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Self-repair of compacted Vertisols from Central Queensland, Australia

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Abstract

Vertisols have the inherent ability to self-repair because of high clay contents and clay type that govern volume change. A study was undertaken to correlate soil inherent properties with two indicators of structure improvement based on tensile strength and clod porosity of compacted soil cores before and after wet/dry cycles. In order to minimize inter-soil differences Vertisols under similar cropping regimes and from the same climatic region in Queensland, Australia were selected. A soil repair index ($R_{T(1)}$) based on compressive strength of soil cores was related to soil inherent properties and shrinkage indices, $COLE_{STD}$ and LS_{MOD} using multiple regression. Results showed that compressive strength of soil cores after a single wet/dry cycle after compaction was sufficient to rank Vertisols in terms of their capacity to improve structure after compaction. Clay content and clay activity (CEC/clay) on their own were poor indicators of soil repair. Fine sand was shown to be an important component in the repair process. LS_{MOD} and $COLE_{STD}$ predicted $R_{T(1)}$ equally well and indicated that Vertisols with $COLE_{STD}$ values > 0.15 and LS_{MOD} > 12% would be expected to have sharper reductions in tensile strength compared to those with lower values after just one wet/dry cycle. Clod porosity was poorly related to soil inherent properties.

Keywords: Shrinkage indices; Structure repair; Soil properties; COLE; Soil compaction; Vertisols; Wet/dry cycles

1. Introduction

Soil compaction, depending on water content, can cause significant change in soil structure in terms of reduced total porosity and pore continuity (e.g. Ball et al., 1988; McGarry, 1989), pore size distribution and stability of pores (Pagliai, 1987; Gupta et al., 1989; Richard et al., 2001). These in turn can lead to changes in three commonly used indicators of soil structure i.e. air-filled porosity, bulk density and strength (Henderson et al., 1988; McGarry, 1990; Guérif, 1990; McNabb et al., 2001). Hence soil management strategies to improve or regenerate degraded soil structure such as tillage, rotation cropping (Hulme et al., 1991; Hulugalle et al., 2002) and incorporation of organic matter (Francis et al., 1999; Milne and Haynes, 2004) aim to increase soil porosity and reduce bulk density and strength. The degree and rate of structure regeneration (Reeve and Hall, 1978) are governed by inherent soil properties that influence shrink/swell (or volume change) and by external processes such as wet/dry cycles (Pillai-McGarry et al., 1995; Sarmah et al., 1996; Pillai and McGarry, 1999), freezing and thawing cycles (Eigenbrod, 2003), soil organisms and the persistence of these processes (Kay, 1990). Measurements used to assess shrink/swell potential of a soil include volumetric shrinkage (VS), coefficient of extensibility (COLE) (De Jong et al., 1992; Gray and Allbrook, 2002), plasticity index (PI) and Atterberg limits (Smith et al., 1985). These predictors are often related to clay content (McCormack and Wilding, 1975) but studies have shown that clay mineralogy rather than clay content has greater influence (Mbagwu and Abeh, 1998; Gray and Allbrook, 2002; Boivin et al., 2004). A linear relationship between clay mineralogy of naturally occurring clays and liquid limit was found by Schmitz et al. (2004) and studies of 30 Nigerian soils by Mbagwu and Abeh (1998) showed that trace amounts of smectite or vermiculite (2:1 clay) in kaolinite-dominated soils were sufficient to increase VS from < 10% (kaolinite only soils) to 10–30%. Coughlan et al. (1978) found that the void ratio of

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dry aggregates formed from clay–sand mixtures using swelling (smectite) and non-swelling (kaolinite) clays decreased as clay content increased from 10%–40%, but for higher clay percentages, void ratio either increased (for kaolinite) or remained constant (for smectite). The decrease in void ratio was attributed to a "coarse particle matrix" where clay-filling of pores between sand particles was predominant. The increase of void ratio at higher clay percentages for the non-swelling clay indicated a "fine particle matrix" where the clay produced stable micro-aggregates with greater inter-aggregate porosity. In the smectite dominated aggregates the transition between coarse and fine particle matrix (30–40% clay) was less clear, but at ≥40% clay content shrinkage was highest indicating that at high clay contents aggregate swelling could be entirely attributed to the clay matrix. Similar results were found by Boivin et al. (2004) using shrinkage curves of soil aggregates from a range of kaolinite:smectite mixtures. Although soils with low smectite content had low shrinkage capacity, the shrinkage of specific micropore volume increased as clay content decreased particularly for clay contents<40%.

Soil properties such as cation exchange capacity (CEC) is an important soil property utilized in pedotranfer functions (Bouma, 1989) owing to its general correlation with soil physical properties. In particular the ratio of CEC to clay content, a commonly used indicator of clay activity, has been a useful predictor of soil water retention in a range of soils (Pachepsky and Rawls, 1999). Variation in CEC and exchangeable cations has also been found to directly influence shrink/swell capacity (Gill and Reaves, 1957; McGarry, 1996) and subsequently soil structure (Hubble, 1984). Coughlan (1984) associated increasing coarseness of seedbeds for three Vertisols to decreasing CEC values and Pillai-McGarry and Collis-George (1990) found that strongly self-mulching Vertisols had much greater CEC and Ca/Mg ratio compared to non self-mulching Vertisols. Farrar and Coleman (1967) and Franzmeier and Ross (1968) found strong positive correlations between COLE on the one hand and clay content and CEC on the other. Varied reports exist on the role of organic carbon in shrink/swell capacity of soils. De Jong et al. (1992) found poor correlation between COLE and organic carbon (OC) for 27 Canadian Chernozemic clay soils (% OC ranged from 0.13 to 4.92%) whereas Reeve et al. (1980) found the reverse in 19 British smectite–mica clay soils that had a much wider range in OC (% OC ranged from 0.4 to 11%).

Vertisols are particularly prone to structure degradation by compaction (McGarry, 1993) because of their high clay content (>35%) (Isbell, 1996) and clay type dominated by expanding clay minerals (2:1 layer silicates). However this combination also provides these soils with a natural ability to improve or "self-repair" their structure once applied stresses are removed. Natural processes such as wetting and drying cause the soils to crack and break into smaller aggregates and regain soil porosity. In a study of self-mulching (formation of granular surface structure) in three Australian Vertisols, Pillai-McGarry and Collis-George (1990) found that high fine sand content and a dominance of illite and kaolinite in the clay fraction was associated with poor self-mulching ability from sieved and puddled states after repeated wetting and drying. High sand percentage can negatively affect aggregate formation and structure repair of compacted soils by diluting the shrink–swell capacity of the clay fraction and providing greater internal friction in the soil matrix (Wilding and Tessier, 1988). In other studies of structure improvement in clay soils, such as tilth mellowing, improvement in structure of remolded aggregates (Dexter et al., 1984; Hussein and Addey, 1995) and laboratory prepared soil discs (McKenzie and Dexter, 1985) was indicated by a progressive decrease in tensile strength with increasing number of wet/dry cycles. Studies of structure repair in Vertisols using intact field cores from compacted and uncompacted sites have indicated changes in infiltration rate, clod bulk density and shear strength when subject to wet/dry cycles only (Sarmah et al., 1996) and when combined with plant growth (Pillai and McGarry, 1999).

Past studies indicate that volume change and swell/shrink potential play a major role in structure development. It is also evident from the literature that the main indicators of soil aggregation and structure improvement are reduction in soil strength and increase in porosity. Using these indicators the aim of our study was to develop a predictive laboratory method, specifically for Vertisols, to relate soil inherent properties and the ease with which they undergo structure repair (or improve their structure) after wet/dry cycles and plant growth. Such a relationship could be used to rank compacted Vertisols with respect to their ability to self-repair. In order to minimize inter-soil differences the focus was on Vertisols under similar cropping regimes and from the same climatic region in Queensland, Australia.

2. Materials and methods

2.1. Sites and soil

Eight clay soils with a range of texture were collected from two cropping areas in Central Queensland, Australia (Fig. 1). The region has a sub-tropical to sub-humid climate with large seasonal variability in rainfall, temperature and evaporation.

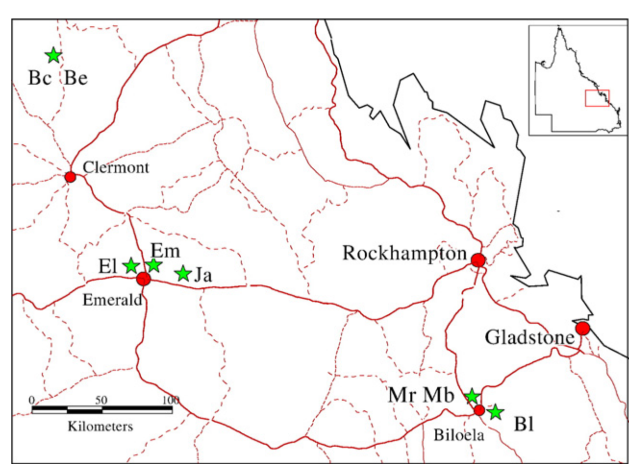

Fig. 1. Map of Central Queensland with soil sampling sites denoted with the star symbol.