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Research Paper

A comparison of four instruments for measuring the effects of organic matter on the strength of compacted agricultural soils

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Soil strength estimates from shear vane, Proctor and drop cone penetrometer were obtained alongside cohesion and angle of internal friction measured with the triaxial test. Two organic materials (peat and farmyard manure) were incorporated at the rates of 0%, 4%, 8% and 12% to two soils (one sandy loam and the other clay), and compacted with 25 blows of the Proctor hammer. For the shear vane and the penetrometers, the soils were tested at moisture contents ranging from 5% to 55%, while for the triaxial tests, the soils were tested at three moisture states (5% below optimum, optimum and 5% above optimum moisture content). Although organic matter addition decreases soil strength of compacted soils at lower moisture contents, the effect decreases as moisture content increases, and there is a small increase in strength at the highest moisture contents. Organic matter decreased the strength of the soils at the three moisture states by decreasing the angle of friction rather than soil cohesion. Proctor penetrometer strength estimates were the highest followed by those from the drop cone, shear vane and the triaxial test. The shear vane overestimated the cohesion in the soil when compared with the triaxial test measurement. The penetration resistance measured with the Proctor and the drop cone penetrometers were correlated as were the shear strength measurements from the triaxial and the shear vane instrument. The Proctor penetrometer was the quickest to use, followed by the drop cone penetrometer, shear vane and the triaxial test.

1. Introduction

Soil compaction is defined (TRRL., 1952) as the process whereby soil particles are constrained to pack more closely together, mainly through mechanical compression, and this leads to a reduction or total elimination of air voids. Soil compaction is undesirable in agricultural production since it reduces soil water permeability, so that run off and erosion may occur. It also imparts high mechanical impedance to root growth (Thompson, Jansen, & Hooks, 1987).

Compaction affects agricultural soils world-wide (Henderson, Levett, & Lisle, 1988) but the ease with which a soil can be compacted depends on soil type, particle size distribution and textural characteristics (Akinmusuru, Omotosho, & Omotosho, 1984). Organic matter has also been found to reduce the compaction of soils in many past studies

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(De Kimpe, Bernier-Cardou, & Jolicoeur, 1982; Soane, 1990; Stone & Ekwue, 1993). Since different soils respond differently to compaction, it is generally necessary to find ways to quantify this response for individual soils. Soil compaction is seldom measured directly but rather the usual practice is to determine the change in a parameter or set of parameters as a consequence of compacting effort (Ohu, 1985). Several workers (Manuwa & Olaiya, 2013; Newaz, Bourrie, & Trolard, 2013; Ohu, 1985) have therefore utilised soil strength, density and water transmission properties as means of quantifying the effect of compaction.

Soil strength is a very complex parameter that is used to describe the physical status of soils. It refers to the ability or capability of a particular soil in a particular condition to resist or endure an applied force (Ohu, 1985). Many researchers have invented or designed apparatus capable of measuring soil shear strength. Some of these include direct shear machine, translational shear box, shear graph, annular torsional shear apparatus and shear vane (Johnson, Wright, & Bailey, 1983; Ohu, 1985). Soil penetrometers are also driven into the soil at certain rates and used to measure in-situ soil strength. Various types of cone penetrometers were reviewed by Perumpral (1987) and Jones and Kunze (2004). They include the static and dynamic penetrometers. Static penetrometers are subject to a constant hydraulic, mechanical, or electric power or other motorised source and record data deep into the soil profile (Jones & Kunze, 2004). Dynamic cone penetrometers like the drop cone penetrometer apply a known amount of kinetic energy to the cone, which causes the penetrometer to move a distance through the soil (Herrick & Jones, 2002). Cone penetrometers have been generally employed for the determination of the effect of bulk density and water content on root penetration or crop emergence (O'Sullivan & Ball, 1982; Raghavan & McKeyes, 1978).

O'Sullivan and Ball (1982) reviewed the performance of five instruments for measuring soil strength in cultivated and uncultivated cereal seedbeds: vane shear tester, static recording penetrometer, drop-cone penetrometer, torsional shear box and pocket penetrometer. They stated that the torsional shear box allowed cohesion and friction to be estimated from the torque required to shear soil on a circular, horizontal plane at different normal stresses. The shear vane measured cohesion and angle of friction, which are particularly important in compaction studies. They added that the different instruments or methods measured different strength properties of the soils, as evidenced by the variance in the values obtained, and suggested that any method for measuring soil strength should be related to specific applications being considered.

Many workers have investigated the effect of organic matter on soil strength and obtained varying results. Blanco-Canqui, Lal, Owens, Post, and Izaurraide (2005) and Ohu (1985) reported a decrease of soil shear strength with the application of organic matter. They attributed this to the reduction of bulk density in soils by organic matter. Davies (1985), Gantzer, Buyanovsky, Alberts, and Remley (1987) and Rachman, Anderson, Gantzer, and Thompson (2003) found an increase in shear strength with organic matter. Ekwue (1990) noted that organic materials reduce or increase soil shear strength depending on their bonding and dilution effects on the soil. While organic matter from grass increased shear strength, that from fibrous peat reduced it. For compacted soils, the effect of organic matter on soil strength is also not fully well defined. Ekwue and Stone (1995), working with shear vane and Proctor spring-type penetrometers, noted that soils with higher organic matter contents had lower soil strength than soils with lower organic contents at low moisture contents and the reverse was true at high moisture contents. Ohu (1985) found similar results using the static cone penetrometer, but with the shear vane he found that values of soil shear strength were reduced by organic matter in the form of peat at all the water contents studied. It is therefore possible that the results obtained in soil compaction studies involving organic matter may depend on the type of instrument utilised in the measurements as well as the different moisture contents for compacting the soils. Moreover, most past workers (Ohu, 1985; Wuddivira, Stone, & Ekwue, 2013) did not use triaxial tests which could help to fully explain the role of organic materials on the strength of compacted soils.

This paper utilises four instruments to measure the effect of peat and farmyard manure on the strength properties of compacted agricultural soils. It is aimed specifically at comparing the strength estimates obtained with three laboratory instruments with the cohesion and angle of friction measured with the triaxial test. This was done to identify, compare and evaluate the performance of each instrument and to quantify and determine the role of organic matter on compacted soils. This will give a fuller understanding of the role of organic matter on the strength of compacted soils.

2. Materials and methods

Two soils, Piarco sandy loam and Talparo clay (Table 1) were selected and used to represent some of the major agricultural soils in Trinidad. They were collected from the 0–20 cm depth of the soil profile, air-dried and ground to pass a 5 mm sieve. Particle size distribution was determined using the hydrometer method (Lambe, 1951). Organic matter content in the samples was measured using the Walkley and Black (1934) method. Organic matter content in the samples was

Table 1 – Classification, organic matter, and the particle size distribution (%) of the soils.

Soil series	Classification[a]	Organic matter content (%)	Sand (0.06–0.002) mm	Silt (0.06–0.002) mm	Clay (<0.002) mm
Piarco	Aquoxic Tropudults[b]	1.7	64.9	17.0	18.1
Talparo	Aquentic Chromuderts	2.7	25.4	28.3	46.3

[a] Classification according to the Soil Taxonomy System (Soil survey Staff, 1999).
[b] All values are means of three replicates.