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Prashant Deo Singh
Junior Research Fellow, Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India

Abhilasha Pathak
Ph.D., Research Scholar, Department of Soil Science, G. B. Pant University of Agri. and Tech., Pantnagar, Uttarakhand, India

Anand Singh
PhD, Department of Soil science and Agricultural Chemistry, SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Pramod Kumar
Ph.D. Research Scholar, Department of Agronomy, CSA University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Ashok Kumar
Professor, Department of Soil Science and Agricultural Chemistry, SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India

BP Dhyani
Professor, Department of Soil Science and Agricultural Chemistry, SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Satendra Kumar
Professor, Department of Soil Science and Agricultural Chemistry, SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India

UP Shahi
Associate Professor, Department of Soil Science and Agricultural Chemistry, SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Adesh Singh
Associate Professor, Department of Agronomy, SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Corresponding Author:
Abhilasha Pathak
Ph.D., Research Scholar, Department of Soil Science, G. B. Pant University of Agri. and Tech., Pantnagar, Uttarakhand, India

Identification of critical limits for physical properties of soils as soil physical indicators for preparing soil health card for different textured soil

Prashant Deo Singh, Abhilasha Pathak, Anand Singh, Pramod Kumar, Ashok Kumar, BP Dhyani, Satendra Kumar, UP Shahi and Adesh Singh

Abstract
The investigation entitled "Identification of critical limits for physical properties of soil as soil physical indicators for preparing soil health card for different textured soil" was carried during 2018-19 at department of Soil Science & Agricultural Chemistry, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, UP, India. Different physical properties like hydraulic conductivity, infiltration rate, porosity, aggregate stability and moisture limit were estimated for soil filled in pipe collected from three different locations after 20 days of maintaining the compaction level. The desired ideal and critical limit of various physical properties for better plant growth and poor root development were assessed at established ideal and critical limit of bulk density in the experiment. Since methods to measure physical properties are labour intensive and time consuming therefore soil bulk density measurement is often require as an input parameter for models that predict soil physical properties. Thus, models also have been developed in the study to predict ideal and critical limit values of soil physical properties from bulk density without expending extra money and time for digital mapping and preparation of soil health card.

Keywords: physical, soil health card, textured soil

Introduction
Physical properties are important parameters used in determining infiltration, 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. Physical properties also affect the soil health since soil health is not only the sufficiency of plant nutrients or organic carbon in soil. Soil health includes physical, chemical and biological parameters of soil. Soil health card is a means to understand the soil quality. We need to know the critical levels and rating of all the parameters to enumerate the soil health. 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. It is well known fact that physical properties directly affect the plant growth and productivity. (Defossez and Richard 2002; Ahmad *et al.* 2009) [3, 1] found that soil compaction cause considerable damage to the structure of the tilled soil and consequently to crop production, soil workability and the environment. Compaction of soil affects nearly all properties of the soils: physical, chemical and biological. Soil compaction alters its structure by crushing aggregates or combining them into larger units, increasing its bulk density and decreasing the number of coarser pores leading to reduced permeability of water and air. It also increases surface runoff, erosion and reduces groundwater recharge Batey (2009) [2].
Compaction is one of the major threats to soil quality as it reduces pore volume and modifies pore geometry. Critical limit is the desirable range of values for a selected soil indicator that must be maintained for normal functioning of the soil ecosystem Tolon Becerra *et al.* (2012) [4]. Within this critical range, the soil performs its normal functions in natural ecosystems. For example the ideal bulk density for loamy sand, sandy loam and sandy clay loam is 1.60, 1.40 and 1.40 Mg m^{-3} however bulk density that restrict root growth of plant in these soil is 1.80, 1.80 and 1.75Mg m^{-3}, respectively (USDA-NRCS). Selection of critical limits for soil quality indicators poses several difficulties. The ability to supply moisture, nutrients and physical rooting support in the absence of toxic substances can be affected by many physical, chemical and biological parameters. A detrimental change in any of these can reduce the quality of the

soil, but the quantitative values beyond which these properties will be limiting depend strongly on the crop. For example, a pH below 6.5 reduces the yield of alfalfa, but pH must drop below about 4.0 before critical yield reduction occurs in blueberries (Doll, 1964). A critical limit of a soil indicator can be ameliorated or exacerbated by limits of other soil properties and the interactions among soil quality indicators. Given the complexities of yield response to critical soil parameter values, perhaps, the best we can do is to develop a set of guidelines that can be helpful to decide limits for definecrop/environment situations. Keeping this in mind the present investigation was carried out to identified the critical values of the physical properties of soil so that a scoring function graph to rate the soil quality can be develop.

Materials and Methods

The investigation entitled "Identification of critical limits for physical properties of soil as soil physical indicators for preparing soil health card for different textured soil" was carried out using various research materials and analytical techniques in the laboratory of department of Soil Science & Agricultural Chemistry, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, UP, India. Soils collected from three different locations having different textural class were processed and filled in the 12inch length plastic pipe of 4 inch diameter. Bulk density of soil in pipe was considered the level of compaction. The different limits of bulk density (1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7 and 1.8 Mg m^{-3}) of the soil was maintained by adopting the formula of bulk density *i.e.* ratio of mass to volume of soil in column. Different physical properties like hydraulic conductivity, infiltration rate, porosity, aggregate stability and moisture limit were estimated for soil filled in pipe after 20 days of maintaining the compaction level. Bulk density identified by USDA-NRCS for different textured soil was considered as ideal and critical limits for these estimated values. Ideal and critical limits of physical properties were also identified based on establishing relationship between different physical properties with compaction levels for different textured soil. Ideal or critical limits of bulk density identified by earlier scientist were put in regression equation to estimate the different physical properties. The value of these estimated properties were considered ideal or critical limits of physical properties

Result and Discussion

Estimated values of different physical properties at ideal bulk density at which plant performed better growth were considered ideal similarly values of different properties corresponding to critical bulk density at which growth of root restricts were considered critical value of loamy sand, sandy loam and sandy clay loam soil. Results obtained from the study are presented in Table1. The ideal bulk density identified by USDA-NRCS for loamy sand, sandy loam and sandy clay loam was 1.60, 1.40 and 1.40 Mg m^{-3} while bulk density at which root growth restrict were 1.80, 1.80 and 1.75 Mg m^{-3}, respectively. Data presented in table 1 indicates that infiltration rate corresponding to ideal and critical bulk density for plant growth and root restriction was 4.7 & 2.4 cm h^{-1} , 4.05 & 1.05 cm h^{-1} and 2.95 & 0.40 cm h^{-1} for loamy sand, sandy loam and sandy clay loam soil, respectively. Ideal limit of hydraulic conductivity for better plant growth was 4.49, 4.0 and 4.04 cm h^{-1} whereas for root restriction the critical limits were 2.54 cm h^{-1}, 0.25 cm h^{-1} and 0.21 cm h^{-1} for loamy sand, sandy loam and sandy clay loam soil, respectively. Limits of porosity for plant growth were 40.23, 46.6 and 44% while for root restriction 31.44, 31.44 and 34% for loamy sand, sandy loam and sandy clay loam soil, respectively. Similarly, ideal aggregate stability for plant growth were11, 18 and 44% while 4.5, 6 & 9% was found as critical limit for root growth in loamy sand, sandy loam and sandy clay loam soil, respectively. In moisture limit, ideal liquid limit for plant growth were 19.75, 26.4 and 36.29 whereas for root restriction 19, 20.50 & 22.20 for loamy sand, sandy loam and sandy clay loam soil, respectively. Plastic limit and plasticity index could not assess for loamy sand soil due to high level of sand percentage (80%) in soil whereas ideal plastic limit for plant growth is 13.8 and 16.44 and critical limits for root restriction 11.95 and 13.40% for sandy loam and sandy clay loam soil. Limits of plasticity index for plant growth and root restriction were found 12.6 & 8.55 and 19.85 & 8.80 for sandy loam and sandy clay loam soil, respectively. United States department of Agriculture has also done the similar study in 1999. Soil test kit guide USDA. Soil quality Institute, Washington, D.C.

Ideal and critical limits of hydraulic Conductivity, infiltration rate, porosity, aggregate stability and moisture limits as soil physical indicators were also identified based on relationship of different physical properties with compaction levels for different textured soil. Data regarding predicted ideal and critical limits identified through regression equation in the study are presented in Table 2, 3 and 4.

Regression equation developed between bulk density and different physical properties presented in Table 2, 3 & 4 for loamy sand, sandy loam and sandy clay loam soil, respectively were used to estimate the ideal and critical value for different properties indicates that predicted values are very close to the observed values.

To estimate the infiltration rate from known bulk density, the developed regression equation was IR = 36.8547 – 19.7619 BD, IR = 31.0994 – 17.7798 BD and IR = 17.9658 – 10.1333 BD for loamy sand, sandy loam and sandy clay loam soil, respectively. The ideal bulk density for loamy sand, sandy loam and sandy clay loam soil 1.6, 1.4 and 1.4 Mgm^{-3}, respectively was used to predict the infiltration rate. The predicted values for ideal and critical levels for infiltration rate were5.23 & 1.28, 6.2 & 0.896 and 3.78 & 0.23for loamy sand, sandy loam and sandy clay loam soil, respectively.

To estimate the hydraulic conductivity from known bulk density the developed regression equation were HC= 25.9578-13.1321 BD, HC = 26.2817-15.2107 BD and HC= 15.1796-8.5928 BD for loamy sand, sandy loam and sandy clay loam soil, respectively. The ideal bulk density for loamy sand, sandy loam and sandy clay loam soil 1.6, 1.4 and 1.4 Mg m^{-3}, respectively was used to predict the hydraulic conductivity. The predicted value for ideal and critical levels for hydraulic conductivity were 4.9&2.32, 4.98 & 1.09, 3.14 &0.14 for loamy sand, sandy loam and sandy clay loam soil, respectively.

Regression equation developed for porosity were Porosity = 98.9929 – 37.2012 BD, Porosity = 89.9538 – 32.4345 BD and Porosity = 91.1071 – 32.1429 BD for loamy sand, sandy loam and sandy clay loam soil, respectively. The ideal bulk density for loamy sand, sandy loam and sandy clay loam soil 1.6, 1.4 and 1.4 Mg m^{-3}, respectively was used to predict the porosity. The predicted value for ideal and critical levels for porosity were 39.47 &32.01, 44.60 &31.57, 46.14 and 34.85percent for loamy sand, sandy loam and sandy clay loam soil, respectively.

Regression equation for aggregate stability were Aggregate stability = 56.375 – 28.75 BD, Aggregate stability = 58.6785 – 28.5714 BD and Aggregate stability = 121.4524 – 59.881 BD for loamy sand, sandy loam and sandy clay loam soil, respectively by which we can estimate the aggregate stability from known bulk density, of these textural soil. The ideal bulk density for loamy sand, sandy loam and sandy clay loam soil 1.6, 1.4 and 1.4 Mg m^{-3}, respectively was used to predict the aggregate stability. The predicted value for ideal and critical levels for aggregate stability were 10.37 &4.63, 18.68 &7.24, 37.61 & 16.66 for loamy sand, sandy loam and sandy clay loam soil, respectively.

Regression equation for loamy sand soil for plasticity index could not developed while for sandy loam and sandy clay loam soil the equation was Plasticity index = 25.3269 – 9.5047 BD and Plasticity index = 43.4772 – 18.7369 BD by which the plasticity index of these known textural soil may be estimate. To predict the plasticity index 1.6, 1.4, 1.4 and 1.8, 1.8 and 1.75 Mg m^{-3} bulk density for loamy sand, sandy loam and sandy clay loam soils was used. The ideal and critical predicted plasticity index for loamy sand soil was not predicted whereas for loamy sand and sandy clay loam the values were 12.03 & 8.22, 17.25 & 10.69, respectively.

Table 1: Observed ideal and critical limits of physical properties that permits better plant growth or restrict roots for different textured soil

Soil Property		Ideal level for plant growth			Critical Level for root restriction			Remark
Soil type		Loamy sand	Sandy loam	Sandy Clay loam	Loamy sand	Sandy loam	Sandy Clay loam	
Bulk Density(Mg m^{-3})		1.60	1.40	1.40	1.80	1.80	1.75	Ref: USDA-NRCS (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053260.pdf)
Infiltration rate (cm h^{-1})		4.70	4.05	2.95	2.40	1.05	0.40	
Hydraulic conductivity(cm h^{-1})		4.49	4.00	2.70	2.54	0.25	0.21	
Porosity (%)		40.23	46.6	44.00	31.44	31.44	34.00	
Aggregate stability (%)		11	18.0	44	4.50	6.0	9	
Moisture Limits	Liquid limit	19.75	26.40	36.29	19	20.5	22.20	
	Plastic limit	NF	13.80	16.44	NF	11.95	13.44	
	Plasticity Index	NF	12.60	19.85	NF	8.55	8.80	

Table 2: Estimated ideal and critical limits for different physical properties through regression equation between different level of compaction (BD) and other physical properties of loamy sand soil

S. No.	Regression equation	Ideal level for plant Growth		Critical level for root restriction	
		Observed value	Predicted Value	Observed value	Predicted Value
1.	IR =36.8547 – 19.7619 BD	4.7	5.23	2.40	1.28
2.	HC = 25.9578 – 13.1321 BD	4.49	4.90	2.54	2.32
3.	P = 98.9929 – 37.2012 BD	40.23	39.47	31.44	32.01
4.	AS = 56.375 – 28.75 BD	11	10.37	4.5	4.63
5.	PI= Not Found	NF	NF	NF	NF

Table 3: Estimated ideal and critical limits for different physical properties through regression equation between different level of compaction (BD) and other physical properties of sandy loam soil

S. No	Regression equation	Ideal level for plant Growth		Critical level for root restriction	
		Observed value	Predicted Value	Observed value	Predicted Value
1.	IR = 31.0994 – 17.7798 BD	4.05	6.2	1.05	0.896
2.	HC = 26.2817 – 15.2107 BD	4.0	4.98	0.25	1.09
3.	P = 89.9538 – 32.4345 BD	46.6	44.60	31.44	31.57
4.	AS = 58.6785 – 28.5714 BD	18	18.68	6.0	7.24
5.	PI = 25.3269 – 9.5047 BD	12.6	12.03	8.55	8.22

Table 4: Estimated ideal and critical limits for different physical properties through regression equation between different level of compaction (BD) and other physical properties of sandy clay loam soil

S. No	Regression equation	Ideal level for plant Growth		Critical level for root restriction	
		Observed value	Predicted Value	Observed value	Predicted Value
1.	IR = 17.9658 – 10.1333 BD	2.95	3.78	0.40	0.23
2.	HC = 15.1796 – 8.5928 BD	2.7	3.14	0.21	0.14
3.	P = 91.1071 – 32.1429 BD	44	46.14	34.00	34.85
4.	AS = 121.4524 – 59.881 BD	44	37.61	9.0	16.66
5.	PI = 43.4772 – 18.7369 BD	19.85	17.25	8.8	10.69

IR=Infiltration Rate (cm hr^{-1}),HC=hydraulic conductivity(cm hr^{-1}), P= Porosity(%),
AS= Aggregate stability (%), PI=Plasticity Index

Conclusion

At ideal bulk density the soil will hold sufficient air and water to meet the needs of plants with enough porosity for easy root penetration, while at critical bulk density soil would have inadequate air and water to meet the needs of plants with low pore space which restrict the root growth. Hence soil bulk

density is a basic soil property that affects plant growth by regulating some soil physical and chemical properties.
From the study it can be concluded that for better plant growth and proper root development the desired physical properties must be maintained. Soil physical properties assessed at ideal and critical bulk density in the experiment was assumed ideal and critical. Since methods to measure physical properties are labour intensive and time consuming therefore soil bulk density measurements is often required as an input parameter for models that predict soil physical properties. Thus, models have been developed to predict ideal and critical soil physical properties from bulk density without expending extra money and time for digital mapping and preparation of soil health card.

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