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Prediction of related Soil Properties using Empirical Modelling Approach in Vertisols

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ABSTRACT: Soil, as a growth medium and through its various functions, plays a vital role in the production system. Empirical models are functions to explore widely available dataset to generate the impedance of one property on other correlated soil properties. In this paper, we tried to develop some empirical equations and easily understandable graphical representations for gaining better knowledge, particularly for vertisols of central India. The soil samples were collected from research farm of JNKVV, Jabalpur, India during the period 2018-2019. The samples from surface and sub-surface soil were analysed for SOC, cation exchange capacity, bulk density, penetration resistance and soil textural analysis, compiled to develop a regression models. The relationship of SOC with cation exchange capacity and bulk density; clay content with cation exchange capacity, bulk density, penetration resistance and liquid limit were developed. The models were found statistically significant with good predictability. Soil clay content had direct linear correlation ($p < 0.05\%$) with coefficient of determination (R^2) = 0.64 for CEC, 0.607 for bulk density, 0.732 for penetration resistance and 0.738 for liquid limit of soil. Soil organic carbon also had direct linear correlation ($p < 0.05\%$) with coefficient of determination (R^2) 0.849 while, bulk density (R^2 = 0.74) was found inversely correlated with of soil organic carbon.

Keywords: Empirical model, SOC, BD, Clay content, Penetration resistance.

INTRODUCTION

Soil is a heterogeneous material composed of organic matter from plant, animal, and microbial wastes, minerals from weathering rocks, soil organisms, soil water, and soil air. Soil organic carbon (SOC) strongly impacts the soil quality, functionality and health (Blanco-Canqui *et al*., 2013: Lal, 2016). Due to the interdependence of physical, chemical, and biological qualities, improving one soil property through SOC simultaneously influences other properties and processes (FAO, 2017). The presence of organic matter and clay contributes to enhanced nutrient retention which is vital for plant growth and overall soil health (Javed *et al*., 2022). Soil Organic matter and clay helps in regulating various soil properties through the negative charges (cation exchange capacity) and pore size distribution (Bi *et al*., 2023).

Soil carbon, bulk density, penetration resistance, and numerous other physical and chemical parameters could be measured using both field and laboratory methods. For field-scale applications that need a large volume of data, these techniques are workable. These approaches become unworkable for large-scale applications since they are expensive and time-consuming. Alternatively, the more accessible soil characteristics, like the organic carbon content (OC) or particle size distribution might be used to indirectly infer these attributes. Techniques for quick and accurate soil measurement are important in agricultural experimentation. These strategies can be broadly divided into two categories: direct and indirect. Soil sampling and laboratory analysis are examples of direct procedures, while regression and radiation approaches are examples of indirect methods. The most popular methods are the classic ones, although they take a long time and are challenging to apply when sampling different soil depths. Compared to direct procedures, indirect methods seem to be more accurate. A method such as this one makes use of gamma radiation, but soil depth has a big impact on how accurate it is. Regression analysis is a cost-effective technique since it can produce indirect measurements; however, it requires high-quality data on soil qualities such as texture and organic matter content, as well as information on climate and location. This substitute makes use of pedotransfer functions (PTFs).

"Pedotransfer" refers to the process of moving existing soil data to required data (Brahim *et al*., 2012). These functions are empirical formulas to predict CEC, bulk density, liquid limit from easy and available measures in the soil surveys databases such as particle size distribution, and organic carbon content (Abdelbaki, 2018). Pedo-transfer functions (PTFs) are predictive functions based on raw soil data used to estimate strongly correlated soil properties, such as soil organic matter (SOM), soil texture, clay minerals, depth, and other environment and management covariates (Al-Shammary *et al*., 2018).

Various geographical regions throughout the world can be explored using such functions for the prediction of linked soil properties. There is enough data set available on soil clay content, bulk density, organic carbon and CEC for vertisols of central India, whereas the prediction models are less common. In this paper, we tried to develop some empirical equations and also worked on easily understandable graphical representations for gaining better knowledge, particularly of this region.

MATERIAL AND METHODS

A. Study Area and dataset

The study area covers Jabalpur district 23°10′ N latitude and 79°57′ E longitude and an elevation of 393.0 meter above mean sea level (AMSL), situated in the central India. This area offers medium to deep black soil belongs to *Kheri* series of fine montmorillonitic hyperthermic family of *Typic Haplustert*. The climate of the region is sub-tropical, lies in the Kymore Plateau and Satpura hills agro-climatic zone of Madhya Pradesh characterized by hot dry summers and cool winters. The average annual rainfall, average humidity and average evaporation are 1274 mm, 73 percent and 3.93 mm/day, respectively.

The dataset used in this study originates from experimental field of Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, India containing data from a single site (Rice-wheat cropping system) with 48 sample points. The site comes under on-going long-term experiment of AICRP on STCR initiated in 2008 during 2018-2019.

B. Soil Chemical and Physical Properties

At each site a soil profile was sampled to a depth of 60 cm varing from 0-15, 15-30, 30-45 and 45-60 cm of soil depth. Soil samples were air dried under shade and sieved at 2 mm for chemical analyses. SOC was measured using $K_2Cr_2O_7$ as oxidizing agent (1N) and back titrating with 0.5 N FAS method as suggested by Walkley and Black 1934. Samples collected with core sampler were used to determine bulk density soil samples. Particle size analysis and penetration resistance was done using hydrometer method described by Bouyoucos (1927) and cone penetrometer (Eijelkamp Agrisearch equipment) respectively. The cation exchange capacity (CEC) of soil was computed using value of clay content (%) and organic matter content (%) in soil using the following relationship with the assumption of average CEC of OM = 200 Cmol (P+) kg^{-1} and average CEC of clay = 50 Cmol (P+) kg^{-1}.

CEC (Cmol (P+) kg^{-1}) of soil = [OC (%)× 1.724 × 200] + [Clay (%) × 50]

C. Statistical Analysis

The data generated form investigation was subjected to statistically analysis by applying the ANOVA for split plot design using Microsoft excel. The empirical models of correlated properties were generated by exploiting correlation and multiple regressions techniques as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

A. Relation between CEC, SOC and clay percentage

The SOC is significantly related to the CEC of soil system at surface and sub-surface level with high positive correlation (*p*- value< 0.05) at surface soil followed by sub-surface. The CEC and SOC had linear, positive correlation with a higher degree (R^2= 0.849) correlativity. The prediction model had high predictability of 84.9 per cent. The negative charges of soil organic matter contribute substantially to effective CEC in top soils (Ramos *et al*., 2018; Solly *et al*., 2020).

CEC [C mol (P^+) kg^{-1}] = 3.397 × OC (g kg^{-1}) + 17.78

The relationship between CEC and clay content of the soil revealed that CEC can be predicted based on clay (%) to the extent of 64 per cent (coefficient of determination; R^2 = 0.64) using the following equation. A positive and linear correlation (*p*- value< 0.05) was observed between clay and CEC. This positive correlation between these two were may be because of capacity of clay to exchange more cations. The negative charges on clay minerals and pedogenic oxides and hydroxides adsorb oppositely-charged metal cations (Weil *et al.*, 2016), which may thereby bind SOC through exchangeable bridges and ionic bonds (Rasmussen *et al*., 2018; Rowley *et al*., 2018). The regression model developed for the cation exchange capacity and soil organic carbon is given below:

CEC [C mol (P^+) kg^{-1}] = 0.613 × Clay (%) + 12.14

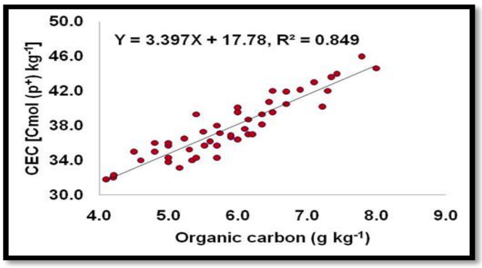

Fig. 1. Relationship between organic carbon and CEC of soil.

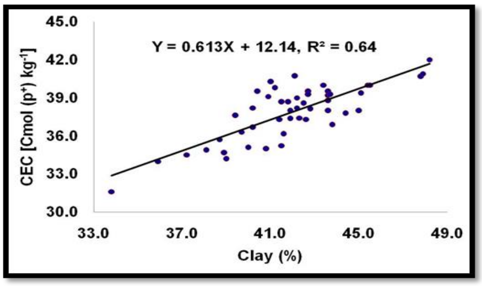

Fig. 2. Relationship between clay content and CEC of soil.

B. Relation between bulk density, SOC and clay percentage

The bulk density of soil is a very foundation soil property which determines the health of the soil through maintaining porosity. The bulk density of soil had negative correlation (p- value< 0.05) with SOC content of soil with the coefficient of determination (R^2) = 0.74. The bulk density (Mg/m^3) decreased linearly with every point increase in organic carbon. Both the properties were inversely correlated to each other to a greater extent. It indicates that bulk density is lower if the soil is higher in SOC. Soils become more friable, porous and chemically active if rich in SOC which tend to make soil lower in bulk density. The results were supported by Sakin (2012); Athira *et al.* (2019); Crnobrna *et al.* (2022). The multiple regression equation for bulk density and organic carbon is as follows:

Bulk density (Mg m^{-3}) = - 0.04 × OC (g kg^{-1}) + 1.601

Further soil bulk density (Mg/m^3) and clay content (%) was plotted (Fig. 4), and the results evident direct and linear (p- value< 0.05) relationship of bulk density with clay percentage. The predictability of bulk density with this regression equation is about (R^2 = 0.607) 60.7 per cent. Kumar *et al*. (2009) indicated that soil texture specific tests would be required to determine the correct organic matter level to achieve a target bulk density to avoid the problem of compaction. Nath (2015) suggested that high content of clay fraction and organic matter on soil should be incorporated to the soils with decreasing bulk density. The multiple regression equation developed is given below:

Bulk Density (Mg m^{-3}) = 0.015 × Clay (%) + 0.742

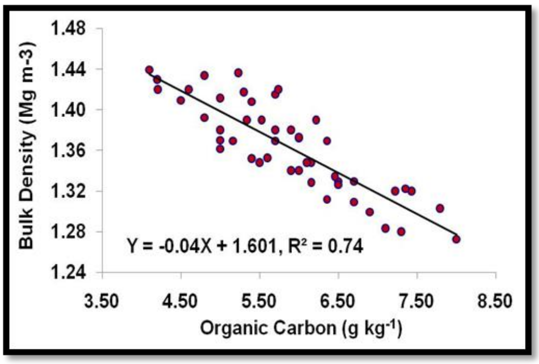

Fig. 3. Relationship between organic carbon and bulk density of soil.

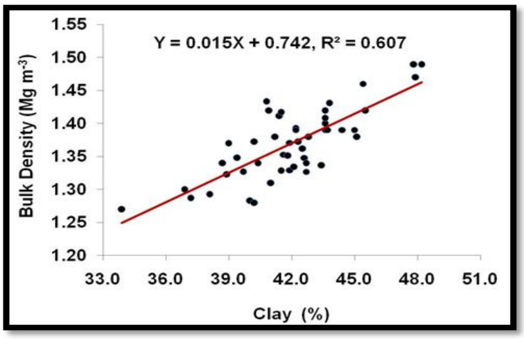

Fig. 4. Relationship between clay percentage and bulk density of soil.

C. Relation between Penetration resistance and clay content

Penetration resistance is a key property of soil and reflects the compactness of the soil. It plays an important role in water and air movement in soil; affect the emergence of shoot and development of root. The model revealed direct and linear correlation (p- value< 0.05) between penetration resistance and clay content in the soil. The coefficient of determination (R^2) was 0.73, indicating that the model was effective in predicting the penetration resistance. Positive and significant relationship between penetration resistance and clay content was also reported by Stefanou and Papazafeiriou (2013). The empirical model obtained is given below:

Penetration Resistance (kPa) = 6.985 × Clay (%) + 80.4

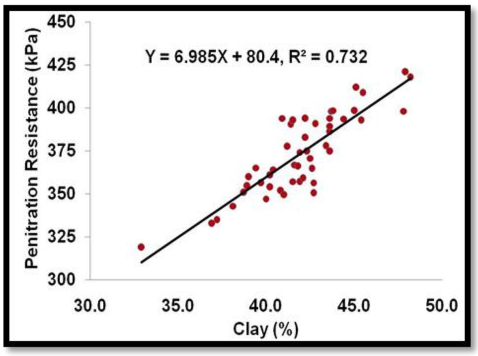

Fig. 5. Relationship between clay content and penetration resistance of soil.

D. Relation between Liquid limit of soil and clay percentage

The liquid limit of soil is one of the most important Atterberg's limits which indicate the level of moisture content in soil at which soil tends to flow and is important for water erosion. The relationship between liquid limit (%) and clay content (%) of soil was worked out (Fig. 6). The graphical representation of data set revealed a direct and linear correlation (p< 0.05%) with coefficient of determination (R^2) 73.2 per cent. It may be due the greater water absorbing capacity of clay particle. The regression equation developed for liquid limit and per cent clay content is as follows:

Moisture content at Liquid limit (%) = 0.893 × Clay (%) - 4.832

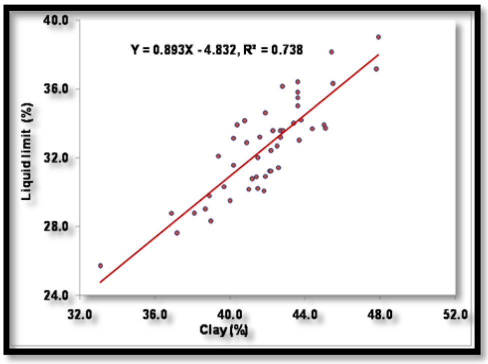

Fig. 6. Relationship between clay content and liquid limit of soil.

CONCLUSIONS

For vertisols of central India the predicted models can be used for evaluating the existing soil management practices, soil fertility assessment and nutrient recycling. The models are statistically significant and suggestions are accepted. The function can be utilized to generate expensive and laborious soil properties. Utilising PTFs is a practical tool, an affordable approach, and a simple methodology for determining the properties of soil, assessing its capacity to retain water, and helping farmers manage their water resources.

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Conflict of Interest. None.

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