Environment and Ecology 42 (1) : 49—54, January—March 2024
Article DOI: https://doi.org/10.60151/envec/ZJXO2607
ISSN 0970-0420

Exploring the Regression Models for the Relationship Between Soil Compaction, Electrical Conductivity and Various Soil Properties for Soil Characterization

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Received 19 July 2023, Accepted 28 November 2023, Published on 31 January 2024

ABSTRACT

Soil properties such as electrical conductivity and soil compaction have been found to be important properties of the soil due to their association with other properties of soil such as soil texture, moisture content, organic matter percentage, cation exchange volume, drainage conditions, salinity, clay pan depth, and subsoil properties that affect crop growth and productivity. The samples were collected during field experiments from two different locations in sandy loam and loamy soil. Simple regression analysis was performed for the determination of the correlation of the soil properties. There was a strong correlation between the soil compaction and electrical conductivity at both the locations in sandy loam ($R^2 = 0.97$) and loamy soil ($R^2 = 0.81$). it also showed a strong correlation with other engineering properties of soil that affect soil compaction and electrical conductivity of the soil.

Keywords Regression models, Soil compaction, Electrical conductivity, Soil salinity distribution, Soil sensors, Tillage treatments.

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INTRODUCTION

Soil-plant-water relations are strongly affected by resisting the penetration of roots, their growth and development due to the formation of the compact layer at any depth and a further reduction in root growth and density also causes a decrease in nutrient uptake and ultimately crop yield (Kumar and Bector 2022). In these physical constraints, high mechanical resistance to soil is important, especially in dry environments, as reduced water content significantly increases soil penetration resistance, while root growth decreases sharply and plant performance is poor (Shahgholi and Abuali 2015). When the soil penetration resistance is about 2 MPa, the radical or root growth of most crops is reduced, and when reaches above 4 MPa, the root growth of many plants stops. However, the development of root growth values differs based on the plant species. It was recommended that the soil compaction values should be offered with the description of the field conditions such as the amount of water content (Antille *et al.* 2013). A relationship between soil compaction (CI) and moisture content (MC) was developed by Voorhees and Walker in 1977 while studying the effect of moisture content on the cone index (CI) values on silt loam soil. Although the effects of density were not taken into account in the study, the observations in experiments were quite in agreement with expected cone index values.

$$CI=4527.75-137.09\ MC \qquad (1)$$

Where MC is the moisture content percent on dry bases and CI is the cone index in kPa

In 1970, the first experiment on electrical conductivity was conducted to measure soil salinity at the USDA-ARS Salinity Laboratory in Riverside. Electrical conductivity measurement techniques provide the simplest means of assessment of spatial variability of fundamental properties of soil that affect crop productivity and soil health. It provides quick and reliable measurements that can be frequently used for the assessment of soil quality, soil salinity percentage, pH, moisture content, and topsoil depth which can be correlated with yield variation (Zhao *et al.* 2020). In addition to this, other properties were also recorded with the electrical conductivity measurements using calibrated techniques such as moisture content in the soil, clay content of soil, clay pan depth identification, and fertility status of soil (Yu *et al.* 2021). A general equation was reformulated from different parameters that influence acquiring accurate estimation of electrical conductivity measurements is

$$EC_W = EC_e\ \rho b S_b \times 1000\theta_W \qquad (2)$$

Where EC_w is the average electrical conductivity of the soil water-saturated paste (dSm^{-1}), EC_e is the electrical conductivity of the saturation extract (dSm^{-1}), ρb is the bulk density (mg m^{-3}), S_P is the saturation percentage, θ_W is the total volumetric water content ($cm^3\ cm^{-3}$). Numerous techniques and research have been performed to understand the relationship between crop output yield, and soil physical and chemical properties. However, producers and researchers are still unsure of what analysis to use, how the results are interpreted or both. Therefore, the main aim of the study was to establish the relationship between the soil compaction and electrical conductivity of the soil and the different major factors affecting these two parameters.

MATERIALS AND METHODS

Study areas

The field experiment was carried out at two different locations in sandy loam (L1) and loamy soil (L2) at the research farms of the Department of Farm Machinery and Power Engineering, PAU Ludhiana, India. The physical characteristics and location of the study area on the map is shown in Table 1 and Fig. 1, respectively.

Table 1. Physical characteristics of selected soil and location of plots.

Particulars	Soil type-I	Soil type-II
Texture class	Sandy loam soil	Loamy soil
Composition of soil texture (sand, silt and clay %)	61.07, 27.13, 11.80	70, 13.8, 21.2
Location	Research farm of DFMPE, near gate no. 4, PAU, Ludhiana.	Soil research farm of DSS, near gate no. 8, PAU, Ludhiana
GPS coordinates	75° 49'08.19" E, 30° 54'38.78" N	75° 52'.10" E, 30° 56'.04" N

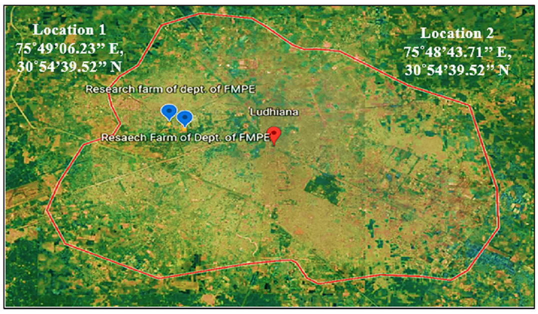

Fig. 1. Two different locations selected for a field experiment in Ludhiana.

Data collection

Many studies have revealed that there was a relationship between the cone index, bulk density, and moisture content. Therefore, to understand the relation between these parameters, a relationship was established between the selected parameters up to 60 cm depth. The soil compaction (cone index) was determined with the help of a manual digital cone penetrometer (Rimik CP40II) in MPa and the bulk density of the soil was measured with the help of a core sampler according to the Indian standards and procedures (IS2720 Part 29). The penetrometer was pressed into the soil at a uniform rate to measure the penetration. The data were retrieved from the cone penetrometer through an RS232 data cable by using Rimik CP40II data extraction software. The core sampler of 20 cm in length and 5 cm in diameter was used for the collection of soil samples by gradually inserting it up to the desired depth. The volume of the core and mass of the soil samples were initially measured and bulk density was measured by using the standard formula (Eq 3). Simultaneously, some amount of soil sample was placed in the moisture box and initial weight was measured. The moisture box was oven-dried for 24 hrs at 105^{0}C and moisture content was measured using a relation (Eq. 4). Electrical conductivity of soil was measured by standard laboratory methods (USDA standards) for the samples collection in sandy loam and loamy soil at two different locations of PAU, Ludhiana. The electrical conductivity of soil, bulk density, and moisture content was measured near the same point of penetration where cone index was to minimize the error and acquire maximum accuracy for measurement.

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

$$\text{Moisture content (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 \qquad (4)$$

RESULTS AND DISCUSSION

Relation between electrical conductivity (dS/m) and soil compaction (MPa)

A total of 810 samples were collected from both locations in both types of soil, 405 samples were determined in sandy loam soil at location one, and 405 samples were determined in loamy soil at location two. The samples were collected from three depth intervals i.e., at 20 cm, 40 cm, and 60 cm. The mean values of the total samples at three levels of depth were examined statistically. The field experiment for sample collection was laid out in a Randomized Com-

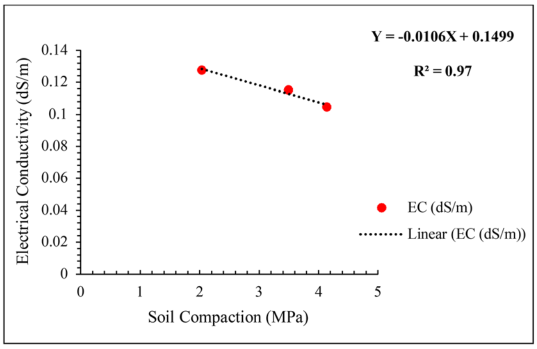

Fig. 2. Correlation between electrical conductivity and soil compaction in sandy loam soil at location one.

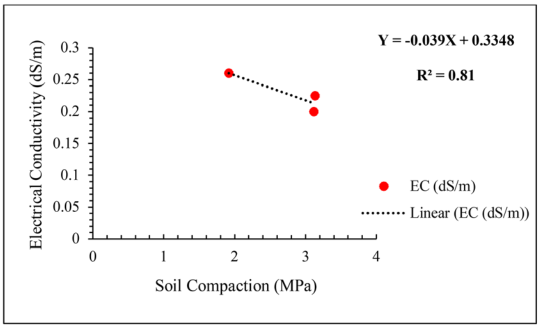

Fig. 3. Correlation between electrical conductivity and soil compaction in loamy soil at location two.

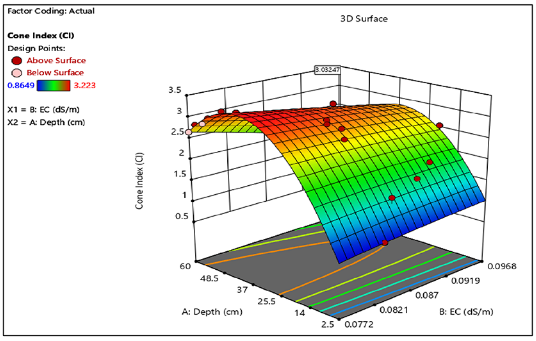

Fig. 4. 3D graph for the combined trend of soil compaction (C1) and electrical conductivity (EC) correspondence to depth in sandy loam soil (S1) with the developed soil sensor (DSS).

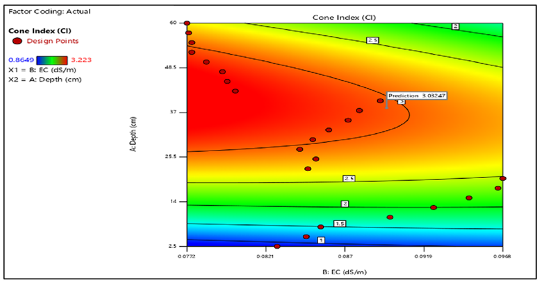

Fig. 5. Contour map for the combined trend of soil compaction (CI) and electrical conductivity (EC) correspondence to depth in sandy loam soil (S1) with the developed soil sensor (DSS).

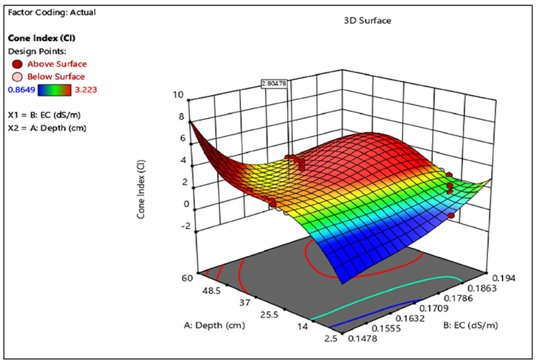

Fig. 6. 3D graph for the combined trend of soil compaction (CI) and electrical conductivity (EC) correspondence to depth in loamy soil (S2) with the developed soil sensor (DSS).

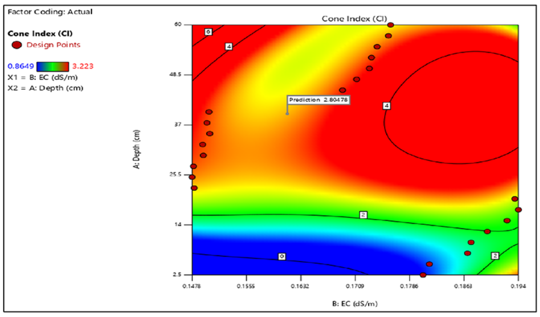

Fig. 7. Contour map for the combined trend of soil compaction (C1) and electrical conductivity (EC) correspondence to depth in loamy soil (S2) with the developed soil sensor (DSS).

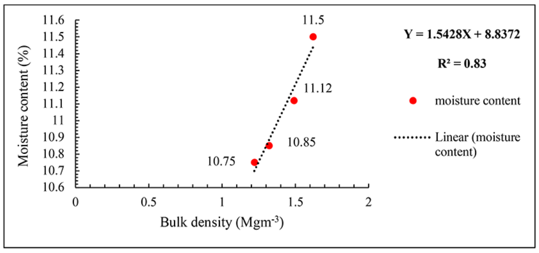

Fig. 8. Correlation between moisture content and bulk density.

plete Block Design (RCBD) and Statistical Analysis Software (SAS) was used to perform linear regression analysis. It was found that electrical conductivity and soil compaction were strong in sandy loam soil and loamy ($R^2 = 0.97$) soil ($R^2 = 0.81$) as shown in Figs. 2–3, respectively.

A 3D graph and contour map for the mean soil

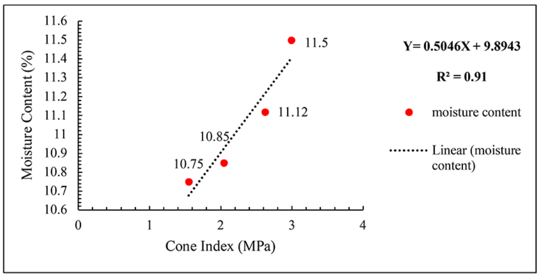

Fig. 9. Correlation between moisture content and cone index.

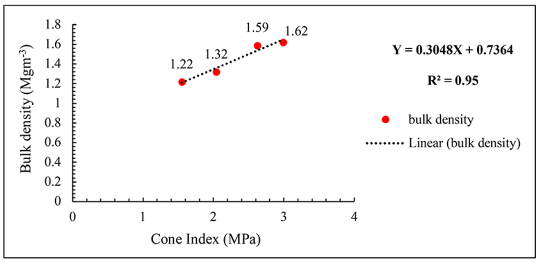

Fig. 10. Correlation between bulk density and cone index.

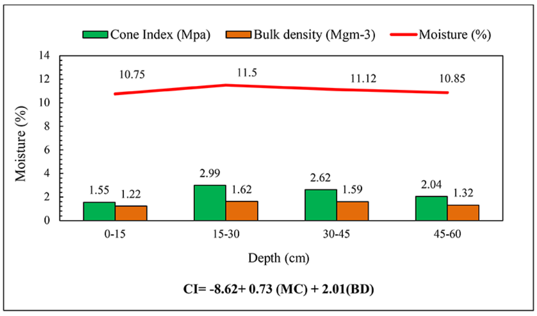

Fig. 11. Relation between bulk density, cone index and moisture at various depth level.

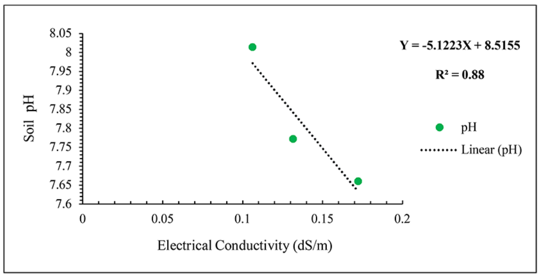

Fig. 12. Correlation between electrical conductivity and pH of the soil.

compaction and mean electrical conductivity for sandy loam soil up to 60 cm depth in sandy loam soil

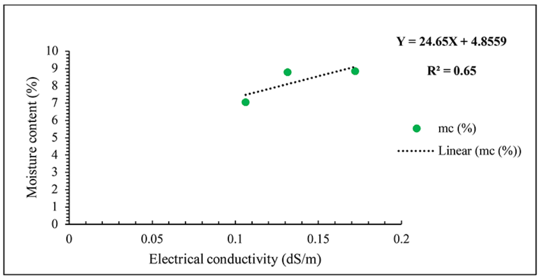

Fig. 13. Correlation between electrical conductivity and pH of the soil.

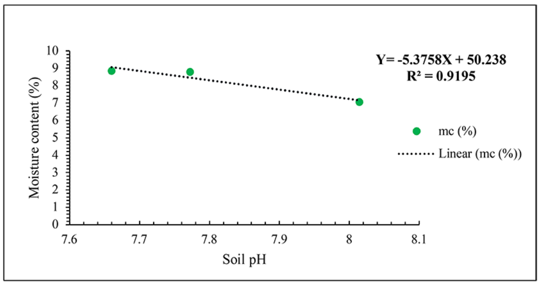

Fig. 14. Correlation of pH and moisture content of the soil.

(S1) was plotted in design expert software to illustrate the effect of depth on soil compaction and electrical conductivity as shown in Figs. 4–5, respectively. Similarly, a 3D graph and contour map for the mean soil compaction and mean electrical conductivity for loamy soil up to 60 cm depth in loamy soil (S2) was plotted to illustrate the effect of depth on soil compaction and electrical conductivity as shown in Figs. 6–7 respectively.

Relation between moisture content (MC), bulk density (BD), and cone index (CI) at different depth levels

Linear regression analysis was performed to find the correlation between the moisture content, bulk density, and cone index which showed an increasing trend with increasing depth and a decreasing trend at a certain depth of approx, 45 to 60 cm. It was found that moisture content was strongly correlated with bulk density (R^2 = 0.83) and cone index (R^2 = 0.83) as shown in Figs. 8–9 respectively. Similarly, a very strong correlation was revealed between bulk density and cone index (R^2 = 0.83) as shown in Fig. 10. A

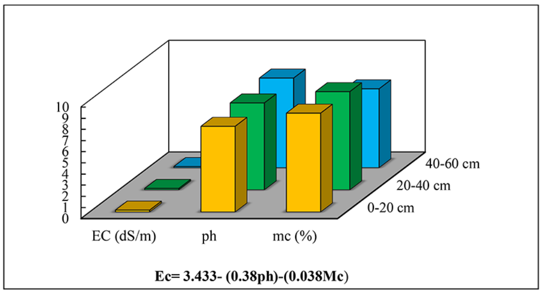

Fig. 15. Relationship model between electrical conductivity, pH, and moisture content (%).

combined relation was derived from the regression analysis between cone index, bulk density, and cone index in sandy loam soil (Fig. 11).

Relation between electrical conductivity (EC), soil pH, and moisture content at different depth levels

Linear regression analysis was performed to find the correlation between the electrical conductivity, pH, and moisture content of the soil for the same location and same depth in sandy clay loam soil up to 60 cm at an interval of 20 cm. It was found that the pH of the soil was strongly correlated with the electrical conductivity of soil (R^2 = 0.88) and moisture content (R^2 = 0.65) as shown in Figs. 12–13, respectively. Similarly, a very strong correlation was revealed between the pH and moisture content of soil (R^2 = 0.91) as shown in Fig. 14. A combined relation was derived from the regression analysis between electrical conductivity, pH and moisture content (%) of soil in sandy loam soil as shown in Fig.15.

CONCLUSION

In modern literature, scientific papers related to the relationship between electrical conductivity and soil compactions are lacking. In this study, two major soil properties and factors that influenced these properties were analyzed. There was a significant qualitative and quantitative correlation between soil compaction, electrical conductivity, and factors affecting the type of soil selected for the study. The correlations obtained between electrical conductivity, soil compaction, and various soil properties showed a greater possibility of using a conductivity and soil compaction survey as an effective assessment tool for predicting some soil properties for the type of soil selected for the study. The mechanism behind more authenticated and powerful good relationships is yet to be discovered through extensive testing. Further, more field and laboratory experiments are required to be conducted in different types of soil to establish a more precise and generalized correlation between soil compaction and the electrical conductivity of the soil.

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