Compaction on Vertisols: Can it be predicted?

G. Kirchhof and H.B.. So

The University of Queensland, Department of Agriculture, Brisbane, Qld 4074, Australia

Abstract

A simple laboratory method was developed to assess compactibility of clay soils using a Uni-Axial Compaction apparatus. Models were derived to predict maximum bulk density and optimum soil water content for compaction and the bulk density at water contents below maximum compaction at a range of pressures and clay contents. Amongst texture dependant soil properties, such as liquid limit, permanent wilting point or cation exchange capacity, the lower plastic limit was best suited to assess compactibility for maximum compaction as well as compaction occurring before maximum compaction was reached. The models can potentially be used as a decision making tool to reduce compaction on clay soil.

Introduction

Soil compaction is generally accepted as a major limiting factor to crop productivity. Its effect and magnitude depends on soil type, climatic conditions and crop type. Despite the large body of information and its effects, the information available on compaction of clay soil with vertic properties, *i.e.* vertisols, is inadequate. These soils have high yield potential and are used intensively for crop production in Australia and other countries. Their high clay content and likely high soil water content during field preparation makes them intrinsically sensitive to compaction. Compaction on vertisols may be reduced by the potential of the soils to self-ameliorate during wetting and drying cycles. This could happen during a single cropping cycle and may contribute to contrasting reports on crop performance. It is unlikely that all soils within the order of vertisols respond to compaction in the same manner, as vertisols can be quite different in soil structure and their response to compactive forces may therefore vary (So and Cull 1984).

This paper briefly describes a simple method to assess the compactibility of Vertisols, how it can be predicted and the potential implications on plant growth.

Materials and Methods

The determination of soil compactibility was made using a Uni-Axial Compaction test(UACT). It was considered appropriate to simulate soil compaction resulting from pressures applied to the soil by agricultural machinery (Koolen 1974). Although this type of test is commonly used by engineers to measure compactibility, no appropriate procedure is available for use in agricultural compaction studies.

The design of the simple apparatus used in this study is shown in Figure 1. A movable beam was fitted with a piston which was positioned at a distance (x) from the pivot point, to ensure the application of a perpendicular load with very little resistance to movement. The counter weight (A) was used to compensate for the weight of the beam and internal friction of the apparatus. Weight (B), located on the same side as the piston at a known multiplier to the unit distance x, was used to apply a force through the piston onto the soil. The force applied is equal to the product of weight and the multiplier factor for the distance from the pivot point. The compactive pressure applied to the soil is the force at the pressure arm divided by the surface area of the piston. It could be altered by varying the weights and distances from the pivot point. The apparatus could be used to obtain a maximum uni-axial pressure of up to 590KPa on a soil sample placed into a brass ring with 5 cm diameter.

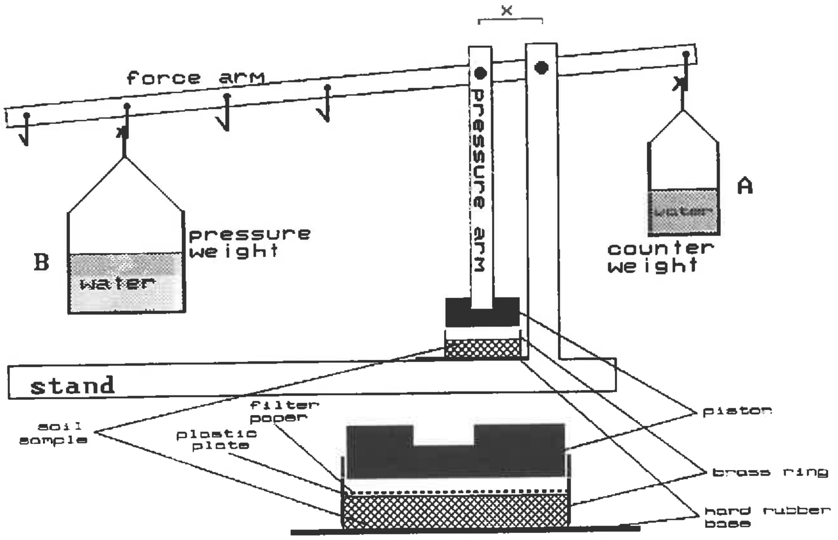

Figure 1. The Uni-axial Compaction apparatus.

Preliminary investigations were conducted into the effect of period of load application, depth to height ratio of the samples and the effect of repeated application of load. A standard procedure was then adopted to study the response of soils to compaction.

The standard procedure in using the uni axial compaction test was as follows. Soil samples (<2 mm) were prewetted to a water content at approximately permanent wilting point using a spray gun. 25g of prewetted soil was transferred into the ring (5 cm diameter, 2.5 cm height) and water added using a pipette to further increase the water content. Initial wetting by spraying was found necessary to increase the rate of wetting of the air dry soil and accelerate the equilibration process. The soil filled ring was then left for two days to equilibrate before the soil was compacted.

For the compaction process, the ring with the moist soil was placed onto a hard rubber base to prevent water extrusion during loading through the lower boundary (Figure 1). A plastic plate (4.9 cm diameter) was put on top of the soil to prevent adhesion between piston and soil. For samples where compaction was expected to be on the wet side of the compaction curve, a filter paper (4.95 cm diameter) was placed between plastic plate and piston and the amount of water that may be extruded through the upper boundary was measured by weighing the filter paper before and after loading the soil. The prepared samples were loaded for 3 seconds.

On those cores where compaction occurred at the wet side of the optimum, bulk density was calculated assuming water was not extruded. The volume of water absorbed by the filter paper was added to the volume of soil. This procedure was considered valid in these cases because the bulk density/gravimetric water content relationship follows the saturation line and in the water would not be lost during compaction.

The test was used to determine 90 compaction curves from 37 different soils collected from a range of locations including South-Eastern Darling Down, Lockyer Valley and Emerald Irrigation Area. Pressures used were 20 to 590 KPa, with the majority of pressures to correspond to those under vehicular tyres, *i.e.* 50 and 150 KPa. Clay contents of the soils ranged from 30 to 73%.

Results and Discussion

A wide range of compaction curves was obtained from the uni-axial compaction test. Figure 2 shows the effect of compaction on a range of soil types at 50 KPa load.. The compaction curve tended to be 'flatter' with the peak shifted toward higher water contents as clay content and organic carbon contents increased. These changes were associated with lower matric potential at the same water contents for soils with higher clay contents. Therefore, aggregate strength would have been greater resulting in lower bulk densities. This suggested that the compaction curves for different soils would be similar if expressed as bulk density against matric potential rather than water content. However, unlike soil water content, the matric potential of the soil may be altered during compaction and therefore the use of matric potential in lieu of water content would not be practical. In addition it was not possible to measure the change in matric potential with the compaction apparatus used in this study.

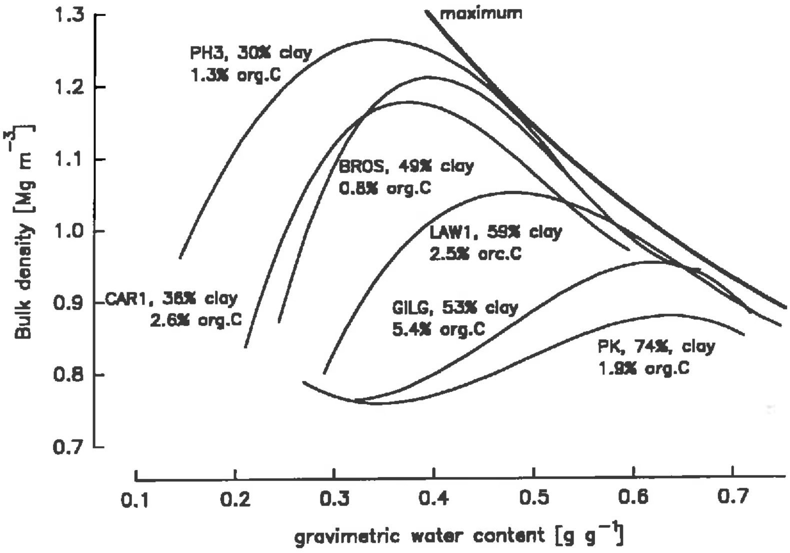

Figure 2. Uni-axial compaction curves at 50 KPa for a range of clay and organic matter contents.

For analysis the uni-axial compaction curves were divided into three sections: (i) the compaction curve before maximum bulk density, i.e. the dry side of the optimum water content, (ii) the point of maximum bulk density at the optimum water content for compaction and (iii) the compaction curve after maximum bulk density, i.e. the wet side of the optimum water content. Third degree polynomial equations as well as broken linear regressions (Greenhalgh *et al.* 1987) were fitted to the data. The maximum bulk density was obtained (i) as the common point of the two linear regression equation and (ii) by differentiating the 3rd degree polynomial equations. The maximum bulk densities derived from the two procedures were almost identical and highly correlated. However, the procedure using a broken linear regression required that sufficient observations were available to obtain linear equations for both the wet and dry side of the optimum. The use of a 3rd degree polynomial expression made it possible to extrapolate to a maximum and beyond in such cases. The latter was therefore regarded as a more versatile method to obtain the points of maximum bulk density.

When the maximum bulk density and the optimum water content for maximum compaction were plotted, the points followed the saturation line at 90-95% of maximum possible bulk density (Figure 3). A quadratic regression through these data points was parallel to the saturation line within the water contents observed. Maximum compaction could therefore be considered relatively constant at an average value of 0.08 m^3m^{-3} air filled porosity, or 92% potential maximum compaction.

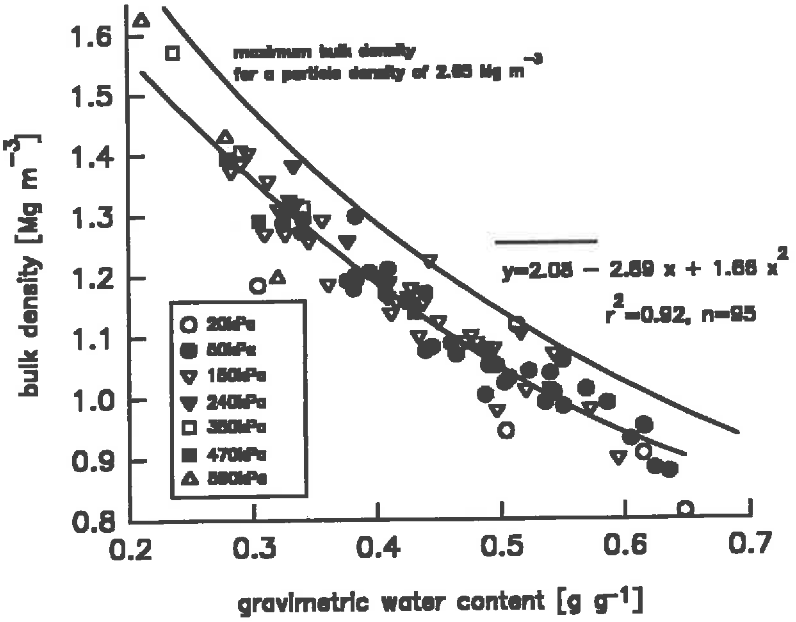

Figure 3. The position of points for maximum uni-axial position in relation to absolute maximum compaction.

For each compaction pressure, the maximum bulk densities and optimum water contents were closely related to *texture dependant properties* other than CEC and could be predicted from these properties. Prediction was improved if the organic matter content was included. It tended to reduce the maximum bulk density (and increase the optimum water content). This was consistent with the observations of Soane (1990) who attributed the effects of organic matter to a dilution effect, increased aggregate strength due to organic bondings and increased shear resistance. Table 1 shows the relevant equations.

The models to predict maximum bulk density (Table 1) was derived using data associated with a wide range of clay soils and should therefore be applicable to other Vertisols. Its validity was verified for 4 other clay soils which were used in the study by Cook (1988). For this purpose, the maximum bulk density was calculated from the equations which used (i) clay content and organic carbon or (ii) the plastic limit. The soils were then wetted to a water content approximately 3% greater than that corresponding to the optimum water content to account for water lost by evaporation during sample mixing and equilibration. The uni-axial compaction test was then performed using 2 replicates and 3 different pressures (50, 100 and 150kPa). Since the samples were not at optimum water content, the bulk densities were corrected to the predicted optimum water content assuming normal shrinkage. The experimentally derived maximum bulk densities shown were in very close agreement to the predicted values (Figure 4).

Similar to the point of maximum compaction, bulk densities at water contents lower than those for maximum compaction could be predicted using texture related properties. These models are potentially useful for soil management techniques that aim to reduce soil compaction by predicting resulting bulk density (ρ [Mg m^{-3}]) from soil water content (θ_g [g g^{-1}]) and applied load [KPa] if, for example clay content [in g g^{-1}] of the soil is known:

$$\rho = 1.425 - 0.986\,clay + 0.144\,Ln(p) + 0.530\theta_g$$

$$n = 507, \quad r^2 = 0.71$$

Table 1. Equations to predict maximum bulk density, minimum void ratio and optimum water content from textural properties, pressure P, with and without organic carbon content. Type of function used: $y = a + bx + c \ln(p) + d\ orgC$.

x^*	a	b	c^{**}	d^{***}	r^2
y = maximum bulk density [Mgm^{-3}]					
plastic limit	1.595	-1.333	0.105	-	0.907
	1.609	-1.243	0.111	-0.0222	0.931
liquid limit	1.596	-0.678	0.106	-	0.866
	1.604	-0.629	0.111	-0.0200	0.885
clay content	1.585	-0.776	0.099	-	0.803
θ_{pwp}^{***}	1.629	-1.747	0.111	-	0.853
y = optimum water content [gg^{-1}]					
plastic limit	0.136	0.889	-0.066	-	0.830
liquid limit	0.142	0.446	-0.067	-	0.781
clay content	0.128	0.542	-0.061	-	0.738
θ_{pwp}^{***}	0.141	1.250	-0.058	-	0.802

* units of the textural properties are in [gg^{-1}]

** pressure in [100KPa] (the factor c is the compression index)

*** organic carbon content in [%]

**** water content at permanent wilting point (-1.5MPa water content) in [gg^{-1}]

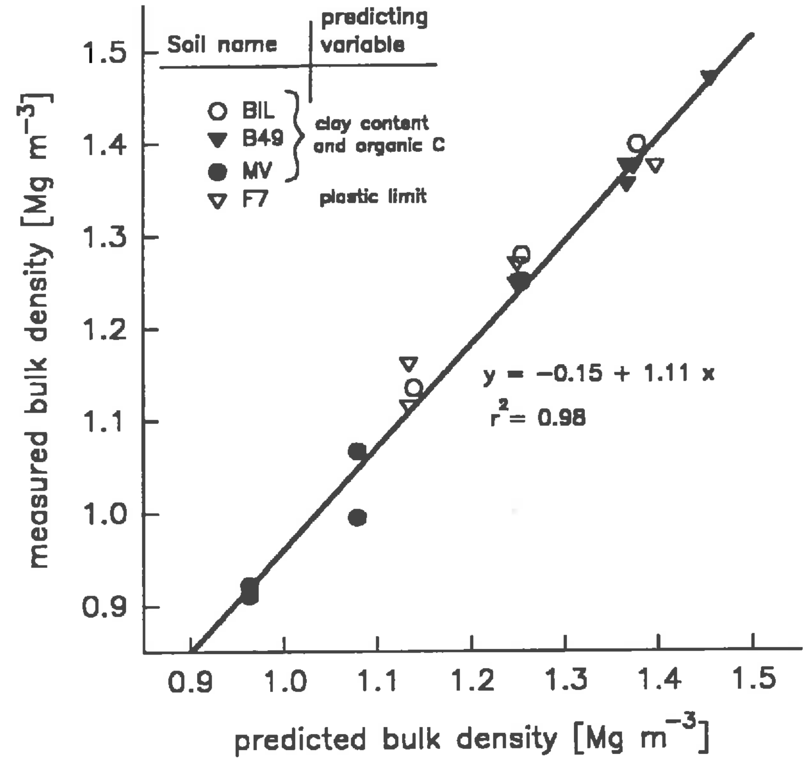

Figure 4. Comparison of predicted and measured points of maximum bulk density.

Conclusion

A simple uni-axial compaction test was found to be a convenient and reliable method to determine the compactibility of soils and to derive their compaction curves. The point of maximum compaction derived from the uni-axial compaction test could be predicted with high precision ($r^2 > 0.80$) from the soil's clay content, organic carbon content and uni-axial pressure. Similarly, the optimum water content to achieve maximum bulk density can be predicted using the same parameters. Compaction to bulk densities lower than maximum bulk density could be predicted from clay content, applied pressure and soil water contents. Refinement of these models and adaptation to cloddier field soils will be a potentially valuable tool to minimise soil compaction.

References

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