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Prediction of Soil Compaction from Cone Index and Moisture Content Data

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ABSTRACT. Soil compaction has many deleterious effects on plant growth and consequently on the society as a whole. Therefore, it has to be monitored carefully in order to reduce its direct and indirect effects. Soil bulk density provides direct information on the level of soil compaction. The difficulties in determining the degree of soil compaction directly in the field necessitate alternate methods to be developed for the above purpose. In this study an attempt was made to predict soil bulk density from cone index and moisture content data for two selected soils, namely, Reddish Brown Earth (RBE) and Reddish Brown Latasol (RBL). All the models tested in the laboratory gave R^2 values greater than 0.80. The bulk density - cone index - moisture content models for each soil were statistically selected. The selected models, except the one selected for the gravelly subsoil layer of RBE, performed well in the field. Since these models were statistically selected, care should be taken in using them directly in the field. It would be of benefit to have a few samples checked at the particular location before using the equations.

INTRODUCTION

The compactness of soil affects the soil physical environment for crop production. It reduces permeability to water, so that runoff and erosion may occur and adequate recharge of ground water is prevented. It reduces soil aeration, so that metabolic activities of roots are hampered. Compaction increases mechanical strength of the soil, so that root growth is impeded. All these may affect the quality and quantity of food and fibre grown in the soil.

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The bulk density of soil is defined as the weight of dry soil/unit volume. Although air permeability, saturated hydraulic conductivity and cone index data are used by some researchers to indicate the level of soil compaction, soil bulk density provides direct information on the level of soil compaction. Soil bulk density can be determined directly using the soil core methods and excavation methods, and indirectly, using the radiation methods and cone index models.

Although the excavation method gives accurate results at the surface; it becomes less accurate when the data is taken from subsoil layers, because of the difficulty in determining the undisturbed volume of excavated soil. The most commonly used soil core method becomes tedious and labour intensive, when the samples must be collected from deep soil profiles. The gamma-ray densitometers perform well in clay and sandy soils. They perform poorly in loamy soils; due to the presence of large amounts of stones and pyrite, which can change attenuation properties of the soil (Gameda *et. al.*, 1987). The potential health hazards have also limited the use of gamma-ray densitometers in measuring soil bulk density.

The force required to push the cone penetrometer into the soil is called the penetration resistance. Penetration resistance divided by the base area of the cone is called "cone index" (Anonymous, 1988). Some researchers have attempted to use cone index alone as a measure of soil compaction, since it is quickly determinable. It has been found that the cone index is highly influenced by bulk density and the moisture content of the soil, even though the relationship between these three parameters may vary depending on the soil type. Cone index increases with the increasing bulk density, and decreases with increasing moisture content (Knight, 1961).

The difficulties in determining the degree of soil compaction directly in the field necessitate the development of alternate methods for the above purpose. If the degree of soil compaction can be predicted using easily measurable parameters, such as, cone index and moisture content, it will lead to large savings of time and money. Therefore, this study was aimed at the development of models for two selected soils, namely, Reddish Brown Earth (Rhodustalfs) and Reddish Brown Latasol (Rhodudults), so that the outcome of this study could be used for any future research on compaction or tillage studies on these soils. In order to predict soil bulk density (BD) using cone index (CI) and moisture content (MC) of a particular soil, it is important to investigate the inter-relationship among these parameters.

MATERIALS AND METHODS

The experimental field for RBE was located near the sub campus, Maha Illuppallama. In the field a gravelly subsoil layer was located at 10 cm depth from the surface and continued beyond 30 cm. Throughout this presentation, 0-10 cm and 10-30 cm depth of the RBE is described as topsoil layer and subsoil layer of RBE respectively. Since these two layers had different textures, the lab analysis was carried out separately. The experimental field for RBL was located in the University Farm, Dodangolla. This site had a uniform textured profile.

Bulk samples were collected from the layers mentioned above from a randomly selected location for each soil sample. These samples were air dried, and roots and plant residue were removed. These samples were then crushed into individual particles by a wooden piece. Since the subsoil samples could not be pulverized using this process, a 2 kg hammer was used to break clods. The soil particles were separated using a No. 30 (0.5 mm opening size) sieve. After sieving, each soil sample was brought to the desired moisture content by spraying small quantities of water over time, while mixing thoroughly. These moistened samples were left covered for more than 24 h to allow moisture to spread evenly within the samples.

Test samples were prepared in the mould using the procedure described by Ayers and Perumpral (1982). The samples were prepared in a 14.6 cm diameter mould, which consisted of two sections. The bottom section was 20 cm high, and the 6 cm upper section was removable. The mould was made up of Poly Vinyl Chloride (PVC). The soil sample was prepared by placing five equal layers. Each soil layer was compacted in the mould by dropping a 9.5 kg weight through 30 cm distance onto a 2 mm thick steel plate for a predetermined number of times. After the soil column was compacted in the mould; the upper collar of the mould was removed, and excess soil above the top edge of the bottom section was shaved off. The weight of the remainder was then recorded. The penetration test on the prepared sample was then conducted using the hydraulically-operated, tractor-mounted, recording type penetrometer developed by Manokararajah and Jayatissa (1993). Then, soil was compacted again in the mould after it was crushed by hand.

Four different compaction levels were obtained using 3, 6, 12, and 18 blows/layer. Each compaction level was replicated thrice. A regression analysis was conducted to develop a model, which would express the bulk density of soil as a function of cone index and moisture content.

The General Linear Model procedure (PROC GLM) in the SAS (Statistical Analysis Systems) program (Anonymous, 1993) was used to fit the linear models to the data sets collected. Exponential models were converted into linear models using log transformation. Nonlinear models were fitted using the Marquart method in the nonlinear regression procedure (PROC NLIN) of the SAS program.

The coefficient of determination (R^2) and the surface of prediction of each model were used to select a particular model for each soil layer. In order to evaluate the surface of prediction, sets of cone index values were generated for each of the model considered using bulk density and moisture content values within the ranges obtained in the laboratory tests.

If the predicted soil bulk density corresponding to a given cone index value was unreasonably low or high at extreme moisture condition, the model was not selected even though it contained the highest R^2. Instead, the model that contained the next highest R^2 was evaluated. Besides, residual plots were drawn to see any pattern in prediction error. If two models giving close R^2 values were found, then the model with fewer variables was selected. This was verified using the linear regression procedure (PROC REG) with the stepwise method, which gave an indication about the contribution of individual independent variables to the F statistic. These procedures were repeated until an appropriate model was found for each soil sample.

After the models fitting the laboratory data were selected, their performances were verified using actual field data. In the field, cone index data were obtained from three places at 1 cm intervals up to 25 cm depth. Soil bulk density and moisture content data were determined using core samples collected from locations close to these penetration tests. The first three cone index values collected from the depth ranges of those soil core samples were selected for further analysis, since the cone was confined within that layer when those data were collected. These cone index values with the corresponding moisture contents were then used in the models selected, and the average of all predicted bulk density values within each of these depths were determined. These predicted bulk density averages were plotted against those determined from the soil core samples.

RESULTS AND DISCUSSION

The texture for the topsoil layer of the RBE at the test site was sandy clay loam (sand 70.0%, silt 6.3% and clay 23.7%). The liquid limit and the plastic limit were 27.4% and 18.2%, respectively. The texture of the RBE subsoil layer was sandy clay loam (sand 61.6%, silt 6.4% and clay 32.0%). The liquid limit and the plastic limit were 29.0% and 15.5%, respectively. The texture of RBL at the test site was sandy loam (sand 78.8%, silt 2.5% and clay 18.7%). The liquid limit and the plastic limit were 27.8% and 16.9%, respectively. In the laboratory bulk density and moisture content, values varied in the ranges of 1.2 to 1.9 g/cm^3 and 4.5 to 20.5 %, respectively.

Several models fitted to the RBE topsoil layer had close R^2 values (R^2=0.97). Their prediction surfaces were similar. Therefore, the contribution of individual independent variables to the F statistic was considered. A model with ln(CI), ln(MC) and $(\ln(MC))^3$ as independent variables was found to be significant (R^2=0.9716). Therefore, the model selected for the topsoil of RBE was,

$$\ln(BD) = 0.35 + 0.10 \ln(CI) - 0.67 \ln(MC) + 0.06 (\ln(MC))^3 \quad [1]$$

where, *BD* = Bulk density (g/cm^3),
MC = Average moisture content (%), and
CI = Cone index (kPa).

In the field, the topsoil of RBE had bulk density values ranging from 1.23 to 1.42 g/cm^3 with an average of 1.32 g/cm^3. The average moisture content varied between 8.09 and 14.38%. The cone index values ranged from 956.3 to 1505.3 kPa with an average of 1162.5 kPa.

As shown in Figure 1, the model selected for the topsoil layer of RBE predicted bulk density very close to the observed values. Hence, the selected model can be used to predict bulk density from cone index and moisture content values for the topsoil layer of RBE.

In general, the models fitted to the subsoil layer of RBE gave higher cone index values. This may lead to under-prediction of bulk density. The model selected for the RBE topsoil, with different coefficients was selected for this layer. The value of R^2 was lower (R^2= 0.9262).

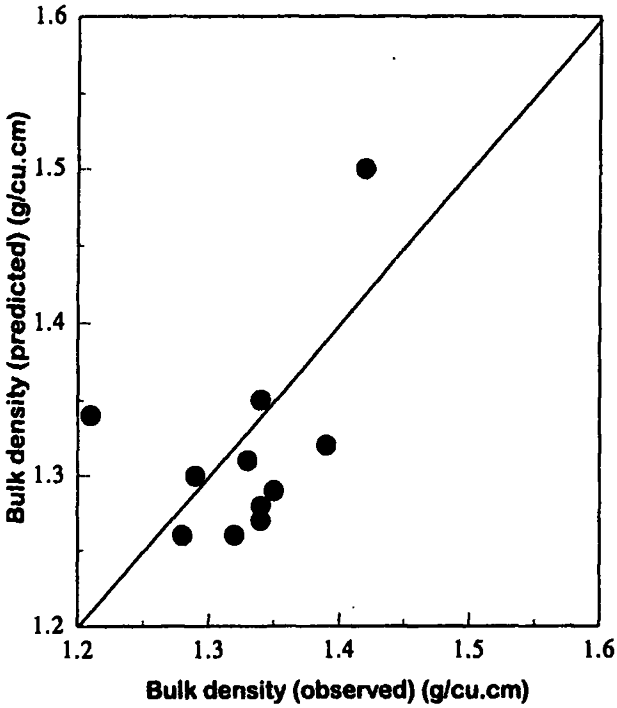

Figure 1. **Performance of the selected model in the topsoil layer of Reddish Brown Earth.**

The model selected for the subsoil of RBE was,

$$\ln(BD) = 0.90 + 0.11 \ln(CI) - 1.10 \ln(MC) + 0.09 (\ln(MC))^3 \quad [2]$$

where, the symbols and units are as in equation 1.

The subsoil of RBE, had bulk density values ranging from 1.48 to 1.82 g/cm3 with a mean of 1.70 g/cm3. The moisture content ranged between 7.92 and 15.26 % with an average of 10.36%. The minimum, maximum and average values of cone index reported in the field were 1580.7, 5415.7 and 3257.7 kPa, respectively.

As seen in Figure 2, the model selected for the subsoil of RBE under-predicted bulk density. The error of prediction ranged from 6 to 25%. A possible reason for this phenomena is that, in the field, the subsoil of RBE contained more gravel. In the lab test, since the soil sample was screened for particles larger than 0.5 mm, the bulk density values were lower. For soil like the RBE subsoil layer, which has a distinct gravel layer using a larger diameter, cone may give better results.

Many models tested for RBL had close R^2 values. Besides, the surfaces of prediction of these models were similar. The regression analysis showed that a model with ln(CI), MC and $(\ln(MC))^2$ was significant (R^2=0.9484). Therefore, the above model was selected. Thus, the model selected for the RBL was,

$$\ln(BD) = -0.70 + 0.11 \ln(CI) + 0.14\, MC - 0.23 (\ln(MC))^2 \quad [3]$$

where, the symbols and units are as in equation 1.

The RBL had bulk density values ranging from 1.47 to 1.70 g/cm^3 with an average of 1.61 g/cm^3. The moisture content varied from 9.64 to 16.76% with an average of 11.69%. The minimum, maximum and average values of cone index were 943.6, 5436.2 and 3405.7 kPa, respectively.

The predicted bulk density values were plotted against the values determined from core samples. As seen in Figure 3, the model selected for RBL under-predicted bulk density.

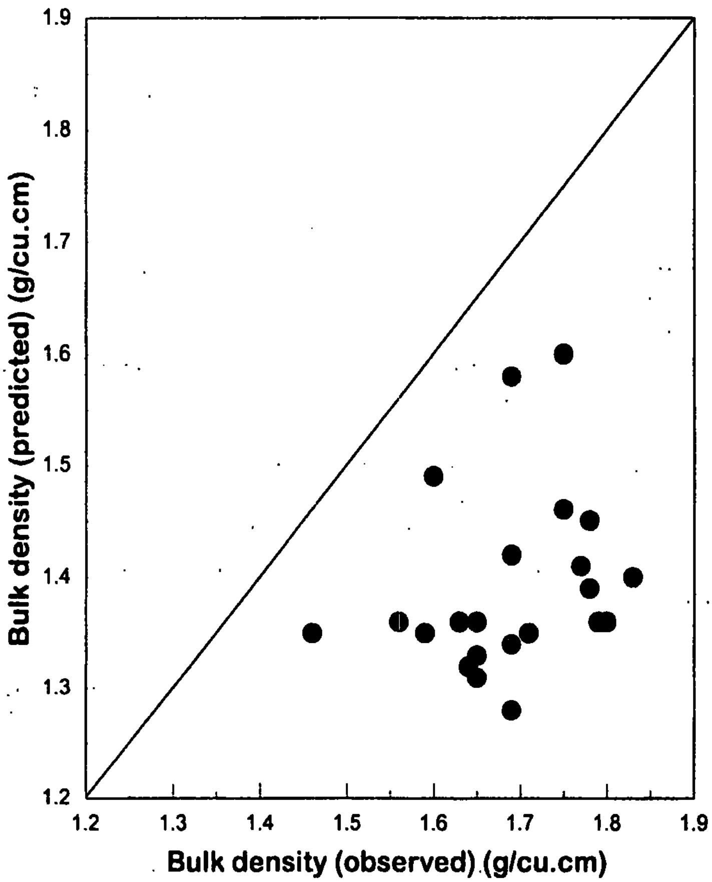

Figure 2. **Performance of the selected model in the subsoil layer of Reddish Brown Earth.**

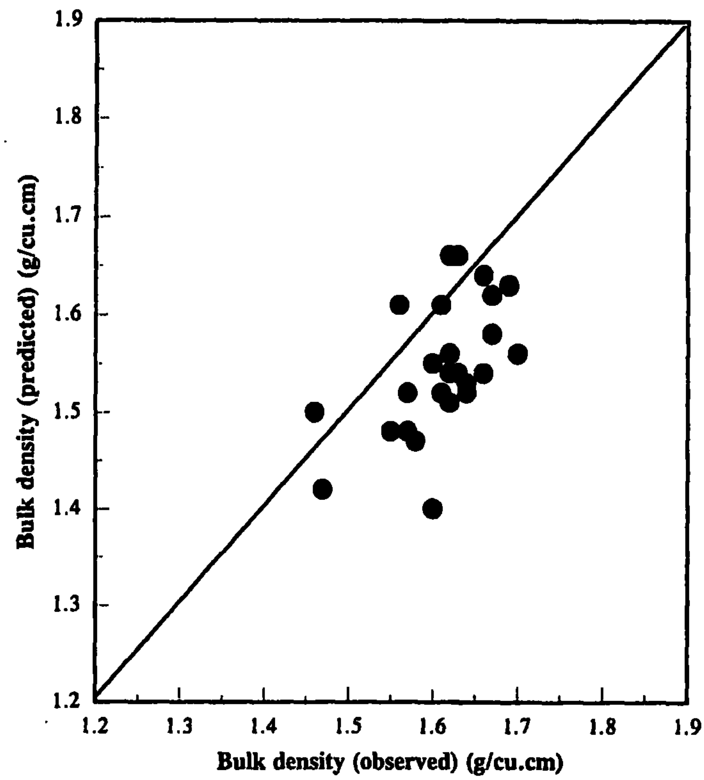

Figure 3. **Performance of the selected model for Reddish Brown Latasol.**

CONCLUSIONS

It is shown statistically, that the model selected for the RBE topsoil can be used to predict soil bulk density in the topsoil layer of Reddish Brown Earth. Although a model was statistically selected for the gravelly subsoil layer of Reddish Brown Earth, it cannot be used as it severely under-predicts soil bulk density. Further investigation has to be carried out with a larger sized cone. The model selected for Reddish Brown Latasol under-predicts soil bulk density.

It is shown that for a given soil, there exist some correlation among the parameters considered. As prediction equations are statistically selected for those two soils, care should be taken in direct usage of them for predicting soil bulk density. It would be of benefit to have a few samples checked at the particular location, before using the equations. Further, it is possible to develop similar relationships among soil bulk density, cone index and moisture content data for the other soil types as well.

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