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Shifting soil dynamics: Unveiling physicochemical changes in Punjab region

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Abstract
A review conducted in the state of Punjab, located in north-west India, within the geographical coordinates of $73^0$53 and $76^0$55 E longitude and $29^0$33 and $32^0$31 N latitude. The review covers a total area of 503,762 square kilometers. The Punjab region is renowned for its exceptional fertility within the Indian subcontinent. Following the green revolution, the soil in the Punjab region has deteriorated due to the widespread practice of intensive agriculture and commercial farming. This review provides an overview of multiple research studies conducted over a ten-year period on the physiochemical features of soil in the Punjab region. Our focus is on studying the alterations in the physiochemical characteristics of soil resulting from intensive agricultural practices. The soil in the Punjab region is undergoing desertification due to unsustainable farming practices, resulting in significant negative effects on crop productivity and soil fertility. To comprehend the dynamic nature of soil physiochemical characteristics, it is necessary to review previous research studies. This study of soil focuses on its physio-chemical properties, which include factors such as pH, electrical conductivity, texture, soil organic carbon, accessible nitrogen, phosphorus, and potassium. This information will benefit anybody with an interest in pursuing a career in the agricultural industry.

Keywords: Physiochemical properties, Punjab region, Punjab soil order, soil type

Introduction

India encompasses a total geographic area of 328 million hectares, accounting for 2.5% of the world's total land area. Punjab possesses a varied topography spanning an area of 50,362 km^2 located in the north-western region of the country. It accounts for 1.54% of India's overall land area. Punjab is widely recognized as one of the most agriculturally productive states in India. Approximately 84% of the state's land is used for agriculture, whereas only 6% is shaded by forests. Through forest restoration and agroforestry practices, Punjab has managed to increase the amount of forest land from 3.72% in 1966 to 6.07% in 2012. Punjab is a major producer of rice and wheat, accounting for approximately 20-30% and 10^{-1}2% of the total production, respectively. Additionally, Punjab contributes around 9^{-1}1% of cotton production, 20-30% of honey production, 45-50% of mushroom production, and 9^{-1}0% of milk production. Punjab has been the largest producer of food grain from 1960-61 to 2007-08, with production increasing from 3.16 to 26 million tons. It has maintained its status as the top producer till the year mentioned (Maninder *et al.*, 2020) [27]. The predominant agricultural system in Punjab is rice-wheat, which covers 60 percent of the total farmed land. The average productivity of rice (unhusked paddy) is 6.0 tons per hectare, while wheat has an average output of 4.7 tons per hectare. Punjab's cropping intensity stands at 190.3 percent. The implementation of the green revolution in Punjab, India involved the application of significant amounts of inorganic fertilizer. This led to alterations in the physiochemical characteristics of the soil, negatively impacting its health. Consequently, this may contribute to a future increase in nutrient deficiencies in Indian agriculture, exacerbating the crisis of nutrient scarcity. The Punjab region is primarily partitioned into three distinct regions known as Doaba, Majha, and Malwa.

Doaba region

Doaba region of Punjab, located between the Sutlej and Beas rivers, is renowned for its exceptional fertility and is commonly referred to as the "Center of the green revolution." Doaba encompasses around 6402 km2 of Punjab's total territory, predominantly characterized by alluvial soil. The majority of this region exhibits the soil order of inceptisol, with a subgroup classification of ustic. The climatic condition of this region is characterized by a sub-humid environment, resulting in significant variations in temperature between summer and winter. The southwest monsoon, which occurs from June to September, accounts for approximately 80 percent of the total rainfall received during this period. The Doaba region comprises the districts of Jalandhar, Kapurthala, Hoshiarpur, and Nawan Shahr.

Majha Region

The Majha division of Punjab is located in the northwestern part of Punjab, covering an area of around 5182 square kilometers. The distance of 7 square kilometers encompasses the region located between the Beas and Ravi rivers. The northern section of Sutlej, beyond the point where Beas and Sutlej rivers meet in Tarn Taran district, and stretching up to the Ravi River, is also included in the Majha region (Singh *et al.*, 2021) [45]. The term "Majha" signifies being positioned in the middle or at the center. The geographical location of this area lies in the central part of the traditional Punjab province, which is why it is referred to as Majha. The 4 districts of Punjab that are included in this region are Amritsar, Gurdaspur, Pathankot, and Tarn Taran (Kumar, 2021) [22].

Malwa region

The territory on the opposite side of the Sutlej River in the Punjab region is known as Malwa. It encompasses an approximate area of 48780 square kilometers in Punjab and consists of two subsoil orders, ustic and udic (Bast and Balasubrahmanyan 2021) [2]. This region encompasses around 60-70% of the total land area of Punjab state. The region includes fifteen districts of Punjab: Barnala, Bathinda, Fatehgarh Sahib, Faridkot, Fazilka, Firozpur, Ludhiana, Mansa, Moga, Mohali, Muktsar, Patiala, Ropar, and Sangrur (Central Ground Water Board Punjab, 2016) [8]. The Malwa region is classified as having a semi-arid climate. The average temperature fluctuates between 5 °C during the winter months (December-January) and 45 °C during the summer months (May-June). The region experiences an average annual precipitation of 600 mm. However, the majority of this rainfall, around 70%, is concentrated between the months of July and September, mostly due to the influence of the southwest monsoon season (Meena *et al.*, 2024) [29].

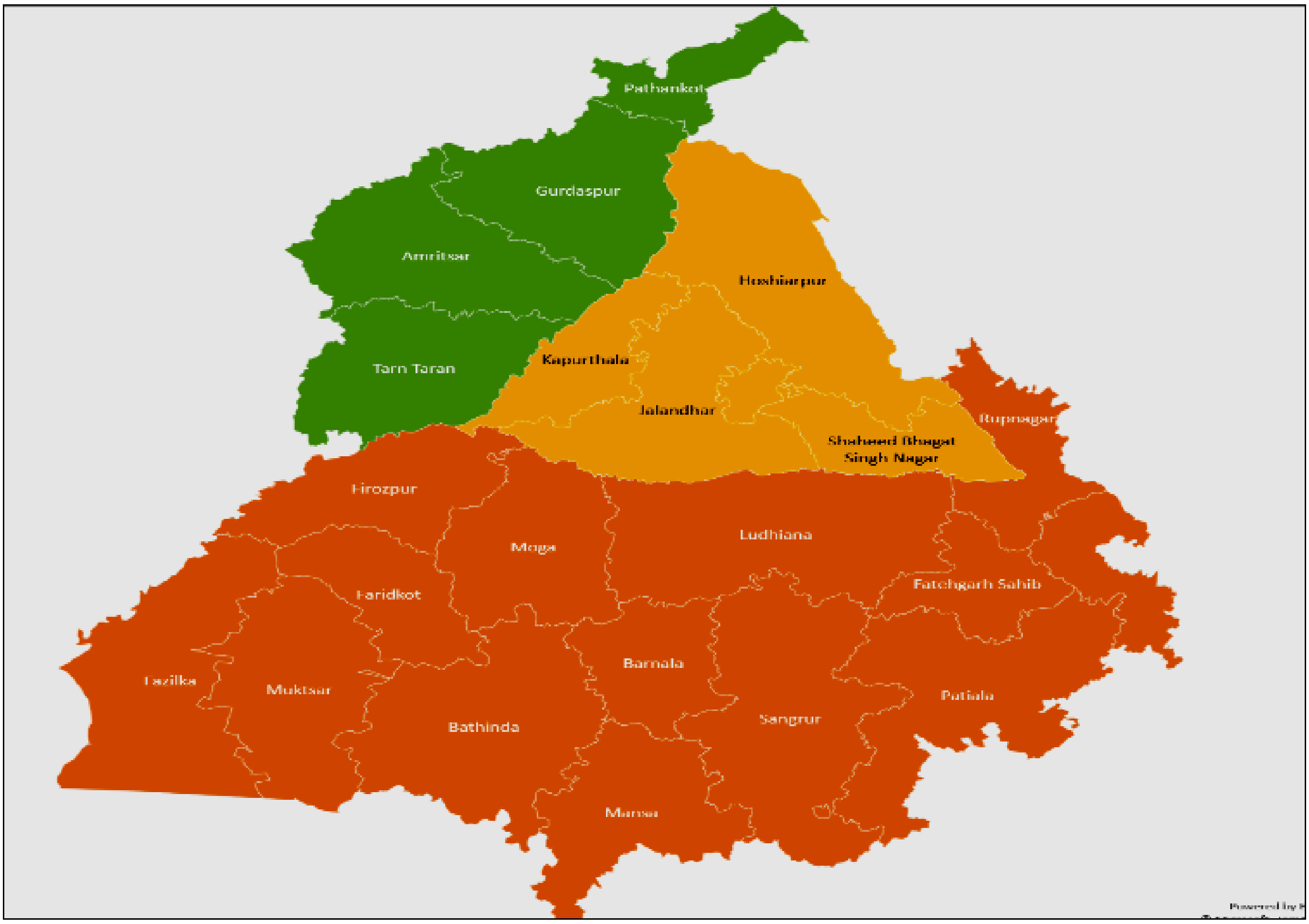

Fig 1: Malwa region

Soil of Punjab

The soil in Punjab is classified as three different moisture regimes: ustic zone, udic zone, and Aridic zone.

Ustic zone

Encompasses a significant portion of the Doaba region as well as most of the Majha and Malwa regions. The soil orders present in this region are Entisols, Inceptisols, Entisols-Inceptisols, and

Inceptisols-Alfisols (Sagar, 2017) [38]. Ustic zone soil has developed in the central Punjab region, which experiences semi-arid and moderately hot climatic conditions. These circumstances are different from the aridic zone soils found in the south-western part of the region (Sharma *et al.*, 2005) [41].

Udic zone

Udic zone is in the northeastern part of Punjab and encompasses the district of Pathankot. The soil order consists of Entisols, Inceptisols, and Inceptisols of the udic zone, as described by Kumar *et al.* in 2008 [23]. The topographic area of this zone consists of hills, a piedmont plain, and a flood plain, with a composition of fertile sand and silt loam. The soil quality is likewise devoid of macronutrients. Areas with adequate irrigation but limited water supply may experience issues with soil alkalinity or salinity. Additionally, arid regions may face significant erosion concerns (Chopra 1990) [9].

Aridic zone

Aridic zone is in the southwestern part of Punjab and includes four districts: Fazilka, Muktsar, and Bhatinda in the Malwa region. The majority of this area has soil types classified as Entisols, Aridisols, Entisols-Inceptisols, and Entisols-Aridisols. Some areas in this region are currently covered by a layer of wind-blown sand. This area is characterized by a prevailing dry and hot environment. The soils experience prolonged periods of aridity during the majority of the year. The surface of the soil consists of light-colored sandy loam to loam soils with a pH ranging from 8.0 to 8.3. Lime nodules are present in the sub-surface horizon of these soils. An ochric epipedon is a layer of soil that is found within one meter of the surface and is situated above a cambic and/or calcic horizon. Dry circumstances greatly increase the susceptibility of soil to air erosion, and this type of soil is deficient in macronutrients (Singh *et al.*, 2016) [47].

Physical properties of soil

Soil texture

Soil texture is a significant factor in determining the composition percentage of soil. The composition of sand, silt, and clay, which is immutable, may be quantified both in the field and in a laboratory setting. Soil texture has a significant impact on soil quality, particularly in terms of aeration, root penetration, and the uptake of soil nutrients. Soil texture can be accurately determined by measuring its electrical conductivity.

Table 1: Soil texture

Majha region						
District	**Author**	**Year**	**Sand**	**Silt**	**Clay**	**Texture**
Amritsar	Singh *et al.*	2020	49-69%	22-38%	7-21%	Loam- sandy loam
Gurdaspur	Elbaalawy *et al.*,	2016	31.5	46.5	22	Loam
Tarn Taran	Bhatt, R., & Singh, M.	2021	64.30%	28.90%	6.80%	Sandy loam
Doaba region						
District	**Author**	**Year**	**Sand**	**Silt**	**Clay**	**Texture**
Hoshiarpur	Kukal *et al.*,	2004	81.2	9.5	9.3	Loamy sand
Jalandhar	Raya *et al.*,	2004	82.58	8.05	9.37	Loamy sand
Jalandhar	Sharma *et al.*,	2017	79.75	21.58	6.69	Sandy Loam
Jalandhar	Surya *et al.*,	2019	45.03-94.05	9.00 - 28.72	7.55-34.25	Sandy loam to loamy sand
Kapurthala	Bhatt *et al.*,	2020	----------	-------------	--------	Sandy Loam -clay loam
SBS Nagar	Bhusan *et al.*,	2009	56.6-89.7%	6.4-37.6	3.3-8.6	Sandy Loam Loamy Sand
Malwa Region						
District	**Author**	**Year**	**Sand**	**Silt**	**Clay**	**Texture**
Barnala	Elbaalawy *et al.*	2016	55.8	20.5	23.6	Sandy clay loam
Bhatinda	Elbaalawy *et al.*,	2016	55.9	20.5	23.6	Sandy clay loam
Sangrur	Elbaalawy *et al.*,	2016	62.8	20.6	16.6	Sandy loam
Ludhiana	Singh, B., & Sharma, K. N.	2007			-	Loamy sand-silt loam
Ludhiana	Elbaalawy *et al.*,	2016	87.9	8.2	3.9	Sandy
Ropar	Kukal *et al.*,	2004	59.6	25.9	14.7	Sandy loam

The predominant texture of the soil in the Doaba region, which includes Hoshiarpur and Jalandhar, is primarily loamy sand. While certain areas of Jalandhar and Kapurthala are characterized by sandy loam soil, as indicated by Kukal *et al.*, (2004) [20], Raya *et al.*, (2004) [36], Sharma *et al.*, (2017) [42], Surya *et al.*, (2019) [50], Bhatt *et al.*, (2020) [5]. The Majha region soil texture in the districts of Amritsar, Gurdaspur, and Tarn Taran has been classified as loamy to sandy loam by researchers Singh *et al.*, (2020) [48], Elbaalawy *et al.*, (2006) [11], and Bhatt and Singh (2021) [3] accordingly. The present investigation in the Malwa region found that much of the area has soil texture ranging from sandy clay loam to sandy loam. The southern half of the Malwa region, including Barnala, Bhatinda, and Ludhiana districts, has identified a soil texture that is sandy clay loam. Elbaalawy *et al.*, (2016) also documented the presence of sandy soil in this area.

Chemical properties of soil

pH: Soil pH is determined by the negative logarithm of the concentration of hydrogen ions [H+]. It is measured on a scale from 0 to 14. A pH of 7 is considered neutral, representing pure water. A pH less than 7 indicates acidity, whereas a pH greater than 7 indicates alkalinity (Graham, 2006) [13].

The pH of soil has a substantial impact on the availability of nutrients, the accessibility of trace elements, the biochemical processes, and the microbial activity in the soil, all of which affect plant development and biomass production. Soil pH is characterized as substantial variations in soil acidity or alkalinity. The pH of soil is affected by both acidic substances and ions that constitute the foundation of soil. Common cations that form acidic ions include hydrogen (H+), aluminum (Al3+), and iron (Fe2+ or Fe3+). On the other hand, typical cations that form basic ions include calcium (Ca2+), magnesium (Mg2+), potassium (K+), and sodium (Na+). Earthworms contribute to pH alteration (5%) and, in conjunction with microbial decomposition, help maintain a lower pH in vermicast (Elvira *et al.*, Panjgotra *et al.*, 2019) [32].

Table 2: pH

Doaba Region				
District	**Author**	**Year**	**pH**	**Range**
Hoshiarpur	Jatav *et al.*,	2013	5.0-8.2	Moderate acidic-moderate alkaline
Hoshiarpur	Sunita *et al.*,	2020	6.5-9.3	Slightly acidic -strong alkaline
Jalandhar	Sharma *et al.*,	2017	7.33	Slightly alkaline
Jalandhar	Surya *et al.*,	2019	7.1 -8.8	Neutral -strong alkaline
Majha region				
District	**Author**	**Year**	**pH**	**Range**
Amritsar	Kaur *et al.*	2014	8.14-8.25	Moderate alkaline
Amritsar	Singh *et al.*	2020	5.73±0.19 -8.77±0.51	Moderate acid- mod. alkaline
Amritsar	Sharma, *et al.*,	2019	7-8.9	Neutral -moderate alkaline
Amritsar	Kaur *et al.*	2019	8.2 -9.0.	Moderate-strong alkaline
Amritsar	Singh *et al.*	2016	8.03-9.36	Moderate-strong alkaline
Amritsar	Panjgotra *et al.*	2019	7.51±0.04	Slightly alkaline
Gurdaspur	Sekhon	2012	6.6	Slightly Acidic
Gurdaspur	Dhillon *et al.*	2004	6.8	Slightly Acidic
Gurdaspur	Elbaalawy *et al.*	2016	7.32	Slightly Alkaline
Tarn Taran	Bhatt.R and Singh. p	2017	7.10 - 9.30	Slightly-hight alkaline
Tarn Taran	Bhatt, R., & Singh, M.	2021	8.13	moderate alkaline
Malwa region				
District	**Author**	**Year**	**pH**	**Range**
Barnala	Elbaalawy *et al.*	2016	8.52	Moderate alkaline
Barnala	Singh *et al.*	2016	8.0-9.1	Moderate to high alkaline
Bhatinda	Elbaalawy *et al.*	2016	8.31	Moderate alkaline
Bhatinda	Yadav *et al.*	2016	8.27-8.52	alkaline
Bhatinda	Brijesh kumar Yadav	2020	8.2-8.6	Moderate alkaline
Ferozpur	Singh *et al.*	2016	7.5-9.1	Slight alkaline -strong alkaline
Faridkot	Kang, *et al.*	2010	8.5-9.4	Moderate- strong alkaline
Faridkot	Verma *et al.*	2008	7.14- 9.98.	Slightly alkaline-strong alkaline
Moga	Panjgotra *et al.*	2019	7.50±0.03	Neutral - slightly alkaline
Fathegarh sahib	Kumar *et al.*	2020	4.9-7.79	Strong acidic -slightly alkaline
Mansa	Mittal *et al.*	2020	6.5-7.5	Slightly acidic-slightly alkaline
Mansa	Verma, *et al.*	2005	8.16 - 9.62	Moderate alkaline - strange alkaline
Sangrur	Elbaalawy *et al.*	2016	8.66	Moderate alkaline
Ludhiana	Walia, U. S.	2011	7.5	Slight alkaline
Ludhiana	Singh, B., & Sharma, K. N.	2007	7.55-8.30	Slightly alkaline - moderate alkaline
Ludhiana	Elbaalawy *et al.*	2016	7.7	Slightly alkaline
Rupnagar	Kaur, R., & Goyal, D	2014	8.22 ± 0.1	Moderate alkaline
Rupnagar	Sekhon *et al.*	2012	8.1	Moderate alkaline

The researcher analyzed the soil pH and found that the majority of the soil in the region is alkaline, as shown in Table (). The northern part of the Doaba region, including the Hoshiarpur region, has soil that is slightly acidic in nature. This could be attributed to the higher rainfall in this area compared to the rest of the Doaba region. This information is supported by studies conducted by Jatav *et al.* (2013) [15] and Sunita *et al.* (2020). The soil in the southern and western parts of the Doaba region is classified as slightly to moderately alkaline, according to studies 2009 [16] by Rafie *et al.* (2021) [34], Bhusan *et al.* (2009), and Kang *et al.* (2011). Pangotra *et al.* (2019) reported that the soil in the eastern doaba region is likewise classified as alkaline, which aligns with the findings of Garecha (2016).

Majha region range from acidic to strongly alkaline, with the majority of the land classified as moderately alkaline to slightly alkaline. Kaur *et al.* (2014) [18] found that the soil pH in the district of Amritsar ranged from slightly alkaline to high alkaline. This finding was also supported by Singh *et al.* (2020) [48], Sharma *et al.* (2019) [43], Kaur *et al.* (2019) [19], Singh *et al.* (2016) [47], and Panjgotra *et al.* (2019) [32]. Similarly, Bhatt and Singh (2017) [4] and Bhatt and Singh (2021) [3] observed similar results in Tran Taran. The soil in the Gurdaspur district has a pH level that ranges from slightly acidic to slightly alkaline, as indicated by the investigation reports of Sekhon (2012) [40], Dhillon *et al.* (2006), and Elbaalawy *et al.* (2006) [11].

The fluctuation in pH levels in the Malwa region may be attributed to the alterations in soil composition, namely the presence of Inceptisols and Inceptisols-Aridisols.

The majority of districts in the Malwa region have a moderate alkaline composition. In their investigation, Harmandeep *et al.* (2008) observed that the Malwa region has a slightly alkaline and strong alanine composition. Elbaalawy *et al.* (2006) [11] discovered that the district of Barnala, Bhatinda has a pH level of moderate alkalinity. Similar findings were reported by Singh *et al.* (2016) [47] and Yadav *et al.* (2020) [55]. Some researchers have also discovered that the districts of Faridkot, Ferozpur, Mansa, and Barnala have a high alkaline content. The references cited are Kang, *et al.*, (2010) and Verma *et al.*, (2008) [52]. The remaining districts, including Moga, Mansa, and Ludhiana in the Malwa area, have a slightly alkaline nature. The following studies have been conducted: Panjgotra *et al.* (2019) [32], Mittal *et al.* (2020) [30], Singh *et al.* (2007) [44], and Elbaalawy *et al.* (2006) [11]. The districts of Fazilka, Faridkot, Muktsar, and Bhatinda in southwestern Punjab feature aridisols and entisols-aridisols soil orders. These soil types have little water holding ability, leading to soil accumulation and increased pH levels.

Electrical Conductivity

The electrical conductivity of the solution is directly linked to the presence of fully charged cations or anions in the solution.

The ions present in soil solution can be classified as cations (Ca++, Mg++, K+, Na+, H+) or anions (NO3-, SO4-, Cl-, HCO3-, CO3-, OH-). Electricity is commonly used to determine the salt content of the earth. However, it may also be used to measure the amount of soluble nutrients, including both cations and anions. Therefore, within a specific range, the electrical conductivity (EC) will indicate efficient absorption of nutrients by plants, whereas the lower end will indicate nutrient-deficient and readily scattered soils, as well as issues with salt tolerance. EC units are commonly expressed as mhos/cm, mmhos/cm, or 1/1000 mhos/cm, which are equivalent to Siemens per meter (S/m) or Deci Siemens meter (dS/m). The link between these two units is millimhos per centimeter equals deciSiemens.

Table 3: Electrical conductivity

Doaba Region				
District	**Author**	**Year**	**EC**	**Range**
Hoshiarpur	Sunita *et al.,*	2020	0.16-0.67 mmhos cm^{-1}	Non-saline
Jalandhar	Sharma *et al.,*	2017	0.04 to 0.19 dSm^{-1}.	Non-saline
Kapurthala	Singh *et al.,*	2016	0.1 to 1.9 dSm^{-1}	Non-saline
Kapurthala	Jaihoon rafie *et al.,*	2019	Below 1 dSm^{-1}	Non-saline
Kapurthala	Bhat and Singh	2020	0.38 mmhos cm^{-1}	Non-saline
SBS nagar	Panjgotra *et al.,*	2019	0.61±0.01	Non-saline
SBS Nagar	Bhusan *et al.,*	2008	0.149	Non-saline
SBS Nagar	Garecha *et al.,*	2016	0.27	Non-saline
Nawan shahr	Kang, *et al.,*	2011	0.2 to 0.3	Non-saline
Majha Region				
District	**Author**	**year**	**EC**	**Ranges**
Amritsar	Singh *et al.*	2020	214.32±0.95 µS cm^{-1}	Very slightly saline
Amritsar	Sharma *et al.*	2019	247-2042 µS cm^{-1}	Very slightly saline
Amritsar	Kaur *et al.*	2019	0.20 to 1.00 mS cm^{-1}	Non-saline
Amritsar	Panjgotra *et al.*	2019	0.61±0.08 dSm^{-1}	Non-saline
Gurdaspur	Sekhon *et al.,*	2012	0.07 dSm^{-1}	Non-saline
Gurdaspur	Dhillon and Dhillon	2004	0.27 dSm^{-1}	Non-saline
Gurdaspur	Elbaalawy *et al.,*	2006	0.11 dSm^{-1}	Non-saline
Tarn Taran	Bhatt.R and singh. P	2017	0.10 to 0.52 m mho cm^{-1}	Non-saline
Malwa Region				
District	**Author**	**Year**	**EC**	**Range**
Barnala	A m Elbaalawy *et al.,*	2016	0.33 dSm^{-1}	Non-saline
Barnala	Singh *et al.,*	2016	0.07-34 dSm^{-1}	Non-saline
Bhatinda	A m Elbaalawy *et al.,*	2016	0.86 dSm^{-1}	Non-saline
Bhatinda	Yadav *et al.,*	2016	0.16 to 0.26 dSm^{-1}	Non-saline
Bhatinda	kumar *et al.,*	2016	0.08-0.99 dSm^{-1}	Non-saline
Bhatinda	Brijeshkumar Yadav	2020	0.38 $^{-1}$.29 dSm^{-1}	Non-saline
Ferozpur	Singh *et al.,*	2016	0.13-1.05 dSm^{-1}	Non-saline
Faridkot	Kang *et al.,*	2009	0.2 to 0.4 dSm^{-1}	Non-saline
Fathegarh sahib	kumar *et al.,*	2020	228-1001 µS/cm	Non-saline
Mansa	Verma *et al.,*	2005	0.07 to 0.77 dSm^{-1}	Non-saline
Moga	Panjgotra *et al.,*	2019	0.62±0.01 dSm^{-1}	Non-saline
Sangrur	Elbaalawy *et al.,*	2016	0.21 dSm^{-1}	Non-saline
Ludhiana	Walia, M. K., & Walia, S. S.	2011	0.32 dSm^{-1}	Non-saline
Ludhiana	Walia, U. S.	2011	0.42 dSm^{-1}	Non-saline
Ludhiana	Singh, B., & Sharma, K. N.	2007	0.29-0.65 dSm^{-1}	Non-saline
Ludhiana	Elbaalawy *et al.,*	2006	0.06 dSm^{-1}	Non-saline
Rupnagar	Kaur, R., & Goyal, D	2015	2.45 - 3.75 µS cm^{-1}	Very slightly saline
Rupnagar	Sekhon *et al.,*	2012	0.24 dSm^{-1}	Non-saline

Research undertaken by several groups to estimate the electrical conductivity of the Doaba region revealed that the majority of the soil in the area is non-saline in nature. The electrical conductivity ranged from 0.2 to 1.9 mmhos/cm. The aforementioned agreement was reached by Sunita *et al.*, 2020, Sharma *et al.*, (2017) [42], Singh *et al.*, (2016) [47]; Bhat and Singh (2020) [5], Panjgotra *et al.*, (2019) [32].

In the malwa region, the soil's electrical conductivity ranges from somewhat saline to non-saline. The Amritsar district is located in the central part of the Majha region and the northwestern part of Punjab. Salinity has been recorded in certain areas of the district, as documented by Singh *et al.* (2020) [48] and confirmed by Sharma *et al.* (2019) [43]. The researchers Sekhon *et al.*, (2012) [40], Dhillon and Dhillon (2004) [10], Elbaalawy *et al.*, (2006) [11], and Bhatt.R and singh.P have determined that the soil in the Gurdaspur and Tarn Tran districts has low electrical conductivity and is non-saline.

Malwa region indicates that the soil's electrical conductivity is non-saline. The researcher has gathered data from the years 2006 to 2020 for all districts in Malwa. The data shows that the electrical conductivity levels in these districts are consistently below 1 dSm^{-1}, which is within the normal range. In their study, Elbaalawy *et al.* (2016) [11] found that the soil in different districts of the Malwa region, namely Bhatinda, Barnala, Sangrur, and Ludhiana, falls under the non-saline category. Similar results were observed in the districts of Ferozpur, Faridkot, Fathegarh Sahib, Mansa, Moga, Sangrur, Ludhiana, and Rupnagar by Singh *et al.* (2016) [47], Kang *et al.* (2009) [16], Kumar *et al.* (2020) [25], Verma *et al.* (2005) [51], Panjgotra *et al.* (2019) [32], Elbaalawy *et al.* (2016) [11], and Walia, M. K., &

Walia, S. S. (2011) [53]. Sekhon *et al.* (2012) [40]. The researchers Kaur, R., & Goyal, D conducted a study in Rupnagar district to analyze a soil sample taken near the Guru Gobind Singh Super Thermal Power Plant in Ropar. The results showed that the soil had a small salinity, which is likely due to pollution from the ash produced by the thermal plant's industrial waste. The non-saline electrical conductivity refers to the range of soil salinity that does not have any detrimental impact on plants in terms of soil salinity and crop tolerance.

Organic carbon

In order to promote soil fertility, plant protection, and agricultural sustainability, soil organic carbon is an important indication of soil health. There are two types of carbon in soil: organic carbon, which is found in organic matter, and inorganic carbon, which is abundant in carbonate minerals. Soil carbonate minerals, which are present at the start of parental activity, are formed during melting, hence not all soils contain inorganic C. All agricultural soil contains organic carbon, though. When the soil is dry and composed of calcareous parent material, the inorganic concentration often exceeds the organic C content. The carbon found in soil is an element of the soil's organic composition. Carbon accounts for most of the organic matter's mass (58%), with water and various nutrients like potassium and nitrogen making up the rest. Soils that are rich in organic carbon provide several benefits, including improved water retention, increased microbial activity, a lower pH, regulation of various soil physiochemical properties, and a more favorable response to nitrogen fertilizer. Composted organic materials, such as animal manure, compost, etc., can be applied to soil. Soil organic matter decreases as one moves down the slope, because of balance.

Table 4: Organic carbon

Doaba region				
District	**Author**	**Year**	**OC**	**Range**
Hoshiarpur	Kukal. *et al.,*	2004	0.09-0.33	low
Hoshiarpur	Jatav *et al.,*	2013	0.3- >0.5	Low-medium
Hoshiarpur	Sunita *et al.,*	2020	0.45-0.77%	Low-medium
Jalandhar	Sharma *et al.,*	2017	0.43 g kg-1	low
Jalandhar	Surya *et al.,*	2019	0.12 to 0.76	Low-medium
Kapurthala	Singh	2016	0.15 - 1.07	Low -high
Kapurthala	Bhat and Singh	2020	87%low	Low-medium
SBS nagar	Panjgotra	2019	0.54 ± 0.02	medium
SBS Nagar	Bhusan *et al.,*	2008	0.09 - 0.421	low
SBS Nagar	Garecha *et al.,*	2016	0.20 - 47	Low- medium
Nawan shahar	Kang *et al.,*	2011	0.4 to 0.6	Low-medium
Majha region				
District	**Author**	**year**	**OC**	**Range**
Amritsar	Singh *et al.,*	2020	1.89 ± 0.25%	High
Amritsar	Singh *et al.,*	2016	1.62	High
Amritsar	Panjgotra *et al.,*	2019	0.50 ± 0.01	Medium
Tarn Taran	Bhatt.R and Singh P	2017	0.4 to 0.75%	Low-Medium
Tarn Taran	Bhatt, R., & Singh, M.	2021	0.61%	medium
Gurdaspur	Singh *et al.,*	2016	0.18 - 1.20	Low-high
Gurdaspur	Paul O.O *et al.,*	2012	4.5	low
Gurdaspur	Dhillon *et al.,*	2004	0.38	low
Gurdaspur	Elbaalawy *et al.,*	2006	0.64	Medium
Malwa region.				
District	**Author**	**Year**	**OC**	**Range**
Barnala	Elbaalawy *et al.,*	2016	0.79%	high
Barnala	Singh *et al.,*	2016	0.15-0.72	Low
Bhatinda	Elbaalawy *et al.,*	2016	1.27%	high
Bhatinda	Yadav *et al.,*	2016	3.2 to 8.7 g kg^{-1}	Low -medium
Bhatinda	kumar *et al.,*	2016	0.12-1.10%	Low- High
Ferozpur	Singh *et al.,*	2016	0.06-0.63	Low-medium
Faridkot	Kang, *et al.,*	2009	0.2 to 0.6%	Low-medium
Mansa	Verma *et al.,*	2005	0.02-0.40%	low
Moga	panjgotra *et al.,*	2019	0.45 ± 0.02%	low
Sangrur	Elbaalawy *et al.,*	2016	0.65%	low
Ludhiana	Hargopal, S., & Pritpal, S	2011	0.26	low
Ludhiana	Walia, M. K., & Walia, S. S.	2011	0.31%	low
Ludhiana	Walia, U. S.	2011	0.473%	low
Ludhiana	Singh, B., & Sharma, K. N.	2007	2.15-8.23	medium
ROPAR	Kukal *et al.,*	2004	0.33	low

Most of the soil in the Doaba region is within the medium category in terms of organic carbon content. The researchers' studies are provided in tables. The organic carbon content in soil ranges from 0.09% to 1.0%. Except for the southern part of the Doaba region, the district of Kapurthala has soil with a medium to high organic carbon concentration.

There is a favorable correlation between high levels of organic carbon in soil and agricultural productivity. Singh (2016) [49] and Bhat and Singh (2020) [5]. All remaining districts, namely Hoshiarpur, Jalandhar, SBS Nagar, and Nawan Shahar, exhibit low to medium levels of organic carbon. The following studies have been referenced: Kukal *et al.* (2004) [20], Jatav *et al.* (2013)

[15], Sharma *et al.* (2017) [42], Surya *et al.* (2019) [50], Panjgotra *et al.* (2019) [32].

The soil in the Majha region generally has a moderate level of organic carbon concentration. The researcher Singh *et al.* (2016, 2020) [47] discovered a high concentration of organic carbon in the soil in Amritsar district, followed by medium levels in Tran Taran. Bhatt. R and Singh.P (2017) [4] and Bhatt, R., & Singh, M. (2021) [3] also found similar results. In Gurdaspur, the soil has a low organic carbon content. Paul *et al.* (2012), Dhillon *et al.* (2004) [10], and Elbaalawy *et al.* (2006) [11].

The data acquired from the research conducted in the Malwa region indicates that almost half of the region has a soil organic carbon level ranging from high to medium. While the southern middle part of the Malwa region has districts like Barnala, Bhatinda, Ferozpur, and Faridkot with medium to low range, the analysis conducted by Singh *et al.*, Elbaalawy *et al.*, (2016) [11] Yadav *et al.*, (2016) [56] and Kumar *et al.* (2016) [24] reveals that these districts are classified as high and medium range respectively. The researcher's data collection in the eastern half of the Malwa region reveals that the districts of Mansa, Moga, Sangrur, Ludhiana, and Rupnagar (Ropar) have a low organic carbon content in the soil. The presence of low organic carbon in soil indicates poor soil fertility and unstable physical properties. The cause of this low organic carbon content may be attributed to various factors such as different soil orders found in different regions of Punjab, including aridisols and Entisols-aridisols, as well as practices like stubble-burning and inadequate management of crop residues.

Nitrogen

Nitrogen is crucial for plants as they require it in significant amounts. Additionally, supplying nitrogen can be quite costly, and it is prone to being lost from the soil. Nitrogen primarily exists in the form of proteins and nucleoproteins, with minor and diverse quantities of amines, amino acids, polypeptides, and several other molecules. The predominant nitrogenous chemicals are primarily found in the protoplasm and nucleus of plant and animal cells. Among them are enzymes, which are proteins that accelerate biological processes. Each plant cell needs more nitrogen molecules to achieve optimal rates of reproduction, growth, and respiration (Robertson and Groffman 2024) [37]. The chlorophyll found in green leaves, which allows plants to utilize sunlight to synthesize sugar, starch, and carbon dioxide in water, is composed of nitrogen compounds. Many non-nitrogen molecules, closely associated with nitrogenous chemicals, act as a potent energy source for numerous biological processes. Certain non-protein nitrogen compounds may not exhibit significant biological activity, but they are expected to largely serve as components of the body's structure, like cellulose and lignin (Niazifar *et al.*, 2024) [31]. One example is chitin, a complex organic compound linked to carbohydrates. It is present in microorganisms, fungi, parasites, and in the exoskeletons of crustaceans and insects. Nitrogen is mostly present in the delicate and tender portions of plant tissues, such as the apical meristems, buds, and nascent foliage (Kumar *et al.*, 2024) [21]. Nitrogen, primarily present in the form of proteins, undergoes continuous movement and chemical transformations. During the process of cell formation, a significant amount of protein can be transferred from older cells to newly formed ones, particularly if the plant's overall nitrogen levels are insufficient. Subsequently, the plant optimizes its utilization of the limited resources. Nitrogen is an indispensable component present in plants derived from the soil, playing a vital role in promoting plant development (Li and Gao 2024) [26]. Nitrogen gas constitutes approximately 80% of the Earth's atmosphere. Nitrogen gas is dissolved in water, where it undergoes conversion by blue algae into ammonia, which is utilized by the algae. Inorganic nitrogen and ammonia can infiltrate ponds and streams as forms of nitrogen. Due to the various pathways through which nitrogen can infiltrate water systems, there is a plentiful supply of nitrogen present in these systems. Earthworms enhance N-mineral digestion by actively mineralizing carbon, such as decaying plant roots and leaf litter, during the process of gut passage (Barron *et al.*, 2024) [1].

Table 5: Nitrogen

Doaba Region				
District	**Author**	**Year**	**N**	**Range**
Hoshiarpur	Jatav,m.k *et al.*,	2013	150-280 kg ha^{-1}	Moderate-high
SBS nagar	Shilpa panjgotra., *et al.*,	2019	142.22 ± 3.25 kg ha^{-1}	Low
SBS Nagar	S. garecha *et al.*,	2016	176-376 kg ha^{-1}	low
Majha Region				
District	**Author**	**year**	**N**	**Range**
Amritsar	Kaur *et al.*,	2014	0.004-0.016 mg kg^{-1}	Low
Amritsar	Singh *et al.*,	2020	0.39±0.01 (g Kg^{-1})	Low
Amritsar	Sharma *et al.*,	2019	1.4-0.47mg L^{-1}	Low
Amritsar	Panjgotra *et al.*,	2019	137.56±2.82 kg ha^{-1}	Low
Tarn Taran	Bhatt, R., & Singh, M.	2021	261.4 kg ha^{-1}	Moderate
Malwa Region				
District	**Author**	**year**	**N**	**Range**
Fathegarh sahib	Kumar *et al.*,	2020	0.04 - 0.14%	Low
Moga	Panjgotra *et al.*,	2019	134.83 ± 1.69 kg ha^{-1}	Low
Bhatinda	Yadav, B. K.	2020	260-325 kg ha^{-1}	Medium
Ludhiana	Hargopal, S., & Pritpal, S	2011	66.0 kg ha^{-1}	Low
Ludhiana	Walia, M. K., & Walia, S. S.	2011	143 kg ha^{-1}	Low
Rupnagar	Kaur, R., & Goyal, D	2015	0.007 to 0.05% mg kg^{-1} (total nitrogen)	Low

The soil in the majority of the Doaba region has a low nitrogen level. Only a limited number of researchers have investigated the levels of nitrogen in the soil in the Doaba region. One such study conducted by Jatav *et al.* (2013) [15] found that in the Hoshiarpur district, the accessible nitrogen in the soil ranged from 186.3 to 3556 kg ha^{-1}, which falls within the low to medium range. In SBS Nagar, researchers Shilpa Panjgotra *et al.* (2019) [32] and S. Garecha *et al.* (2016) found a comparable range of nitrogen availability. According to S. Garecha *et al.* (2016), the available nitrogen ranged from 142.22 ± 3.25 to 176-

376. The researcher discovered that the Majha region has a low nitrogen concentration in the soil, as documented by other researchers in the Amritsar and Tran Taran Kaur districts, including Tran Taran Kaur *et al.* (2014) [18], Singh *et al.* (2020), Sharma *et al.* (2019) [43], Panjgotra *et al.* (2019) [32], and Bhatt, R., & Singh, M. (2021) [3]. An investigation of the Malwa region revealed that the nitrogen content in the soil was found to be insufficient for optimal plant growth, specifically in the Bhatinda district. Yadav *et al.* (2020) [55] reported that the available nitrogen in the soil ranged from 26 to 325 kg ha^{-1}, which falls within the medium range. This trend was observed in the remaining districts of Fathegarh Sahib, Moga, Ludhiana, and Rupnagar. The researcher's findings have a limited range. The following references were cited: Kumar *et al.*, (2020), Panjgotra *et al.*, 2019 [32], Hargopal, S., & Pritpal, S (2011) Walia, M. K., & Walia, S. S. (2011) [53], Kaur, R., & Goyal, D (2015) [19]. Most of the Punjab's territory suffers from a lack of nitrogen content, indicating the need for increased use of nitrogenous fertilizers to enhance crop production. Additionally, there is a need to improve crop residue management to increase organic matter in the soil, which in turn stimulates microbial activity and indirectly increases the availability of nitrogen.

Phosphorus

Phosphorus (P) is a crucial macronutrient that plays a vital role in various plant functions, such as energy production, nucleic acid synthesis, photosynthesis, glycolysis, respiration, membrane bonding and stabilization, enzyme activation, redox reactions, gene expression, carbohydrate metabolism, and nitrogen fixation (Abel *et al.*, 2002; Vance *et al.*, 2003). Simultaneously, the absence of phosphorus (P) is seen as a significant constraint in agricultural productivity (Schachtman *et al.*, 1998; Lynch and Brown, 2008). Phosphorus is present in large quantities in the soil, in both organic and inorganic forms. However, its accessibility is restricted since it is primarily found in places where it is insoluble. The typical phosphorus level in the soil is approximately 0.05% (w / w). However, only 0.1% of this phosphorus is accessible for plant utilization. Most of the phosphorus fertilizer utilized is not absorbed by plants. However, excessive application of inorganic fertilizers, above the typical amount required to compensate for this deficiency, can result in environmental issues such as groundwater contamination and water eutrophication. Phosphorus (P) is a significant growth suppressant, and unlike nitrogen, there is no prominent biological origin for it. Ezawa and colleagues (2002).

Table 6: Phosphorus

Doaba Region				
District	**Author**	**Year**	**P**	**Range**
Hoshiarpur	Sunita *et al.*,	2020	4.4^{-1}3.8 kg/acre	low
Jalandhar	Ray *et al.*,	2004	28.54ppm	high
Kapurthala	Singh *et al.*	2016	16.7 to 24.2 kg/ha	Medium - high
Kapurthala	Bhat and Singh	2020	14.983 mg kg^{-1}	medium
SBS nagar	Panjgotra *et al.*	2019	32.55±0.77	high
SBS Nagar	Garcha *et al.*,	2016	15-60 kg ha^{-1}	Medium to high
Nawan shahr	Kang *et al.*	2011	6.8 to 13.5 kg ha^{-1}	low
Majha Region				
District	**Author**	**year**	**p**	**Range**
Amritsar	Rana.p	2020	3%,20% and 77%	Low, medium and high
Amritsar	Kaur *et al.*	2014	0.614-0.76 µg kg^{-1}	Medium and high
Amritsar	Singh *et al.*	2020	4.71±0.03 (g/Kg)	high
Amritsar	Sharma *et al.*	2019	0.2^{-1}.5mg L1	Low, moderate
Amritsar	Pangotra *et al.*	2019	31.98±0.62 kg/ha	high
Gurdaspur	Singh *et al.*	2016	3.18 (g /kg)	medium
Gurdaspur	Rana. P	2020	3%, 10% and 87%	Low, medium and high
Tarn Taran	Bhatt R. and Singh. P	2017	3.7 to 31.5 kg/acre	high
Tarn Taran	Bhatt, R., & Singh, M.	2021	21.73 kg/ha	high
Malwa Region				
District	**Author**	**year**	**P**	**Range**
Barnala	Singh, S., & Benbi, D. K.	2016	5--37	Low - high
Bhatinda	Yadav *et al.*	2016	17.5 to 21.5 kg ha^{-1}	Low medium
Bhatinda	Kumar *et al.*	2016	2-53.73 (mg kg^{-1})	Low - high
Bhatinda	Yadav, B. K.	2020	34.2- 45.9 kg	High
Ferozpur	Singh, S., & Benbi, D. K.	2016	3-75 mg/kg	Low
Faridkot	Kang, *et al.*	2010	9.2 to 24.8 kg/ha	Low to medium
Faridkot	Verma *et al.*	2008	12.5-45.0 kg / ha	Medium to high
Fathegarh sahib	Kumar *et al.*	2020	43.69 -518 mg/kg	High
Mansa	Verma, *et al.*	2005	1.8 to 59.6 kg ha	Low - high
Mansa	Rana, P.	2020	4%,17% and 38%	Low, medium and high
Moga	Panjgotra *et al.*	2019	29.49±0.45kg/ha	high
Ludhiana	Rana, P.	2020	2%,10%, and 88%	Low medium and High
Ludhiana	Walia, M. K., & Walia, S. S.	2011	11.2 kg ha^{-1}	Low
Rupnagar	Kaur, R., & Goyal, D	2015	7.43 0.2 mg kg^{-1})	Low
Rupnagar	Sekhon *et al.*,	2012	38 kg/ha	High
Mukstar	Rana, P.	2020	24%,44% and 32%	Low medium and High
Patiala	Rana, P.	2020	23%,29%and 48%	Low medium and High

An analysis of soil phosphorus content in the doaba region reveals that a significant portion of the territory exhibits medium to high levels of phosphorus. However, the south-western section of the region, specifically District Nawan shahr, has a low level of phosphorus. Kang *et al.* (2011) discovered that the soil phosphorus level varies between 6.8 and 13.5 kg ha^{-1}, which aligns with the findings of Sunita *et al.* (2020) in Hoshiarpur. The investigator reported high phosphorus content in district

Hoshiarpur, Jalandhar, Kapurthala, and SBS Nagar, as documented by Jatav *et al.* (2013) [15], Ray *et al.* (2004), Singh *et al.* (2016) [47], Bhat and Singh (2020) [5], Panjgotra *et al.* (2019) [32], and Garcha *et al.* (2016) [12].

Multiple authors have conducted studies on the phosphorus content (P) in various districts of the Majha region. The results have been classified into three categories: low, medium, and high levels. Rana, P. (2020) [35] The reported phosphorus content values are 3%, 20%, and 77%, which correspond to low, medium, and high amounts accordingly. This indicates a broad spectrum of phosphorus accessibility in the soil. The study conducted by Kaur *et al.* in 2014 [18]. The phosphorus concentration reported ranges from 0.614 to 0.76 µg kg⁻¹, which falls within the medium and high classifications. Singh *et al.* (2020) [48], Sharma *et al.* (2019) [43], and Pangotra *et al.* (2019) have documented that the soil exhibits a notably elevated concentration of phosphorus. The Majha regions exhibit significant heterogeneity in soil phosphorus concentration, with levels ranging from low to high across various districts. In areas with low to moderate phosphorus levels, it is advisable to implement appropriate fertilization techniques to rectify deficiencies. Conversely, in regions with high phosphorus content, management practices should focus on preserving nutrient equilibrium.

All studies conducted in the Malwa region have consistently shown that the phosphorus concentration in the soil is predominantly classified as high. In a study conducted by researcher Rana.p (2020) [35], it was found that 77% of the land in the Amritsar district had a high phosphorus level in the soil. Similarly, in the Gurdaspur district, 87% of the territory had a high phosphorus content. The district of Tarn Taran is likewise characterized by a high concentration of phosphorus, as reported by Bhatt and Singh (2017) [4] and Bhatt and Singh (2021) [3].

Potassium (K)

Potassium is crucial in numerous plant physiological processes and is a fundamental element in plant growth and development. The process encompasses a wide range of plant metabolic reactions, including the synthesis of lignin and cellulose for cellular structures, the control of photosynthesis, and the generation of plant sugars to fulfill diverse plant requirements. In regard to the phosphorus levels in the soil, the rise in accessible phosphorus could be attributed to a 5% enhancement in pH caused by the presence of earthworms, as reported by Basker *et al.*, 1993.

Table 7: Potassium (K)

Doaba Region				
District	**Author**	**Year**	**K**	**Range**
Hoshiarpur	Jatav *et al.*,	2013	83% low, 17% medium	Medium
Hoshiarpur	Sunita *et al.*,	2020	14.43-72.85 kg/acre	Low
Jalandhar	Ray *et al.*	2004	100.34 ppm	Medium
Kapurthala	Gobinder Singh *et al.*	2016	$98.7^{-1}95$ kg/ha	Low-medium
Kapurthala	Bhat and Singh	2020	83.021(mg kg^{-1})	Low-high
SBS nagar	Shilpa Panjgotra	2019	149.92±6.74	medium
SBS nagar	S. Garecha *et al.*,	2016	90-281 kg ha^{-1}	Low-high
Nawan shahr	B.S. Kang, *et al.*	2011	202 -397kg ha^{-1}	Medium-high
Majha Region				
District	**Author**	**Year**	**K**	**Range**
Amritsar	Rana.P	2020	5%, 51% and 44%	Low, medium and high
Amritsar	Kaur M *et al.*	2014	0.12-0.35 mg g^{-1}	Low
Amritsar	Shilpa Panjgotra *et al.*	2019	144.30±3.01 kg/ha	Medium
Gurdaspur	Singh, S., & Benbi, D. K. *et al.*	2016	54-288 mg/kg	Low-high
Gurdaspur	Sekhon B.S *et al.*	2012	326.1 kg/ha	High
Gurdaspur	Rana P	2020	50% and 50%	Low and medium
Tarn Taran	Bhatt.R and singh.P	2017	24.5 to 357 kg/acre	High
Tarn Taran	Bhatt, R., & Singh, M.	2021	258.2 kg ha^{-1}	High
Malwa Region				
District	**Author**	**Year**	**K**	**Range**
Barnala	singh, S., & Benbi, D. K.	2016	102-225 mg/kg	Low-medium
Bhatinda	Yadav *et al.*	2016	220 to 610 kg ha^{-1}	Med-High
Bhatinda	Yadav, B. K.	2020	301.3- 440.5 kg ha^{-1}	High
Ferozpur	Singh, S., & Benbi, D. K. (2016).	2016	102-276mg/kg	Low-medium
Faridkot	B.S. Kang, *et al.*	2010	405 to 562 kg/ha	High
Faridkot	V.K. Verma *et al.*	2008	(135-235 kg / ha)	high
Fathegarh sahib	Kumar *et al.*	2020	67-702 mg/kg	Low-high
Rupnagar	Sekhon *et al.*,	2012	145 kg/ha	
Mansa	Verma, *et al.*	2005	67.2 to 851.2 kg ha^{-1}	Low-high
Moga	Shilpa Panjgotra *et al.*	2019	140.08±2.49 kg/ha	Medium
Ludhiana	Hargopal, S., & Pritpal, S	2011	151.0 kg ha^{-1}.	Medium
Ludhiana	Walia, M. K., & Walia, S. S.	2011	(101 kg ha^{-1}).	Low

The potassium levels in the soil were found to be highest in Nawan shahr (202 to 397kg ha^{-1}), followed by SBS nagar (90-281 kg ha^{-1}) as reported by S. Garecha *et al.* (2016) and Shilpa Panjgotra (2019) [32]. In Kapurthala district, the potassium levels were reported to be $98.7^{-1}95$ kg/ha and 83.021 (mg kg^{-1}) by Gobinder Singh *et al.* (2016) [47] and Bhat and Singh (2020) respectively. The potassium levels available in Jalandhar fall within the median range. In the district of Hoshiarpur, Jatav *et al.* (2013) [15] indicated that 17% of the area is classified as medium, while 83% is classified as low. This information was also confirmed by Sunita *et al.* (2020). Bhatt and Sharma (2011) observed that almost 65% of samples from district Kapurthala had a low potassium status, with available potassium levels below 137.5 kg/ha. Researchers have observed that the potassium level in soil in the Majha region is predominantly medium to high. The researcher Rana.P (2020) [35] found that 44% of the region in Amritsar is classified as high range. Similarly, Sekhon B.S *et al.* (2012) [40] discovered that Gurdaspur has a similar percentage. In district tran tarn, Bhatt. R and Singh. P (2017) [4], Bhatt, R., & Singh, M. (2021) [3] reported a yield of 258.2Kg/Ha. The chosen researcher in the Malwa region investigates the variability of potassium levels in soil across different districts. However, the majority of districts fall within a certain range. The districts of Bhatinda, Faridkot, and Mansa have a high potassium level, while the districts of Ferozpur, Moga, and Fathegarh Sahib have a medium potassium content. Researchers Hargopal, S., & Pritpal, S, Walia, M. K., & Walia, S. S. (2011) [53] observed that certain districts in the Malwa region have a low potassium level in the soil, specifically in the Ludhiana district. In the study conducted by Barnala Singh, S., & Benbi, D. K. (2016).

Conclusion

The different physicochemical features of the soil in Punjab contribute to a wide spectrum of agricultural productivity. The main objective of this research was to analyze the soil condition in the Punjab region. The findings indicated that the soil properties of the three regions exhibited substantial dissimilarities. The soil chemical properties of the Doaba region were determined to be superior compared to those of the Majha and Malwa regions. The Doaba region exhibited moderate soil nitrogen levels, but the Majha region displayed low levels. Implementing effective soil management practices in the Malwa region of Punjab was necessary. The Majha region typically has a moderate level of alkalinity in its soil, whereas districts like Amritsar and Tarn Taran have localized areas with significant alkalinity. The soil pH in this area varies from moderately acidic in the northern parts to strongly alkaline in the southwestern parts. Although certain industrial areas, like Amritsar, may have slightly elevated salt levels, the electrical conductivity (EC) measurements indicate that the overall environment is not excessively saline. Consequently, this makes it suitable for cultivating a diverse range of crops. The organic carbon content in soil varies significantly, ranging from extremely low to extremely high. The regions of Majha and Malwa have the highest prevalence of this wide range, resulting in better soil fertility. However, areas with low levels of organic carbon indicate a necessity for improved management of crop wastes and organic additions. When nitrogen availability is predominantly low to medium, it becomes evident that there is a requirement for improved soil management practices and higher levels of nitrogenous fertilization. Due to the elevated phosphorus concentration, it is crucial to apply appropriate fertilization methods to prevent nutritional imbalances. This is particularly important in Majha and certain areas of Doaba and Malwa. In addition, there are variations in potassium levels in different regions of Malwa. Some areas in Malwa have insufficient potassium levels, requiring specific soil amendments, while Majha region has moderate to high levels of potassium. Ultimately, the study of soil dynamics in Punjab reveals that the interplay between natural and human factors has complex effects on the physicochemical characteristics. In order to maintain agricultural output and soil health in this ever-changing agricultural environment, it is crucial to comprehend and regulate these transformations by employing specific fertilization strategies and implementing novel soil management techniques.

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