__Original Research Article__

Characterizing of Sandy Loam Soil Electrical Conductivity and Cone Index Relationship at Varying Depths in Punjab Region

Abstract

Soil constitutes a fundamental resource for the production of food and fiber, thereby meeting diverse human needs and sustaining global ecosystems. Soil compaction and electrical conductivity are key soil properties that can significantly impact soil health and contribute to environmental challenges. The findings of the study shed light on the severity of soil compaction, with the highest cone index 4495 kPa value recorded at a depth of 225 mm in sandy loam soil. This highlights the potential limitations on root growth and nutrient uptake, which can have implications for plant productivity and the overall ecosystem. Furthermore, the study examined the electrical conductivity of the soil, which serves as an indicator of soil salinity. Elevated electrical conductivity levels can lead to adverse effects such as reduced crop yields and environmental stress. Bulk density was increased (1.4 to 1.73 Mg/m^3) as well as the moisture content of the soil was decreased (7.6 to 4.3 %). Understanding the range of electrical conductivity values observed in the study (11 to 29 mS/m) helps to assess the extent of salinity-related challenges in the studied region. By establishing regression equations between cone index and soil properties like bulk density and moisture content, the study provides valuable insights into the underlying relationships that contribute to soil compaction and its environmental implications. The coefficient of determination (R^2) between the bulk density with moisture content and cone index was 0.99 and 0.95, respectively. These findings can assist in the development of strategies to mitigate soil degradation, promote sustainable land management practices, and address environmental concerns related to soil health.

Keywords: Cone index, Bulk density, Electrical conductivity, moisture content, soil compaction

Introduction

In India, the total geographical area spans 329 million hectares, out of which the gross cropped area is 198.9 million hectares, with a cropping intensity of 140.5 percent. Punjab, specifically, encompasses a total geographical area of 5.03 million hectares, with 4.1 million hectares dedicated to cultivation. The gross cropped area in Punjab is 7.9 million hectares, with a cropping intensity of 204 percent (Anon, 2019). Soil serves as a fundamental resource for the production of food and fiber, thereby meeting diverse human needs and sustaining global ecosystems (Doran, 2002). According to the widely accepted definition, soil health refers to "the capacity of soil to function as a vital living system, operating within ecosystem and land-use boundaries, to support plant and animal productivity, preserve or enhance water and air quality, and promote plant and animal health (Doran and Zeiss, 2000).

Soil compaction and electrical conductivity are two significant soil properties that play a crucial role in soil degradation. Soil compaction directly hinders plant root growth, and soil moisture content is often used as a reference point when soil compaction values reach 2 MPa (Collares et al., 2006). In the case of cotton crops, root growth was found to be limited when soil penetration resistance (SPR) values reached 3.5 MPa (Roque et al., 2003). The adverse effect of electrical conductivity (EC) is an increase in soil salinity, which can also contribute to soil compaction (Chauhan et al., 2015). It is recommended that soil should have an electrical conductivity of less than 40 mS/m, as values above this indicate saline soil conditions.

However, in recent times, India has been facing second-generation challenges arising from the Green Revolution, including a decline in factor productivity, poor soil health, loss of soil organic carbon, water-related stresses on both ground and surface levels, increased incidence of pests and diseases, rising input costs, and a decline in farm profits. The decline in soil fertility and health can be attributed to factors such as the removal or burning of crop residues, reduced application of manure, intensive cropping practices, imbalanced and excessive use of fertilizers and pesticides, as well as subsoil compaction. Furthermore, farmers are now grappling with the adverse impacts of climate change and the frequent occurrence of natural disasters such as droughts, floods, cyclones, storms, and more (Chaudhari et al., 2018).

Soil health degradation has been observed in the Indian state of Punjab, where the usage of chemical fertilizers (NPK - nitrogen, phosphorus, and potassium) has increased significantly over the years. From 38 kg/ha in 1970-1971, the usage has risen to 247 kg/ha in 2017-2018 (Anon., 2018). In comparison, the average fertilizer usage across India as a whole is 135 kg/ha (Anon., 2017). The intensive use of fertilizers initially led to rapid yield growth in wheat production from 1970-71 to 2011-12. However, for the year 2017, wheat production in Punjab began to decline. This decline can be attributed to soil deterioration caused by excessive fertilizer use and higher mechanization index in Punjab (Singh, 2016). As a pioneer of India's Green

Revolution, Punjab experienced both positive and negative effects of the implemented technologies. Initially, Punjab farmers achieved high productivity levels through the adoption of high-yielding varieties, irrigation networks, chemical inputs, and credit facilities. However, over time, the reliance on chemical-based inputs and machine-oriented farming systems led to the overexploitation of natural resources, particularly groundwater and soil. As a result, many farming practices in Punjab have become environmentally unsustainable (Anon., 2013).

The measurement of bulk density and electrical conductivity of soil is a time-consuming process, usually taking approximately 24 hours. The study conducted aimed to explore the linkages between soil compaction, electrical conductivity, and various soil properties, with a specific focus on sandy loam soils in the Punjab region. By investigating these relationships, the research sought to contribute to the understanding of soil degradation and its implications for the environment and climate change. Therefore, there is a need to establish a relationship that simplifies the calculation of bulk density using cone index as well as electrical conductivity at different depths. The main objectives of this study were to examine the correlation between soil cone index and electrical conductivity with specific soil physical properties across different soil types and depths in Punjab. Additionally, the study aimed to develop regression equations that relate cone index to soil properties such as bulk density and moisture at various depths.

Material and methods

The study was conducted at the Research Farms of the Department of Farm Machinery and Power Engineering in Ludhiana, Punjab. The study focused on sandy loam soil at different depths. The soil samples were collected from specific geo-referenced points, with the sandy loam soil (S1) located at coordinates 30°54'37"N 75°49’10"E. Sampling was carried out at 15 cm intervals, ranging from 0 to 60 cm depth. A core sampler with a height of 15 cm and a diameter of 5 cm was used. The depth intervals obtained were as follows: 0-15 cm (D1), 15-30 cm (D2), 30-45 cm (D3), and 45-60 cm (D4). For cone index measurement, an ultrasonic sensor present in a digital cone penetrometer was used, which provided depth intervals of 2.5 cm. Cone index, bulk density with soil moisture content, and electrical conductivity were the response variables analyzed in this study, and they will be discussed in detail in the subsequent sections.

Cone index – it is an important parameter used to assess soil compaction and is typically measured in units of kPa (kilopascals) or MPa (megapascals). It represents the penetration resistance or the force per unit area required to insert a cone into the soil. In this study, the

CP40II hand-operated cone penetrometer was utilized for measuring soil compaction. This device records the cone index values, load required for cone penetration, date, time, and GPS coordinates. It also generates graphical representations by plotting cone index values against depth, providing a simplified visualization of soil hardness. The penetrometer used in the study had a probe diameter of 9.53 mm and a cone area of 130 mm² with a 30° angle. Depth measurement was performed using ultrasonic sensors. The maximum force can be determined by the cone index relationship presented in equation 1.

$$\text{Maximum force (N)} = \text{cone index } (\mathrm{N/mm^2}) \times \text{base area of cone } (\mathrm{mm^2}) \quad \ldots (1)$$

Standards of soil cone penetrometer at 30^0 Cone angle (ASABE standard S313.2)

1. Base area of cone 323 mm^2 and 20.27 mm base diameter with a 15.88 mm diameter probe for soft soil.
2. Base area of cone 130 mm^2 and 12.83 mm base diameter with a 9.53 mm diameter probe for hard soil.

a) b) c)

Fig. 1 Measurement of cone index using hand operated cone penetrometer a) Field view, b) Used cone penetrometer (RIMIK CP40II) and c) Standard dimensions of penetrometer

Bulk Density and moisture content of soil

The soil bulk density (BD), also known as dry bulk density, is the weight of dry soil (M solids) divided by the total soil volume (Vsoil). The total soil volume is the combined volume of solids and pores which may contain air (Vair) or water (Vwater), or both. Determination of Bulk density and moisture content of the soil (equation 2 and 3) was conducted according to the Indian Standard procedures (Fig. 2) (Mehta et al., 2005).

1. Selected the core sampler of size 20 cm in length, 5 cm in diameter and inserted upto the required depth.
2. The core was gradually retracted from the soil and soil sample was collected.
3. The initial mass of the soil and volume of the core sampler were measured. A fraction of the sample was placed in the moisture box to measure the moisture content of the soil. The moisture box was then kept in the oven drying for 24 hours at 105°C.

$$\text{Moisture Content (\%)} = \frac{Fresh\ weight - Dry\ weight}{Dry\ weight} \times 100 \qquad \dots\dots\dots (2)$$

$$Bulk\ Density = \frac{Mass}{Volume} \quad (\text{kg/ cm}^3) \qquad \dots\dots\dots (3)$$

Fig. 2 Collecting soil sample and its analysis for measurement of bulk density and moisture content of soil

Electrical conductivity- Electrical conductivity (EC) is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of milli Siemens per meter (mS/m). Soil EC measurements may also be reported in units of desi Siemens per meter (dS/m), which is equal to the reading in mS/m divided by 100 (Friedman, 2005).

Steps followed for determination of EC of soil in the laboratory

1. Extraction of soil sample at different depth with the help of auger.

2. Weighing the soil sample was carried out by mixing soil and distilled water (1:2) in a beaker.
3. The mixture was stirred into a paste and incubated overnight in saturated state.
4. EC was measured using EC meter without disturbing the soil (Fig 3).

Fig. 3 Measurement of electrical conductivity of soil samples

Results and discussions

Effect of soil depth on cone index

To examine the variation of CI with soil physical properties, the data were plotted between CI and each variable, pooling over all the other variables. Linear trend lines were generated for describing the relationships. The coefficient of determination (R^2) of the trend lines were generally low, which were expected due to greater variability of soil properties among different soils and climate conditions. The intentions were to learn the range of CI variations and the general trends of CI as influenced by different soil physical properties. The results are discussed in the following sections.

The variation in Cone index with increase in depth in all four penetrations in sandy loam soil at Ludhiana was observed (Fig. 4) in the insertions I1, I2, I3 and I4 and I5. The maximum cone index 4495 kPa was recorded at a depth of 225-250 mm. The graph shows that the cone index increased initially with the increment of depth and after coming the hardpan the trend is decreased. The cone index 4083 kPa was noted at the depth of 200 mm in the fifth insertion which is more than the limit of 2000 kPa at the same depth and it notified that the soil was compacted (Raper et al., 2001). The variation in Cone index with depth in all six penetrations in the soil.

In Fig. 4 also shows that the variation of cone index with the soil depth, initially the cone index increases linearly up to 175 mm depth in all the 6 penetrations whereas the maximum in between 200 to 250 mm depth and then decreases from 275 to 600 mm depth. The maximum cone index in 4th insertion at 225 mm depth was 4495 kPa and it clearly depicts that the soil was highly compacted at near to tillage depth.

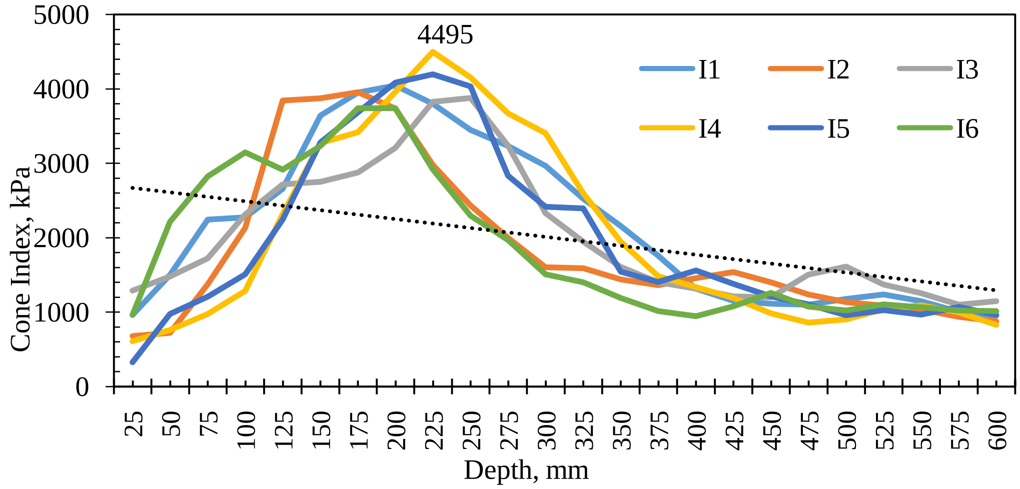

Fig. 4 Relation between cone index and depth of sandy loam soil

Relation between bulk density (BD), cone index (CI) and moisture content with depth

The BD and CI were increased whereas moisture content was decreased with increase in depth (Fig. 5). It was also revealed from the regression analysis that BD of soil was strongly correlated ($R^2 = 0.99$) with the moisture of soil. Similarly, the CI with soil moisture ($R^2 = 0.91$) and BD with CI ($R^2 = 0.955$) (Table 1). From the fig. 5 it was revealed that the bulk density of the soil was increasing 1.4 to 1.73 Mg/m^3 with increasing the cone index 0.5 to 2.9 Mpa at soil depth varying from 0-60 cm on each 15 cm interval. Whereas, the soil moisture decreased 7.6 to 4.3% with increasing the soil depth. Cone index was increased with increasing the depth because of hard pan exists after the tillage depth. As the soil becomes more compacted, the spaces between soil particles decrease, limiting the movement of air, water, and roots. This restricted movement affects plant growth and nutrient uptake, ultimately impacting agricultural productivity and ecosystem health. In general, as soil moisture content increases, the bulk density tends to decrease. This is because water occupies space between soil particles, reducing their compactness and increasing the volume occupied by the soil. As a result, the bulk density decreases, indicating a less dense soil.

Table 1 Regression equation of bulk density, cone index and moisture content.

S. No.	Interaction	Regression equation	R^2 value
1	Bulk density * moisture	y = -10.255x + 22.075	0.99
2	Cone index * moisture	y = -1.3217x + 8.5274	0.91
3	Bulk density * cone index	y = 7.297x - 9.5245	0.95

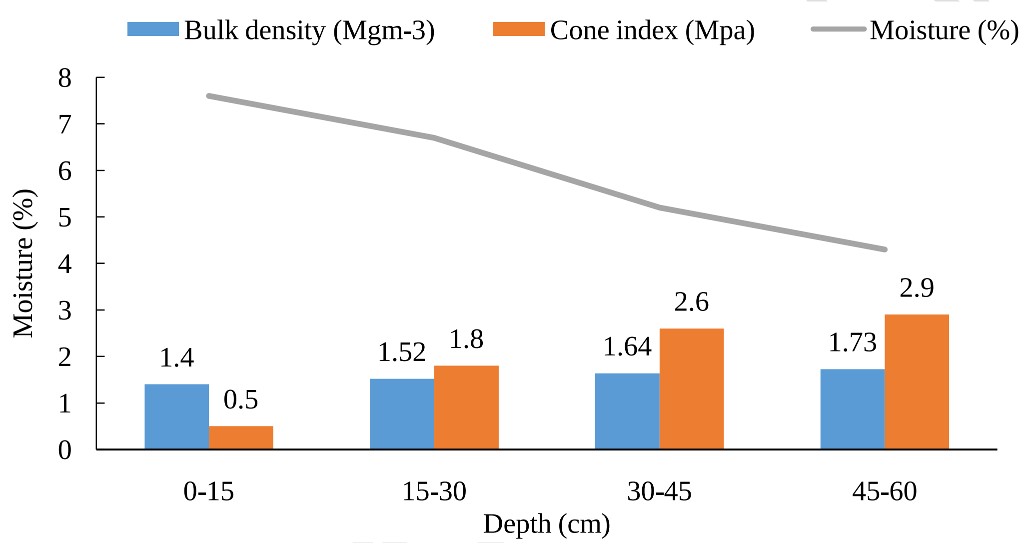

Fig. 5 Relation between bulk density, cone index and moisture varied with depth

The relationship between cone index and moisture content is more complex and can vary depending on several factors, including soil type, composition, and compaction level. In some cases, an increase in moisture content can lead to a decrease in cone index. This is because the presence of water lubricates the soil particles, reducing friction and making it easier for the cone to penetrate the soil. A relation was derived after the regression analysis between CI, BD and moisture was presented below in (equation 4)

$$\boldsymbol{CI = -33.837 + (18.59 \times BD) + (1.10 \times M)} \quad (4)$$

Where,

$CI = cone\ index\ (MPa)$

$BD = bulk\ desnity\ (Mg/m^3)$

$M = moisture\ (\%)$

Relation between electrical conductivity and moisture content

The data showed that the relation between EC, BD and moisture content of soil at different depth up to 60 cm (Fig. 6). It was clearly depicted from the graph that the bulk density was increased (1.4 to 1.73 Mg/m^3) as well as the moisture content of the soil was decreased (7.6 to 4.3 %) and also the electrical conductivity of the soil was decreased (29 to 11 mS/m) with the increment in depth (0 to 60 cm). A relationship was developed between the soil properties such as cone index, bulk density, electrical conductivity and moisture content of soil which was shown in equation 5 and the data was given in Table 2 as mentioned below. Moisture content increasing from 4.3 to 7.6% can increase the electrical conductivity 11 to 29 mS/mof the soil. This is because water serves as a conductor of electrical currents, and the presence of more water in the soil enhances the movement of ions, leading to higher EC values. Additionally, the presence of dissolved salts in the soil solution can further contribute to elevated EC values.

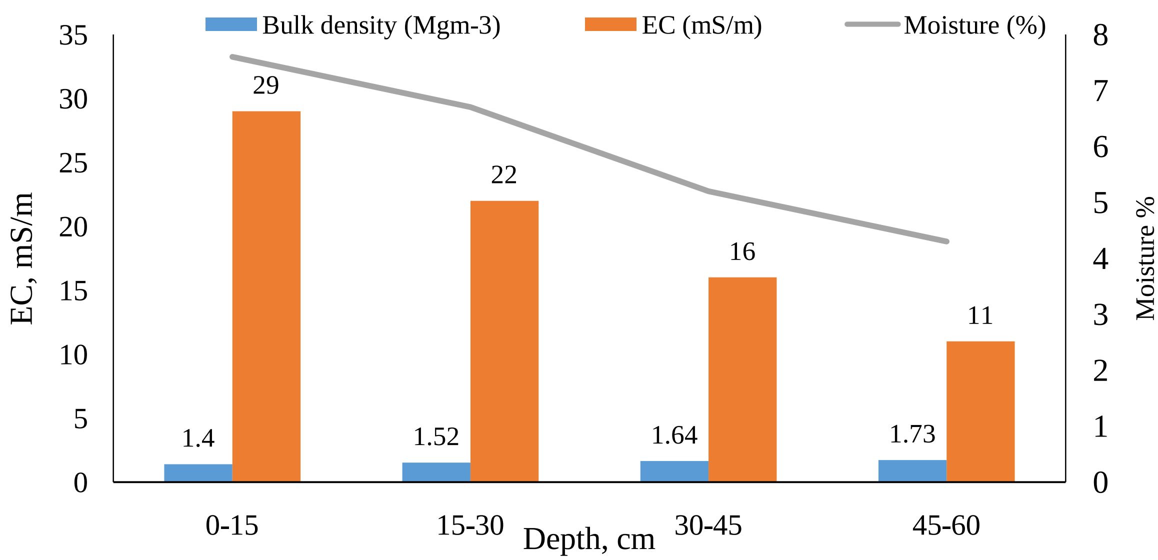

Fig. 6 Relation between bulk density, EC and moisture content at varied depth

Table 2 :

Depth (cm)	Bulk density (Mg/m^3)	EC (mS/m)	Moisture (%)
0-15	1.4	29	7.6
15-30	1.52	22	6.7
30-45	1.64	16	5.2
45-60	1.73	11	4.3

$$\boldsymbol{CI = -579 + (293.33 \times BD) + (7.33 \times M) + (3.9 \times EC)} \quad (5)$$

Conclusion

The following conclusions were drawn from the conducted experiment

- Overall average cone index was 3794 kPa observed at 200 mm depth and the maximum cone index was 4495 kPa observed at 225 - 250 mm depth
- The average electrical conductivity measured by laboratory method varied from 11 to 29 $mS \cdot m^{-1}$, also the electrical conductivity and moisture (7.6 to 4.3 %) of soil decreased whereas the bulk density increased with the increment of soil depth. Initially, cone index increases linearly up to 200-250 mm depth of soil insertion and it decreases after getting the hardpan at 300 mm depth of soil.
- Process to determine the soil parameters such as cone index, electrical conductivity and moisture content of the soil was a laborious and time taking process. So, there is a need of machine which measure all three parameters at real time soil data and helpful for making the spatial map with geo referenced locations.
- The relationship between electrical conductivity, moisture content, bulk density, and cone index of the soil provides valuable information for soil health assessment, fertility management, crop performance prediction, soil conservation, and precision agriculture. It aids in making informed decisions to improve soil productivity, optimize resource use, and promote sustainable land management practices.
- This research contributes to the understanding of soil degradation in the context of environmental and climate change challenges. The findings emphasize the importance of managing soil compaction and salinity, as well as implementing sustainable soil management practices to preserve soil health, support agricultural productivity, and mitigate environmental impacts.

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