Compactibility of Soils Used for Cotton Production

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Abstract

To investigate soil response to compaction, a range of cracking clay soils (Vertisols) were collected from major cotton growing areas in Queensland and subjected to a uni-axial-compression. Large differences in compactibility were observed between the different soil types.

A range of textural properties including plastic and liquid limits, water contents at -1.5 MPa, and clay contents were determined. These properties were found to be strongly correlated with each other and either one could be used together with soil water and organic carbon contents to predict soil bulk density at the applied pressure.

The term compactibility is defined to describe the relative degree of response in different soils to compactive forces. Weakly structured soils were found to be less compactible than strongly structured soils at given moisture levels. The effect of soil structure on the compactive behaviour of these soils was thought to be related to degree of structural development and soil water content at time of cultivation. However, despite the lower compactibility of weakly structured soils, their reduced hydraulic conductivity could result in a wetter soil state for prolonged periods, following a watering event. Ensuing mechanical tillage operations thus could still cause compaction with possible deleterious effects on cotton growth and yield.

Introduction

Compaction of predominantly cracking clay soils and its effect on cotton yield is a controversial issue. In the Emerald Irrigation Area, declining cotton yields have been linked with compacted soil layers (Brimblecombe and Pyke, 1983; Wilkox and Cull, 1984; So, 1984; So and Cull, 1985). Using standard terminology, McGarry and McDonald (1984) failed to describe the presence of compacted layers in these soils although So (1984) observed that plant roots appeared to be affected by dense layers below the surface and were associated with poor crop growth and yield. Examination of seedlings with poor vigour showed almost invariably the presence of bent or twisted taproots. He related this to high mechanical resistance and low available nitrogen levels in the compacted layers suggesting that plants reacted to a range of soil properties which, if modified by compaction, could result in a range of plant responses.

This paper reports an investigation into the properties which are deemed to affect the compactibility of Vertisols. Attempts are made to predict soil bulk density from these properties and thus provide a basis for predicting soil response to agricultural machinery traffic.

Materials and Methods

Soil samples were collected from a total of 70 sites located in the Emerald Irrigation Area, Darling Downs and Lockyer Valley at 5 - 30 cm depth where compaction layers are commonly found. They were analysed for particle size analysis, plastic and liquid limits, -1.5 MPa water content, organic carbon and structural stability (Black et al 1965, Cook 1988). The response to compaction was determined using a uni-axial compression test as described by Kirchhof and So (1987).

Results and Discussion

The samples represented a wide range of different types of cracking clay soils with clay contents ranging from 30 to 73%, organic carbon ranging from 0.8 to 5.7% and dispersible clay content ranging from 2 to 22%. Compaction curves were obtained and presented as the effect of soil water content on bulk densities at different applied pressures. The pressures used were those expected to develop under agricultural equipment during tillage operations (Tullberg pers comm., Soane et al 1980/81).

With increasing soil water content, the bulk density values increased (dry side of optimum) towards a maximum followed by a decrease (wet side of optimum) as shown in Figure 1. At higher compaction efforts these curves were shifted toward higher bulk densities at lower water contents (Fig.2). These data clearly demonstrate the well accepted principle that soil, as a three phase system, consists of solids, water and air where the latter is the only compressible phase. With increasing water content the soil strength decreases which increases soil susceptibility to compressive forces. However, with

Figure 1. The effect of clay content on the compaction curves for 50 KPa Uni-Axial pressure.

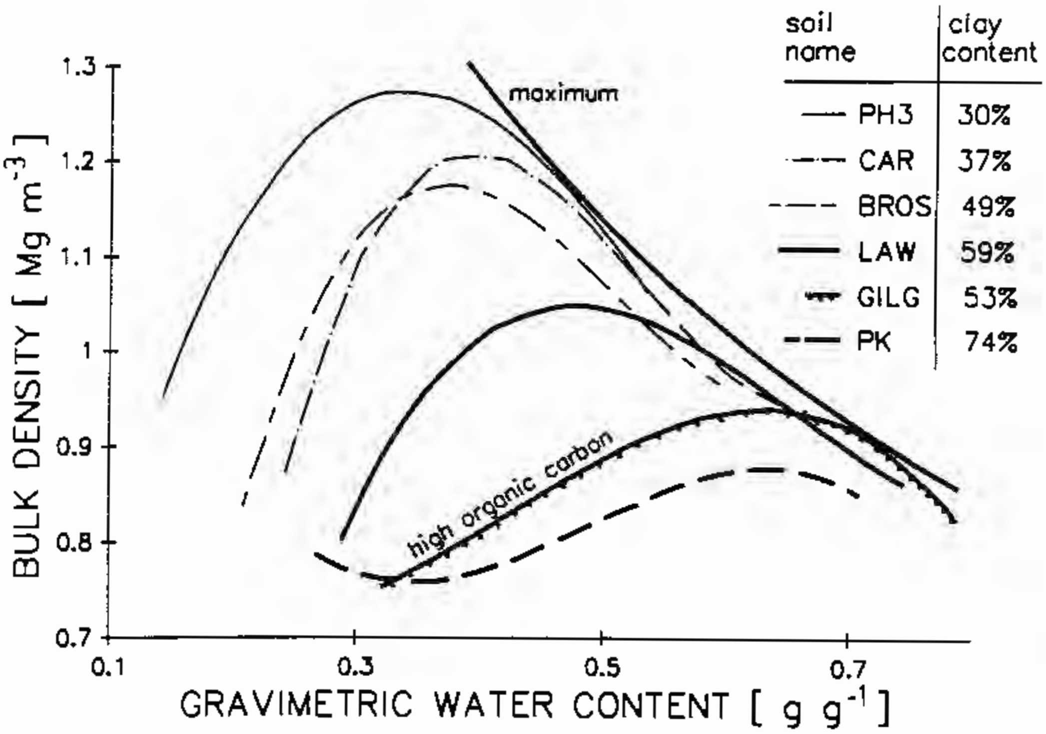
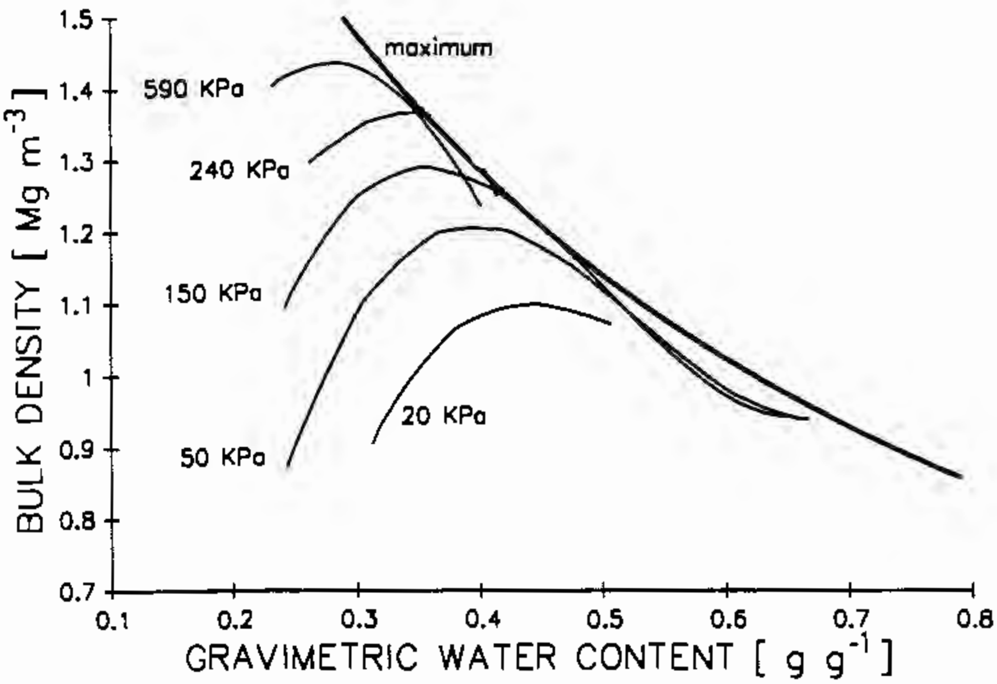


Figure 2. The effect of Uni-Axial pressure on the compaction curves.



increasing water content the amount of compressible air becomes less and after most air has been expelled from the soil body, no further compression is possible. As the soil swells with increasing water content, bulk density decreases and at near saturation the compaction curve follows the maximum compaction line. At these soil water contents apparently no compaction by static loads is possible but deformations by shear are very likely to occur (Kirby 1987).

On the dry side of the optimum, compaction was mainly caused by static loads as shown by increased bulk density (Fig.2). This finding has been related to crop growth (Kirchhof et al 1986). However, further work is required to elucidate suitable soil water contents in order to optimise soil management for specific soil types. Tillage operations are commonly carried out at soil water states less than saturation and thus determinations of compaction for unsaturated soils are of major importance in defining suitable conditions for tillage operations. The data show that the various soils respond differently to compactive forces but there is no terminology to describe this phenomenon. The term compactibility is used here to describe this relative degree of response in different soils and is defined as: the compactive behaviour of a specific soil to compression and shearing forces which cause compaction at states of water content below that for maximum densification.

Compactibility is best predicted by soil clay content and soil organic carbon as shown in Figure 1. The decreasing compactibility with increasing clay content supported the packing theory described by Bodman and Constantin (1965) whilst the effect of soil organic carbon was probably related to increased shear resistance as indicated by Free et al (1947). These effects were quantified by using multivariate regression analysis and a model, similar to that of Gupta and Larson (1979) was derived.

For soil water contents on the dry side of the optimum and pressures larger than the preconsolidation pressure

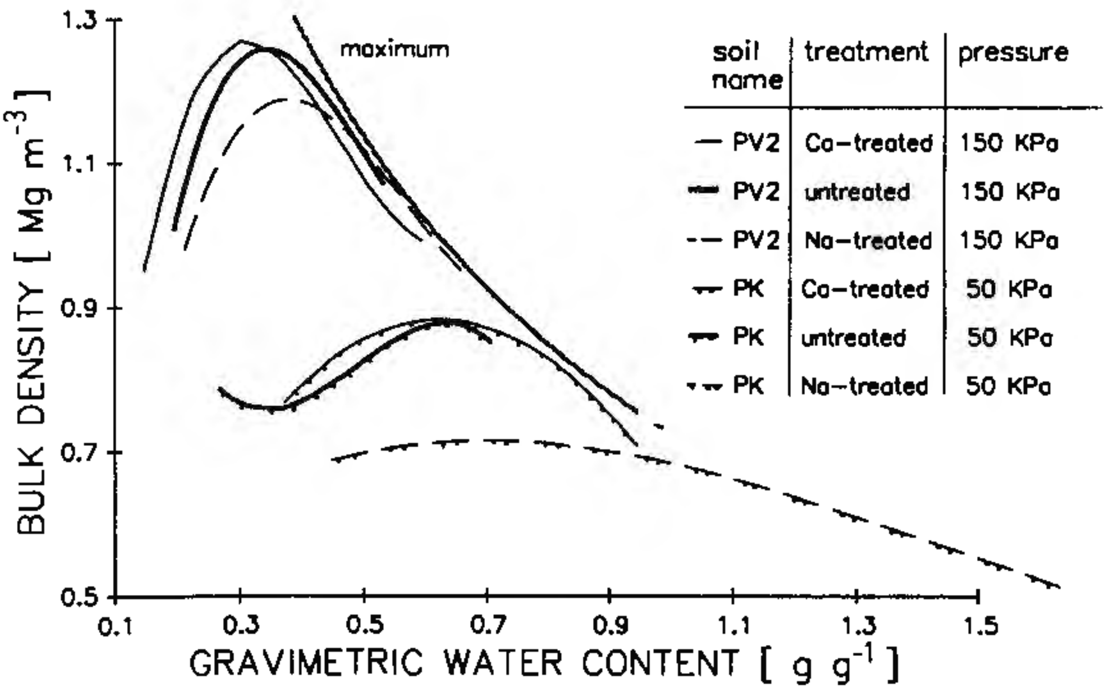
$$Bd = 1.217 - 0.551\,clay + 0.152\,\ln(P) + 1.340\,\Theta g - 1.360\,\Theta g \cdot clay - 0.036\,orgC.$$

where Bd = bulk density [Mg m^{-3}]
clay = clay content [Mg Mg^{-1}]
Θg = gravimetric soil water content [Mg Mg^{-1}]
orgC = organic Carbon content [%]
P = uni axial pressure [100 KPa]
with n = 507 and r^2 = 0.72.

The investigations did not show any effect of soil structure on compactibility, which did not correspond to field observations where weakly structured soil have been observed to compact more easily than strongly structured soils (Abbott et al 1988). To clarify these effects the structure of selected samples was modified by saturating the exchange surfaces of one subsample with sodium and another with calcium. Subsequent analysis on these samples for amounts of dispersible clay showed that the sodium treated sample represented weakly structured, and the calcium treated samples strongly structured soils.

Results from compaction tests on these soils (Fig.3) demonstrated that the compactibility was lower in weakly structured soils which did not conform with field observations. However, research has shown that hydraulic conductivity was negatively related to increasing soil structural stability (Cook 1988). This would result in wetter soil condition over prolonged periods of time where unfavorable conditions for cultivation operations would prevail. Under these conditions the field observations do not contradict the observations on compactibility.

Figure 3. The effect of structural degradation on the compaction curves.



These findings emphasise the importance of soil water content on the compactibility of a soil. Intrinsic soil properties alone are not sufficient to describe the compaction which is likely to occur in the field. For a specific field condition where intrinsic properties can be regarded as fairly constant the use of the model requires the knowledge of soil water content prior to cultivation. Thus, inclusion of a variable term for soil water content in the compactibility model would make it dynamic. This then could be used for developing strategies to minimize or overcome compaction where it is deleterious to cotton growth.

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