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Predicting physical properties of soil through empirical equation developed from relationship between bulk density and different physical properties of soil

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Abstract
Measurement of soil properties continuously at each location throughout the globe is impossible for digitally mapping the global soil resources. It is necessary to have a strong system that can predict soil properties at a given location in short time and without extra expenditure. Developing models to predict the physical properties with the help of one out of several strongly related properties to each other is an attempt of this study. Bulk density which is an important factor influencing soils other properties and easy to estimate has been used as an independent variable .The study indicates a strong negative correlation (r= -0.936 to - 0.999) between bulk density and different physical properties. Data shows that by using the regression equation developed in this study predicted value of different physical properties are almost 99.961 to 100 percent similar to observed values only 0.039 to 0 percent deviations in observed than predicted value was recorded. Hence these equations can be used to predict the physical properties for different textured soil in case the estimation is not practicable and may be functional to digital mapping of global soil resources.

Keywords: Digital mapping, regression equation, physical property, soil health

Introduction
Soil physical properties characterize flow of air and water through soil and processes affecting germination, root growth, and erosion. A healthy soil should have sufficient air and water to meet the needs of plants with enough pore space for easy root penetration, while the mineral soil particles would provide physical support and plant essential nutrients. Among the physical properties bulk density which governs other physical property is most dynamic. Soils with lower bulk densities reflecting good structure and less compaction helps in good root growth of plants, whereas the soils with higher bulk densities and greater compaction reduce or restrict root growth. Bulk density can vary considerably within a textural class because of variation in organic matter status and management practices which improve porosity (less compaction).
Soil physical properties affected by land use pattern affects several chemical and biological processes. Soil physical properties altered soil environment, which may greatly influence growth and production of crops. Some key soil physical properties in relation to plant growth and productivity include bulk density, infiltration rate, hydraulic conductivity, porosity, aggregate stability and moisture status etc. It is now well established that unless the soil physical, chemical and biological environment is maintained at its optimum level, the genetic yield potential of a crop cannot be realized. Assessment of nutrient availability is not only the criteria of soil health but it also includes study of physical and biological parameters of soil. To rate the soil health knowledge of critical levels of all the parameter is essential. Information regarding the critical levels of physical indicators to rate the soil health for different soil texture in India is lacking. Study of physical properties in Indian soil testing laboratories for study the soil health is not getting due attention since estimation of these properties are labour intensive and time consuming. Among the physical properties estimation of bulk density is easy, require fewer instruments and moreover have strong (positively or negatively) correlation with other physical properties. This relationship can be helpful to predict the other properties by developing a regression equation without extra cost and time. A considerable amount of soil information is available from soil fertility research of thousand of experimental plots. Both the soil survey and soil fertility data can be used to predict soil properties in areas

where no data are available or can be used to predict for a given area, like for example bulk density from the soil organic carbon and clay content .Such prediction are highly relevant in light of the current efforts to digitally map the global soil resources (Sanchez *et al.* 2009) [17]. Akgül and Özdemir (1986) [12] studied the relationships of soil bulk density with some soil properties and explained that these constants can be estimated by means of regression models. T. Aşkın and N. Özdemir (2003) obtained the relation of soil bulk density with soil particle size distribution and organic matter content. Gupta *et al.* (1989) [7] also emphasized that bulk density is an important factor influencing soil microscopic properties (e. g., large pores, hydraulic conductivity, penetration resistance) which is significant in land utilization. Measurement of soil properties continuously at each location throughout the globe is impossible for digitization of global soil resources. Therefore for digitalization of global soil resources it is necessary to have strong system that can predict soil properties at a given location. Thus models should be developed to predict infiltration rate, hydraulic conductivity, porosity, aggregate stability and moisture limits from bulk density of soils. Keeping this in mind it was proposed to develop empirical equations to predict some important physical properties.

Materials and Methods

The investigation entitled "Predicting physical properties of soil through empirical equation developed from relationship between bulk density and different physical properties of soil" was carried out using various research materials and analytical techniques during 2017-18 at department laboratory of soil science at Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, UP, India.The study area falls in the district of Meerut from 29°04' N latitude and 77°42' E longitude at an altitude of 237 meter above the mean sea level (MSL).Study area enjoys sub tropical and semi arid climate with hot desiccating summers and cold winters.

Soil texture for soils collected from three locations was determined using hydrometer method. Different level of compaction was created by maintaining different bulk density (1.1 to 1.8 Mg/m^3) in 12 inch long plastic pipe of 4 inch diameter pipe through adopting the formula of bulk density equals to mass of soil divided by volume of soil. Different physical properties of soil like Hydraulic conductivity, Infiltration rate, Porosity, Aggregate stability and Moisture limits were assessed in the laboratory and furthermore correlation and regression equation were established using statistical procedure between different level of compactions (bulk densities maintained in the pipes of different textured soil). Percent deviation of observed value from predicted values was also calculated for which the average value of bulk densities and observed values of different properties were taken into consideration.

Results and Discussion

Different physical properties *viz* hydraulic conductivity, Infiltration rate, porosity, aggregate stability and moisture limits estimated from the soil filled in pipe at different level of compaction (1.1 to 1.8 Mg/m^3) i.e. bulk densities are presented in Fig 1-5. Data presented in Fig 1 indicates that more hydraulic conductivity was recorded in loamy sand (12.0 cm /hr) followed by sandy loam (10.5 cm/hr) and minimum was noticed in sandy clay loam (6.55 cm/hr) at same degree of compaction (1.1 Mg/m^3) and as the compaction increases the hydraulic conductivity decreases and reached up to 2.54, 0.25 and 0.21 cm/hr for loamy sand, sandy loam and sandy clay loam soil, respectively at 1.8 Mg/m^3 bulk density. Data clearly indicates that higher hydraulic conductivity was recorded from the soil having lower bulk density and data also indicates that as the bulk density increases the hydraulic conductivity decreases. Statistical correlation studies presented in Table 1, 2 and 3 showed a strong negative correlation (r = - 0.991,-0.967 and -0.977 among bulk density and hydraulic conductivity for loamy sand, sandy loam and sandy clay loam soil, respectively). Agrawal *et al* (1987) [1] and Meek *et al.* (1992) [14] also observed the similar relation between bulk density and hydraulic conductivity

Infiltration rate is controlled by the pores and pores size distribution. Data presented in Fig 2 indicates that alike to hydraulic conductivity, the infiltration rate decreases as the bulk density increases .The maximum infiltration rate 16.8, 13.8 and 8.1 cm/hr for loamy sand, sandy loam and sandy clay loam soil, respectively was found for the soil with low bulk density (1.1 Mg/m^3) and with increasing bulk density the infiltration rate decreases. Minimum infiltration rate 2.4, 1.05 and 0.40 cm/hr for loamy sand, sandy loam and sandy clay loam soil, respectively was noticed at high degree of compaction (1.8 Mg/m^3). A strong negative correlation (r = -0.973,-0.936 and -0.957 among the bulk density and infiltration rate for loamy sand, sandy loam and sandy clay loam soil, respectively) was found (Table1, 2 and 3). Agrawal *et al.* (1987) [1] also found that infiltration increases with the decrease in bulk density, similarly Meek *et al.* (1992) [14] also recorded the same trend.

Bulk density indirectly provides a measure of the soil porosity. Soil porosity is the ratio of the volume of soil pores to the total soil volume. Thus the bulk density of a soil is inversely related to the porosity. We also found a strong negative correlation (r = -0.999, -0.991 and -0.943 of bulk density with porosity for loamy sand, sandy loam and sandy clay loam soil, respectively (Table 1, 2 and 3). The highest porosity 58.23, 54.4 and 55 % for loamy sand, sandy loam and sandy clay loam soil, respectively was noticed with the lowest bulk density (1.1 Mg/m^3) and as the bulk density increases the porosity decreases. Lowest porosity 31.44, 31.44 and 34 % was recorded with highest (1.8 Mg/m^3) bulk density samples (Fig. 3). Ahad *et al.* (2015) [2] also recorded a strong negative correlation (r = -0.79) between porosity and bulk density of soil. Similarly a negative correlation (r = -0.64) with pore space was also observed by Walia and Rao (1996) in Bundelkhand region of Uttar Pradesh.

Aggregation of soil particles improves porosity of the soil and decrease the bulk density. Organic matters which produce cementing agents bind the soil particles and influenced the stability. Hence it can be stated that bulk density is inversely correlated with aggregate stability. We also found a strong negative correlation (r = - 0.997,-0.988 and -0.943) of bulk density with aggregate stability for loamy sand, sandy loam and sandy clay loam soil, respectively. (Table 1, 2 and 3). As the bulk densities increase the aggregate stability decreases. From the Fig.4 it is evident that the highest aggregate stability 25, 28 and 50 was found from the samples which have lowest bulk density (1.1 Mg/m^3) and lowest aggregate stability 4.5, 6 and 9 was found from the samples which have high degree of compaction (1.8 Mg/m^3 bulk density). Ball *et al.* (1988) [3] also found an inverse linear relationship (r^2=0.94) between MBD and aggregate stability index (wet sieving) of the disturbed Gleysols and cambisols.

Plasticity index (PI) is a measure of the plasticity of a soil. Soil with a high plasticity index tend to be clay, those with a lower PI tend to be silt and those with a PI of o (non- plastic) tend to have little or no silt or clay. Data on PI presented in Fig. 5 indicates that maximum PI was found in sandy clay loam soil followed by sandy loam and minimum PI was recorded in loamy sand. More PI (20.6%) was recorded at low degree of compaction (1.1 Mg/m^3 BD) in sandy clay loam soil followed by sandy loam soil (14.05%) while in loamy sand plasticity index could not be recorded. Data presented in Fig. 5 clearly indicates that as the compaction level (bulk density) increases the plasticity index decreases. Minimum PI (8.8, 8.5 and 0%) was noticed at highest degree of compaction (1.8 Mg/m^3 BD) in sandy clay loamy followed by sandy loam and loamy sand. Statistical correlation studies presented in Table 1, 2 and 3 showed strong negative correlation (r = -0.966 and -0.946) of bulk density with plasticity index for sandy loam and sandy clay loam soil, respectively. No correlation was found between bulk density and PI in loamy sand soil may be because little clay is found in this texture. Similarly Ramaih *et al.* (1970) also found a linear relationship between MBD-liquid limit and CWC-liquid limit but no definite correlation with either plastic limit or plasticity index. Ring *et al.* (1962) using artificially mixed soil, examined simple relationship between CWC and MBD with plastic limit, liquid limit, average particle size and particles finer than 0.001 mm. They found good correlations of CWC with the Atterberg limits and of MBD with CWC and plastic limit.

Prediction of different physical properties and their validation using estimated bulk density of different textured soil

Physical properties are important parameters used in determining irrigation practices, drainage design, runoff, ground water recharge and other agricultural and hydrological processes. Measurements of these properties in the field are costly and time consuming. Therefore a statistical evaluation procedure (correlation coefficient (r)) which measures the level of association with degree of compaction (bulk density) was used to predict different physical properties. Similarly standard deviation from measured to predicted data was also calculated to validate the predicted properties.

Regression equation between physical properties and bulk density were developed to predict the physical properties and presented in Table 1, 2 and 3. Standard deviation from observed values to predicted values were also calculated and presented in table. Data presented in table shows that by using the regression equation developed in this study predicted value of different physical properties are almost 99.961 to 100 percent similar to observed values only 0.039 to 0 percent deviation in observed than predicted value was recorded. Hence these equation can be used to predict the physical properties for different textured soil in case the estimation is not practicable .Numerous studies have been made to predict soil physical properties using empirical equations (Arya and Paris 1981, Rawls and Brakensiek, 1982 and Ahuja *et al.* 1989) [16] for establishment the relationship. This relationship can be useful for estimating hydraulic conductivity, infiltration rate, porosity, aggregate stability and moisture limits for planning and management purpose where data are not available and measurement are not feasible (Jabro 1992) [9].

Physical properties of different textured soil under different level of compaction

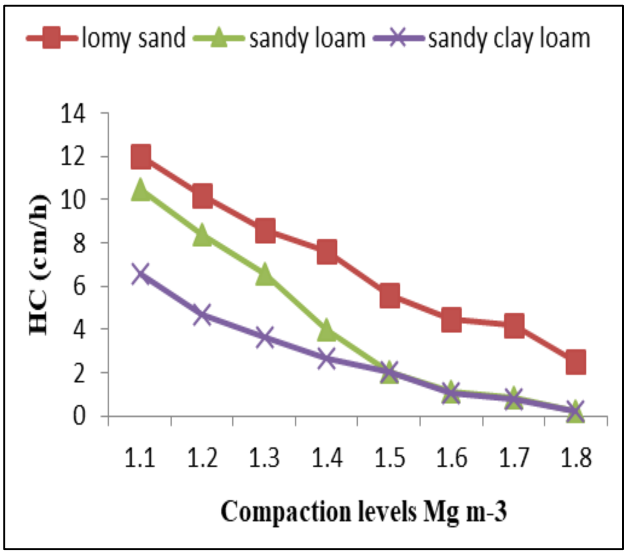

Fig 1: Hydraulic conductivity of different textured soil under different level of compaction

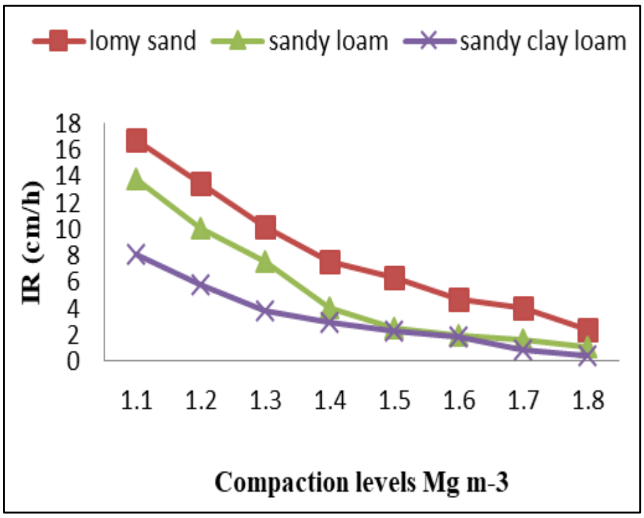

Fig 2: Infiltration rate of different textured soil under different level of compaction

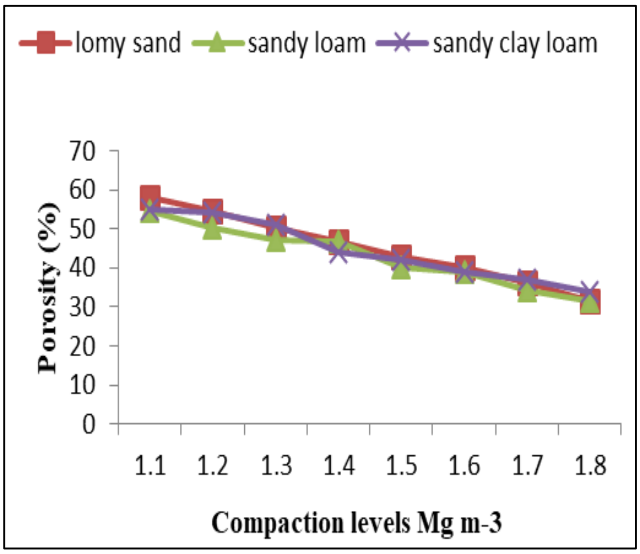

Fig 3: Porosity of different textured soil under different level of compaction

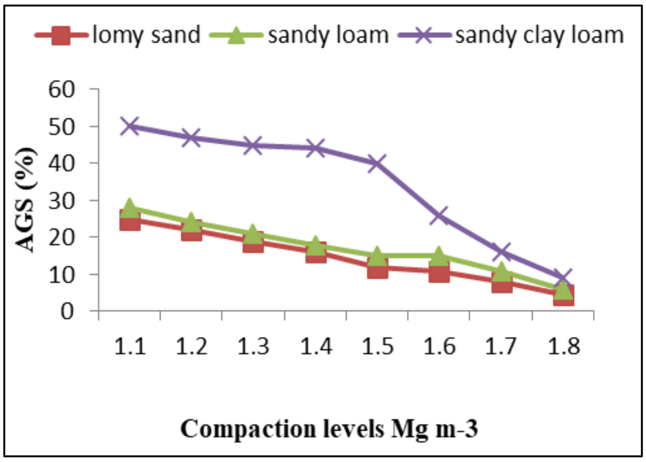

Fig 4: Aggregate stability of different textured soil under different level of compaction

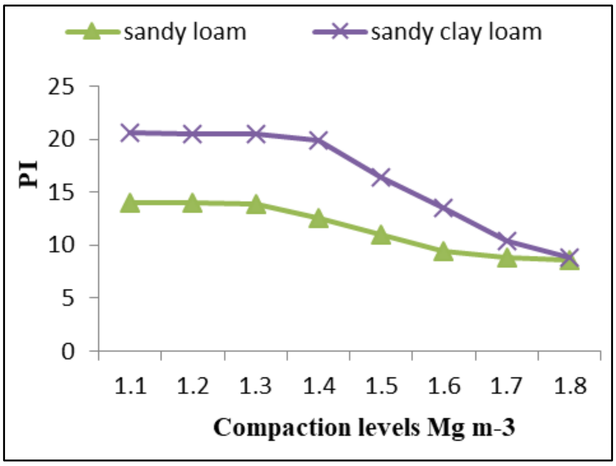

Fig 5: Plasticity index of different textured soil under different level of compaction

Where, IR= Infiltration rate, HC= Hydraulic conductivity, AGS= Aggregate stability, PI= Plasticity index.

Table 1: Correlation coefficient and Regression equation between different level of compaction (BD) and other physical properties of loamy sand soil and %deviation in predicted values from observed values:

S. No.	Related Soil Parameters	Regression equation	Correlation coefficient(r)	Average Observed value	Predicted Value	% Deviation from Observed Value
1.	IR-BD	IR =36.8547 – 19.7619 BD	-0.973	8.2	8.2	0
2.	HC- BD	HC = 25.9578 – 13.1321 BD	-0.991	6.92	6.90	-0.003
3.	Porosity-BD	Porosity = 98.9929 – 37.2012 BD	-0.999	45.05	45.06	0.0002
4.	Aggregate stability- BD	Aggregate stability = 56.375 – 28.75 BD	-0.997	14.68	14.62	- 0.004
5.	Plasticity index – BD	Not Available	Not Available	NA		

Table 2: Correlation coefficient and Regression equation between different level compaction (BD) and other physical properties of sandy loam soil and %deviation in predicted values from observed values

S. No.	Related Soil Parameters	Regression equation	Correlation coefficient(r)	Average Observed value	Predicted Value	% Deviation from Observed Value
1.	IR- BD	IR = 31.0994 – 17.7798 BD	-0.936	5.32	5.11	-0.039
2.	HC—BD	HC = 26.2817 – 15.2107 BD	-0.967	4.22	4.22	0
3.	Porosity- BD	Porosity = 89.9538 – 32.4345 BD	-0.991	42.92	43.02	0.002
4.	Aggregate stability –BD	Aggregate stability = 58.6785 – 28.5714 BD	-0.988	17.25	17.26	0.0006
5.	Plasticity index – BD	Plasticity index = 25.3269 – 9.5047 BD	-0.966	11.54	11.54	0

Table 3: Correlation coefficient and Regression equation between different level of compaction (BD) and other physical properties of sandy clay loam soil and %deviation in predicted values from observed values

S. No.	Related Soil Parameters	Regression equation	Correlation coefficient(r)	Average Observed value	Predicted Value	% Deviation from Observed Value
1.	IR -BD	IR = 17.9658 – 10.1333 BD	-0.957	3.27	3.27	0
2.	HC- BD	HC = 15.1796 – 8.5928 BD	-0.977	2.72	2.71	0.0036
3.	Porosity -BD	Porosity = 91.1071 – 32.1429 BD	-0.986	44.5	44.59	-0.002
4.	Aggregate stability- BD	Aggregate stability = 121.4524 – 59.881 BD	-0.943	34.62	34.63	-0.0002
5.	Plasticity index – BD	Plasticity index = 43.4772 – 18.7369 BD	-0.946	16.31	16.33	-0.0012

Conclusion

From the study it can be concluded that regression equation developed in this study may be used for prediction of different physical properties without expending extra money and time for digital mapping and preparation of soil health card where data are not available.

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