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Soil Properties Influencing Compactability of Alluvial Soils of Haryana

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Abstract

There is growing realization that intensive cropping and increased mechanization used for higher production have led to a gradual compaction of soils. The soil properties which are routinely measured in laboratories and capable of predicting the soil compactability have been identified, and the compaction behavior of alluvial soils of Haryana state is described. A total of 60 surface soil samples were collected from different locations. The maximum bulk density (MBD), critical water content (CWC) and susceptibility of soil to compaction (SC) as obtained using standard proctor test were used as indices of soil compactability. The physical properties measured were sand, silt, clay, particle density, organic carbon, liquid and plastic limit, plasticity index, field capacity moisture content. Data were subjected to simple correlation and multiple regression analysis to assess the influence of different soil properties and their interactions on MBD, CWC and SC. The best prediction of maximum compaction may be obtained on the basis of soil organic carbon content susceptibility of soil to compaction may be estimated using silt content of the soil. The study suggested that the compaction threat can be countered by increased emphasis on achieving higher organic matter levels in alluvial soils of the state which are poor in their organic carbon contents.

Key words : Compaction, Physical properties, Alluvial soils, Haryana.

It has been realized after a gap of almost more than three decades that the intensive cropping and increased mechanization used for higher production in the state of Haryana have, in general, resulted in gradual compaction of soils. The susceptibility of soils to compaction is also arising due to imbalance use of inorganic fertilizers and over tilling that contribute to a gradual reduction in organic matter. Soil compactability is usually specified as a maximum bulk density which can be used as a reference in describing the relative compaction state of soils. It is generally affected by both external (stresses arising from management and environmental characteristics) and internal factors (particle size distribution, organic matter, moisture soil type, plastic behavior of clay, clay mineralogy). Soil resistance to compaction is dependent upon clay content and for given clay content it becomes more susceptible to compaction as its bulk density decreases (1). The highest compaction is reached in soil that has a wide distribution of particles from coarse to fine, and not in soil made up of either coarse or fine particles only (2). Apart from particle size distribution, soil moisture has also been widely recognized as a determinant of soil compactability. Soils having field capacity water content near or above the critical water content are more likely to be compacted (3). It has also been universally recognized that incorporation of organic matter

Table 1. Pearson correlation coefficients (*r*) between compaction indices (MBD, CWC and SC) and selected physical properties of soils of different cropping systems of Haryana. MBD = Maximum bulk density (Mg/m^3) ; CWC = Critical water content (%) ; SC = Susceptibility to compaction ; PD = Particle dencity (Mg/m^3) ; OC = Organic carbon (%) ; LL = Liquid limit (%) ; PL = Plastic limit (%) ; PI = Plastic index ; FC = Field capacity.

n=60	Sand	Silt	Clay	PD	LL	PL	PI	OC	FC	MBD	CWC
MBD	0.33**	–0.37**	–0.26*	–0.06	– 0.60**	– 0.83**	0.24	–0.57**	–0.33*	1.00	
CWC	–0.40**	0.49**	0.27*	–0.13	0.68**	0.89**	– 0.17	0.70**	0.42**	–0.90**	1.00
SC	–0.76**	0.83**	0.57*	–0.28*	0.37*	0.60**	– 0.58**	0.68**	0.73**	–0.22	0.38**

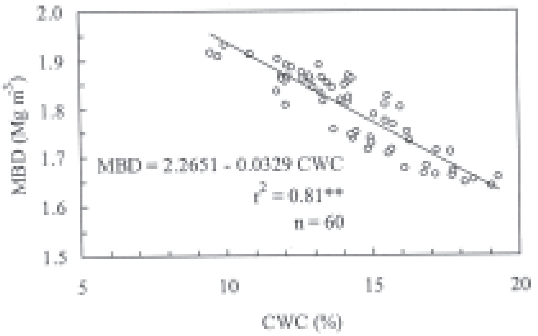

Figure 1. Relationship between maximum bulk density (MBD) and critical water content (CWC) for 60 samples.

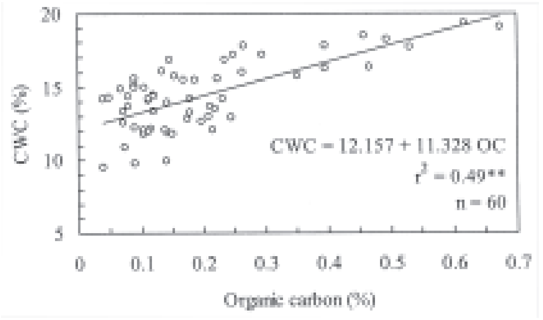

Figure 2. Relationship between critical water content (CWC) and organic carbon content for 60 samples.

reduces compaction and susceptibility of soil to compaction (4, 5). The organic residue particles are reported to be more effective in separating single-grain particles in sandy soils than in fine textured soils due to the lower surface area of the former (6). Since the high organic matter levels are usually associated with higher clay contents, organic matter is unlikely to have any mechanical effect on the more finely textured soils. Therefore, it becomes necessary to determine the soil conditions where organic matter may have optimum effect on soil compactability and the extent to which it can reduce it. The measurement of soil compactability is time consuming, therefore, many researchers have attempted to predict soil compactability from the simpler, cheaper or more readily measurable soil properties including particle size distribution, organic matter or moisture of soil during tillage and other farm operations with varied degree of success (7, 8). The information concerning the compactability behavior of alluvial soils of Haryana, where after green revolution there is a substantial increase in the cropping intensity, and number of tractors and other tillage implements, is scarce. The present study was, therefore, undertaken to identify readily measured soil properties which relate to compactability of alluvial soils, and to determine the compactability behavior of soils for planning management strategies to overcome the problem of soil compaction in the state.

Methods

A total of 60 surface (0—15 cm) soil samples were collected from five different locations during January 2005 in triplicates. The soils were classified as Typic Ustochrepts, Typic Ustipsamments or Typic Torripsamments. The most common texture was loam followed by sandy loam, sand, loamy sand and clay loam. Compactability of each soil sample was measured in term of the maximum bulk density (MBD) as determined by using the standard proctor test (9). From the compaction curve, the MBD and the associated critical water content (CWC) at which MBD is achieved were determined. For clay loam soil (which was of swelling nature), the proctor curve was corrected for swelling by taking compacted soil at different moistures in soil cores and subsequently drying the cores. Upon drying, cracks were developed. The soil in the cores was then broken into different sized clods and their bulk densities were determined. The bulk density value of the clods at different moisture content was taken as bulk density of the soil. susceptibility of soil to compaction (SC) was determined as the slope of the ascending regression line between CWC and MBD.

Soil physical properties included for studying their influence on the compaction indices (MBD, CWC or SC) were particle size distribution, particle density, organic carbon, liquid and plastic limit, plastic index, moisture content at field capacity. The particle density of soil samples was determined by Pycnometer method (10) and the bulk density from the mass and volume relationship of oven dried soil taken in cores. Particle size distribution was obtained using international pipette method (11). Soil moisture was determined gravimetrically (12) and the moisture at field capacity (–33 kPa soil water potential) was determined using pressure plate appara-

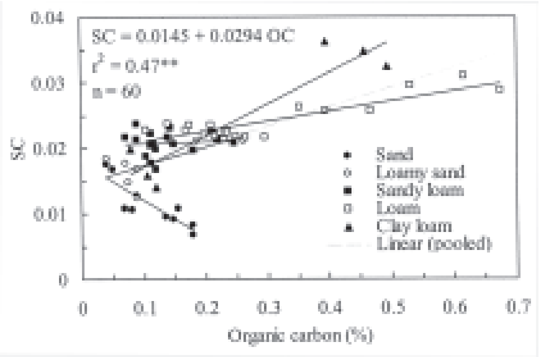

Figure 3. Relationship between susceptibility of soil to compaction (SC) and organic carbon content of soils.

Table 2. Coefficients of determination (r^2 or R^2) between compactability indices and textural parameters, organic carbon, and improvement upon inclusion of organic carbon for 20 sites (n=60). Values in parentheses are the values of R^2 upon inclusion of organic carbon in the regression analysis.

Compactability index	Sand	Silt	Clay	Organic carbon
Maximum bulk density	0.11 (0.33**)	0.14 (0.34**)	0.07 (0.33**)	0.35**
Critical moisture content	0.17 (0.49**)	0.24 (0.49**)	0.08 0.50**	0.49**
Susceptibility to compaction	0.57** (0.66**)	0.68** (0.70**)	0.32* (0.59**)	0.47**

tus (13). Liquid limit and plastic limit of the soil samples were obtained by the one-point Casagrande method and the 3 mm rod formation techniques, respectively (14). The plasticity index was calculated by subtracting plastic limit from liquid limit. Organic carbon of soil samples was estimated using wet digestion method (15).

Data were subjected to simple correlation and multiple regression analysis to assess the influence of different soil properties and their interactions on compaction indices. Step-wise regression analysis was also considered to identify the soil physical properties that can explain variation in the compaction indices even though strong correlations were obtained either by linear or multiple regression.

Results and Discussion

The soil properties of different locations covered an almost entire range of values existing in the soils of Haryana. The range of values obtained for sand was from 41.6 to 94.3%, silt from 1.0 to 26.1%, clay from 4.2 to 34.1%. The particle density ranged from 2.46 to 2.66 Mg / m^3. The range of values for the liquid limit was from 17.4 to 32.1%, plastic limit was from 9.8 to 17.6% and the calculated plastic index was from 6.5 to 14.8%. The organic carbon content ranged from 0.04 to 0.67%. The field capacity of soils varied from 5.9 to 31.7%. Soils also showed a range in MBD (1.65 to 1.93 Mg / m^3), CWC (9.5 to 19.3%) and SC (0.007 to 0.036). The variations in soil properties and associated compactability indices indicate that soil samples were collected from areas having variation in texture (particle size distribution) and organic matter content.

Pearson correlation coefficients (*r*) matrix of relationships between the compaction indices i.e. MBD, CWC and SC (dependent variables) and the selected physical properties of soils (Table 1) show that sand, silt, clay, silt + clay, liquid limit, plastic limit, organic carbon content and moisture content at field capacity were each significantly correlated with MBD, CWC and SC. The SC was also correlated significantly with particle density and plastic index of soils. The better correlation of MBD with plastic limit than with other soil properties obtained may be attributed to the reason that plasticity of soil is governed by finer fraction (clay) and organic carbon content of soils, and these properties are also correlated well with MBD. The significant correlations of CWC with the soil properties may be attributed to the relationship between water holding capacity and soil texture, and organic carbon. Using artificially mixed soils, a good correlation of CWC with the Atterberg limits (16) while a linear relationship between CWC-liquid limit but no definite correlation with either plastic limit or plasticity index was found (17). Several studies correlating CWC with several soil physical properties were reviewed and empirical equations developed (18). These equations were complex involving too many variables. The additional problem in most of the equations developed was the classification of data as independent variable, like plastic

Table 3. The linear regression for linear relationships of maximum bulk density (MBD) and organic carbon content (OC).

Data source	Number of data sets	MBD = a + b OC		
		a	b	r^2
Wagner et al. (21)	39	1.850	– 0.15	0.46
Thomas et al. (22)	36	1.845	– 0.14	0.75
Krzic et al. (8)	93	1.710	– 0.11	0.70
Present study	60	1.859	– 0.34	0.35

Table 4. Step-wise regression model predicting maximum bulk density (MBD) of soils and their susceptibility to compaction (SC).

MBD = 1.859 – 0.336 OC	R^2 = 0.35
CWC = 12.157 + 11.328 OC	R^2 = 0.49
SC = 0.0114 + 0.0008 Silt	R^2 = 0.68

and liquid limit that are difficult to acquire accurately and may even be undefined for certain soil classes such as plastic limit for cohesion less soils as the soils having clay content < 15% does not show plasticity. The moisture content at field capacity is governed by texture and the organic carbon content of the soil. Therefore, it was considered logical to exclude liquid limit, plastic limit, plastic index and moisture content at field capacity in the prediction of soil compactability.

The positive correlation between SC and organic carbon contents of the soil contradicted the results reported in the literature (4, 5). It may be due to the reason that the soil studied were having low amount of organic carbon (only 10% of soils were having organic carbon around 0.4—0.6%) and it is well established that different textured soils respond differentially to the application of organic carbon. The higher correlations achieved between SC and textural parameters as compared to the correlation with organic carbon indicate that the soil texture is overriding in its influence on SC. The amount of organic matter in the soils was inadequate to interfere with the mineral particle interfaces sufficiently to hinder compression of 90% of the samples which were low in their organic carbon content (< 0.4%). It has also been shown that even large additions of crop residues to natural soils did not appreciably affect the SC of soils of various textures (6). It envisages that understanding of the mechanisms of the mineral-organic interface in texturally different soils may precisely define the role of organic matter in the compaction process. The correlation coefficients between compaction indices and soil physical properties thus suggest for the establishment of a procedure involving the determination of textural parameters and organic carbon only for identifying soils most likely to be at risk for excessive compaction to have more reliable assessment of current agricultural practices on soil compactability. Initiating the efforts in this direction, the regression coefficients for the relationships between compaction indices and textural parameters, and improvement in the relationships upon inclusion of organic carbon content were developed.

Percentages of sand, silt, clay and silt + clay did not significantly affect the MBD (Table 2) which needs further investigation as the studies reported in literature e.g. particles size distribution strongly affect the MBD (19), and soil texture is often cited as a critical property affecting the responses to tillage and other forms of mechanical soil disturbance (20). Possible explanations for the lack of a strong correlation between particle size distribution and MBD might be that textural fractions were not in sufficiently wide range ; representation was not even across the range and only few soils with high clay contents were included in the study. Upon inclusion the organic carbon as independent variable into regression equations with textural parameters, the improvement of MBD estimation was not observed. Similar results were also reported (8) but the results are in disagreement with other research findings (21, 7). This may be due to low organic carbon in the soils used for the study. The regression equation derived to relate MBD values to organic carbon values are also shown in Table 3 along with for the works of other researchers. Soil carbon (i.e. organic matter) is usually one of the best predictor for MBD (7, 8). The negative slope of the regression equation (representing reduction of the MBD per unit increase in percentage of organic carbon) obtained was 0.34 Mg/m^3. Some workers however, observed a reduction of 0.15, 0.14 and 0.11Mg m^{-3}, respectively, per unit increase in percentage of organic carbon (8, 21, 22). The higher value of slope of the regression equation in the present investigation may be due to relatively coarser texture and low range of organic matter content of the soils as compared to the other studies reported here. The data suggest that the effect of the organic matter on soil compactability may have regional differences which depend on soil properties other than organic carbon content but the MBD of the alluvial soils of Haryana may be best estimated using organic carbon content only. One implication of the relationship observed between MBD and organic carbon is that an increase in soil organic matter reduces the risk of compactability. This can be particularly important for soils where zero tillage practice is followed, especially in rice-wheat cropping system, where compaction cannot be corrected by tillage implements.

The MBD was found to be strongly related to CWC ($r^2 = 0.81$) showing a general trend of decreasing MBD with increasing CWC (Fig. 1). The strength of this relationship observed is similar to those reported earlier (21, 22, 7, 8). Like MBD, the percentages of sand, silt, clay and silt + clay did not significantly affect the CWC and there was no improvement in the estimation of CWC when organic carbon was included in the regression equations. The CWC was found to be significantly related to organic carbon ($r^2 = 0.49$) showing a trend of increasing CWC with increasing organic carbon content (Fig. 2). The second index of soil compactability i.e. SC was strongly related to organic carbon and significant determination coefficients were also obtained between SC and textural fractions (Table 1). The highest coefficient of determination was, however, found between SC and silt content of the soils. The inclusion of organic carbon as independent variable into these regression equations improved SC estimation relative to the individual textural parameters and the improvement was least with silt fraction (0.02).

As the coefficients of determination were higher for SC than those found for MBD, therefore, SC may be a valuable index of soil compactability over MBD as it can provide information on the extent to which field soil behavior changes in relation to changes in soil water content during compaction through farm operations. The SC has also reported as a valuable index of soil compactability but the coefficients of determination were lower for SC than those found for MBD (8).

When the relationship of SC and OC for different textured soils were plotted separately (Fig. 3), it was found that texturally different soils behave differently to organic matter application with regard to susceptibility to compaction. For sand, SC decreased while in other textured soils and when all the soils were pooled, it was found to be increased.

The study thus, showed that the best prediction of MBD and CWC may be obtained on the basis of organic carbon content while SC may be estimated using silt content of the soil. Other properties (textural parameters for MBD, and sand, clay and organic carbon content for SC) may be excluded from the final regression models for their predictions. The exclusion of these properties may be not because there was no relationship *per se* as in MBD for textural parameters but due to their elimination during the step-wise regression (Table 3). Thus, organic carbon may be selected to explain MBD or CWC variation while silt content may be appropriate parameter of explaining variation in SC.

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Conclusion

It is concluded that the best prediction of maximum compaction may be obtained on the basis of soil organic carbon content while susceptibility of soil to compaction may be estimated using silt content of the soil. The susceptibility of soil to compaction was found to a valuable index of soil compactability over maximum bulk density as it can provide information on the extent to which field soil behavior changes in relation to changes in soil water content during farm operations.

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