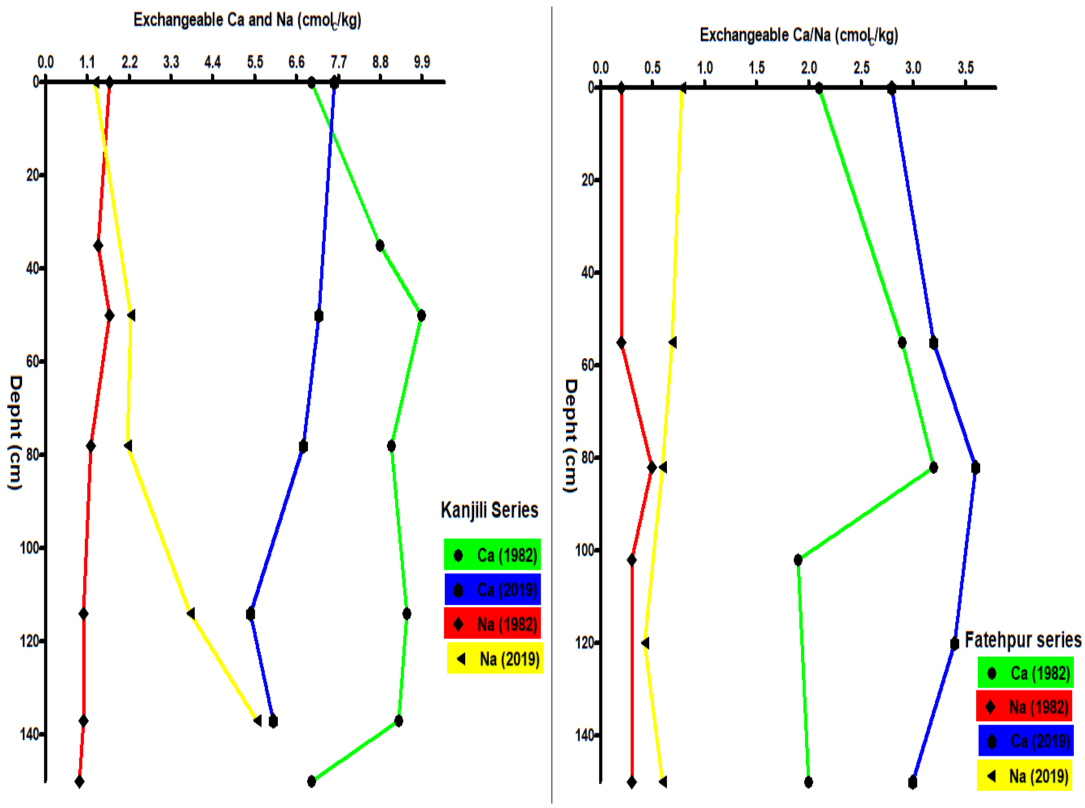
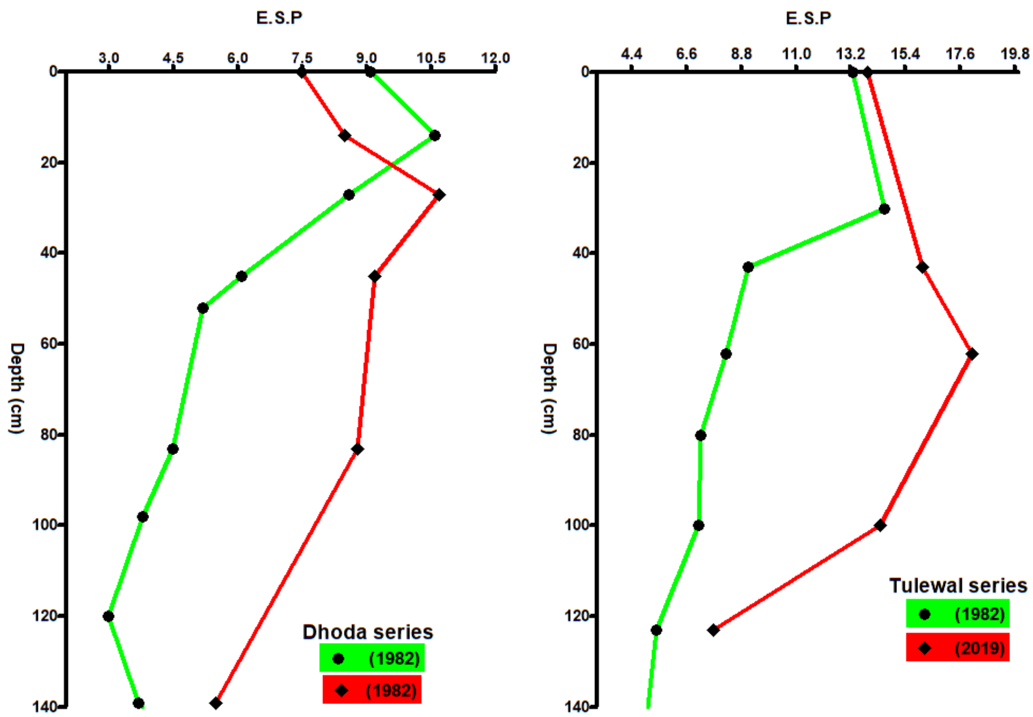
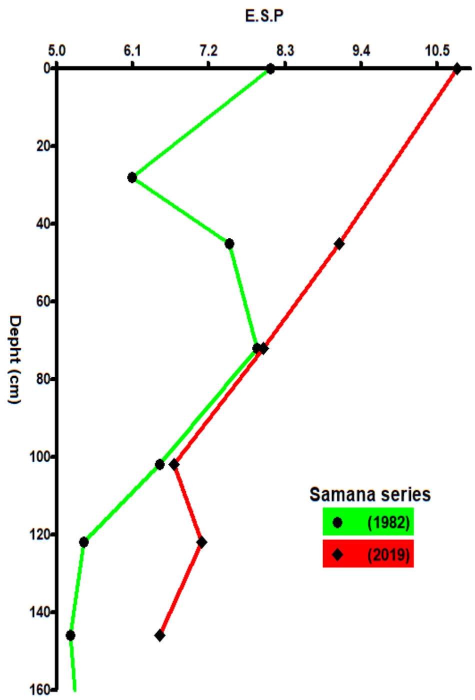
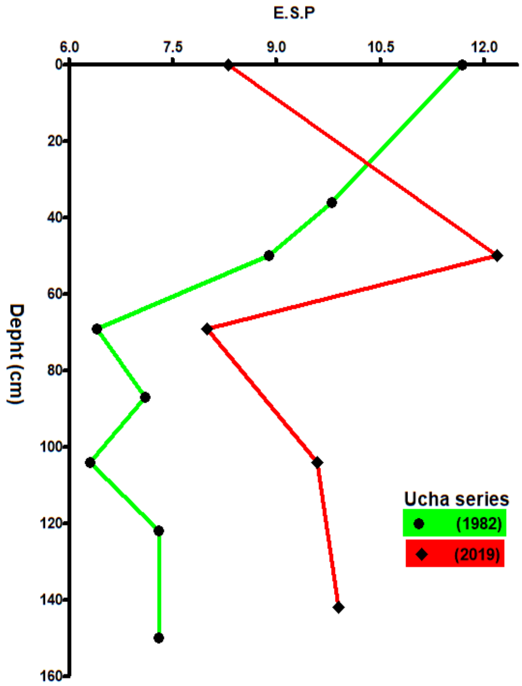
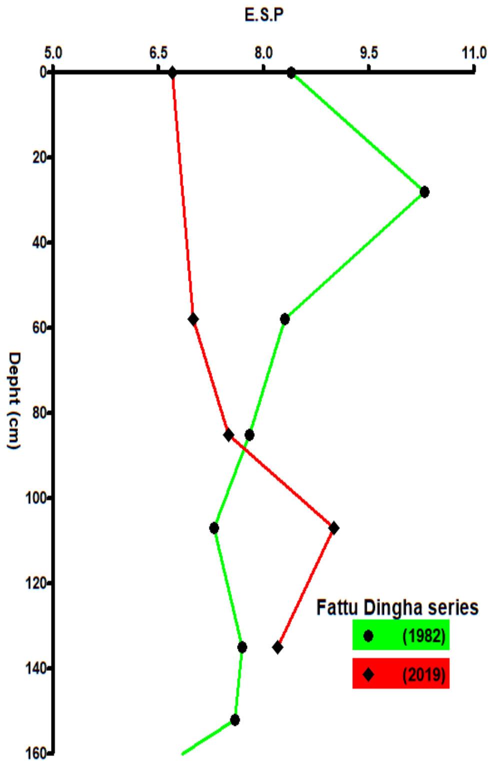


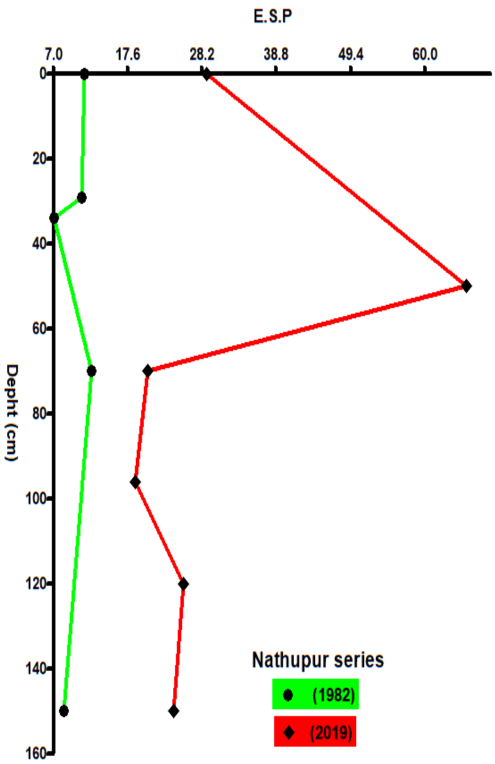

**Figure 5.2.19: Comparison graphs for exchangeable sodium percentage of normal soils of Kapurthala district**

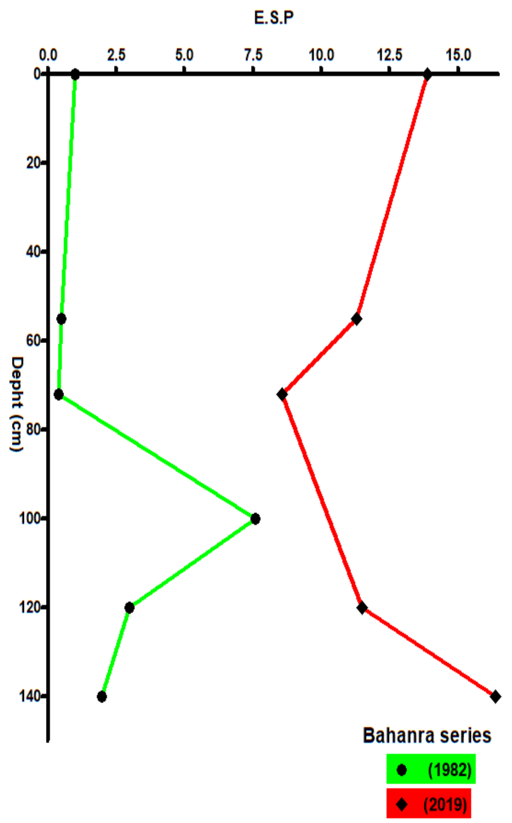


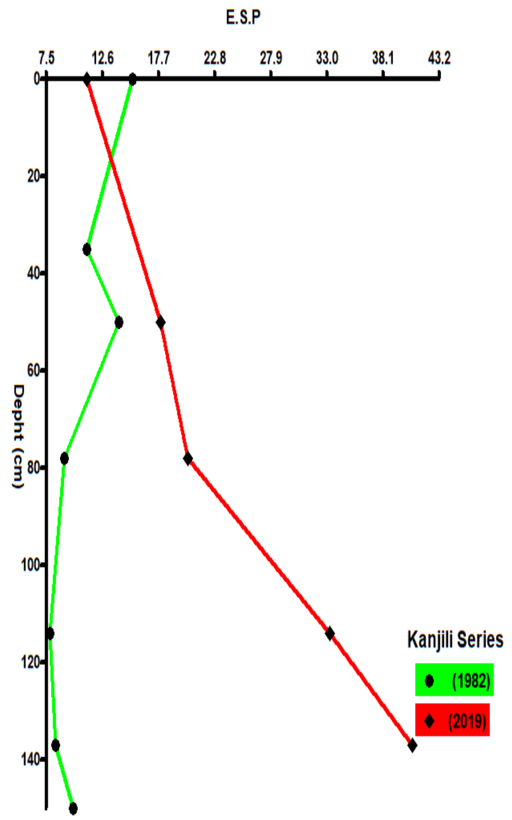

E.S.P
5.0
6.1
7.2
8.3
9.4
10.5
0
20
40
60
80
100
120
140
160
Depht (cm)
Samana series
(1982)
(2019)


E.S.P
6.0
7.5
9.0
10.5
12.0
0
20
40
60
80
100
120
140
160
Depht (cm)
Ucha series
(1982)
(2019)


E.S.P
5.0
6.5
8.0
9.5
11.0
0
20
40
60
80
100
120
140
160
Depht (cm)
Fattu Dingha series
(1982)
(2019)


E.S.P
7.0
17.6
28.2
38.8
49.4
60.0
0
20
40
60
80
100
120
140
160
Depht (cm)
Nathupur series
(1982)
(2019)


E.S.P
0.0
2.5
5.0
7.5
10.0
12.5
15.0
Dephth (cm)
Bahanra series
(1982)
(2019)


E.S.P
7.5
12.6
17.7
22.8
27.9
33.0
38.1
43.2
Dephth (cm)
Kanjili Series
(1982)
(2019)

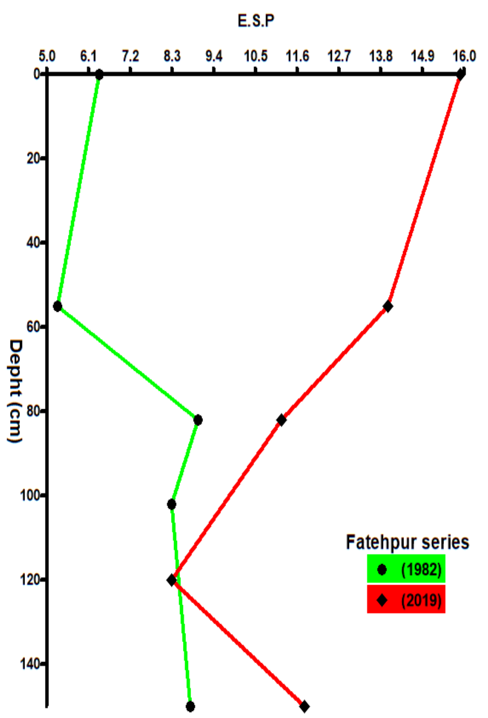
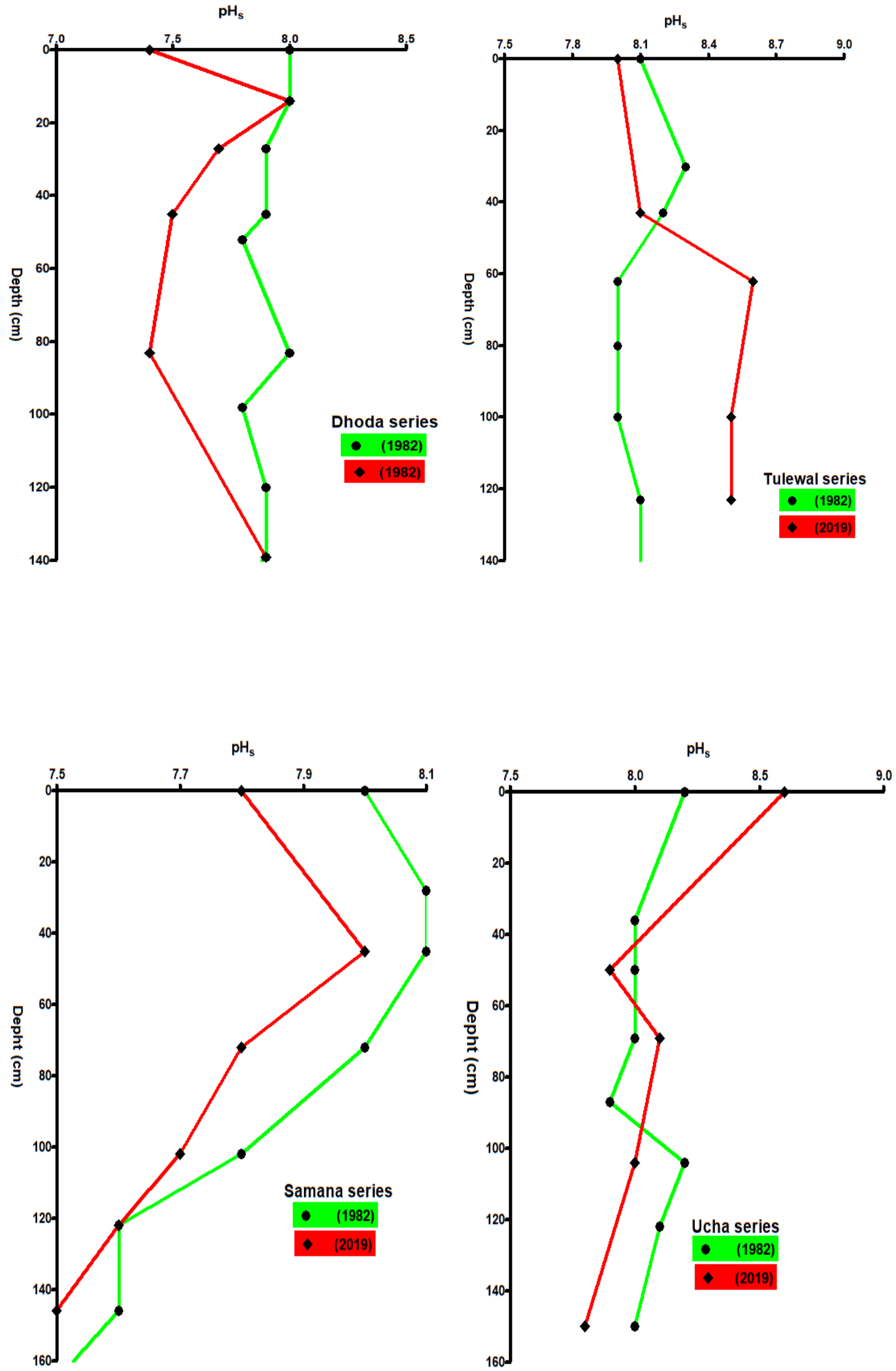
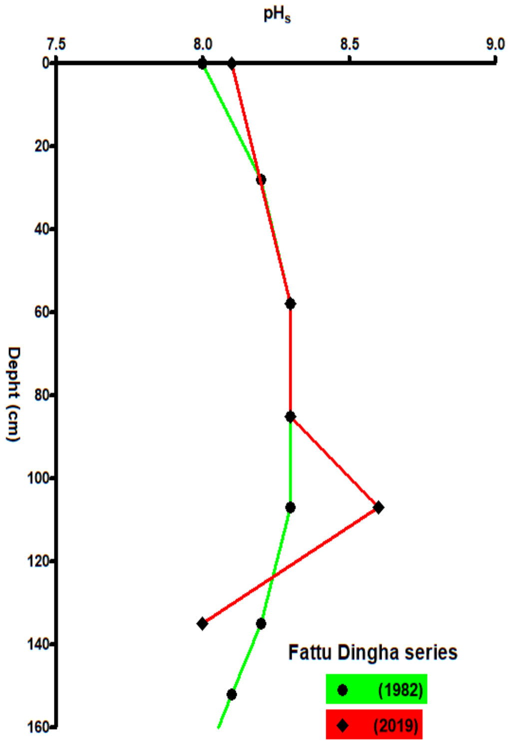
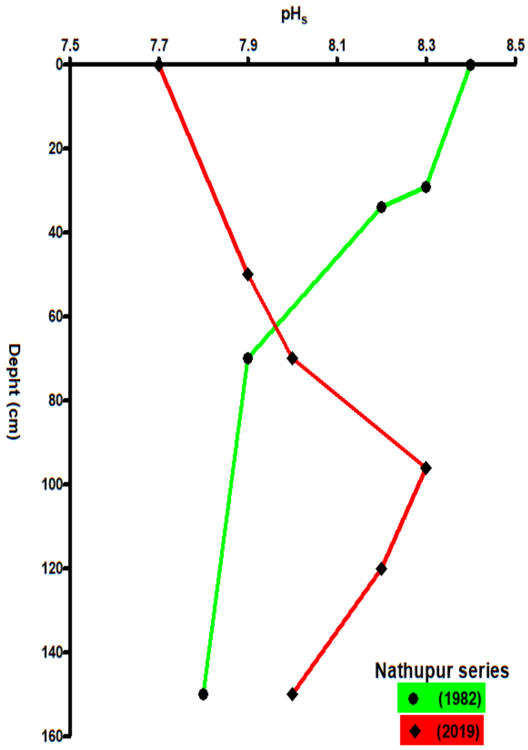
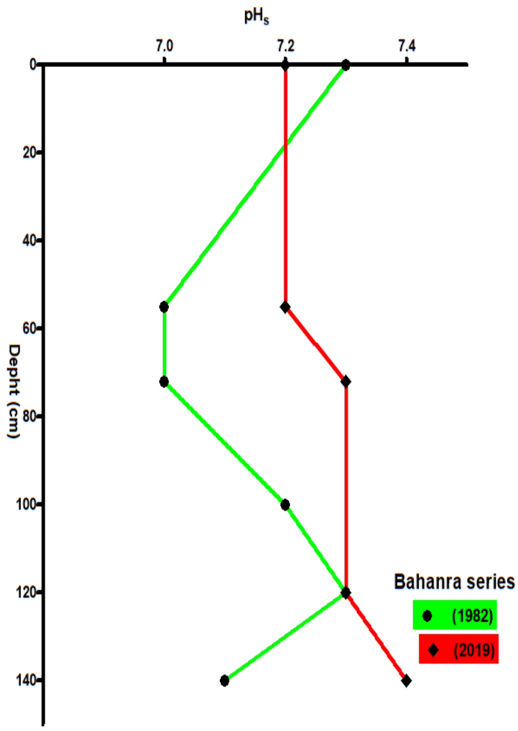

E.S.P
5.0
6.1
7.2
8.3
9.4
10.5
11.6
12.7
13.8
14.9
16.0
Dephth (cm)
Fatehpur series
(1982)
(2019)

**Figure 5.2.20: Comparison graphs for $pH_s$ of normal soils of Kapurthala district**




pHs
7.5
8.0
8.5
9.0
Depht (cm)
Fattu Dingha series
(1982)
(2019)


pHs
7.5
7.7
7.9
8.1
8.3
8.5
Depht (cm)
Nathupur series
(1982)
(2019)


pHs
7.0
7.2
7.4
Depht (cm)
Bahanra series
(1982)
(2019)

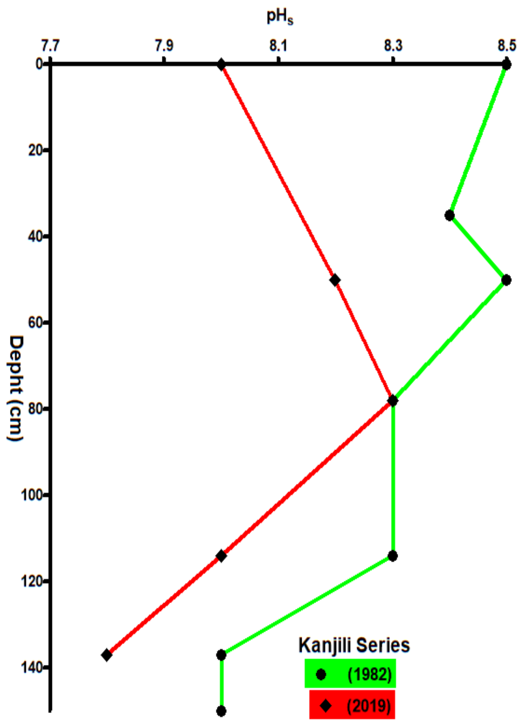
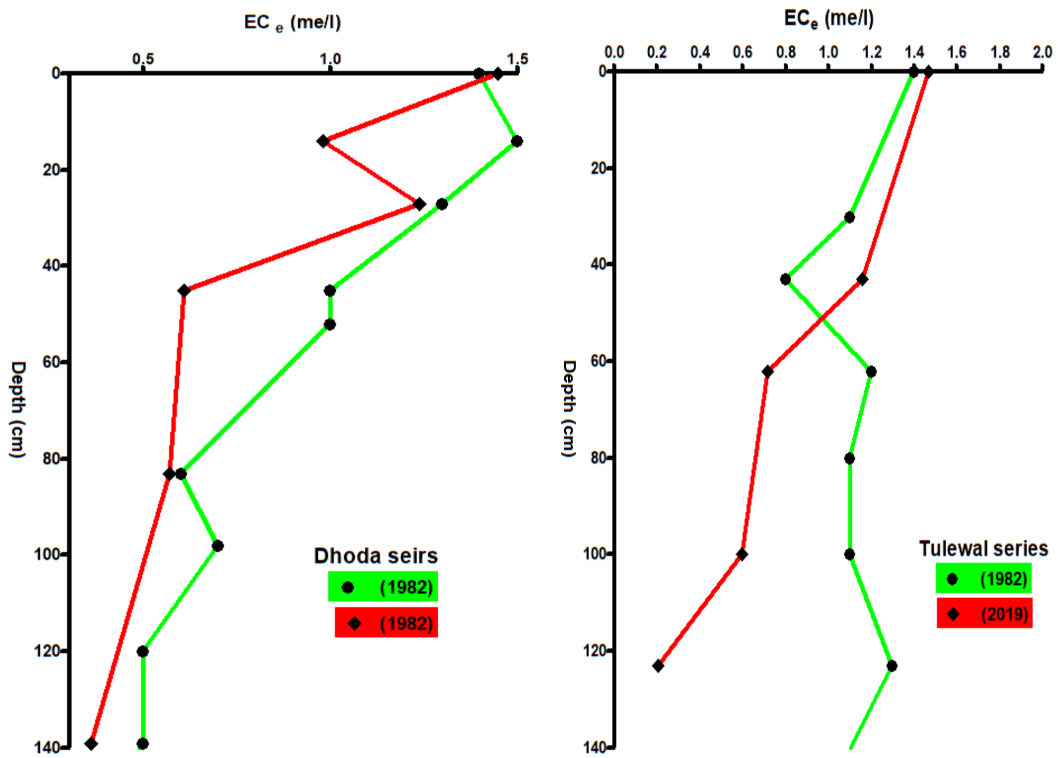
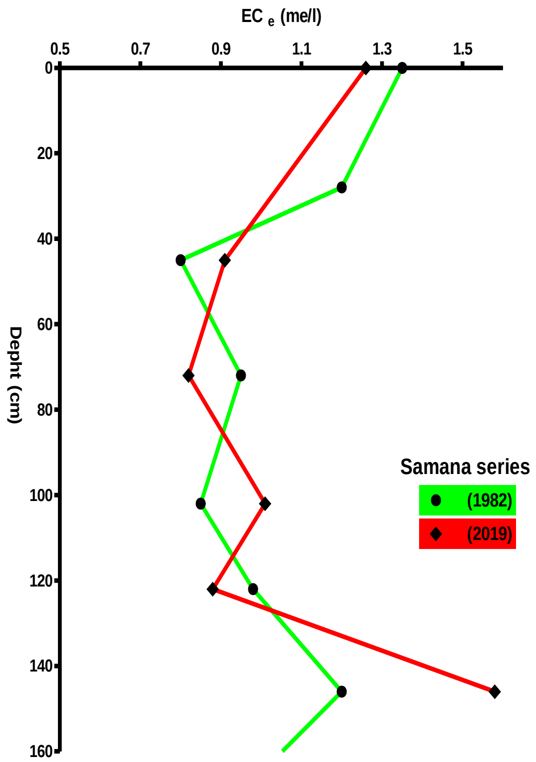
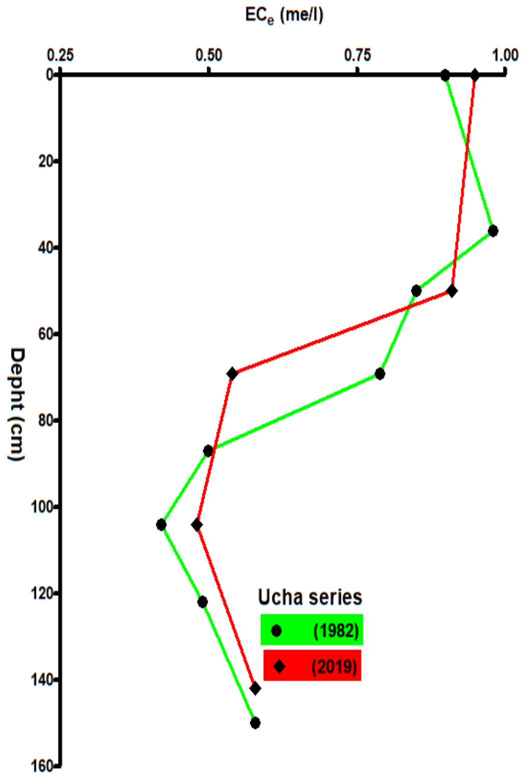
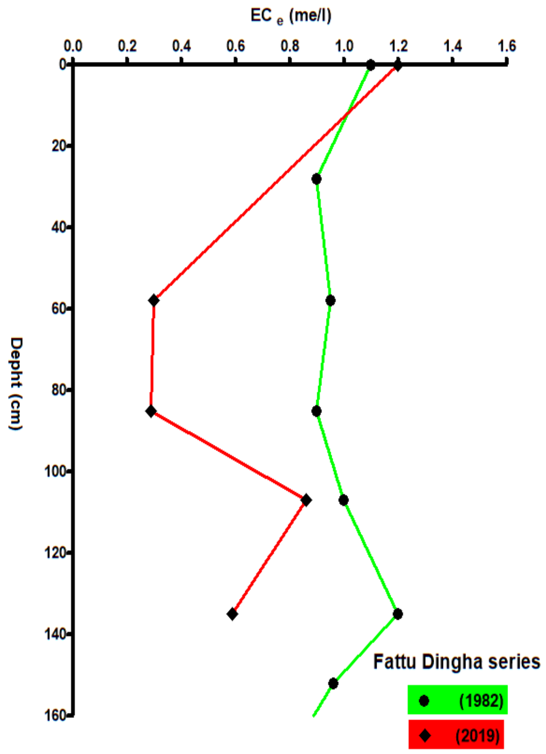

pHs
7.7
7.9
8.1
8.3
8.5
Depht (cm)
Kanjili Series
(1982)
(2019)

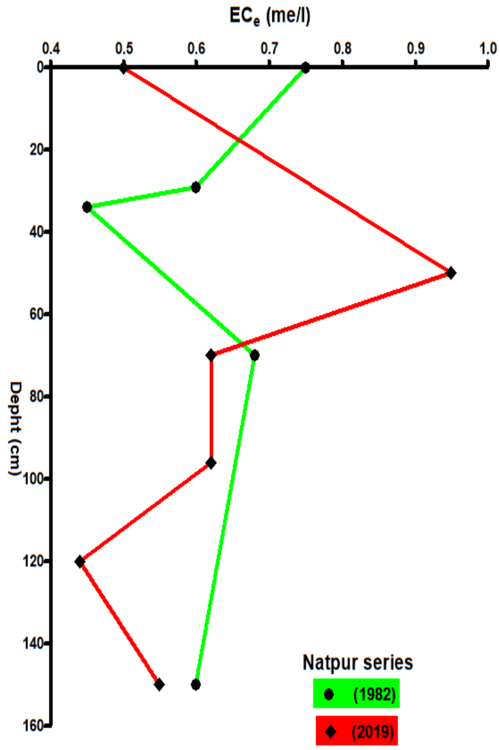

**Figure 5.2.21: Comparison graphs for $EC_e$ of normal soils of Kapurthala district**

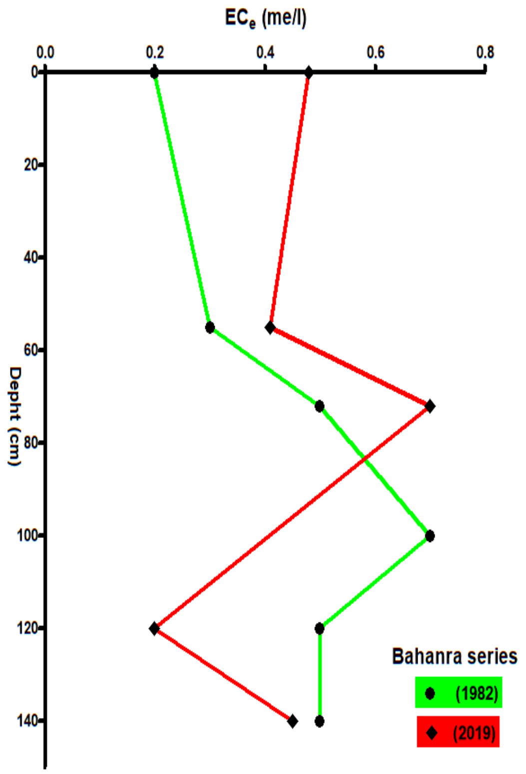


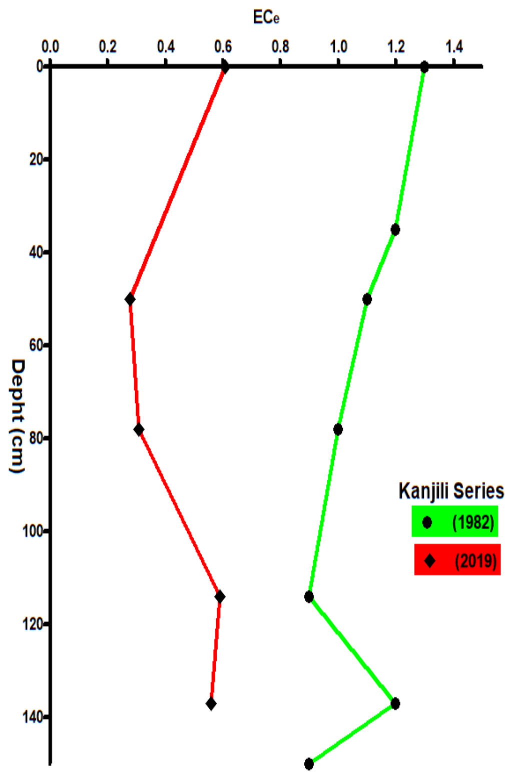

EC e (me/l)
0.5
0.7
0.9
1.1
1.3
1.5
0
20
40
60
80
100
120
140
160
Depht (cm)
Samana series
(1982)
(2019)


ECe (me/l)
0.25
0.50
0.75
1.00
0
20
40
60
80
100
120
140
160
Depht (cm)
Ucha series
(1982)
(2019)


EC e (me/l)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
20
40
60
80
100
120
140
160
Depht (cm)
Fattu Dingha series
(1982)
(2019)


ECe (me/l)
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
20
40
60
80
100
120
140
160
Depht (cm)
Natpur series
(1982)
(2019)


ECe (me/l)
0.0
0.2
0.4
0.6
0.8
0
20
40
60
80
100
120
140
Depht (cm)
Bahanra series
(1982)
(2019)


ECe
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
20
40
60
80
100
120
140
Depht (cm)
Kanjili Series
(1982)
(2019)

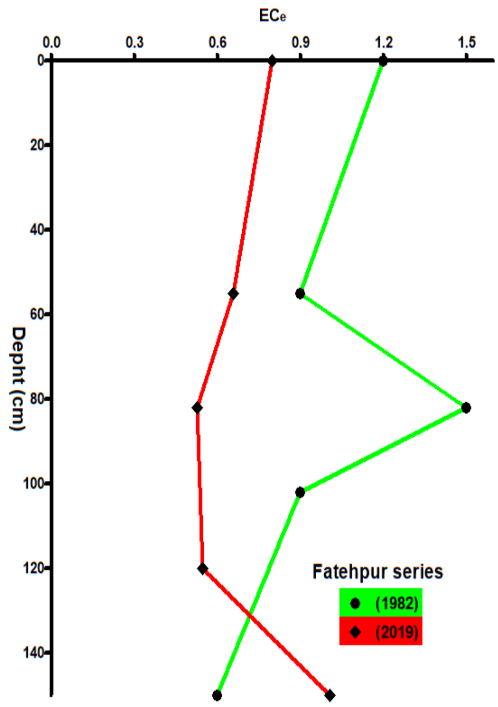
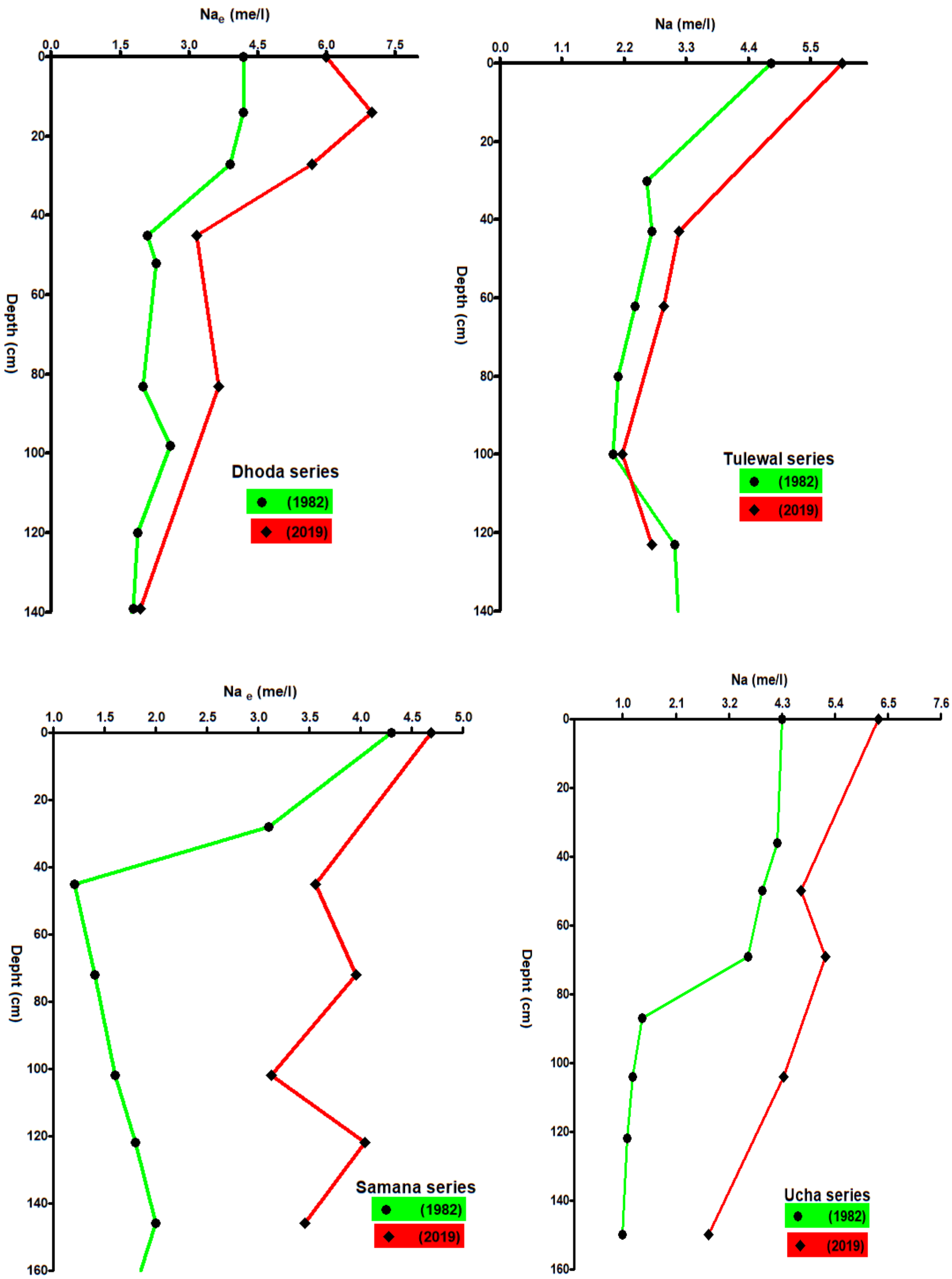
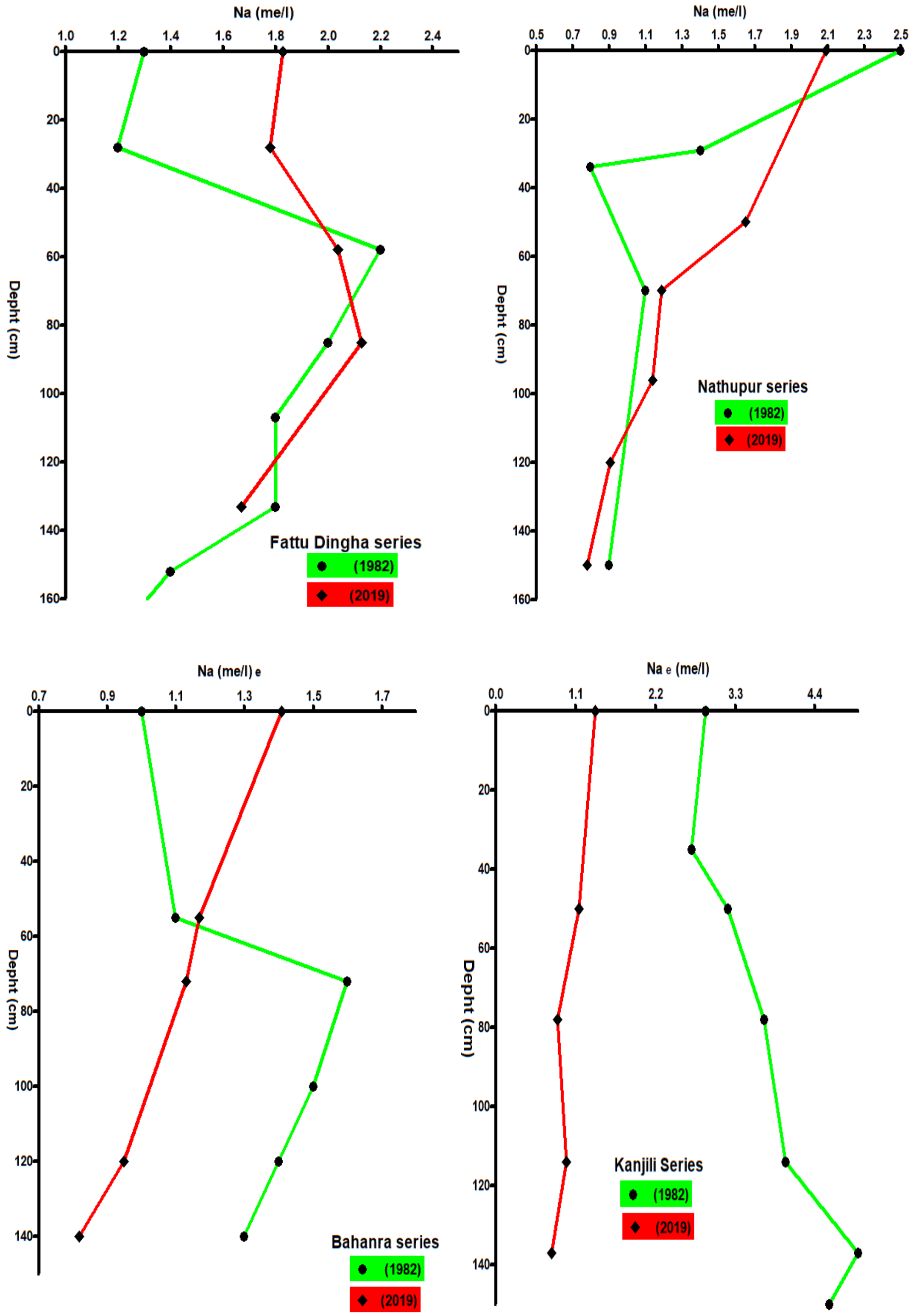
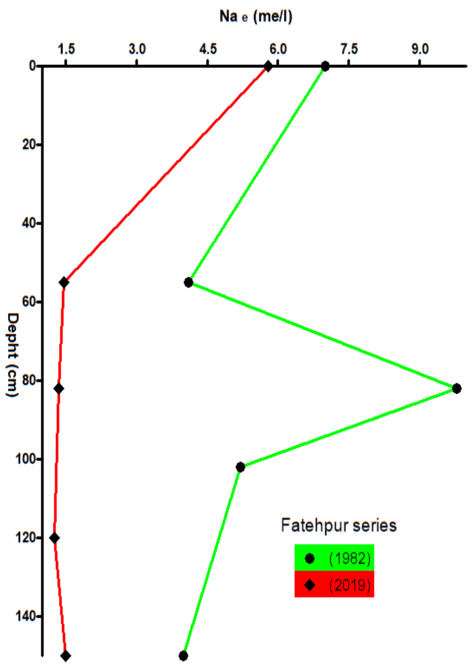

ECe
0.0
0.3
0.6
0.9
1.2
1.5
0
20
40
60
80
100
120
140
Depht (cm)
Fatehpur series
(1982)
(2019)

**Figure 5.2.22: Comparison graphs for Na (me/l) of normal soils of Kapurthala district**




Na (me/l)
Depht (cm)
Fattu Dingha series
(1982)
(2019)
Na (me/l)
Depht (cm)
Nathupur series
(1982)
(2019)
Na (me/l) e
Depht (cm)
Bahanra series
(1982)
(2019)
Na e (me/l)
Depht (cm)
Kanjili Series
(1982)
(2019)




### 5.2.3 Comparison of Soil Taxonomy

As per field investigations, physical and chemical characterization of soil samples by laboratory analysis along with using of Soil Taxonomy (1975) salt-affected soils of Kapurthala district qualified for the orders of Ardisol and Inceptisol in 1982 while in 2019 these soils have been classified under the orders of Inceptisols and Entisols using guidelines of Soil Taxonomy (2015) classification.

Salt affected soils of Jagjitpur, Randhirpur, Fajewal, and Khairanwali qualified under the order of Ardisols and were classified into fine loamy, mixed, hyperthermic, family of Natric Ustochreptic Camborthids, soils of Domeli series qualified under the order of Ardisols and classified into fine loamy mixed hyperthermic family of Aquic Camborthids, and soils of Rawalpindi qualified under the order of Inceptisols and clayey, mixed hyperthermic family of Aguic Ustochrepts (Appendix-III) by Sharma *et al.*, (1982). While in 2019 soils of Rawalpindi, Domeli, Jagjitpur, Khairanwali, and Fajewal series qualified under the order of Inceptisols and were classified as fine loamy, mixed, hyperthermic family of Fluventic Haplustepts, and soil of Fajewal series qualified under the order of Entisols and were classified as coarse loamy, mixed hyperthermic, family of Typic Ustifluvent (Table 5.35).

Normal soils or non-sodic soils of Kapurthala district in 1982 and 2019 qualified under the orders of Inceptisols and Entisols (Appendix IV) and (Table 5.35).

Soils of Dhoda series qualified under the order of Inceptisols, fine loamy mixed hyperthermic family of Udic Ustochrepts in 1982. In 2019 these soils qualified under the order of Inceptisols and were classified fine loamy, mixed calcareous hyperthermic, family of Fluventic Haplustepts as per revised guidelines of Soil Taxonomy (2015). These soils have Fluventic subgroup instead of Udic because the organic carbon content of these soils decrease irregularly and remain above 0.2 per cent at 125 cm.

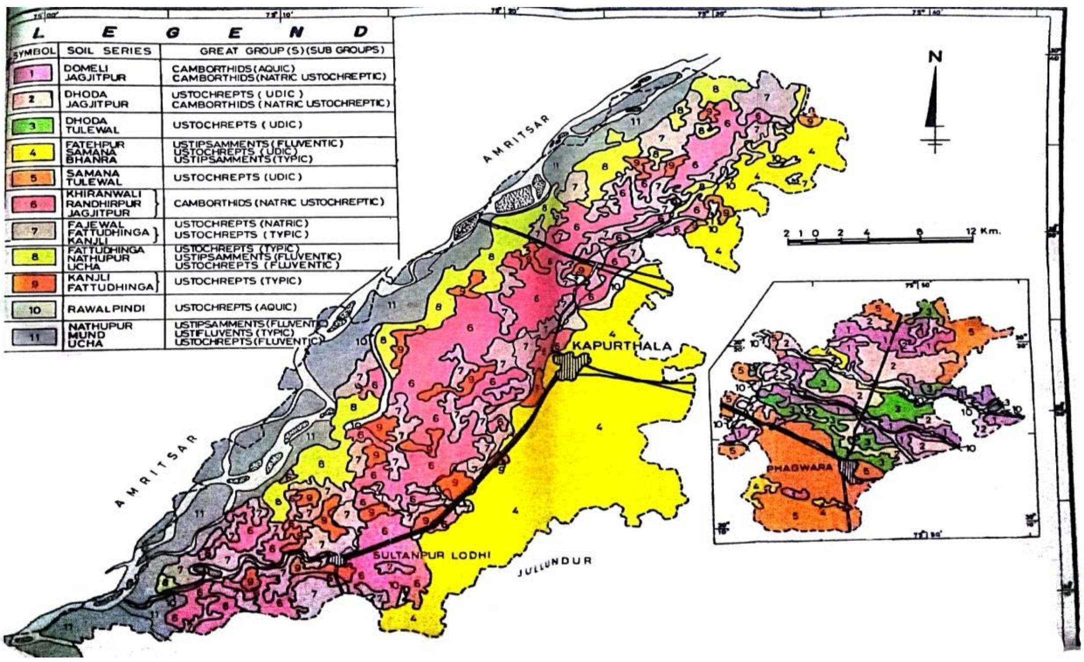
Similarly soils of Kanjili and Fattu Dhinga qualified under the order of Inceptisols and fine loamy, mixed, hyperthermic family of Typic Ustochrepts in 1982 (Appendix-IV). In 2019 soils of Kanjili and Fattu Dhinga series were qualified under the order of Inceptisols and fine loamy, mixed hyperthermic, family of Typic Haplustepts and coarse loamy, mixed hyperthermic family of Fluventic Haplustepts respectively (Table5.35).

Soils of Tulewal, Samana, and Ucha series qualified under Inceptisols in 1982 and 2019. Soils of Tulewal series were classified into the fine loamy, mixed hyperthermic family of Udic Ustochrepts, Samana were classified into the coarse loamy mimed hyperthermic family of Udic Ustochrepts, and soils of Ucha were classified into coarse loamy mixed hyperthermic, family of Fluventic Ustochrepts respectively in 1982 (Appendix-IV), while in 2019 these soils were coarse loamy, mixed, hyperthermic, family of Fluventic Haplustepts (Table 5.35). Change in subgroup is same as discussed in the preceding paragraph discussing the Dhoda and Kanjili series.

Soils of Nathupur, Mund, Bahanra and Fatehpur series classified into the order of Entisols using the Soil Taxonomy (1975) by Sharma *et al.*, (1982), while in 2019 soils of Nathupur, Mund and Bahanra series qualified for the order of Entisols and soils of Fatehpur series qualified for the Inceptisols soil order using Soil Taxonomy (2015). Soils of Nathupur and Fatehpur classified into mixed, hyperthermic family of Fluventic Ustipsamments, soils of Mund series classified into coarse loamy, mixed hyperthermic family of Typic Ustifluvents, and soils of Bhanra series classified into mixed hyperthermic family of Typic Ustipsamments respectively in 1982 (Appendix IV). While in 2019 using Soil Taxonomy (2015) soils of Nathupur, Mund and Bhanra series classified into the sandy mixed hyperthermic family of Typic Ustipsamments, and soils of Fatehpur series classified into coarse loamy, mixed hyperthermic, family of Typic Haplustepts (Table 5.35). Soil of Fatehpur got classified in Inceptisols instead of Entisols because farmers have scraped upper sandy horizons from these soils. Now these soils are no longer sandy and are used for sowing paddy-wheat instead of maize-wheat.

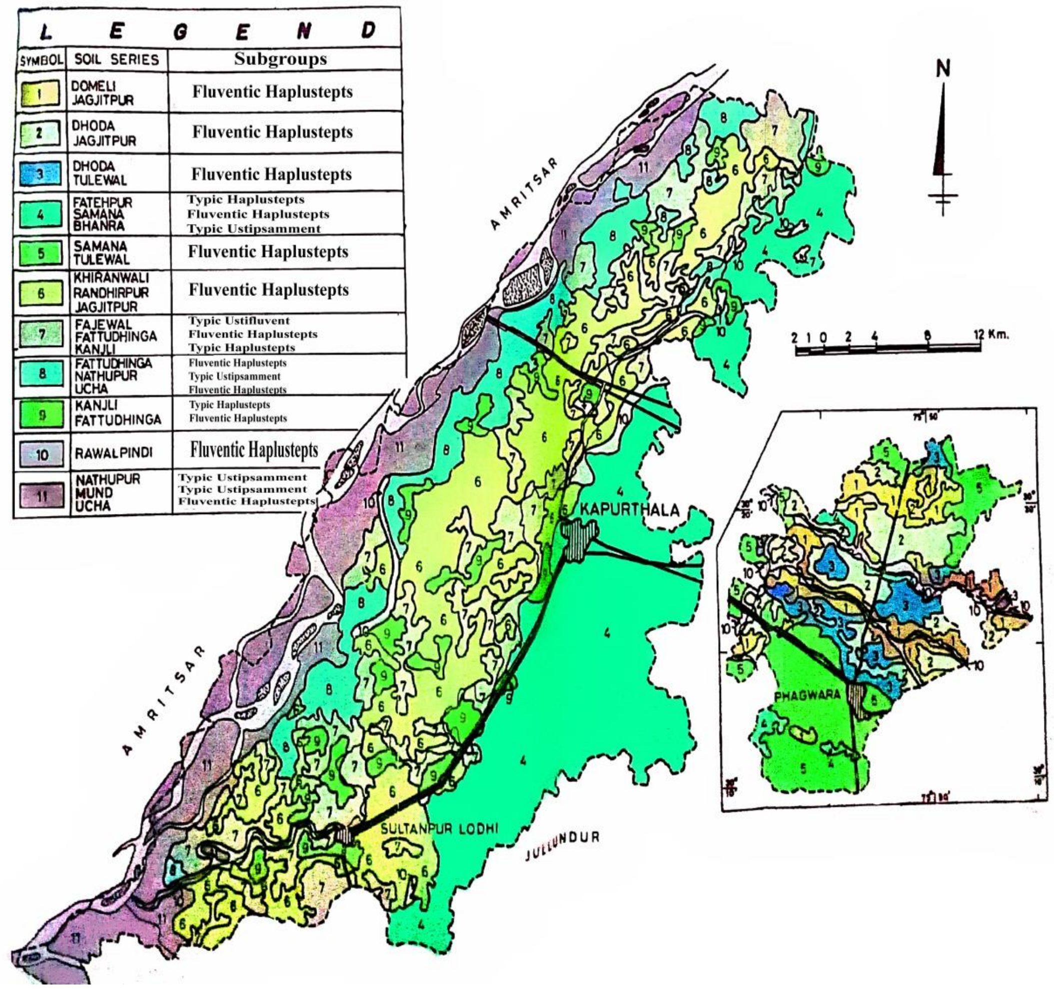
As per soil classification of soils of Kapurthala district, soil map of Kapurthala district were generalized by Sharma *et al.*, (1982) showed that these soils had been classified into 3 orders, 4 sub orders, and four great groups (Figure 5.2.3.1). Soil map of Kapurthala district was edited in this study as per revised classification of the area. It showed that soils of the study area have been classified into (2) orders, (3) suborders and (3) great groups (figure 5.2.3.2).

**Figure 5.2.3.1 Soil map of Kapurthala district 1982**




**Source: Sharma *et al., (1982)***

**Figure 5.2.3.2 Soil map of Kapurthala district (2019)**



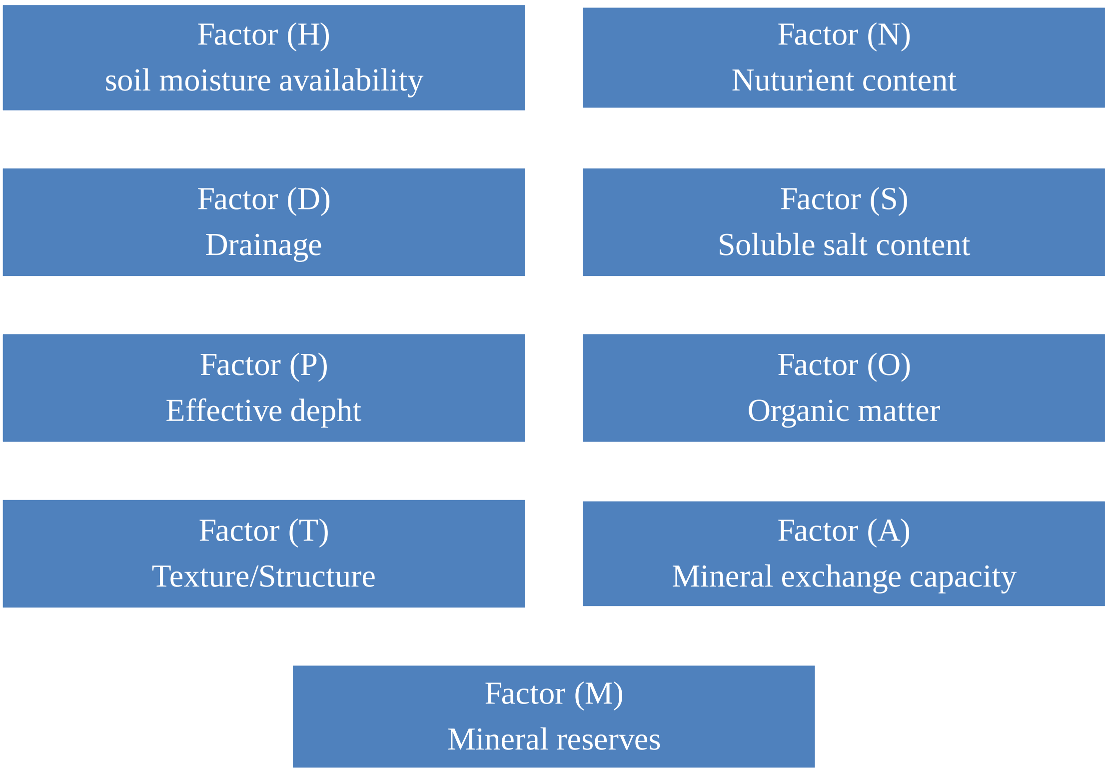
### 5.3 Actual productivity and potential productivity of soils of Kapurthala district

Soil productivity is the capacity of soil in to produce a specific plant or sequence of plants under specific systems of management inputs. Riquier *et al.*, (1970) described soil productivity as the initial soil capacity to produce a certain amount of crop per hectare per annum. Soil potential productivity on the other hand is the productivity of soil when all possible improvements are made. It is thus, the future potentiality of that soil taking into account physical and chemical characteristics which are modified by conservation practices or improvements and also those characteristics which are not modifiable by present day technology (Riquier *et al.*, 1970).

**Riquier Index Model**

In this model, interpretation criteria are modelled based on soil properties traditionally incorporate (Riquier *et al.*, 1970). The structure organization of the Riquier model is summarized in figure 5.3.1.

**Figure 5.3.1 Requier land productivity index**



### 5.3.1 Actual productivity and potential productivity of salt-affected soils of Kapurthala district

Salt-affected soils of the study area were identified into three different classes in terms of actual productivity. Table 5.3.1 and 5.3.2 present the results on the actual productivity and potential productivity of salt affected soils of the study area respectively. According to the results Khairanwali soils has excellent actual productivity class, Rawalpindi, Jagjitpur, Randhirpur and Fajewal series have good productivity class, and Domeli series has average productivity class.

The site parameters and their respective ratings for the computation of Riquier index (RI) indicate that Khairanwali series has well drained, rooting zone below wilting point for 3 months and below field capacity for over 6 month, the rating for soil depth showed that the soil of Khairanwali was very deep (145 cm), texture of this soil is loam in epipedon horizon along with moderate medium sub angular blocky structure, the pH was high with sodium carbonate. The rating of organic matter showed that this soil content has little organic matter content along with a mixture of clays minerals. The RI ratings (65.40) obtained in the Khairanwali series. The RI value obtained at Khairanwali series showed that this soil belongs to the class I having excellent productivity (Table 5.3.1).

The most limiting factors in Khairanwali series is low organic carbon content in the A horizon and presence of sodium carbonate along with rooting zone below wilting point for three months. Accordingly, appropriate management of soils of Khairanwali series require usual drainage, irrigation with flood or furrow irrigation, enriching and maintenance of organic matter content, application of organic manure, green manure, along with application of fertilizers which content nitrogen, and desalting by irrigation. The calculated potential productivity index following the improved characteristics and percentages of increased productivity indices from the management of the soils was (82.67). This index gives the potentiality class I (excellent). The changes in rating show that soils of Khairanwali have improved. The calculated coefficient of improvement at the Khairanwali series was 1.26 (Table5.3.2).

Soils of Rawalpindi, Jagjitpur, Randhirpur and Fajewal series were good in actual productivity. These were moderate drainage, water table sufficiently low, very deep soil and the texture in epipedon is clay loam in Rawalpindi and Fajewal, sandy clay loam in Jagjitpur, and loam in Randhirpur series respectively. Average nutrient content of A horizon were above 75 per cent, total soluble salts including sodium carbonate was above 0.1 per cent, little organic matter in all series in except Jagjitpur which recorded very little less than 1 per cent, having slight erosion. The RI rating in these soils obtained 44.70 in Rawalpindi, 49.88 in Jagjitpur, 47.40 in Randhirpur and 52.67 in Fajewal series. Accordingly it is indicated that these soils belong to the class II (Good productivity).

The most limiting factors identified in these soils were very little or little organic matter content, moderate drainage, presence of sodium carbonate. Massive to large structure in Rawalpindi series, and the rooting zone was recorded below wilting point for 3 months. Thus, these soils required the appropriate managements such as supplementary irrigation, improvement of drainage, texture and structure by mechanical working of soils and by improvement of organic soils. Application of fertilizers, amendments, especially organic manure, green manure, compost and integrated nutrient management with chemical fertilizers, desalting of soils by irrigation and drainage along with the application of gypsum to eliminate sodium.

The results revealed that these soils showed greater scope for improvement in terms of potential productivity after soil management issues are addressed. Soils of all the series were rated (excellent) in potential productivity with a rating of Rawalpindi and Jagjitpur series (65.59), Randhirpur (71.96) and Fajewal (68.52). The calculated coefficient of improvement in these soils was 1.46 in Rawalpindi, 1.31 in Jagjitpur, 1.50 in Randhirpur and 1.30 in Fajewal respectively.

Soil of Domeli series were average (32.7) in actual productivity. Domeli soils were poor in drainage, the water table had being close to the surface to harm deep rooting plants, rooting zone was below wilting point for three months, soils depth showed that the soils of Domeli series was deep, loam soil texture and medium sub angular blocky structure. Soluble salt content was more than 0.1 percent along with sodium carbonate. Accordingly, the organic matter content was low in Domeli soils, and minerals were derived from sandy materials. The RI value in Domeli series obtained (32.70), which showed that this soil is average in term of actual productivity.

The most limiting factors in Domeli soils were recognized as rooting zone below wilting point for three months, poor drainage, little organic matter content, presence of salt content such as sodium carbonate and crusting. Accordingly, soils of Domeli series appropriate managements such as improvement of soil properties, irrigation in these soils are essential, drainage should improve, improvement of soil texture and structure by mechanical working of soils it may be difficult and costly-required heavy machinery. Dealkalisation of Domeli soils is required by irrigation, drainage and application of gypsum to eliminate sodium salts. Enriching and maintenance of organic matter content, application of organic manure, green manure, mulching, and crop rotation are the other management intervention which need to be addressed to Domeli soils. The results revealed that soils of Domeli series showed great scope for improvement in terms of potential productivity after soil management issues are addressed. In other hand soils of Domeli series rated (Excellent I) in term of potential productivity with a Rating of 71.77 (Table 5.3.2). The calculated coefficient of improvement in Domeli series was 2.19 (Table 5.3.3). Therefore, by providing supplementary irrigation, addition of organic matter and fertilizers and taking suitable measures for erosion control, the productivity of these soil units would be improved in the long term (Sumithra *et al.*, 2013).. The results of this study indicated that RI model can be used efficiently to characterized soil actual productivity and potential productivity at specific site if accurate data are available, the same statement was given by Agber and Ali, (2012), evaluated the productivity of soils in Makurdi, Southern Guinea Savanna in Nigeria.

**Table 5.3.1 Actual productivity index of salt affected soils of Kapurthala district**

| Determination of the index of productivity for salt affected soils | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No** | **Pedon** | **H** | **D** | **P** | **T** | **N** | **S** | **O** | **A** | **M** | **Productivity Index** | **Productivity Classes** | **Productivity Rating** |
| **1** | Rawalpindi | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{6a}$ | $N_5$ | $S_7$ | $O_2$ | $A_2$ | $M_{2a}$ | **44.70** | **Good** | **II** |
| | | 100 | 85 | 100 | 80 | 100 | 90 | 90 | 95 | 85 | | | |
| **2** | Domeli | $H_{4C}$ | $D_{2a}$ | $P_5$ | $T_7$ | $N_5$ | $S_7$ | $O_2$ | $A_2$ | $M_{2a}$ | **32.70** | **Average** | **III** |
| | | 100 | 50 | 100 | 100 | 100 | 90 | 90 | 95 | 85 | | | |
| **3** | Jagjitpur | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_1$ | $A_2$ | $M_{2a}$ | **49.88** | **Good** | **II** |
| | | 100 | 85 | 100 | 95 | 100 | 90 | 85 | 95 | 85 | | | |
| **4** | Khairanwali | $H_{4C}$ | $D_4$ | $P_6$ | $T_7$ | $N_5$ | $S_7$ | $O_2$ | $A_2$ | $M_{2a}$ | **65.40** | **Excellent** | **I** |
| | | 100 | 100 | 100 | 100 | 100 | 90 | 90 | 95 | 85 | | | |
| **5** | Randhirpur | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_2$ | $A_1$ | $M_{2a}$ | **47.40** | **Good** | **II** |
| | | 100 | 85 | 100 | 90 | 100 | 90 | 90 | 90 | 85 | | | |
| **6** | Fajewal | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_7$ | $N_5$ | $S_7$ | $O_2$ | $A_1$ | $M_{2a}$ | **52.67** | **Good** | **II** |
| | | 100 | 85 | 100 | 100 | 100 | 90 | 90 | 90 | 85 | | | |

**(H) = soil moisture content**

**(D)= Drainage**

**(P)= Effective depth of soil**

**(T)= Texture and structure of root zone**

**(N)= Average nutrient content**

**(S)= Soluble salts content**

**(o) =Organic matter in A1 horizon**

**(A)=Mineral exchange capacity and nature of the clay in the B horizon**

**(M)= Reserves of weatherable minerals in B horizon**

**Table 5.3.2 Potential productivity index of salt-affected soils of Kapurthala district**

| Index of potentiality of salt-affected soils | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No** | **Pedon** | **H** | **D** | **P** | **T** | **N** | **S** | **O** | **A** | **M** | **Potential productivity** | **Potential productivity Classes** | **Improvement necessary for development** |
| **1** | Rawalpindi | $H_5$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_4$ | $A_2$ | $M_{2a}$ | **65.59** | **Excellent** | **B1B2,E2,H** |
| | | 100 | 85 | 100 | 90 | 100 | 90 | 100 | 95 | 85 | | | |
| **2** | Domeli | $H_5$ | $D_{3a}$ | $P_5$ | $T_7$ | $N_5$ | $S_7$ | $O_4$ | $A_2$ | $M_{2a}$ | **71.77** | **Excellent** | **A,C,H,G2,F** |
| | | 100 | 85 | 100 | 100 | 100 | 90 | 100 | 95 | 85 | | | |
| **3** | Jagjitpur | $H_5$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_4$ | $A_2$ | $M_{2a}$ | **65.59** | **Excellent** | **B1B2,E2,H** |
| | | 100 | 85 | 100 | 90 | 100 | 90 | 100 | 95 | 85 | | | |
| **4** | Khairanwali | $H_5$ | $D_4$ | $P_6$ | $T_7$ | $N_5$ | $S_7$ | $O_4$ | $A_2$ | $M_{2a}$ | **82.67** | **Excellent** | **A,H,J,F** |
| | | 100 | 100 | 100 | 100 | 100 | 90 | 100 | 95 | 85 | | | |
| **5** | Randhirpur | $H_5$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_4$ | $A_1$ | $M_{2a}$ | **71.96** | **Excellent** | **B1B2,E2,H** |
| | | 100 | 85 | 100 | 90 | 100 | 90 | 100 | 90 | 85 | | | |
| **6** | Fajewal | $H_5$ | $D_{3a}$ | $P_6$ | $T_7$ | $N_5$ | $S_7$ | $O_4$ | $A_1$ | $M_{2a}$ | **68.52** | **Excellent** | **B1B2,E2,H** |
| | | 100 | 85 | 100 | 100 | 100 | 90 | 100 | 90 | 85 | | | |

A = Irrigation (essential) and drainage (usually required)

B1= Supplementary irrigation by sprinkling (B2) by flood or furrow irrigation

E2= improvement of texture and structure

G1= desalting by irrigation

G2= desalting by irrigation and drainage and application of gypsum.

F= Application of fertilizers, amendments

H= enriching and maintenance of organic matter content

C= Excess water removal by reclamation, ridging, drain age

**Table 5.3.3 Coefficient of improvement of salt-affected soils of Kapurthala district**

| Serial No | Soil series | Improvement necessary for development | Coefficient of improvement |
|---|---|---|---|
| **1** | Rawalpindi | **B1B2,,E2,H** | 1.45 |
| **2** | Domeli | **A,C,H,G2,F** | 2.19 |
| **3** | Jagjitpur | **B1B2,,E2,H** | 1.31 |
| **4** | Khairanwali | **A,H,J,F** | 1.26 |
| **5** | Randhirpur | **B1B2,,E2,H** | 1.50 |
| **6** | Fajewal | **B1B2,,E2,H** | 1.30 |

### 5.3.2 Actual productivity and potential productivity of normal soils of Kapurthala district

Normal soils of Kapurthala district were categorized into three different classes in term of actual productivity and potential productivity. Results on the actual productivity and potential productivity of normal soils of the study area are presented in Table 5.3.4 and 5.3.5. Data shows that Dhoda, Tulewal, Samana, Nathupur and Kanjili series have good actual productivity. Ucha, Fattu Dhinga, Bhanra and Fatehpur series have average actual productivity and Mund series has poor actual productivity.

The site parameters and their respective ratings for the computation of Riquier Index indicate that soils under good category of productivity classes have moderate to well drainage, rooting zoon below wilting point for three months and wet below field capacity for over six month. The rating for soil depth showed that these soils were very deep over 120 cm, soil texture varied from clay loam in Dhoda, Samana and Kanjili series, sandy clay loam in Tulewal series, and loamy sand in Nathupur series, along with moderate medium sub angular blocky structure in all these soils except soil of Natpur which has weak medium sub angular blocky structure. The pH of these soils was alkaline, low organic matter content in Dhoda, Tulewal, Samana and Bhanra series and very little organic matter content in Kanjili series. The actual productivity ratings were obtained (55.23) in Dhoda, (36.44) in Tulewal, (36.33) in Samana, (36.45) in Nathupur, and (52.50) in Kanjili respectively.

The RI values obtained in these soils showed that these soils belonged to class II (good productivity). This is unlike to the results of (Amara *et al.*, 2016) which stated the soil productivity potentials in hot semi-arid Northern transition zone of India using Required Index and GIS techniques, which found the extremely poor and poor actual productivity.

The most limiting factors of soil productivity in these soils were identified as low organic matter content A horizons of these soils, unstable structure in Nathupur series, rooting zone below wilting point for three months along poor drainage, sandy layers. Accordingly, appropriate management of these soils required improvement in drainage, supplementary irrigation, enriching and maintenance of organic matter content, application of manure, green manure, along with application of fertilizers,. Furthermore, improvement of soil texture and structure is required in these soils. On the other hand, in terms of potential productivity which is the productivity that the soil is expected to show after soil improvements are done, soil of Dhoda, Samana and Kanjili series showed excellent productivity, which identified as (Excellent I) class of potential productivity, while soils of Tulewal and Nathupur identified as (Good II) class of potential productivity. The rating values of potential productivity are 79.04 for Dhoda, 64.91 for Tulewal, 74.60 for Samana, 50.50 for Nathupur, and 65.59 for Kanjili respectively. This is similar to the results indicate by (Heba and Rashed, 2016) A case study in Egypt, reported that 61.77 per cent of the soils hade excellent and good (I and II) in term of potential productivity . The coefficient of improvement was recorded for Dhoda series (1.43), Tulewal (1.78), Samana (2.05), Nathupur (1.38) and Kanjili series (1.24) respectively.

The soils of Ucha, Fattu Dhinga, Bahanra and Fatehpur series were average in actual productivity. These were moderately well drained to well drained, rooting zoon below wilting point for three months, very deep soils over 120 cm, soil texture of sandy loam in the epipedon of Ucha, Fattu Dhinga and Fatehpur series, while loamy sand in Bhanra series, alkaline pH, low organic matter in A horizons of Ucha and Fatehpur series, and very low organic matter in A horizons of Bhanra and Fatehpur series. Minerals derived from sand and sandy materials, exchange capacity less than

20 meq/100 g of soil. The RI value for Ucha, Fattu Dhinga, Bhanra, and Fatehpur was 34.42, 29.26, 26.01, and 29.17 respectively in term of actual productivity. All these soils have average productivity.

The major limitations of these soils were available soil moisture, soil structure, soil texture, organic matter in A horizons of the soils, mineral reserve status. Accordingly these soils required appropriate management such as usually drainage, irrigation by flood and sprinkling, improvement of texture by mechanical working of soils, application of fertilizers, amendments, enriching and maintenance of organic matter content, application of manure, compost, mulching, and crop rotation. Data in Table (5.3.5) revealed that these soils showed greater scope for improvement in term of potential productivity after soil management issues are addressed. Soils of Ucha, Fattu Dhinga, Bhanra and Fatehpur series were rated (Good II) in Potential productivity. The RI value for Ucha, Fattu Dhinga, Bahanra and Fatehpur was 48.25, 42.51, 40.60 and 44.31 in terms of potential productivity. The coefficient of improvement for Ucha, Fattu Dhinga, Bhanra and Fatehpur was (1.40), (1.45), (1.56), and (1.51) respectively (Table 5.3.6).

Soil of Mund series rated (poor) in actual productivity due to several limitation of soil erosion, soil moisture, soil depth, soil texture and structure, organic matter content, slope and mineral reserve status. Soils of Mund series had excessively drainage, fairly deep soil, loamy sand texture with unsuitable structure, and located next to river, accordingly, soil of Mund was not used for crop cultivation, and disturbed soils, and these soils had water erosion. The RI values (16.85) obtained in Mund series showed that these soils were belonging to the (poor productivity) class in term of actual productivity (Table 5.3.4). Therefor by providing supplementary irrigation, addition of organic matter and fertilizers, improvement of soil texture and structure, controlling wind and water erosion, and deepening of top soils these soils unit would be improved in long term. After application of appropriate management these soils rate (Average III) in Potential productivity. The value of potential productivity was 32.03. The calculated coefficient of improvement for Mund series obtained (1.90). This is not in agreement with the finding of Agber and Ali, (2012), evaluation of the productivity of soils in Makurdi, Nigeria.

**Table 5.3.4 Actual productivity index of normal soils in Kapurthala district**

| Determination of the index of productivity of Normal soils | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No** | **Pedon** | **H** | **D** | **P** | **T** | **N** | **S** | **O** | **A** | **M** | **Productivity Index** | **Productivity Class** | **Productivity Rating** |
| **1** | Dhoda | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{6a}$ | $N_5$ | $S_1$ | $O_2$ | $A_2$ | $M_{2c}$ | **55.23** | **Good** | **II** |
| | | 100 | 85 | 100 | 80 | 100 | 100 | 90 | 95 | 95 | | | |
| **2** | Tulewal | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{5a}$ | $N_5$ | $S_1$ | $O_2$ | $A_2$ | $M_{2a}$ | **36.44** | **Good** | **II** |
| | | 100 | 85 | 100 | 50 | 100 | 100 | 90 | 95 | 85 | | | |
| **3** | Samana | $H_{4C}$ | $D_4$ | $P_6$ | $T_{5a}$ | $N_5$ | $S_1$ | $O_2$ | $A_2$ | $M_{2a}$ | **36.33** | **Good** | **II** |
| | | 100 | 100 | 100 | 50 | 100 | 100 | 85 | 95 | 85 | | | |
| **4** | Ucha | $H_{4C}$ | $D_4$ | $P_6$ | $T_{4b}$ | $N_5$ | $S_1$ | $O_2$ | $A_1$ | $M_{2a}$ | **34.42** | **Average** | **III** |
| | | 100 | 100 | 100 | 50 | 100 | 100 | 90 | 90 | 85 | | | |
| **5** | Fattu Dhinga | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{4b}$ | $N_5$ | $S_1$ | $O_2$ | $A_1$ | $M_{2a}$ | **29.26** | **Average** | **III** |
| | | 100 | 85 | 100 | 50 | 100 | 100 | 90 | 90 | 85 | | | |
| **6** | Natpur | $H_{4C}$ | $D_4$ | $P_6$ | $T_{4ba}$ | $N_5$ | $S_1$ | $O_2$ | $A_1$ | $M_{3a}$ | **36.45** | **Good** | **III** |
| | | 100 | 100 | 100 | 50 | 100 | 100 | 90 | 90 | 90 | | | |
| **7** | Mund | $H_{4C}$ | $D_{3a}$ | $P_4$ | $T_{4a}$ | $N_5$ | $S_7$ | $O_1$ | $A_1$ | $M_{3a}$ | **16.85** | **Poor** | **IV** |
| | | 100 | 85 | 80 | 40 | 100 | 90 | 85 | 90 | 90 | | | |
| **8** | Bahanra | $H_{4C}$ | $D_4$ | $P_6$ | $T_{4a}$ | $N_5$ | $S_1$ | $O_1$ | $A_1$ | $M_{2a}$ | **26.01** | **Average** | **III** |
| | | 100 | 100 | 100 | 40 | 100 | 100 | 85 | 90 | 85 | | | |
| **9** | Kanjili | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_1$ | $A_2$ | $M_{2a}$ | **52.50** | **Good** | **II** |
| | | 100 | 85 | 100 | 90 | 100 | 90 | 85 | 95 | 85 | | | |
| **10** | Fatehpur | $H_{4C}$ | $D_{3a}$ | $P_6$ | $T4_b$ | $N_5$ | $S_1$ | $O_1$ | $A_2$ | $M_{2a}$ | **29.17** | **Average** | **III** |
| | | 100 | 85 | 100 | 50 | 100 | 100 | 85 | 95 | 85 | | | |

**Table 5.3.5 Potential productivity of normal soils in Kapurthala district**

| Determination of the index of potentiality of normal soils | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No** | **Pedon** | **H** | **D** | **P** | **T** | **N** | **S** | **O** | **A** | **M** | **Potentiality Productivity** | **Potential productivity Classes** | **Improvement necessary for development** |
| **1** | Dhoda | $H_5$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_1$ | $O_4$ | $A_2$ | $M_{2c}$ | **79.04** | **Excellent** | **A,B,,E,H** |
| | | 100 | 85 | 100 | 90 | 100 | 100 | 100 | 95 | 95 | | | |
| **2** | Tulewal | $H_5$ | $D_{3a}$ | $P_6$ | $T_{5b}$ | $N_5$ | $S_1$ | $O_4$ | $A_2$ | $M_{2a}$ | **64.91** | **Good** | **A,B,,E,H** |
| | | 100 | 85 | 100 | 80 | 100 | 100 | 100 | 95 | 85 | | | |
| **3** | Samana | $H_5$ | $D_4$ | $P_6$ | $T_{5b}$ | $N_5$ | $S_1$ | $O_4$ | $A_2$ | $M_{2a}$ | **74.60** | **Excellent** | **A,B,,E,H** |
| | | 100 | 100 | 100 | 80 | 100 | 100 | 100 | 95 | 85 | | | |
| **4** | Ucha | $H_5$ | $D_4$ | $P_6$ | $T_{4b}$ | $N_5$ | $S_1$ | $O_4$ | $A_1$ | $M_{2a}$ | **48.25** | **Good** | **A,B1,B2,E2,F, H** |
| | | 100 | 100 | 100 | 50 | 100 | 100 | 100 | 90 | 85 | | | |
| **5** | Fattu Dhinga | $H_5$ | $D_{3a}$ | $P_6$ | $T_{4b}$ | $N_5$ | $S_1$ | $O_4$ | $A_1$ | $M_{2a}$ | **42.51** | **Good** | **A,B1,B2,E2,F, H** |
| | | 100 | 85 | 100 | 50 | 100 | 100 | 100 | 90 | 85 | | | |
| **6** | Natpur | $H_5$ | $D_4$ | $P_6$ | $T_{4b}$ | $N_5$ | $S_1$ | $O_4$ | $A_1$ | $M_{3a}$ | **50.50** | **Good** | **A,B,,E,H** |
| | | 100 | 100 | 100 | 50 | 100 | 100 | 100 | 90 | 90 | | | |
| **7** | Mund | $H_5$ | $D_{3a}$ | $P_4$ | $T_{4a}$ | $N_5$ | $S_7$ | $O_4$ | $A_1$ | $M_{3a}$ | **32.03** | **Average** | **A,B1, D E,J, K, H,L** |
| | | 100 | 85 | 80 | 40 | 100 | 90 | 100 | 90 | 90 | | | |
| **8** | Bahanra | $H_5$ | $D_4$ | $P_6$ | $T_{4a}$ | $N_5$ | $S_1$ | $O_4$ | $A_1$ | $M_{2a}$ | **40.60** | **Good** | **A,B1,B2,E2,F, H** |
| | | 100 | 100 | 100 | 40 | 100 | 100 | 100 | 90 | 85 | | | |
| **9** | Kanjili | $H_5$ | $D_{3a}$ | $P_6$ | $T_{6b}$ | $N_5$ | $S_7$ | $O_4$ | $A_2$ | $M_{2a}$ | **65.59** | **Excellent** | **A,B,,E,H** |
| | | 100 | 85 | 100 | 90 | 100 | 90 | 100 | 95 | 85 | | | |
| **10** | Fatehpur | $H_5$ | $D_{3a}$ | $P_6$ | $T4_b$ | $N_5$ | $S_1$ | $O_4$ | $A_2$ | $M_{2a}$ | **44.31** | **Good** | **A,B1,B2,E2,F, H** |
| | | 100 | 85 | 100 | 50 | 100 | 100 | 100 | 95 | 85 | | | |

**Table 5.3.6 Coefficient of improvement of norm soils of Kapurthala district**

| Serial No | Soil series | Improvement necessary for development | Coefficient of improvement |
|---|---|---|---|
| **1** | Dhoda | **A,B,E,H** | 1.43 |
| **2** | Tulewal | **A,B,,E,H** | 1.78 |
| **3** | Samana | **A,B,,E,H** | 2.05 |
| **4** | Ucha | **A,B1,B2,E2,F,H** | 1.40 |
| **5** | Fattu Dhinga | **A,B1,B2,E2,F,H** | 1.45 |
| **6** | Nathupur | **A,B,,E,H** | 1.38 |
| **7** | Mund | **A,B1, D E,J, K, H,L** | 1.90 |
| **8** | Bahanra | **A,B1,B2,E2,F,H** | 1.56 |
| **9** | Kanjili | **A,B,,E,H** | 1.24 |
| **10** | Fatehpur | **A,B1,B2,E2,F,H** | 1.51 |

**Key of improvement necessary for development**

A= Irrigation (essential) and usually drainage

B= Supplementary irrigation

D= Deepening of top soils

E= Improvement of soils texture and structure

F= Fertilizers, amendments

H= enriching and maintenance of organic matter

J= Control wind erosion

K= Control water erosion

L= control mild water erosion

**CHAPTER- VI**

# Summary and Conclusion

Soil resources of Kapurthala district in Punjab, North-West, India were studied. The Kapurthala district lies between the latitudes of 31°07′30″ and 31° 39′ 30″ N and the longitudes of 75° 43′ 55″ and 75° 54′ 60″E. Most of the studies on characteristics of soils of Kapurthala district have been done in the initial years of green revolution/intensive farming. Since then lot of change in cropping pattern and soil characteristics has taken place due to adoption of reclamation of salt affected soils, scrapping of sandy layers and introduction intensive farming practices. Now after about fifty years of intensive cultivation it was high time to revisit these soils. Investigation involved the study of macro-morphological characteristics of sixteen pedons from sixteen villages in the field. Horizon wise samples were collected. Location of all the pedons was recorded with the help of global positioning system (GPS). All soil samples were analysed in laboratory for their physical and chemical characteristics. Soils were classified in the light of changed characteristics of the soil as per Soil Taxonomy (USDA  2015) up to family level. After, effects of intensive farming were studied by comparing the present data with the already established data of Uppal H.L, (1957) Sharma *et al.,* (1982) and Sehgal *et al.,* (1992). Comparison graphs of different parameters of soils of each series were prepared. And the actual productivity and potential productivity of these soils were evaluated so that experimental results can be interpreted in rational manner for effective transfer of technology to the farmers.

The soils of Kapurthala district have been grouped into sixteen soil series, depending upon the variation in soil texture, drainage, profile development, salt content and other physical and chemical characteristics. Six series specifically Rawalpindi, Domeli, Jagjitpur, Khairanwali, Randhirpur and Fajewal series are discussed under salt affected soils and the remaining ten series namely Dhoda, Tulewal, Samana, Ucha, Fattu Dhinga, Nathupur, Mund, Bahanra, Kanjili and Fatehpur series are discussed under normal soils. The findings of this investigation are summarized below separately for salt affected and normal soils.

**Salt-affected soils**

Soil color in salt affected soils showed a great variation and there was a significant variation in grade and size of the structure characteristics within each pedon among horizons and among soil pedons. The shape of structure in most horizons of the pedons recorded as sub angular blocky. The clay content of salt affected soils ranged from 18.1 per cent to 45.1 per cent. Silt content ranged from 19.6 per cent to 58.4 per cent and the sand ranged from 12.7 to 52.2 per. The texture classes in these soils were sandy clay loam, silty clay loam, silty clay, loam and clay loam. The electrical conductivity of these soils was below 1 dS $m^{-1}$ and the pH values of salt-affected soils ranged from 8.5 to 10.3. Calcium carbonate content in salt affected soils ranged from 0.2 per cent 1.1 per cent and organic carbon percentage ranged from 0.11 per cent to 0.93 per cent. The available nitrogen, phosphorus and potassium of salt affected soils ranged from 37.6 kg/ha to 677.3 kg/ha, 24.6 kg/ha to 110 kg/ha and 184.8 kg/ha to 453.6 kg/ha respectively. CEC ranged from 3.51 $cmol_c$/kg to 11.72 $cmol_c$/kg. The exchangeable calcium, magnesium, sodium and potassium content of salt affected soils of Kapurthala district ranged from 0.4 $cmol_c$/kg to 7.0 $cmol_c$/kg, 0.2 $cmol_c$/kg to 4.2 $cmol_c$/kg, 1.21 $cmol_c$/kg to 8.26 $cmol_c$/kg and 0.30 $cmol_c$/kg to 0.97 $cmol_c$/kg. The saturation percentage of salt affected soils ranged 28.10 per cent to 44.40 per cent and the ESP of these soils ranged from 12.6 per cent to 70.4 per cent. Furthermore, the composition of ssaturation paste and saturation extract of salt affected soils such as $pH_s$, $EC_e$, $Ca^{++}$,$Mg^{++}$, $Na^+$, $K^+$, $CO_3^{--}$, $HCO_3^-$, $Cl^-$, and $SO_4^{--}$ were determined in laboratory. The DTPA extractable zinc, iron, manganese and copper in the epipedon of salt affected soils ranged from 0.12 mg/kg of soil to 2.58 mg/kg of soil, 3.36 mg/kg of soil to 24.14 mg/kg of soil, 2.48 mg/kg of soil to 9.40 mg/kg of soil and 0.20 mg/kg of soil to 2.16 mg/kg of soil respectively.

Salt affected soils of Kapurthala district were classified up to the family level as per Soil Taxonomy (USDA 2015). Rawalpindi, Domeli, Jagjitpur, Khairanwali and Randhirpur are classified as fine loamy, mixed, hyper thermic family of Fluventic Haplustepts. Fajewal classified as coarse loamy, mixed hyperthermic family of Typic Ustifluvent

Depth wise graphs of salt affected soils showed that soil pH decreased by 0.5-1.5) in all the pedons except Domeli series in 2019 as compere to 1982, EC decreased in all the pedons, organic carbon increased in all the soil series and calcium carbonate content decreased in all the soil series. The CEC decreased in most of salt affected soil series. Exchangeable calcium decreased in the Rawalpindi, Khairanwali and Fajewal series, no change noticed in Jagjitpur series. Exchangeable sodium percentage in 2019 decreased in all the series except epipedon of Rawalpindi series and increased in Randhirpur series. The $pH_s$ and $EC_e$ graphs showed a decrease in all pedons of salt affected soils except Fajewal series. Intensive irrigation practices accompanied with regular use of chemical fertiliser seem to be responsible for there changes in the soil characteristics.

Actual productivity and potential productivity of salt affected soils of Kapurthala district were evaluated by Riquier Index model. Salt affected soils of the area have grouped into three different classes in terms of actual productivity. Khairanwali soil has excellent actual productivity with riquier index rating of 65.40. Rawalpindi, Jagjitpur, Randhirpur and Fajewal series have good actual productivity classes. The riquier rating in these soils obtained 44.70 in Rawalpindi, 49.88 in Jagjitpur series, 47.40 in Randhirpur and 52.67 in Fajewal series. Domeli series has average actual productivity class with the riquier index rating of 32.7. Salt affected soils of Kapurthala district were rated excellent class in term of potential productivity with a Riquier index rating of 82.67 in Khairanwali, 65.59 in Rawalpindi and Jagjitpur series, 71.96 in Randhirpur series, 68.52 in Fajewal and 71.77 in Domeli series respectively.

**Normal soils of Kapurthala district**

The soil color of normal soils of Kapurthala district showed a great variation within each pedon among horizon and among pedons. The shape of structure in all the pedons recorded as sub angular blocky except some horizons of Nathupur series where the structure had no specific shape. Soil consistence characteristics of normal soils varied from soft to hard (dry). The particle size distribution of normal soils ranged from 0.8 per cent to 36.1 per cent, 0.9 to 41.6 per cent and 23.1 per cent to 98.3 per cent for clay, silt and sand respectively. The texture classes of normal soils were sand, sandy loam, loamy sand, loam, sandy clay loam, and clay loam. The pH of normal soils ranged from 7.5 to 10.9 and the EC values were below 1dS $m^{-1}$. The calcium carbonate and organic carbon of these soils ranged from 0.0 to 0.5 per cent and 0.06 per cent to 0.93 per cent respectively. The available nitrogen, phosphorus and potassium content of normal soils ranged from 37.6 kg/ha to 672.7 kg/ha, 33.8 kg/ha to 122.3 kg/ha, and 184.8 kg/ha to 420 kg/ha respectively. CEC of these soils ranged from 2.03 $cmol_c$/kg to 12.60 $cmol_c$/kg. The exchangeable calcium, magnesium, sodium and potassium of normal soils ranged from 0.6 $cmol_c$/kg to 8.4 $cmol_c$/kg, 0.2 $cmol_c$/kg to 2.4 $cmol_c$/kg, 0.34 $cmol_c$/kg to 5.56 $cmol_c$/kg, and 0.2 $cmol_c$/kg to 0.8 $cmol_c$/kg respectively. The saturation percentage of normal soils ranged from 23.15 per cent to 50.20 per cent and the ESP content of these soils ranged from 5.5 to 66.0 respectively. Furthermore, the composition of soil saturation paste and saturation extract of normal soils such as $pH_s$, $EC_e$, $Ca^{++}$,$Mg^{++}$, $Na^+$, $K^+$, $CO_3^{--}$, $HCO_3^-$, $Cl^-$, and $SO_4^{--}$ were determined in laboratory. The DTPA extractable zinc, iron, manganese and copper of normal soils in Kapurthala district ranged from 0.04 kg/ha of soil to 1.70 kg/ha of soil, 2.16 kg/ha of soil to 31.94 kg/ha of soil, 4.86 kg/ha of soil to 11.14 kg/ha of soil, and 0.2 kg/ha of soil to 2.36 kg/ha of soil respectively.

Normal soils of Kapurthala district were classified up to the family level as per Soil Taxonomy (USDA 2015). Dhoda series classified as fine loamy, mixed, calcareous hyperthermic, family of Fluventic Haplustepts. Tulewal, Samana, Ucha, and Fattu Dhinga classified coarse loamy, mixed calcareous, hyperthermic family of Fluventic Haplustepts. Kanjili fine loamy classified as mixed, hyperthermic, family of Typic Haplustepts. Fatehpur classified as fine loamy, mixed, hyperthermic, family of Typic Haplustepts. Nathupur, Mund, and Bhanra series classified sandy, mixed, hyperthermic, family of Typic Ustipsamment.

Comparison graphs for different parameters of soil and saturation paste extract such as pH, EC, organic carbon, calcium carbonate, CEC, exchangeable cations, ESP, $pH_s$, $EC_e$ and $Na^+$ of each series were prepared. The pH of normal soils in Kapurthala district increased in all the series except Ap horizon of Nathupur series in 2019. The EC slightly increased in Bhanra, Kanjili, and Fatehpur soil series while slightly decreased in Nathupur soil series. Not changed or almost same in other normal soil series. Organic carbon increased in all the normal soils except Kanjili series, calcium carbonate content decreased in Ucha, Fattu Dhinga, Kanjili and epipedon of Tulewal series. CEC slightly increased in Bhanra and Nathupur series, while slightly decreased in Fatehpur series and not changed or almost same in other soil series. The exchangeable sodium in 2019 compare to 1982 increased in Nathupur, Bahanra, Fatehpur and Kanjili series. The graphs for ESP content of these soils showed decrease in Kanjili series except B22 and B3 horizons. It could be due to use of lower layer water for irrigation which as sodicity, this might be increase the pH of the soils and decrease the ESP along with organic carbon percentage in these soils

Normal soils of Kapurthala district were identified into three different classes in tem of actual productivity. Dhoda, Tulewal, Samana, Nathupur, and Kanjili series have good actual productivity with RI rating of 55.23, 56.44, 36.33, 36.45, and 52.50 respectively. Ucha, Fattu Dhinga Bahanra and Fatehpur series have average actual productivity class with RI rating of 34.42, 29.26, 26.01, and 29.17 respectively. Mund series has poor actual productivity, the RI rating for Mund series was 16.85. In terms of potential productivity soils of Dhoda, Samana and Kanjili series showed excellent productivity, which identified as (Excellent I) class of potential productivity, while soils of Tulewal and Nathupur identified as (Good II) class of potential productivity. The rating values of potential productivity are 79.04 for Dhoda, 64.91 for Tulewal, 74.60 for Samana, 50.50 for Nathupur, and 65.59 for Kanjili respectively. Soils of Ucha, Fattu Dhinga, Bhanra and Fatehpur series were rated (Good II) in Potential productivity. The riquier index value for Ucha, Fattu Dhinga, Bahanra and Fatehpur was 48.25, 42.51, 40.60 and 44.31 respectively in terms of potential productivity. Mund soils rate average III in Potential productivity. The value of potential productivity for Mund series was 32.03.

Intensive agriculture practices evolved as a need to feed the large population of human beings. From the results of the investigation, it is clearly visible that these practice led to improvement in pH, EC, OC, $CaCO_3$, levels for higher agriculture production in salt affected soils. However in normal soils these are indications that use mining water from lower layer for continuous irrigation has led to some increase in pH, EC though the level is not very high. In most normal soils as well as salt affected soils use of such practice led to increase in organic carbon percentage. Cultivation of rice- wheat cropping in salt affected soils of Kapurthala district maintained a favorable pH environment and improved soil organic carbon in all the soils of the study area. Use of chemical fertilizers and amendments such as compost, manure, green manure, and etc. buildup the availability of macronutrients ( nitrogen, phosphorus, potassium) and micronutrients (zinc, manganese, iron and copper). Moreover, the productivity of these soils improved and the production of crops per annum also increased. In general intensive agriculture practices have let to improved productivity index of soils as well as crop productivity over the years.

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## Appendices

### Appendix-I: Site characteristics of the pedons and their macro-morphology

### A: Salt affected soil pedons

Morphological features of the salt affected soil pedons under study is presented below

| | |
|---|---|
| **Pedon No** | **: 1 (Rawalpindi Series)** |
| Location | : Longitude: 31°17' 51.534" |
| Latitude | : 75° 47' 42.126" |
| Elevation | : 223 m |
| Relief | : 1-3% |
| Vegetation | : Wheat and paddy |
| Location | : On the north side of West Bein about 45 km to Rawalpindi village, Phagwara tehsil, Dis: Kapurthala, Punjab, India |
| Landform | : Piedmont plain- alluvium |
| Slope | : 1-2% |
| Drainage | : Moderately well drained |

**Morphological description of pedon**

Ap (0-26 cm) gray colour (10YR 6/1) dry, grayish brown (10YR 5/2 moist), clay loam soil texture, moderate medium sub angular blocky structure, when the soil is dry the material is strongly resistant, weakly coherent when moist, many fine roots, pH: 8.5, moderate reaction wit dilute HCl.

AB (26-42 cm) dark yellowish brown (10YR 4/4) when moist, texture by feel Method is Silty clay loam with a moderate medium sub angular blocky structure, weakly coherent when moist, many fine roots, pH: 8.6, slightly reaction with HCl.

B1 (42-58 cm) dark yellowish brown (10YR 4/4) when moist, silty clay loam soil texture, coarse sub angular blocky structure, weakly coherent when moist, many fine roots, pH: 8.7, moderate soil reaction with HCl.

B21 (58-79 cm) yellowish brown (10YR 5/4) when moist, silty clay loam soil texture, moderate coarse sub angular blocky structure, weakly coherent when moist, many fine roots, pH: 8.8, strong reaction with dilute HCl.

B22 (79-105 cm) dark yellowish brown (10YR 5/5) when moist, silty clay loam soil texture, coarse sub angular blocky structure, moderately coherent when moist, pH: 9.0, strong reaction with HCl.

B3 (105-130 cm) light yellowish brown (10YR 6/4) silt clay soil texture, massive structure, moderately coherent when moist, pH: 9.0, strong reaction with HCl.

| | |
|---|---|
| **Pedon No** | **: 2 (Domeli series)** |
| Location | : Longitude: 31°20’ 33.654” |
| Latitude | : 75° 47’ 39.276' |
| Elevation | : 222 m |
| Vegetation | : Wheat, maize |
| Location | : Village of Domeli Phagwara tehsil, Kapurthala District |
| Landform | : piedmont plain |
| Slope | : 1-2% |
| Drainage | : poorly drained |
| Erosion | : e1 |

**Morphological description of pedon**

**Ap (0-18 cm)** gray colour (10YR 5/2) dry, light yellowish brown (10YR6/4 moist), loam soil texture, moderate medium sub angular blocky structure, consistency extremely hard (dry), loose (moist), sticky (wet), many roots, moderate reaction with HCl, pH: 10.3

**AB (18-35 cm)** yellowish brown (10YR 5/4) moist, loam soil texture, moderate medium sub angular blocky structure, consistence extremely (dry), loos (moist), plastic (wet), many roots, strong reaction with HCl, pH: 10.1.

**B1 (35-55 cm)** yellowish brown color (10YR 5/4) moist, loam soil texture, moderate medium sub angular blocky structure, consistency extremely hard (dry), loose (moist), sticky and plastic (wet), strong reaction with HCl, pH: 10.1

**B21 (55-70 cm)** grayish brown (10YR 5/2), moist, loam soil texture, moderate sub angular blocky structure, consistency extremely loose (moist), sticky and plastic (wet), strong reaction with HCl, pH: 10.2.

**B22 (70-95 cm)** grayish brown (10YR 5/2), moist loam soil texture, moderate medium sub angular blocky structure, consistency friable (moist), sticky and plastic (wet), slight reaction with HCl, pH: 10.1.

**BC (95-108 cm)** grayish brown (10YR 5/2), moist, loam soil texture, massive structure, consistency friable (moist), sticky and plastic (wet), slight reaction with HCl, pH: 8.6.

| | |
|---|---|
| **Pedon No** | **: 3 (Jagjitpur series)** |
| **Date** | **: 15/may/2018** |
| Depth | : 135 cm |
| Location | : Longitude: 31°19’ 16.706” |
| Latitude | : 75° 48’ 14.706' |
| Elevation | : 220 m |
| Vegetation | : Eucalyptus, Dalbegia, wheat, paddy, sugarcane |
| Location | : On the left side of Phagwara-Hoshiarpur road, Jagjitpur village, Phagwara tehsil, Kapurthala district |
| Erosion | : ei |
| Slope | : 1-2% |
| Drainage | : Moderate well drained |
| Ground water | : 60-80 |

**Morphological description of Pedon**

**Ap (0-30 cm)** light brownish gray colour (10YR 6/2) dry, dark gray (10YR 4/1) moist, sandy clay loam soil texture, moderate medium sub angular blocky structure, consistency, hard (dry), friable (moist), sticky (wet), many roots, strong reaction with HCl, pH: 9.0.

**AB (30-52 cm)** brown colour (10YR5 /3) moist, loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), friable (moist), plastic (wet), many roots, moderate reaction with HCl, pH: 9.1.

**B21 (52-79 cm)** yellowish brown colour (10YR 5/6) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), friable (moist), sticky and plastic (wet), many fine roots, slight reaction with HCl, pH: 8.9.

**B22 (79-100 cm)** yellowish brown colour (10YR 5/4) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, loose (moist), sticky and plastic (wet), many fine roots, slight reaction with HCl, pH: 9.1.

**B23 (100-125 cm)** dark yellowish brown colour (10YR 4/6) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, loose (moist), sticky and plastic (wet), many fine roots, slight reaction with HCl, pH: 8.9.

**BC (125-135 cm)** yellowish brown colour (10YR 5/6) moist, clay soil texture, massive soil structure, consistency, loose (moist), sticky and plastic (wet), many fine roots, slight reaction with HCl, pH: 9.2.

| | |
|---|---|
| **Pedon No** | **: 4 (Khairanwali series)** |
| Location | : Longitude: 31°23.413’ |
| Latitude | : 75° 15’ .472" |
| Elevation | : 210 m |
| Vegetation | : Wheat, paddy |
| Location | : On Taran-taran road near power house, about 1 km from road in Kapurthala district |
| Erosion | : ei |
| Slope | : 1-2% |
| Classification | : Typic Haplusteps with Lithological discount |
| Salt or alkali | : Previously salt affected |
| Drainage | : Well drained |

**Morphological description of pedon**

**AP (0-23 cm)** grayish brown (10YR 5/2) dry, dark grayish brown (10YR 4/2) moist, loam soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), many roots, strong reaction with HCl, pH: 9.2.

**AB (23-50 cm)** dark yellowish brown (10YR 4/4) moist, loam soil texture, weak medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many roots, moderate reaction with HCl, pH: 9.9.

**B21 (50-82 cm)** yellowish brown (10YR 5/4) moist, loam soil texture, moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many roots, moderate reaction with HCl, pH: 9.8.

**B22 (82-111 cm)** yellowish brown (10YR 5/4) moist loam soil texture moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), strong reaction with HCl, pH: 9.9.

**B23 (111-145 cm)** brown colour (10YR 4/3) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, loose (moist), slightly sticky and slightly plastic (wet), slight reaction with HCl, pH: 9.8

| | |
|---|---|
| **Pedon No** | **: 5 (Randhirpur series)** |
| Location | : Longitude: 31°23.117’ |
| Latitude | : 75° 17’. 821” |
| Elevation | : 209 m |
| Vegetation | : Wheat, Maize, Paddy, Sugar can |
| Location | : About 1 km before Khairanwali village lift site of Tran-tran road in Kapurthala district |
| Erosion | : ei |
| Slope | : 1% |
| Salt or alkali | : Previously salt affected |
| Ground water | : 80 |
| Drainage | : Moderate well drained |

**Morphological description of pedon**

**Ap (0-26 cm)** brown colour (10YR 5/3) dry, grayish brown (10YR 5/2) moist, loam soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), many fine roots, strong reaction with HCl, pH: 9.5.

**AB (26-48 cm)** yellowish brown (10YR 5/4) moist, silty clay loam soil texture, moderate medium sub angular blocky structure, consistency, hard (dry), friable (moist), slightly sticky and slightly plastic (wet), many fine roots, moderate reaction with HCl, pH: 9.8.

**B1 (48-76 cm)** dark yellowish brown (10YR 4/4) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, moderate reaction with HCl, pH: 9.9.

**B21 (76-95 cm)** yellowish brown (10YR 5/4) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, strong reaction with HCl, pH: 10.0.

**B22 (95-118 cm)** yellowish brown (10YR 5/4) moist, silty clay loam soil texture, moderate coarse sub angular blocky structure, consistency, loose (moist), sticky and plastic many fine roots, slight reaction with HCl, pH: 9.9.

**B23 (118-138 cm)** dark yellowish brown (10YR 4/6) moist, clay loam soil texture, moderate coarse sub angular blocky structure, consistency, loose (moist), sticky and plastic many fine roots, HCl, pH: 10.0.

| | |
|---|---|
| **Pedon No** | **: 6 (Fajewal series)** |
| Location | : Longitude: 31°21.283’ |
| Latitude | : 075° 24’ .226'' |
| Elevation | : 216 m |
| Vegetation | : Watermelon, melon |

Location : About 1.2 km south east of Mansurwal Dona village, Kapurthala tehsil

Erosion : ei

Slope : 1%

Salt or alkali : Previously sand area, sand removed

Drainage : Moderate well drained

**Morphological description of pedon**

**Ap (0-24 cm)** light brownish gray colour (10YR 6/2) dry, grayish brown (10YR 5/2) moist, clay loam soil texture, weak fin sub angular blocky structure, soft (dry), friable (moist), non-sticky and non-plastic (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.8.

**AB (24-55 cm)** yellowish brown colour (10YR 5/4) moist, loam soil texture, weak fine sub angular blocky structure, soft (dry), friable (moist), non-sticky and non-plastic when its wet, medium roots are available, nil reaction with dilute HCl, pH: 9.0.

**B11 (55-85 cm)** grayish brown (10YR 5/2) moist, loam soil texture, weak fine sub angular blocky structure, soft (dry), friable (moist), non-sticky and non- plastic (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.9.

**B12 (85-113cm)** yellowish brown (10YR 5/4) moist, silty loam soil texture, weak fine sub angular blocky structure, soft (dry), friable (moist), non-sticky and non- plastic (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.7.

**B13 (113-148 cm)** dark yellowish brown (10YR 4/4) moist, silty loam soil texture, weak fine sub angular blocky structure, soft (dry), friable (moist), non-sticky and non-plastic (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.7.

**B: Normal soil Pedons**

Morphological features of normal pedons under study is presented below

**Pedon No : 7 (Dhoda series)**

Location : Longitude: 31°19’ 19.392”

Latitude : 75° 49’ 8.982”

Elevation : 220 m

Vegetation : Wheat, paddy

Location : About 600 m near north east of Jagjitpur village outside of Phagwara-Hoshiarpur road, Phagwara tehsil, Kapurthala district

Erosion : ei

Slope : 1-2%

Drainage : Moderate well drained

**Morphological description of pedon**

**Ap (0-24 cm)** gray colour (10YR 6/1) dry, yellowish brown (10YR 5/4) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, hard (dry), loose (moist), sticky and plastic (wet), many fine roots, strong reaction with HCl, pH: 8.9.

**AB (24-45 cm)** light yellowish brown (10YR 6/4) moist, clay loam soil texture, consistency, moderate medium sub angular blocky structure, strongly hard (dry), loose (moist), sticky and plastic (wet), fine roots, strong reaction with HCl, pH: 9.1.

**B1 (45-65 cm)** yellowish brown (10YR 5/6) moist, sandy clay loam soil texture, moderate coarse sub angular blocky structure, consistency, hard (dry), loose (moist), sticky and plastic (wet), many fine roots, medium reaction with HCl, pH: 9.1.

**B21 (65-87 cm)** yellowish brown (10YR 5/4) moist clay loam soil texture, moderate coarse sub angular blocky structure, consistency, hard (dry), loose (moist), sticky and plastic (wet), many fine roots, strong reaction with HCl, pH: 9.2.

**B22 (87-113)** brown (10YR 5/3) moist, clay loam soil texture, moderate course sub angular blocky structure, consistency, loose (moist), sticky and plastic (wet), many fine roots, medium reaction with HCl, pH: 9.3.

**BC (113-139 cm)** dark yellowish brown (10YR 4/6) moist, clay loam soil texture, massive soil structure, consistency, loose (moist), sticky and plastic (wet), loose reaction with HCl, pH: 9.0.

**Pedon No** **: 8 (Tulewal series)**

Location : Longitude: 31°16’ 40.548”

Latitude : 75° 42’ 33.126”

Elevation : 218 m

Vegetation : Dalbegia, Eucalypts

Location : Modhapur road, 650 m south of Modhapur village, Phagwara tehsil, Kapurthala district

Landform : Piedmont alluvial plain

Slope : 1-2%

Drainage : Well drained

**Morphological description of pedon**

**Ap (0-25 cm)** brown colour (10YR 5/3) dry, dark grayish brown (10YR 4/2) moist, sandy clay loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), many fine roots, slight reaction with HCl, pH: 8.8.

**AB (25- 41 cm)** light yellowish brown (10YR 6/4) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency friable (moist), slightly sticky and slightly plastic (wet), many roots, moderate reaction with HCl, pH: 9.6.

**B1 (41-62 cm)** yellowish brown (10YR 5/4) moist, sandy clay loam texture, weak course sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many roots, slight reaction with HCl, pH: 8.6.

**B2 (62-90 cm)** brownish yellow (10YR 6/6) moist, sandy clay loam soil texture, weak course sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, slight reaction with HCl, pH: 8.8.

**BC (90-123 cm)** brownish yellow (10YR 6/6) moist, sandy loam soil texture, massive soil structure, consistency, friable (moist), slightly sticky and slightly plastic moist, slightly plastic (wet), many fine roots, slight reaction with HCl, pH: 8.9.

**Pedon No** **: 9 (Samana series)**

Location : Longitude: 31°11’ 683”

Latitude : 75° 42’ 115'

Elevation : 234 m

Vegetation : Wheat, paddy

Location : More than one km north of Dakh Darweshpind on Phagwara-Jadiala road, Phagwara tehsil, Kapurthala district

Erosion : ei

Slope : 1-2%

Classification : Typic Haplusteps

Ground water : 80

Drainage : Well drained

**Morphological description of pedon**

**Ap (0-30 cm)** grayish brown colour (10YR 5/2) dry, dark gray (10YR 4/1) moist, clay loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), (moist), friable slightly sticky and slightly plastic (wet), many fine roots, moderate reaction with HCl, pH: 8.8.

**AB (30-50 cm)** pale brown colour (10YR 6/3) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, moderate reaction with HCl, pH: 9.1.

**B1 (50-69 cm)** yellowish brown colour (10YR 5/4) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, (moist), friable slightly sticky and slightly plastic (wet), many fine roots, moderate reaction with HCl, pH: 9.8.

**B21 (69-90 cm)** yellowish brown (10YR 5/6) moist, sandy loam soil texture, moderate course sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, slight reaction with HCl, pH: 9.6.

**B22 (90-114 cm)** yellowish brown colour (10YR 5/4) moist, sandy loam soil texture, moderate course sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, slight reaction with HCl, pH: 8.7.

**B23 (114-142 cm)** light yellowish brown (10YR 6/4) moist, sandy loam soil texture, medium sub angular blocky structure, consistency, friable (moist), friable slightly sticky and slightly plastic (wet), many fine roots, HCl, pH: 9.6.

| | |
|---|---|
| **Pedon No** | **: 10 (Ucha series)** |
| Location | : Longitude: 31°10.592” |
| Latitude | : 75° 42 .132' |
| Elevation | : 229 m |
| Vegetation | : Wheat, paddy |
| Location | : Near to Ucha pind, in the village of Ucha, Kapurthala tehsil |
| Erosion | : ei |
| Slope | : 1-2% |
| Classification | : Typic Haplusteps |
| Permeability | : Normal |
| Drainage | : Well drained |

**Morphological description of Ucha series**

**Ap (0-22 cm)** grayish brown colour (10YR 5/3) dry, dark grayish brown (10YR 4/2) moist, sandy loam soil texture, weak sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), many roots, moderate reaction with HCL, pH: 9.5.

**AB (22-45 cm)** yellowish brown (10YR 5/6) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many roots, moderate reaction with HCl, pH: 9.4.

**B1 (45-73 cm)** yellowish brown (10YR 5/4) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), many fine roots, slight reaction with HCl, pH: 9.1.

**B2 (73-108 cm)** dark yellowish brown (10YR 4/6) moist, sandy loam soil texture, moderate course sub angular blocky structure, consistency, friable (moist), slightly sticky and slight plastic (wet), many fine roots, slight reaction with HCl, pH: 9.5.

**B3 (108-142 cm)** dark yellowish brown (10YR 4/6) moist, loam soil texture, massive sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (we), many fine roots, slight reaction with HCl, pH: 9.4.

| | |
|---|---|
| **Pedon No** | **: 11 (Fattu Dhinga series)** |
| Location | : Longitude: 31°32.804’ |
| Latitude | : 75° 29’ .639'' |
| Elevation | : 207 m |
| Vegetation | : Wheat, Maize, Sugar can |
| Location | : 300 m south of Nadal-Bholath road, Bolath village |
| Erosion | : ei |
| Slope | : 1% |
| Classification | : Typic Haplustept |
| Land form | : Alluvial plain |
| Salt or alkali | : Previously salt affected |
| Ground water | : 70-80 |
| Drainage | : Moderate well drained |

**Morphological description of pedon**

**Ap (0-25 cm)** grayish brown (10YR 5/2) dry, brown (10YR 4/3) moist, sandy loam soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), course roots, moderate reaction with HCl, pH: 9.9.

**AB (25-56 cm)** yellowish brown colour (10YR 5/4) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), fine roots, moderate reaction with HCl, pH: 10.6.

**B21 (56-77 cm)** dark yellowish brown colour (10YR 4/4) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), fine roots, slight reaction with HCl, pH: 10.9.

**B22 (77-107 cm)** yellowish brown colour (10YR 5/4) moist, sandy loam soil texture, moderate medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), fine roots, HCl, pH: 10.6.

**B23 (107-135 cm)** yellowish brown colour (10YR 5/4) moist, loamy sand soil texture, weak sub angular blocky structure, consistency, soft (dry), loose (moist), slightly sticky and slightly plastic (wet), fine roots, HCl, pH: 10.6.

| | |
|---|---|
| **Pedon No** | **: 12 (Nathupur series)** |
| Location | : Longitude: 31°37’ 119” |
| | : Latitude: 075° 28’ 290” |
| Elevation | : 213 m |
| Vegetation | : Wheat, Paddy |
| Location | : In the old bed of beas river-Nangal Labana village, Kapurthala tehsil in Kapurthala district |
| Erosion | : ei |
| Slope | : 1% |
| Classification | : Typic Hstorthent |
| Land form | : Alluvial plain |
| Drainage | : Well drained |

**Morphological description of pedon**

**Ap (0-26 cm)** grayish brown (10YR 5/2) dry, brown (10YR 4/3) moist, loamy sand soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and slightly plastic (wet), course roots, strong reaction with HCl, pH: 8.7.

**AB (26-50 cm)** dark yellowish brown colour (10YR 4/6) moist, sandy loam soil texture, weak medium sub angular blocky structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), fine roots, moderate reaction with HCl, pH: 9.0.

**AC (50-73 cm)** dark yellowish brown (10YR 4/6) moist, sand soil texture, non-specific soil structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), course roots are available, moderate reaction with HCl, pH: 9.3.

**C2 (73-96 cm)** grayish brown colour (10YR 5/2) moist, sand soil texture, non-specific soil structure, consistency, friable (moist), slightly sticky and slightly plastic (wet), fine roots, slight reaction with HCl, pH: 9.7

**C3 (96-120 cm)** gray colour (10YR 5/1) moist, sand soil texture, non-specific soil structure, consistency, loose (moist), slightly sticky and slightly plastic (wet), course roots, slight reaction with HCl, pH: 9.5.

**C4 (120+ cm)** grayish brown colour (10YR 5/2) moist, sand soil texture, non-specific soil structure, course roots, slight reaction with HCl, pH: 9.9.

| | |
|---|---|
| **Pedon No** | **: 13 (Mund series)** |
| Location | : Longitude: 31°33.585’ |
| | : Latitude: 075° 21’.278” |
| Elevation | : 233 m |
| Vegetation | : Forest plant, pinus nigra |
| Location | : Mand village, next to Bias River in Mund village, Kapurthala tehsil |
| Erosion | : $e_2$ |
| Slope | : 1-2% |
| Ground water | : River bed |
| Drainage | : Excessively drained |

**Morphological description of pedon**

**A1 (0-25 cm)** light yellowish brown (10YR 6/5) dry, brown (10YR 4/3) moist, loamy sand soil texture, non-specific structure, consistency, soft (dry), friable (moist), non-sticky and non-plastic (wet), course roots, strong reaction with HCl, pH: 9.2

**C1 (28-50 cm)** dark yellowish brown colour (10YR 4/6) moist, loam soil texture, non-specific structure, consistency, friable (moist), non- sticky and non-plastic (wet), fine roots, moderate reaction with HCl, pH: 9.0.

**C2 (50-69+ cm)** gray colour (10YR 6/1) moist, sand soil texture, non-specific structure, consistency, friable (moist), non-sticky and non-plastic (wet), fine roots, nil reaction with HCl, pH: 9.6.

| | |
|---|---|
| **Pedon No** | **: 14 (Bhanra series)** |
| Location | : Longitude: 31°24.075’ |
| Latitude | : 75° 29’.212'’ |
| Elevation | : 180 m |
| Vegetation | : Wheat, maize |
| Location | : About 100 m north east of the village Fatehjalal, about 500 m from Kapurthala district |
| Erosion | : ei |
| Slope | : 1-2 % |
| Salt or alkali | : Previously sandy, formers removed sand from the surface of their lands |
| Drainage | : Well drained |

**Morphological description of pedon**

**Ap (0-25 cm)** grayish brown (10YR 5/2) dry, dark yellowish brown (10YR 4/2) moist, loamy sand soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and non-plastic (wet), medium roots are available, nil reaction with HCl, pH: 7.5.

**AB (25-55 cm)** light yellowish brown colour (10YR 6/4) moist, loamy sand soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), slightly sticky and non-plastic (wet), fine roots are available, nil reaction with dilute HCl, pH: 8.3.

**B1 (55-79 cm)** yellowish brown colour (10YR 5/6) when moist, sandy loam soil texture, weak medium sub angular blocky structure, consistency, soft (dry), friable (moist), non-sticky and non-plastic (wet), fine roots are available, nil reaction with dilute HCl, pH: 8.5,.

**B2 (79-120 cm)** dark yellowish brown colour (10YR 4/6) moist, sandy loam soil texture, weak medium sub angular blocky structure, soft (dry), friable (moist), non-sticky and non-plastic (wet), fine roots are available, nil reaction with dilute HCl, pH: 8.9.

**BC (120-140 cm)** yellowish brown colour (10YR 5/6) moist, loamy sand soil texture, weak medium sub angular blocky structure, soft (dry), loos (moist), non-sticky and non-plastic (wet), fine roots nil reaction with dilute HCl, pH: 8.0,.

| | |
|---|---|
| **Pedon No** | **: 15 (Kanjili series)** |
| Location | : Longitude: 31°24.831’ |
| Latitude | : 075° 22’ .717" |
| Elevation | : 209 m |
| Vegetation | : Wheat, paddy, trees |
| Location | : About 200 m near to Kanjili Bridge and boat club, Kanjili village |
| Erosion | : ei |
| Slope | : 1-2 % |
| Salt or alkali | : Previously |
| Ground water | : 70-80 |
| Drainage | : Moderate well drained |

**Morphological description of Kanjili series**

**Ap (0-23 cm)** grayish brown colour (10YR 5/2) dry, very dark yellowish brown (10YR 3/2) moist, clay loam soil texture, moderate medium sub angular blocky structure, soft (dry), friable (moist), sticky and plastic (wet), medium roots are available, strong effectiveness wit dilute HCl, pH: 8.9.

**B1 (23-50 cm)** yellowish brown colour (10YR 5/4) when the soil is moist, texture by feel method clay loam with a moderate medium sub angular blocky structure, friable (moist), sticky and plastic (wet), moderate reaction with dilute HCl pH: 9.6,.

**B21 (50-78 cm)** dark yellowish brown colour (10YR 4/4) moist, sandy clay loam soil texture, moderate course sub angular blocky structure, friable (moist), sticky and plastic (wet), fine roots are available, moderate reaction with dilute HCl, pH: 9.0,.

**B22 (78-105 cm)** dark yellowish brown colour (10YR 5/4) moist, sandy clay loam soil texture, with a moderate course sub angular blocky structure, friable (moist), sticky and plastic (wet), fine roots are available, slight reaction with dilute HCl, pH: 9.6.

**B23 (105-137 cm)** dark yellowish brown colour (10YR 4/6) moist, sandy clay loam soil texture, moderate course sub angular blocky structure, friable (moist), sticky and plastic (wet), fine roots are available, nil reaction with dilute HCl, pH: 9.2.

| | |
|---|---|
| **Pedon No** | **: 16 (Fatehpur series)** |
| Location | : Longitude: 31°15.196’’ |
| Latitude | : 075° 27’ .423" |
| Elevation | : 227 m |
| Vegetation | : Wheat, maize |
| Location | : Muradpur Dona village opposite of Rampur village, Sultanpur Lodhi tehsil, Kapurthal district |
| Erosion | : ei |
| Slope | : 1-2 % |
| Salt or alkali | : Previously |
| Ground water | : 80 |
| Drainage | : Moderate well drained |

**Morphological description of Fatehpur series**

**Ap (0-24 cm)** grayish brown colour (10YR 5/2) dry, brown (10YR 4/3) moist, sandy loam soil texture, weak medium sub angular blocky structure, soft (dry), friable (moist), slightly sticky and slightly plastic when (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.4.

**AB (24-55 cm)** light yellowish brown (10YR 4/6) moist, loamy sand soil texture, with a moderate medium sub angular blocky structure, friable (moist), slightly sticky and slightly plastic when (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.9.

**B1 (55-78 cm)** yellowish brown (10YR 5/6) moist, sandy loam soil texture, moderate medium sub angular blocky structure, friable (moist), slightly sticky and slightly plastic when (wet), slightly sticky and slightly plastic when its wet, medium roots are available, nil reaction with dilute HCl, pH: 8.7.

**B21 (78-120 cm)** dark yellowish brown (10YR 6/4) moist, sand soil texture, moderate course sub angular blocky structure, friable (moist), slightly sticky and slightly plastic when (wet), medium roots are available, nil reaction with dilute HCl, pH: 8.8.

**B22 (120-145 cm)** dark yellowish brown (10YR 5/6) moist, loamy sand soil texture, weak course sub angular blocky structure, loose (moist), slightly sticky and slightly plastic when (wet), medium roots are available, nil reaction with dilute HCl, pH: 9.0.

## Appendix-II: Physical and chemical characteristics of soils of Kapurthala district (Sharma *et al.*, 1982)

### A: Salt affected soils

### Physical and chemical characteristics of Rawalpindi series

| Horizon | Depth (cm) | pH 1:2 | EC dS m⁻1 | OC (%) | $CaCO_3$ (%) | Particle size Distribution (%) | | | Sand:silt ratio | Texture classes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand | Silt | Clay | | |
| Ap | 0-17 | 8.4 | 0.30 | 0.30 | 1.9 | 6.4 | 67.4 | 26.2 | 0.09 | scl |
| B1 | 17-32 | 8.9 | 0.27 | 0.11 | 0.7 | 6.9 | 53.5 | 39.7 | 0.13 | scl |
| B21 | 32-45 | 9.2 | 0.21 | 0.09 | 1.1 | 5.2 | 63.8 | 31.0 | 0.08 | scl |
| B22 | 45-71 | 9.3 | 0.32 | 0.09 | 5.7 | 9.9 | 42.1 | 48.0 | 0.23 | scl |
| B23 | 71-92 | 9.5 | 0.80 | 0.08 | 5.2 | 10.2 | 40.4 | 49.4 | 0.22 | scl |
| B24 | 92-127 | 9.4 | 0.82 | 0.07 | 2.8 | 11.3 | 45.1 | 43.6 | 0.22 | scl |
| ll B3 | 127+ | 9.4 | 0.37 | 0.08 | 7.6 | 24.3 | 45.9 | 29.8 | 0.53 | cl |

| Horizon | C.E.C (Me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 6.7 | 4.0 | 1.2 | 1.2 | 0.2 | 17.9 | 47.5 | 8.2 | 0.82 | 5.8 | 3.8 | 0.3 | 6.0 | 4.0 | 1.8 |
| B1 | 10.6 | 6.6 | 1.3 | 2.0 | 0.1 | 18.8 | 48.5 | 8.5 | 0.95 | 6.2 | 4.0 | 0.1 | 4.0 | 2.0 | 1.4 |
| B21 | 9.9 | 5.8 | 2.0 | 1.8 | 0.3 | 18.1 | 55.3 | 8.5 | 1.30 | 6.9 | 4.9 | 0.2 | 6.0 | 6.0 | 1.8 |
| B22 | 10.8 | 6.1 | 2.4 | 1.9 | 0.3 | 17.1 | 59.9 | 8.7 | 0.95 | 5.8 | 3.2 | 0.3 | 6.0 | 3.5 | 1.7 |
| B23 | 10.3 | 6.0 | 2.2 | 1.8 | 0.3 | 17.4 | 55.8 | 8.9 | 0.70 | 4.6 | 3.5 | 0.2 | 4.0 | 3.5 | 0.0 |
| B24 | 8.9 | 5.4 | 1.7 | 1.5 | 0.2 | 16.6 | 58.0 | 9.0 | 0.70 | 3.8 | 3.9 | 0.1 | 4.0 | 4.0 | 0.0 |
| ll B3 | 6.4 | 3.7 | 1.4 | 1.0 | 0.2 | 15.6 | 45.7 | 8.9 | 0.50 | 2.4 | 4.1 | 0.2 | 2.0 | 4.0 | 0.0 |

## Physical and chemical characteristics of Domeli series

| Horizon | Depth (cm) | pH (1:2) | EC dS/m | OC (%) | $CaCO_3$ (%) | Particle size Distribution (%) | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand | Silt | Clay | | |
| A2 | 0-4 | 9.8 | 0.34 | 0.43 | 2.0 | 50.4 | 38.4 | 11.6 | 1.31 | l |
| A3 | 4-20 | 10.0 | 0.60 | 0.90 | 2.2 | 48.2 | 37.4 | 14.4 | 1.28 | l |
| B21 | 20-42 | 9.7 | 0.28 | 0.30 | 0.9 | 42.8 | 39.8 | 17.4 | 1.07 | l |
| B22 | 42-65 | 9.6 | 0.14 | 0.28 | 1.5 | 42.9 | 39.0 | 18.1 | 1.10 | l |
| B23 | 65-96 | 9.1 | 0.07 | 0.17 | 1.9 | 39.6 | 41.2 | 19.2 | 0.96 | l |
| ll B31 | 96-120 | 9.0 | 0.07 | 0.14 | 0.7 | 34.8 | 48.5 | 17.7 | 0.71 | sl |
| 1ll B32 Ca | 120-141 | 8.9 | 0.11 | 0.11 | 0.7 | 43.1 | 42.6 | 14.6 | 1.00 | l |
| 1V C1 | 141-160 | 8.9 | 0.14 | 0.09 | 0.4 | 49.4 | 40.4 | 11.2 | 1.22 | l |
| 1V C2 | 160+ | 8.8 | 0.13 | 0.07 | 0.2 | 81.3 | 15.0 | 3.7 | 5.42 | ls |

| Horizon | C.E.C (me/100g ) | Exchangeable cations (Me/100 g) | | | E.S.P | Saturated paste and saturation extract analysis Me/l | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca+Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
| A2 | 7.0 | 3.00 | 3.8 | 0.30 | 54.2 | 32.0 | 9.7 | 1.8 | 8.3 | 9.5 | 0.2 | 0.0 | 9.4 | 8.5 | 2.3 |
| A3 | 6.5 | 1.90 | 4.4 | 0.30 | 67.6 | 33.5 | 9.8 | 2.9 | 9.9 | 18.8 | 0.3 | 0.0 | 21.7 | 7.5 | 1.8 |
| B21 | 9.5 | 6.25 | 3.0 | 0.20 | 31.5 | 33.7 | 9.5 | 1.6 | 7.0 | 8.8 | 0.2 | 0.0 | 9.1 | 7.0 | 1.8 |
| B22 | 9.8 | 6.15 | 3.4 | 0.20 | 34.7 | 34.8 | 9.4 | 0.7 | 4.0 | 2.8 | 0.2 | 0.0 | 4.7 | 2.5 | 1.7 |
| B23 | 7.8 | 5.20 | 2.5 | 0.15 | 32.0 | 32.8 | 8.9 | 0.5 | 2.6 | 2.9 | 0.2 | 0.0 | 3.1 | 2.0 | 1.3 |
| ll B31 | 8.7 | 6.15 | 2.3 | 0.20 | 26.4 | 39.5 | 8.8 | 0.4 | 2.6 | 2.8 | 0.2 | 0.0 | 3.1 | 1.9 | 1.6 |
| 1ll B32 Ca | 7.6 | 5.40 | 2.0 | 0.25 | 26.3 | 33.8 | 8.7 | 0.5 | 3.6 | 2.9 | 0.2 | 0.0 | 3.8 | 2.3 | 1.4 |
| 1V C1 | 6.5 | 4.85 | 1.4 | 0.25 | 21.5 | 31.2 | 8.7 | 0.5 | 3.6 | 2.9 | 0.2 | 0.0 | 3.9 | 2.0 | 1.4 |
| 1V C2 | 3.8 | 3.00 | 0.6 | 0.20 | 15.7 | 21.0 | 8.5 | 0.4 | 2.1 | 1.7 | 0.1 | 0.0 | 2.3 | 1.7 | 0.6 |

## Physical and chemical characteristics of Jagjitpur series

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| A1 | 0-10 | 10.2 | 2.4 | 0.3 | Nil | 62.0 | 19.8 | 18.2 | 3.10 | sl |
| II B1 | 10-28 | 10.5 | 2.3 | 0.2 | 0.2 | 48.4 | 30.1 | 21.5 | 1.60 | l |
| III B21 | 28-48 | 10.3 | 1.8 | 0.2 | 0.5 | 35.9 | 35.6 | 28.5 | 1.00 | cl |
| III B22 | 48-72 | 10.3 | 1.9 | 0.2 | 0.6 | 32.0 | 37.0 | 31.0 | 0.86 | cl |
| lv B 23 | 72-95 | 10.0 | 1.2 | 0.1 | 0.7 | 25.4 | 42.5 | 32.1 | 0.57 | cl |
| v B24 | 95-115 | 10.0 | 0.7 | 0.1 | 0.8 | 33.2 | 36.8 | 30.0 | 0.92 | cl |
| v C1 | 115-135 | 9.8 | 0.5 | 0.1 | 1.5 | 38.9 | 34.8 | 26.3 | 1.10 | l |
| v C2 | 135-180 | 9.6 | 0.6 | 0.06 | 0.9 | 40.4 | 35.6 | 24.0 | 1.10 | l |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (Me/l) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
| A1 | 8.5 | 1.4 | 0.7 | 6.8 | 0.3 | 80.0 | 30.4 | 9.9 | 7.2 | 11.8 | 62.5 | 0.4 | Nil | 31.5 | 42.6 | 4.9 |
| II B1 | 8.2 | 1.2 | 0.5 | 6.8 | 0.2 | 83.0 | 36.8 | 10.2 | 6.1 | 7.2 | 58.6 | 0.6 | “ | 28.6 | 25.6 | 4.3 |
| III B21 | 11.4 | 4.3 | 0.9 | 6.5 | 0.4 | 57.0 | 39.5 | 10.0 | 5.9 | 7.2 | 60.5 | 0.4 | “ | 29.8 | 22.8 | 3.6 |
| III B22 | 12.5 | 4.7 | 1.1 | 7.4 | 0.5 | 59.2 | 40.0 | 10.0 | 5.2 | 9.0 | 43.6 | 0.3 | “ | 30.6 | 22.0 | 2.2 |
| lV B 23 | 12.8 | 6.0 | 1.0 | 6.5 | 0.4 | 50.8 | 42.6 | 9.8 | 4.6 | 7.0 | 41.3 | 0.5 | “ | 20.4 | 18.7 | 3.4 |
| V B24 | 10.5 | 4.3 | 0.8 | 5.8 | 0.4 | 55.2 | 43.4 | 9.7 | 2.6 | 6.4 | 20.0 | 0.3 | “ | 18.4 | 10.5 | 4.2 |
| V C1 | 9.8 | 4.2 | 0.7 | 5.3 | 0.3 | 54.1 | 41.1 | 9.5 | 1.8 | 5.4 | 13.4 | 0.3 | “ | 11.6 | 11.0 | 4.9 |
| V C2 | 9.8 | 4.6 | 0.7 | 4.8 | 0.3 | 49.0 | 44.5 | 9.2 | 1.6 | 5.6 | 10.8 | 0.2 | “ | 9.2 | 7.6 | 1.2 |

**Physical and chemical characteristics of Khairanwali series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| A1 | 0-10 | 9.5 | 1.15 | 0.23 | 2.9 | 60.4 | 21.0 | 18.0 | 2.80 | sl |
| II B1 | 10-18 | 10.4 | 2.00 | 0.29 | 3.5 | 52.2 | 24.2 | 23.6 | 2.15 | scl |
| III B21 | 18-35 | 10.2 | 1.60 | 0.17 | 2.4 | 51.4 | 29.6 | 19.0 | 1.74 | l |
| IV B22 | 35-63 | 10.2 | 0.80 | 0.18 | 1.1 | 53.2 | 24.0 | 17.8 | 2.42 | sl |
| V B23 | 63-84 | 10.2 | 1.00 | 0.10 | 3.0 | 39.6 | 32.2 | 22.2 | 1.22 | l |
| V B3 | 84-108 | 10.2 | 0.54 | 0.09 | 6.0 | 40.8 | 33.7 | 26.1 | 1.21 | l |
| V C | 108-128 | 9.4 | 0.24 | 0.11 | 7.9 | 42.0 | 31.2 | 26.8 | 1.34 | l |
| VI C | 128-150 | 9.3 | 0.21 | 0.10 | 5.8 | 54.1 | 26.0 | 19.9 | 2.80 | sl |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+Mg | Na | K | $CO_3$+H $CO_3$ | Cl | $SO_4$ |
| A1 | 9.8 | 1.0 | 0.6 | 6.8 | 0.6 | 69.3 | 34.7 | 9.5 | 4.8 | 7.5 | 41.5 | 0.5 | 19.4 | 28.5 | 0.7 |
| II B1 | 8.4 | 1.5 | 0.5 | 6.4 | 0.4 | 76.2 | 36.8 | 9.8 | 8.2 | 8.0 | 78.6 | 0.6 | 37.4 | 45.0 | 0.9 |
| III B21 | 7.6 | 1.3 | 0.6 | 6.0 | 0.3 | 78.9 | 34.7 | 9.7 | 7.3 | 6.8 | 68.5 | 0.6 | 34.0 | 41.0 | 1.2 |
| IV B22 | 7.8 | 1.5 | 0.6 | 6.0 | 0.3 | 76.9 | 32.4 | 9.7 | 3.0 | 5.2 | 48.2 | 0.4 | 14.8 | 16.4 | 0.8 |
| V B23 | 9.7 | 3.7 | 0.4 | 5.6 | 0.4 | 57.7 | 38.5 | 9.5 | 3.6 | 4.8 | 31.0 | 0.4 | 14.5 | 16.8 | 3.4 |
| V B3 | 10.0 | 4.0 | 0.3 | 5.4 | 0.5 | 54.0 | 39.4 | 9.1 | 2.4 | 3.6 | 20.1 | 0.4 | 8.9 | 14.7 | 0.9 |
| V C | 8.0 | 4.2 | 0.4 | 3.6 | 0.2 | 45.0 | 34.0 | 9.0 | 1.7 | 4.1 | 15.4 | 0.3 | 6.4 | 13.8 | 0.8 |
| VI C | 7.4 | 4.8 | 0.5 | 2.4 | 0.2 | 32.4 | 31.8 | 8.8 | 1.0 | 2.9 | 8.0 | 0.2 | 4.2 | 7.1 | 1.0 |

## Physical and chemical characteristics of Randhirpur series

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| A1 | 0-8 | 10.2 | 2.6 | 0.20 | 1.98 | 48.5 | 32.2 | 18.3 | 1.051 | l |
| B1 | 8-27 | 10.2 | 1.7 | 0.16 | 1.25 | 23.7 | 47.3 | 29.0 | 0.51 | cl |
| B21 | 27-55 | 10.0 | 1.5 | 0.09 | 0.75 | 28.1 | 43.7 | 28.2 | 0.64 | cl |
| B22 | 55-71 | 10.0 | 1.2 | 0.07 | 0.80 | 22.1 | 48.4 | 30.8 | 0.45 | cl |
| B23 | 71-84 | 10.0 | 1.1 | 0.07 | 3.15 | 21.8 | 50.0 | 29.5 | 0.43 | cl |
| B24 | 84-100 | 9.9 | 0.9 | 0.05 | 2.72 | 24.5 | 44.7 | 30.8 | 0.54 | cl |
| B25 | 100-117 | 9.9 | 0.7 | 0.03 | 3.15 | 20.8 | 30.1 | 29.1 | 0.69 | cl |
| B3 | 117-150 | 9.3 | 0.3 | 0.03 | 3.40 | 19.7 | 47.5 | 32.8 | 0.24 | scl |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca+Mg | Na | K | | Sat% | pH | EC | Ca+Mg | Na | K | $CO_3$+$HCO_3$ | Cl | $SO_4$ |
| A1 | 9.2 | 2.0 | 6.5 | 0.5 | 70.8 | 40.7 | 10.0 | 9.2 | 15.0 | 82.5 | 0.3 | 37.5 | 8.1 | 4.2 |
| B1 | 9.2 | 2.1 | 5.9 | 0.6 | 64.1 | 37.5 | 10.0 | 7.3 | 13.0 | 69.8 | 0.3 | 36.0 | 8.1 | 5.1 |
| B21 | 7.7 | 2.5 | 4.7 | 0.4 | 61.0 | 40.5 | 9.8 | 6.7 | 11.2 | 60.2 | 0.2 | 35.5 | 7.5 | 2.8 |
| B22 | 7.9 | 2.4 | 4.8 | 0.5 | 61.0 | 43.2 | 9.8 | 5.7 | 12.5 | 48.4 | 0.2 | 51.2 | 6.5 | 2.9 |
| B23 | 9.8 | 2.0 | 5.4 | 0.3 | 55.1 | 46.5 | 9.7 | 5.2 | 5.0 | 43.8 | 0.2 | 50.0 | 5.6 | 2.9 |
| B24 | 12.0 | 5.6 | 6.0 | 0.4 | 50.0 | 48.0 | 9.6 | 4.2 | 3.8 | 46.2 | 0.3 | 42.6 | 5.6 | 3.2 |
| B25 | 12.2 | 5.5 | 6.4 | 0.2 | 51.6 | 48.0 | 9.7 | 3.1 | 3.6 | 26.8 | 0.1 | 30.5 | 5.2 | 0.8 |
| B3 | 12.5 | 7.5 | 4.7 | 0.3 | 36.7 | 45.2 | 9.1 | 1.9 | 2.7 | 19.6 | 0.1 | 15.0 | 5.0 | 1.0 |

**Physical and chemical characteristics of Fajewal series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand: silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-16 | 9.6 | 0.65 | 0.06 | 1.1 | 18.5 | 65.8 | 15.7 | 0.28 | sil |
| B1 | 16-49 | 9.7 | 0.70 | 0.04 | 0.5 | 19.6 | 62.8 | 17.6 | 0.31 | sil |
| B21 | 49-65 | 9.8 | 0.70 | 0.07 | 1.9 | 18.9 | 59.7 | 21.4 | 0.31 | sil |
| B22 | 65-86 | 9.6 | 0.50 | 0.09 | 0.7 | 24.6 | 59.5 | 20.9 | 0.41 | sil |
| B23 | 86-100 | 9.5 | 0.60 | 0.03 | 1.8 | 22.8 | 52.6 | 24.6 | 0.43 | l |
| B3 | 100-120 | 9.0 | 0.40 | 0.02 | 1.6 | 26.7 | 50.5 | 22.8 | 0.52 | sil |
| C | 120-150 | 8.7 | 0.30 | 0.03 | 1.9 | 20.4 | 41.9 | 17.9 | 0.48 | l |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 8.9 | 2.1 | 0.8 | 5.7 | 0.3 | 64.0 | 34.3 | 9.3 | 2.1 | 4.8 | 15.0 | 0.3 | 14.8 | 6.1 | 0.30 |
| B1 | 9.5 | 2.2 | 0.9 | 6.0 | 0.4 | 63.1 | 35.7 | 9.4 | 1.9 | 3.2 | 14.8 | 0.2 | 12.6 | 6.8 | 0.80 |
| B21 | 9.2 | 2.1 | 1.1 | 5.6 | 0.4 | 60.8 | 36.4 | 9.4 | 1.9 | 3.6 | 15.2 | 0.2 | 13.0 | 6.5 | 3.40 |
| B22 | 10.0 | 4.0 | 0.7 | 5.1 | 0.3 | 51.0 | 35.8 | 9.2 | 1.3 | 3.2 | 9.7 | 0.2 | 8.8 | 4.5 | 1.90 |
| B23 | 10.5 | 4.2 | 1.1 | 4.9 | 0.2 | 47.0 | 36.3 | 9.1 | 1.3 | 3.6 | 9.4 | 0.3 | 8.7 | 4.8 | 1.70 |
| B3 | 8.5 | 4.1 | 1.1 | 3.0 | 0.3 | 35.2 | 35.3 | 8.1 | 1.2 | 6.8 | 5.2 | 0.3 | 8.0 | 4.6 | 0.40 |
| C | 8.0 | 3.0 | 1.0 | 2.8 | 0.2 | 35.0 | 30.5 | 8.3 | 1.2 | 5.0 | 3.7 | 0.2 | 5.0 | 3.8 | 0.40 |

**B: Normal soil samples**

**Physical and chemical characteristics of Dhoda series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand: silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-14 | 8.3 | 0.30 | 0.56 | 0.0 | 64.8 | 21.4 | 14.8 | 3.02 | sl |
| 11 B1 | 14-27 | 8.3 | 0.28 | 0.37 | 0.0 | 50.7 | 28.5 | 20.8 | 1.77 | l |
| 11 B21 | 27-42 | 8.3 | 0.28 | 0.24 | 0.0 | 50.0 | 31.5 | 18.5 | 1.58 | l |
| 11 B22 | 42-52 | 8.2 | 0.24 | 0.26 | 0.0 | 44.0 | 32.0 | 24.0 | 1.37 | l |
| 11 B23 | 52-60 | 8.3 | 0.22 | 0.18 | 0.0 | 39.7 | 31.8 | 28.5 | 1.24 | cl |
| 111 B24 | 60-83 | 8.4 | 0.12 | 0.18 | 0.0 | 28.8 | 36.0 | 35.2 | 0.80 | cl |
| 111 B25 | 83-98 | 8.3 | 0.18 | 0.16 | 0.0 | 23.7 | 38.5 | 37.8 | 0.61 | cl |
| 1V B31 | 98-120 | 8.1 | 0.14 | 0.14 | 0.0 | 35.0 | 29.8 | 35.2 | 1.20 | cl |
| V B31 | 120-139 | 8.2 | 0.14 | 0.14 | 0.0 | 47.4 | 28.0 | 24.6 | 1.68 | scl |
| V1 B32 | 139+ | 8.1 | 0.15 | 0.12 | 0.0 | 54.9 | 21.5 | 23.6 | 2.55 | scl |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 8.8 | 5.4 | 2.3 | 0.8 | 0.2 | 9.1 | 34.2 | 8.0 | 1.4 | 10.5 | 4.2 | 0.2 | 8.5 | 5.4 | 2.8 |
| 11 B1 | 7.5 | 4.7 | 1.8 | 0.8 | 0.2 | 10.6 | 35.7 | 8.0 | 1.5 | 10.5 | 4.2 | 0.2 | 7.8 | 6.8 | 2.9 |
| 11 B21 | 7.0 | 4.3 | 1.8 | 0.6 | 0.3 | 8.6 | 37.8 | 7.9 | 1.3 | 8.2 | 3.9 | 0.3 | 8.0 | 4.9 | 1.2 |
| 11 B22 | 9.8 | 7.6 | 2.1 | 0.6 | 0.4 | 6.1 | 39.8 | 7.9 | 1.0 | 7.6 | 2.1 | 0.3 | 6.5 | 3.7 | 0.8 |
| 11 B23 | 10.5 | 7.0 | 2.5 | 0.6 | 0.4 | 5.2 | 41.6 | 7.8 | 1.0 | 7.2 | 2.3 | 0.2 | 5.1 | 3.9 | 0.2 |
| 111 B24 | 11.0 | 7.8 | 2.3 | 0.5 | 0.4 | 4.5 | 43.8 | 8.0 | 0.6 | 3.4 | 2.0 | 0.2 | 3.1 | 2.4 | 0.4 |
| 111 B25 | 12.8 | 9.2 | 2.9 | 0.5 | 0.2 | 3.8 | 42.9 | 7.8 | 0.7 | 3.4 | 2.6 | 0.3 | 3.4 | 2.1 | 1.0 |
| 1V B31 | 14.0 | 10.4 | 2.7 | 0.4 | 0.4 | 3.0 | 44.5 | 7.9 | 0.5 | 3.1 | 1.9 | 0.2 | 2.8 | 2.4 | 0.2 |
| V B31 | 10.2 | 8.5 | 1.2 | 0.4 | 0.3 | 3.7 | 46.6 | 7.9 | 0.5 | 2.8 | 1.8 | 0.2 | 2.2 | 2.6 | 0.3 |
| V1 B32 | 7.1 | 5.2 | 1.3 | 0.4 | 0.2 | 4.9 | 32.1 | 7.7 | 0.4 | 1.9 | 1.4 | 0.1 | 1.4 | 2.2 | 0.3 |

**Physical and chemical characteristics of Tulewal series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size Distribution (%) | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-13 | 8.3 | 0.35 | 0.52 | 0.7 | 64.3 | 22.5 | 13.2 | 2.81 | sl |
| A3 | 13-30 | 8.6 | 0.30 | 0.27 | 0.6 | 62.6 | 21.0 | 16.4 | 2.98 | sl |
| 11 B1 | 30-43 | 8.5 | 0.32 | 0.28 | 0.0 | 58.6 | 23.2 | 18.2 | 0.52 | sl |
| 11B21 | 43-62 | 8.3 | 0.34 | 0.19 | 0.0 | 57.2 | 22.4 | 20.4 | 2.50 | scl |
| 111 B22 | 62-80 | 8.4 | 0.23 | 0.11 | 0.0 | 46.2 | 20.8 | 23.0 | 2.70 | scl |
| 1V B23 | 80-117 | 8.3 | 0.22 | 0.16 | 0.0 | 53.0 | 29.4 | 17.6 | 1.80 | sl |
| V B24 | 117-131 | 8.4 | 0.23 | 0.18 | 0.0 | 55.8 | 28.2 | 16.0 | 1.98 | sl |
| V1 B31 | 131-149 | 8.5 | 0.23 | 0.18 | 0.0 | 64.8 | 19.8 | 15.4 | 3.27 | sl |
| V11 B32 | 149-160 | 8.5 | 0.31 | 0.15 | 0.0 | 74.8 | 13.0 | 12.2 | 5.75 | sl |
| V111C1 | 160-175 | 8.4 | 0.20 | 0.12 | 0.0 | 82.0 | 8.4 | 9.6 | 9.76 | ls |
| V111 C2 | 175+ | 8.3 | 0.20 | 0.12 | 0.0 | 92.4 | 4.8 | 2.8 | 19.25 | s |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (Me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 7.5 | 5.0 | 1.3 | 1.0 | 0.2 | 13.3 | 32.0 | 8.1 | 1.4 | 9.5 | 4.8 | 0.2 | 9.2 | 3.9 | 3.0 |
| A3 | 8.2 | 5.4 | 1.2 | 1.2 | 0.3 | 14.6 | 31.0 | 8.3 | 1.1 | 8.3 | 2.6 | 0.2 | 7.0 | 3.1 | 3.7 |
| 11 B1 | 8.8 | 6.3 | 1.4 | 0.8 | 0.3 | 9.11 | 34.3 | 8.2 | 0.8 | 7.0 | 2.7 | 0.3 | 6.4 | 3.0 | 1.2 |
| 11B21 | 8.5 | 6.1 | 1.4 | 0.7 | 0.3 | 8.2 | 37.4 | 8.0 | 1.2 | 9.0 | 2.4 | 0.3 | 7.2 | 5.2 | 0.7 |
| 111 B22 | 9.6 | 6.9 | 1.7 | 0.7 | 0.3 | 7.2 | 39.3 | 8.0 | 1.1 | 8.8 | 2.1 | 0.2 | 7.8 | 3.6 | 0.5 |
| 1V B23 | 9.8 | 7.5 | 1.4 | 0.7 | 0.2 | 7.1 | 40.4 | 8.0 | 1.1 | 8.1 | 2.0 | 0.3 | 7.0 | 3.6 | 0.2 |
| V B24 | 11.0 | 8.8 | 1.3 | 0.6 | 0.3 | 5.4 | 42.0 | 8.1 | 1.3 | 8.6 | 3.1 | 0.2 | 6.5 | 5.2 | 0.8 |
| V1 B31 | 10.2 | 8.8 | 1.3 | 0.5 | 0.3 | 4.9 | 40.6 | 8.1 | 1.0 | 6.0 | 3.2 | 0.2 | 5.8 | 4.1 | 0.6 |
| V11 B32 | 8.5 | 7.3 | 0.9 | 0.4 | 0.1 | 4.7 | 40.5 | 8.2 | 0.6 | 4.1 | 2.0 | 0.3 | 5.2 | 2.0 | 0.2 |
| V111C1 | 6.0 | 4.7 | 0.8 | 0.3 | 0.1 | 5.0 | 37.6 | 8.0 | 0.4 | 2.6 | 1.5 | 0.2 | 2.7 | 1.8 | 0.2 |
| V111 C2 | 3.4 | 2.4 | 0.5 | 0.2 | 0.2 | 5.9 | 21.4 | 8.0 | 0.5 | 2.3 | 1.6 | 0.2 | 2.4 | 1.5 | 0.2 |

**Physical and chemical characteristics of Samana series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-11 | 8.2 | 0.35 | 0.58 | 0.0 | 68.8 | 20.0 | 14.2 | 3.44 | sl |
| 11 B1 | 11-28 | 8.4 | 0.32 | 0.31 | 0.0 | 59.8 | 26.0 | 14.2 | 2.30 | sl |
| 111 B21 | 28-45 | 8.4 | 0.16 | 0.29 | 0.0 | 54.8 | 28.2 | 17.0 | 1.94 | sl |
| 111B22 | 45-72 | 8.3 | 0.25 | 0.23 | 0.0 | 54.0 | 27.4 | 18.6 | 1.96 | sl |
| 1V B23 | 72-102 | 8.1 | 0.20 | 0.19 | 0.0 | 65.0 | 18.0 | 17.0 | 3.61 | sl |
| V B24 | 102-122 | 7.9 | 0.23 | 0.17 | 0.0 | 68.8 | 15.2 | 16.0 | 4.52 | sl |
| V B25 | 122-146 | 8.0 | 0.30 | 0.16 | 0.0 | 69.7 | 15.5 | 14.8 | 4.49 | sl |
| V B3 | 146-165 | 7.8 | 0.21 | 0.19 | 0.0 | 71.4 | 16.4 | 13.2 | 4.35 | sl |

| Horizon | C.E.C ($cmol_c$/kg) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (Me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 6.2 | 4.6 | 0.7 | 0.5 | 0.3 | 8.1 | 29.4 | 8.0 | 1.35 | 9.1 | 4.3 | 0.4 | 8.0 | 3.8 | 2.40 |
| 11 B1 | 7.9 | 6.2 | 0.7 | 0.5 | 0.3 | 6.1 | 30.1 | 8.1 | 1.20 | 8.5 | 3.1 | 0.3 | 7.3 | 2.7 | 1.10 |
| 111 B21 | 8.0 | 6.6 | 0.5 | 0.6 | 0.2 | 7.5 | 32.0 | 8.1 | 0.80 | 6.7 | 1.2 | 0.3 | 5.8 | 2.1 | 0.60 |
| 111B22 | 8.8 | 7.1 | 0.7 | 0.7 | 0.2 | 7.9 | 32.5 | 8.0 | 0.95 | 6.7 | 1.4 | 0.2 | 6.7 | 2.4 | 0.45 |
| 1V B23 | 9.1 | 7.3 | 0.7 | 0.6 | 0.2 | 6.5 | 33.2 | 7.8 | 0.85 | 6.6 | 1.6 | 0.2 | 6.8 | 1.6 | 0.20 |
| V B24 | 9.2 | 7.4 | 0.8 | 0.5 | 0.3 | 5.4 | 32.0 | 7.6 | 0.98 | 7.2 | 1.8 | 0.2 | 7.8 | 1.5 | 0.20 |
| V B25 | 9.5 | 7.5 | 1.0 | 0.5 | 0.3 | 5.2 | 30.9 | 7.6 | 1.20 | 9.2 | 2.0 | 0.3 | 9.5 | 2.0 | 0.70 |
| V B3 | 7.5 | 6.3 | 0.6 | 0.4 | 0.1 | 5.3 | 30.7 | 7.5 | 1.00 | 7.8 | 1.8 | 0.2 | 8.0 | 1.8 | 0.30 |

## Physical and chemical characteristics of Ucha series

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-19 | 8.3 | 0.21 | 0.38 | 1.8 | 75.0 | 17.0 | 8.0 | 4.41 | sl |
| 11 C1 | 19-36 | 8.2 | 0.27 | 0.16 | 3.4 | 70.0 | 22.0 | 8.0 | 3.48 | sl |
| 11 C2 | 36-50 | 8.2 | 0.20 | 0.17 | 1.8 | 68.0 | 21.0 | 11.0 | 3.23 | sl |
| 111 C3 | 50-69 | 8.1 | 0.26 | 0.15 | 5.5 | 66.0 | 24.0 | 10.0 | 2.75 | sl |
| 1V C4 | 69-87 | 8.1 | 0.13 | 0.09 | 0.4 | 98.0 | 2.0 | NIL | 49.00 | s |
| V C5 | 87-104 | 8.4 | 0.07 | 0.09 | 0.3 | 98.0 | 2.0 | NIL | 49.00 | s |
| V C6 | 104-122 | 8.3 | 0.14 | 0.07 | 3.2 | 86.0 | 11.0 | 3.0 | 7.81 | sl |
| V1 C7 | 122-150 | 8.2 | 0.11 | 0.05 | 2.2 | 97.0 | 2.0 | 1.0 | 48.50 | s |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca+Mg | Na | K | | Sat% | pH | EC | Ca+Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 6.8 | 5.9 | 0.8 | 0.1 | 11.7 | 28.0 | 8.2 | 0.90 | 5.6 | 4.3 | 0.1 | 3.4 | 5.7 | 0.8 |
| 11 C1 | 6.1 | 5.2 | 0.6 | 0.2 | 9.8 | 29.5 | 8.0 | 0.98 | 5.4 | 4.2 | 0.3 | 4.4 | 5.2 | 0.6 |
| 11 C2 | 6.7 | 6.0 | 0.6 | 0.2 | 8.9 | 31.0 | 8.0 | 0.85 | 4.8 | 3.9 | 0.1 | 4.6 | 4.0 | 9.7 |
| 111 C3 | 6.5 | 5.2 | 0.4 | 0.2 | 6.4 | 31.8 | 8.0 | 0.79 | 4.1 | 3.6 | 0.1 | 3.8 | 4.2 | 1.8 |
| 1V C4 | 4.2 | 3.8 | 0.3 | 0.2 | 7.1 | 19.3 | 7.9 | 0.50 | 3.8 | 1.4 | 0.1 | 3.0 | 2.5 | 0.5 |
| V C5 | 4.7 | 4.2 | 0.3 | 0.2 | 6.3 | 24.8 | 8.2 | 0.42 | 3.5 | 1.2 | 0.1 | 2.9 | 2.5 | 0.8 |
| V C6 | 3.8 | 3.4 | 0.3 | 0.2 | 7.3 | 26.5 | 8.1 | 0.49 | 3.6 | 1.1 | 0.2 | 2.9 | 2.3 | 0.4 |
| V1 C7 | 3.4 | 3.0 | 0.3 | 0.1 | 7.3 | 27.8 | 8.0 | 0.28 | 3.0 | 1.0 | 0.1 | 2.0 | 1.3 | 0.2 |

**Physical and chemical characteristics of Fattu Dhinga series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-11 | 8.5 | 0.41 | 0.47 | 0.5 | 73.6 | 15.6 | 10.8 | 4.71 | sl |
| 11 A3 | 11-28 | 8.7 | 0.28 | 0.43 | 0.3 | 69.8 | 21.8 | 8.4 | 3.20 | l |
| 111 B21 | 28-58 | 8.9 | 0.29 | 0.30 | 0.4 | 64.6 | 23.2 | 12.2 | 2.78 | sl |
| 1V B22 | 58-85 | 8.6 | 0.37 | 0.23 | 2.8 | 69.4 | 17.9 | 12.7 | 3.87 | sl |
| V B23 | 85-117 | 8.6 | 0.42 | 0.22 | 2.2 | 63.0 | 28.8 | 8.2 | 2.18 | sl |
| V1 B24 | 117-133 | 8.5 | 0.39 | 0.19 | 2.5 | 69.8 | 22.6 | 7.6 | 3.08 | sl |
| V11 B3 | 133-152 | 8.6 | 0.32 | 0.19 | 1.4 | 70.4 | 24.0 | 5.6 | 2.93 | sl |
| V111 C | 152+ | 8.5 | 0.23 | 0.14 | 1.2 | 78.6 | 16.6 | 4.8 | 4.73 | ls |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (Me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 9.5 | 6.7 | 1.7 | 0.8 | 0.3 | 8.4 | 35.5 | 8.0 | 1.10 | 9.6 | 1.3 | 0.4 | 5.5 | 6.0 | 2.0 |
| 11 A3 | 8.7 | 6.1 | 1.4 | 0.9 | 0.3 | 10.3 | 35.5 | 8.2 | 0.90 | 7.0 | 1.2 | 0.3 | 4.2 | 4.7 | 1.6 |
| 111 B21 | 7.9 | 5.7 | 1.2 | 0.7 | 0.3 | 8.3 | 33.4 | 8.3 | 0.95 | 7.2 | 2.2 | 0.2 | 4.2 | 5.4 | 0.8 |
| 1V B22 | 7.5 | 5.6 | 1.0 | 0.6 | 0.3 | 7.8 | 38.8 | 8.3 | 0.90 | 7.2 | 2.0 | 0.3 | 4.0 | 5.8 | 0.5 |
| V B23 | 6.8 | 4.8 | 1.3 | 0.5 | 0.3 | 7.3 | 36.4 | 8.3 | 1.00 | 8.4 | 1.8 | 0.3 | 4.2 | 5.9 | 2.2 |
| V1 B24 | 5.8 | 4.1 | 1.1 | 0.5 | 0.2 | 7.7 | 36.0 | 8.2 | 1.20 | 8.8 | 1.8 | 0.3 | 3.4 | 6.0 | 2.2 |
| V11 B3 | 5.9 | 4.3 | 0.9 | 0.5 | 0.1 | 7.6 | 34.8 | 8.1 | 0.96 | 8.2 | 1.4 | 0.2 | 2.6 | 5.2 | 1.2 |
| V111 C | 4.2 | 2.7 | 1.0 | 0.3 | 0.2 | 5.9 | 29.0 | 8.0 | 0.80 | 6.8 | 1.2 | 0.2 | 2.2 | 5.0 | 0.8 |

**Physical and chemical characteristics of Nathupur series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| A1 | 0-10 | 8.9 | 0.23 | 0.12 | 0.12 | 93.8 | 3.9 | 3.9 | 24.0 | s |
| 11 C | 10-29 | 8.7 | 0.20 | 0.06 | 0.06 | 99.0 | 0.5 | 0.5 | 198.0 | s |
| 111 C | 29-34 | 8.6 | 0.16 | 0.19 | 0.20 | 84.2 | 9.6 | 6.2 | 8.7 | s |
| IV V | 34-70 | 8.3 | 0.18 | 0.09 | 0.40 | 99.0 | 0.3 | 0.7 | 330.0 | s |
| V C | 70-150 | 8.3 | 0.16 | 0.12 | 0.60 | 98.0 | 1.1 | 0.9 | 8.9 | s |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| A1 | 1.3 | 0.7 | 0.2 | 0.15 | 0.2 | 11.5 | 29.8 | 8.4 | 0.75 | 4.6 | 2.5 | 0.3 | 3.8 | 4.0 | 0.1 |
| 11 C | 0.9 | 0.5 | 0.2 | 0.10 | 0.1 | 11.1 | 18.4 | 8.3 | 0.60 | 5.6 | 1.4 | 0.2 | 3.0 | 3.4 | 0.2 |
| 111 C | 1.3 | 0.3 | 0.4 | 0.10 | 0.2 | 7.1 | 21.6 | 8.2 | 0.45 | 3.8 | 0.8 | 0.1 | 2.0 | 2.6 | 0.2 |
| IV V | 0.8 | 0.3 | 0.2 | 0.10 | 0.2 | 12.5 | 20.0 | 7.9 | 0.68 | 5.4 | 1.1 | 0.2 | 2.5 | 3.9 | 0.1 |
| V C | 0.7 | 0.3 | 0.2 | 0.06 | 0.1 | 8.5 | 19.7 | 7.8 | 0.60 | 5.0 | 0.9 | 0.2 | 2.6 | 3.8 | 0.1 |

**Physical and chemical characteristics of Mund series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-15 | 8.4 | 0.15 | 0.43 | 1.2 | 72.3 | 18.5 | 9.2 | 3.90 | sl |
| II C | 15-24 | 8.4 | 0.15 | 0.37 | 1.4 | 74.6 | 17.6 | 7.8 | 4.23 | sl |
| III C | 24-40 | 8.4 | 0.14 | 0.29 | 1.3 | 58.3 | 23.0 | 18.7 | 2.53 | sl |
| IV C | 40-60 | 8.4 | 0.06 | 0.17 | 0.9 | 71.0 | 22.8 | 6.2 | 3.11 | sl |
| V C | 60-68 | 8.3 | 0.07 | 0.13 | 1.5 | 84.3 | 12.9 | 2.8 | 6.53 | ls |
| VI C | 68-83 | 8.5 | 0.09 | 0.11 | 1.9 | 62.6 | 28.4 | 9.0 | 2.20 | sl |
| VII C | 83-96 | 8.4 | 0.07 | 0.09 | 0.4 | 65.5 | 26.0 | 8.5 | 2.51 | sl |
| VIII C | 96-150 | 8.1 | 0.05 | 0.10 | 0.0 | 96.4 | 2.6 | 1.0 | 37.07 | s |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 4.5 | 2.9 | 1.00 | 0.40 | 0.20 | 8.8 | 41.8 | 8.2 | 0.68 | 5.00 | 1.30 | 0.20 | 4.3 | 2.3 | 3.9 |
| II C | 3.8 | 3.0 | 0.45 | 0.35 | 0.10 | 9.2 | 38.3 | 8.1 | 0.65 | 4.85 | 1.20 | 0.30 | 4.1 | 2.3 | 2.2 |
| III C | 7.8 | 6.0 | 1.00 | 0.65 | 0.15 | 8.3 | 41.5 | 8.1 | 0.54 | 3.20 | 1.00 | 0.25 | 3.2 | 2.2 | 2.0 |
| IV C | 3.5 | 2.8 | 0.50 | 0.15 | 0.15 | 4.3 | 40.3 | 8.2 | 0.34 | 3.30 | 0.90 | 0.15 | 1.9 | 1.6 | 0.8 |
| V C | 1.2 | 0.7 | 0.30 | 0.10 | 0.20 | 8.3 | 35.3 | 8.2 | 0.36 | 2.70 | 0.75 | 0.15 | 1.9 | 1.8 | 0.4 |
| VI C | 5.4 | 3.9 | 0.85 | 0.50 | 0.15 | 8.2 | 37.5 | 8.2 | 0.45 | 3.10 | 0.50 | 0.15 | 2.3 | 1.8 | 0.6 |
| VII C | 4.8 | 3.1 | 0.90 | 0.55 | 0.20 | 11.5 | 40.0 | 8.1 | 0.32 | 2.40 | 0.60 | 0.10 | 1.8 | 1.2 | 0.4 |
| VIII C | 0.8 | 0.4 | 0.30 | 0.06 | 0.10 | 8.0 | 31.1 | 7.8 | 0.25 | 1.65 | 0.35 | 0.15 | 1.2 | 1.1 | 0.3 |

## Physical and chemical characteristics of Bahanra series

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size Distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0.21 | 7.5 | 0.08 | 0.03 | 0.0 | 96.2 | 1.3 | 2.5 | 74.0 | s |
| II C | 21-55 | 7.2 | 0.09 | 0.03 | 0.0 | 95.8 | 0.8 | 2.4 | 119.3 | s |
| III C | 55-72 | 7.1 | 0.07 | 0.04 | 0.0 | 94.5 | 1..9 | 3.7 | 48.6 | s |
| IV C | 72-100 | 7.6 | 0.08 | 0.05 | 0.0 | 95.0 | 3.2 | 1.8 | 29.3 | s |
| V C | 100-120 | 7.5 | 0.07 | 0.12 | 0.0 | 95.6 | 2.4 | 2.0 | 39.8 | s |
| VI C | 120-150 | 7.2 | 0.06 | 0.16 | 0.0 | 96.1 | 1.9 | 2.2 | 50.5 | s |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | E.S.P | Saturated paste and saturation extract analysis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca+Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 2.0 | 1.8 | 0.02 | 0.04 | 1.0 | 26.5 | 7.3 | 0.2 | 1.5 | 1.0 | 0.2 | 1.6 | 0.6 | 0.10 |
| II C | 2.0 | 1.4 | 0.01 | 0.10 | 0.5 | Nd* | 7.0 | 0.3 | 2.2 | 1.1 | 0.3 | 2.8 | 0.6 | 0.05 |
| III C | 2.5 | 2.4 | 0.01 | 0.10 | 0.4 | 25.5 | 7.0 | 0.5 | 5.5 | 1.6 | 0.2 | 4.4 | 2.6 | 0.10 |
| IV C | 1.3 | 1.2 | 0.10 | 0.15 | 7.6 | Nd | 7.2 | 0.7 | 4.8 | 1.5 | 0.2 | 4.4 | 1.8 | 0.50 |
| V C | 1.0 | 0.8 | 0.03 | 0.05 | 3.0 | 25.0 | 7.3 | 0.5 | 3.2 | 1.4 | 0.2 | 3.9 | 0.5 | 0.30 |
| VI C | 1.0 | 0.8 | 0.02 | 0.05 | 2.0 | Nd | 7.1 | 0.5 | 3.1 | 1.3 | 0.1 | 3.4 | 0.9 | 0.30 |

**Physical and chemical characteristics of Kanjili series**

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-10 | 8.8 | 0.28 | 0.48 | 2.50 | 36.4 | 40.3 | 22.3 | 0.90 | l |
| B21 | 10-35 | 8.6 | 0.21 | 0.43 | 2.30 | 32.5 | 41.3 | 26.2 | 0.78 | cl |
| B22 | 35-63 | 8.7 | 0.22 | 0.32 | 2.80 | 25.8 | 38.2 | 36.0 | 0.67 | cl |
| B23 | 63-94 | 8.5 | 0.21 | 0.33 | 0.90 | 27.0 | 35.8 | 37.2 | 0.75 | cl |
| II B24 | 94-114 | 8.5 | 0.19 | 0.28 | 2.10 | 40.6 | 29.0 | 30.4 | 1.39 | cl |
| III B31 | 114-130 | 8.3 | 0.35 | 0.25 | 0.50 | 25.6 | 24.6 | 22.8 | 2.13 | scl |
| IV B32 | 130-150 | 8.5 | 0.35 | 0.25 | 0.40 | 61.5 | 20.1 | 18.4 | 3.05 | sl |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 10.6 | 7.0 | 16 | 1.7 | 0.4 | 15.4 | 36.5 | 8.5 | 1.3 | 9.8 | 2.9 | 0.3 | 4.2 | 5.4 | 3.8 |
| B21 | 12.5 | 8.8 | 1.9 | 1.4 | 0.4 | 11.2 | 44.8 | 8.4 | 1.2 | 8.6 | 2.7 | 0.2 | 4.0 | 5.0 | 2.9 |
| B22 | 12.0 | 9.9 | 2.1 | 1.7 | 0.3 | 14.1 | 47.5 | 8.5 | 1.1 | 7.8 | 3.2 | 0.4 | 3.8 | 4.1 | 1.6 |
| B23 | 13.0 | 9.1 | 2.4 | 1.2 | 0.4 | 9.2 | 45.2 | 8.3 | 1.0 | 6.4 | 3.7 | 0.2 | 2.8 | 3.7 | 3.2 |
| II B24 | 12.5 | 9.5 | 1.7 | 1.0 | 0.3 | 7.9 | 42.8 | 8.3 | 0.9 | 5.9 | 4.0 | 0.2 | 2.4 | 2.9 | 2.3 |
| III B3 | 11.8 | 9.3 | 1.1 | 1.0 | 0.2 | 8.4 | 38.2 | 8.0 | 1.2 | 6.7 | 5.0 | 0.3 | 2.6 | 4.2 | 3.0 |
| IV B32 | 9.0 | 7.0 | 0.9 | 0.9 | 0.2 | 10.0 | 37.0 | 8.0 | 0.9 | 4.9 | 4.6 | 0.1 | 1.6 | 3.8 | 2.5 |

## Physical and chemical characteristics of Fatehpur series

| Horizon | Depth (cm) | pH (1:2) | EC (1:2) | OC (%) | $CaCO_3$ (%) | Particle size distribution | | | Sand:silt ratio | Texture classes (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand (%) | Silt (%) | Clay (%) | | |
| Ap | 0-15 | 7.7 | 0.25 | 0.12 | 0.0 | 92.4 | 4.0 | 3.6 | 23.1 | s |
| II C1 | 15-55 | 7.5 | 0.17 | 0.06 | 0.0 | 87.1 | 5.9 | 7.0 | 14.7 | ls |
| II C2 | 55-82 | 8.3 | 0.23 | 0.19 | 0.0 | 84.9 | 6.4 | 8.7 | 13.2 | ls |
| III C | 82-102 | 8.5 | 0.21 | 0.08 | 0.0 | 85.6 | 7.8 | 6.6 | 10.9 | ls |
| IV C | 102-150 | 8.3 | 0.14 | 0.03 | 0.0 | 88.3 | 6.5 | 5.2 | 13.4 | ls/s |

| Horizon | C.E.C (me/100g) | Exchangeable cations (Me/100 g) | | | | E.S.P | Saturated paste and saturation extract analysis (me/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | | Sat% | pH | EC | Ca+ Mg | Na | K | $CO_3$+ $HCO_3$ | Cl | $SO_4$ |
| Ap | 3.2 | 2.1 | 0.6 | 0.2 | 0.3 | 6.4 | 24.0 | 7.2 | 1.2 | 5.8 | 7.0 | 0.3 | 4.9 | 8.5 | 0.40 |
| II C1 | 4.1 | 2.9 | 0.7 | 0.2 | 0.3 | 5.3 | 32.7 | 7.2 | 0.9 | 4.7 | 4.1 | 0.4 | 3.2 | 5.5 | 0.80 |
| II C2 | 5.0 | 3.2 | 1.1 | 0.5 | 0.3 | 9.0 | 28.0 | 8.0 | 1.5 | 5.3 | 9.8 | 0.4 | 6.8 | 9.6 | 0.20 |
| III C | 3.6 | 1.9 | 1.0 | 0.3 | 0.4 | 8.3 | 30.7 | 8.3 | 0.9 | 5.4 | 5.2 | 0.2 | 4.0 | 6.2 | 0.20 |
| IV C | 3.4 | 2.0 | 1.0 | 0.3 | 0.2 | 8.8 | 26.8 | 8.0 | 0.6 | 2.6 | 4.0 | 0.1 | 2.3 | 3.5 | 0.35 |

**Appendix III: Taxonomy of salt affected soils in Kapurthala district (Sharma *et a la*., 1982)**

| **Soil series** | **Order** | **Sub-order** | **Great group** | **Subgroup** | **Family** |
|---|---|---|---|---|---|
| Jagjitpur<br>Randhirpur<br>Fajewal<br>Khairanwali | Ardisols | Orthids | Camborthids | Natric Ustochreptic Camborthids | Fine loamy, mixed Hyperthermic |
| Domeli | Ardisols | Orthids | Camborthids | Aquic Camborthids | Fine loamy Mixed hyperthermic |
| Rawalpindi | Inceptisols | Ochrepts | Ustochrepts | Aquic Ustochrepts | Fine loamy, mixed hyperthermic |

**Appendix-IV: Taxonomy of normal soils in Kapurthala district (Sharma *et al.*, 1982)**

| Soil series | Order | Sub-order | Great group | Subgroup | Family |
|---|---|---|---|---|---|
| Dhoda | Inceptisols | Ochrepts | Ustochrepts | Udic Ustochrepts | Fine loamy mxed hyperthermic |
| Kanjili Fattu Dhinga | Inceptisols | Ochrepts | Ustochrepts | Typic Ustochrepts | Fine loamy mixed hyperthermic |
| Tulewal | Inceptisols | Ochrepts | Ustochrepts | Udic Ustochrepts | Fine loamy, mixed hyperthermic |
| Samana | Inceptisols | Ochrepts | Ustochrepts | Udic Ustochrepts | Coarse loamy, mimed hyperthermic |
| Fattu Dhinga Ucha | Inceptisols | Ochrepts | Ustochrepts | Fluventic Ustifluvents | Coarse loamy mixed hyperthermic |
| Mund | Entisols | Fluvents | Ustifluvents | Typic Ustipsamments | Mixed, hyperthermic |
| Fatehpur Nathupur | Entisols | Psamments | Ustipsamments | Fluventic Ustipsamments | Mixed hyperthermic |
| Bahanra | Entisols | Psamments | Ustipsamments | Typic Ustipsamments | Mixed hyperthermic |

**Appendix-V: Aria, production and yield of major crop in India (1950-2016)**

| Year | Wheat | | | Rice | | |
|---|---|---|---|---|---|---|
| | Area | Production | Yield | Area | Production | Yield |
| **1950-51** | 9.75 | 6.46 | 663 | 30.81 | 20.58 | 668 |
| **1960-61** | 12.93 | 11.00 | 851 | 34.13 | 34.58 | 937 |
| **1970-71** | 18.24 | 23.83 | 1307 | 37.59 | 42.22 | 1123 |
| **1980-81** | 22.28 | 36.31 | 1630 | 40.15 | 53.63 | 1336 |
| **1990-91** | 24.17 | 55.14 | 2281 | 42.69 | 74.29 | 1740 |
| **2000-01** | 25.73 | 69.68 | 2708 | 44.71 | 84.98 | 1901 |
| **2010-11** | 29.07 | 86.87 | 2988 | 42.86 | 95.98 | 2239 |
| **2011-12** | 29.86 | 94.88 | 3177 | 44.01 | 105.30 | 2393 |
| **2012-13** | 30.00 | 93.55 | 3117 | 42.75 | 105.23 | 2461 |
| **2013-14** | 30.47 | 95.85 | 3146 | 44.14 | 106.65 | 2416 |
| **2014-15** | 31.47 | 86.53 | 2750 | 44.11 | 105.46 | 2391 |
| **2015-16** | 30.42 | 92.22 | 3034 | 43.50 | 104.41 | 2400 |

| Year | Maize | | | Pulses | | |
|---|---|---|---|---|---|---|
| | Area | Production | Yield | Area | Production | Yield |
| **1950-51** | 3.16 | 1.73 | 547 | 19.09 | 8.41 | 441 |
| **1960-61** | 4.41 | 4.08 | 926 | 23.56 | 12.70 | 539 |
| **1970-71** | 5.85 | 7.49 | 1279 | 22.54 | 11.82 | 524 |
| **1980-81** | 6.01 | 6.96 | 1159 | 22.46 | 10.63 | 473 |
| **1990-91** | 5.90 | 8.96 | 1518 | 24.66 | 14.26 | 578 |
| **2000-01** | 6.61 | 12.04 | 1822 | 20.35 | 11.08 | 544 |
| **2010-11** | 8.55 | 21.73 | 2542 | 26.40 | 18.24 | 691 |
| **2011-12** | 8.87 | 21.76 | 2478 | 24.46 | 17.09 | 699 |
| **2012-13** | 8.67 | 22.26 | 2566 | 23.26 | 18.34 | 789 |
| **2013-14** | 9.07 | 24.26 | 2676 | 25.21 | 19.25 | 764 |
| **2014-15** | 9.19 | 24.17 | 2632 | 23.55 | 17.15 | 728 |
| **2015-16** | 8.81 | 22.57 | 2563 | 24.91 | 16.35 | 656 |

**Appendix- VI: Area, production and yield of major crops in Punjab (1950-2018)**

| Year | Wheat | | | Rice | | |
|---|---|---|---|---|---|---|
| | Area | Production | Yield | Area | Production | Yield |
| 1950-51 | 1137 | | 1024 | 120 | | 892 |
| 1960-61 | 1400 | | 1747 | 227 | | 1009 |
| 1971-72 | 2336 | 5618 | 2405 | 450 | 920 | 2044 |
| 1981-82 | 2914 | 8544 | 2932 | 1269 | 3750 | 2955 |
| 1991-92 | 3237 | 12309 | 3803 | 2069 | 6739 | 3257 |
| 2001-02 | 3420 | 15499 | 4532 | 2487 | 8816 | 3545 |
| 2009-10 | 3522 | 15169 | 4307 | 2802 | 11236 | 4010 |
| 2010-11 | 3510 | 16472 | 4693 | 2826 | 10819 | 3828 |
| 2012-13 | 3512 | 16591 | 3998 | 2845 | 11374 | 4729 |
| 2013-14 | 3512 | 17620 | 5017 | 2851 | 11267 | 3922 |
| 2014-15 | 3505 | 15088 | 4304 | 2894 | 11107 | 3838 |
| 2015-16 | 3506 | 16068 | 4583 | 2970 | 11830 | 3974 |
| 2017-18 | 3512 | 17830 | 5777 | 3065 | 13382 | 4366 |

| Year | Maize | | | Pulses | | |
|---|---|---|---|---|---|---|
| | Area | Production | Yield | Area | Production | Yield |
| 1950-51 | | | | | | |
| 1960-61 | | | | | | |
| 1971-72 | 548 | 857 | 1564 | 384 | 302 | 786 |
| 1981-82 | 340 | 625 | 1838 | 325 | 161 | 495 |
| 1991-92 | 176 | 345 | 1962 | 90 | 75 | 833 |
| 2001-02 | 165 | 449 | 2722 | 49 | 30 | 612 |
| 2009-10 | 139 | 475 | 3414 | 18 | 16 | 842 |
| 2010-11 | 133 | 491 | 3693 | 20 | 17 | 850 |
| 2012-13 | 124 | | 3680 | | 12 | |
| 2013-14 | 130 | | 3894 | | 12 | |
| 2014-15 | 126 | | 3652 | | 9.1 | |
| 2015-16 | 127 | | 3683 | | 10.0 | |
| 2017-18 | 114 | | 3706 | | 9.0 | |

**Appendix-VII: Indicators of input used during the Green Revolution in Asia**

| Country | Irrigated area (% of agriculture area) | | Fertilizer ( kg/ha) | | Annual growth rate in agriculture work force | Annual growth rate in agricultural land area |
|---|---|---|---|---|---|---|
| | **1970** | **1995** | **1970** | **1995** | **1967-82** | **1967-82** |
| Bangladesh | 11.60 | 376.0 | 15.70 | 135.50 | 1.070 | 0.050 |
| China | 37.20 | 37.00 | 43.00 | 346.10 | 1.920 | 0.030 |
| India | 18.40 | 31.80 | 13.70 | 81.90 | 1.590 | 0.190 |
| Indonesia | 15.00 | 15.20 | 9.20 | 84.70 | 1.410 | 0.000 |
| Malaysia | 5.90 | 4.50 | 43.60 | 148.60 | 1.570 | 1.030 |
| Myanmar | 8.00 | 15.40 | 2.10 | 16.90 | 1.930 | -0.210 |
| Nepal | 5.90 | 29.80 | 2.70 | 31.60 | 1.820 | 1.560 |
| Pakistan | 67.00 | 79.60 | 14.60 | 116.10 | 2.410 | 0.330 |
| Philippines | 11.00 | 16.60 | 28.90 | 63.40 | 1.900 | 1.720 |
| South Korea | 51.50 | 60.80 | 251.70 | 486.70 | -0.070 | -0.380 |
| Sri Lanka | 24.60 | 29.20 | 55.50 | 106.00 | 1.690 | -0.050 |
| Thailand | 14.20 | 22.70 | 5.90 | 76.50 | 2.170 | 2.520 |
| Vietnam | 16.00 | 29.60 | 50.70 | 214.30 | 1.580 | 0.540 |
| **Total** | 25.50 | 33.20 | 23.90 | 171.10 | 1.760 | 0.280 |