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When does organic carbon induce aggregate stability in vertosols?

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ABSTRACT

Two percent organic carbon (OC) (grams C per gram soil) provides a threshold for soil stability; below this threshold, soils become highly erodible as macroaggregates slake to form microaggregates. However, it is a long-held belief that a degree of slaking upon rapid wetting of aggregates is an inherent trait of vertosols, regardless of OC content. This is attributed to their physico-chemical attributes (e.g. high clay content, shrink–swell capacity, cation exchange capacity and pH). Studies investigating the erodibility of vertosols have concentrated on cropping soils, usually with low OC content ($\leq$2%). Therefore, the importance of OC in maintaining structural stability and minimising erosion in vertosols is often dismissed. This study examined vertosol macroaggregate and microaggregate stability in natural ecosystems where OC can be >2%. We found a positive relationship between macroaggregate stability and OC content in vertosols, especially when OC was $\geq$3.5% in the surface soil (0–5 cm). Microaggregate stability was attributed to the dominance of Ca^{2+} over Na^+ on clay-exchange sites. OC was positively correlated with Ca^{2+} and negatively correlated with Na^+ and ESP. OC may play a role in microaggregate stabilisation through its capacity to lower soil pH and increase the availability of Ca^{2+}. We demonstrate that OC can stabilise vertosol aggregates, and is therefore important in preventing erosion on this soil type.

1. Introduction

Vertosols are highly erodible in cropping situations worldwide (Bravo-Garza et al., 2009; Freebairn and Wockner, 1986; Hudson, 1984; Jutzi, 1988; Probert et al., 1987), even on land of very low slope (Donaldson and Marston, 1984). Research into the structural characteristics of vertosols in agricultural situations has revealed various problems including low aggregate stability (Cattle and Field, 2013; Prebble, 1987; Yates, 1972), low infiltration (Little et al., 1992) and high surface crusting and sealing (Pillai-McGarry and Collis-George, 1990), leading to severe sheet erosion (Junor et al., 1979) and crop yield declines (Yates, 1972). In contrast with other soil types where subsoils are wetted slowly by percolation through the surface soil, the subsurface aggregates in vertosols are rapidly wetted through cracks to appreciable depths (>1 m). This has implications for subsoil structure, infiltration and erosion (e.g. tunnelling) (Cattle and Field, 2013).

Addition of organic matter to many soil types improves aggregate stability and reduces the occurrence of soil physical issues such as surface crusting, and sheet and gully erosion (Awadhwal and Thierstein, 1985; Le Bissonnais and Arrouays, 1997; Valentin et al., 2005). Several authors have indicated that 2% total organic carbon (TOC grams C per gram soil: 3.4% organic matter) is an important threshold across a range of soil texture classes, below which general soil quality including aggregate stability declines (see review in Loveland and Webb, 2003). Organic matter has been considered less effective in determining soil aggregate size distribution and stability than other soil physico-chemical characteristics in vertosols (Charman and Roper, 2000; Coughlan and Loch, 1984; Coughlan et al., 1987; Dalal, 1989; Dalal and Bridge, 1996; Freebairn et al., 1996; Prebble, 1987; Reichert and Norton, 1994; Smith, 1984; Yates, 1972; Yates and McGarity, 1984). However, several authors have acknowledged that the use of cover crops, minimum tillage and stubble retention are generally beneficial for vertosol structural conditions (Cattle and Field, 2013; Ringrose-Voase and Nadelko, 2013).

Aggregate slaking upon rapid wetting of dry soil aggregates is generally accepted as an inherent trait of vertosol soils (Coughlan, 1984; Cass, 1999). Adverse physical properties in vertosols, due to the physico-chemical limitations of the proportions and types of clay, make them prone to rapid and extensive slaking and dispersion. Hence the importance and influence of organic matter has often been dismissed in relation to maintenance of structural

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stability. The assumption that vertosol slaking cannot be controlled with organic matter is likely to have originated in studies on cultivated land. The majority of vertosols used for cropping in semi-arid areas in Australia have low organic carbon content, predominantly <2% total organic carbon (TOC), due to repeated disturbance (cultivation) and a change from perennial to annual vegetation (Chan et al., 1988; Dalal and Chan, 2001).

While TOC concentrations in cropped vertosols in Australia are often well below 2%, the TOC content in surface soils in native vegetation can be substantially higher (Smith and Reid, 2013). Stace et al. (1968) recorded 4% TOC in a semi-arid riparian ecosystem near Swan Hill in southern Australia. Aggregate stability in relation to TOC content is rarely investigated in native forest and woodland ecosystems on vertosol soils, hence the influence of high organic matter and carbon concentrations on aggregate stability in these soils is unknown.

This study investigated the relative influence of different amounts of soil organic carbon on aggregate stability in vertosol soils. This was achieved by sampling a range of management regimes from undisturbed, rarely disturbed native vegetation (i.e. uncropped and rarely grazed by domestic livestock) through to frequently grazed native vegetation (including grasslands, woodlands, shrublands and tree plantings), and previously cropped land allowed to return to volunteer pasture. The objective of this study was to determine whether and at what concentration organic C stabilises vertosol macroaggregates (>0.25 mm) and microaggregates (<0.25 mm: Oades, 1984), by studying the range of vegetation types occurring on these soils where OC is supplied by perennial plants. The attributes of each vegetation type were also measured and related to soil variables to determine the contribution of vegetation attributes to aggregate stability under prevailing management.

2. Materials and methods

2.1. Study region

This study was undertaken in the highly modified agricultural environment of the lower Namoi floodplain between Boggabri (−30.7152°, 150.0346°) and Walgett (−30.0318°, 148.1012°) in northern New South Wales, Australia. The region is dominated by black, grey and brown vertosols (Isbell, 1996), typically with self-mulching characteristics. The floodplain is dominated by soils that are slightly to strongly alkaline (Stannard and Kelly, 1977). Many contain free lime or gypsum at varying depths and most are sodic below 20 cm depth (exchangeable sodium percentage ≥6%).

Mean annual rainfall decreases from east to west across the study region, from 600 mm near Boggabri to 400 mm near Walgett, with slight summer dominance (Bureau of Meteorology, 2008). Rainfall across the study region is variable and unpredictable in time and amount (Stannard and Kelly, 1977), with much of the rainfall occurring as high-intensity storms (Kearle et al., 2002; SPCC, 1980). These storms can bring about significant erosion when groundcover is depleted and the soil is dry and cracked to expose the sodic subsoil.

The dominant vegetation types on the vertosol soils of the region include: (1) river red gum (*Eucalyptus camaldulensis*)-dominated riparian forests and woodlands, (2) coolibah (*Eucalyptus coolabah*) woodlands of varying canopy density, grading into (3) black box (*Eucalyptus largiflorens*) woodlands and open woodlands, (4) weeping myall (*Acacia pendula*) tall shrubland and tall open-shrubland, and (5) native and derived perennial grassland. Derived grasslands were originally woodlands that were cleared for agricultural production (cropping or grazing) and may therefore have higher organic C concentrations than other grassland sites as a result of residual woody-derived C (Harms et al., 2005). Sites in each of these five vegetation types plus environmental tree plantings were sampled as part of this study. Thinning of eucalypt woodland through ring-barking was conducted over large parts of the study region from the 1840s (Ferry, 1978) including some of the sites examined during this study. Tree thinning and livestock production may have affected carbon inputs at some sites, particularly where trees have been felled and burnt in situ.

2.2. Field sampling

Soil samples were collected at 56 sites across the lower Namoi floodplain in December and January 2007–2008. Sites were chosen to represent the range of management commonly observed across the six vegetation types on vertosol soils of the region. Because vegetation types varied greatly in extent in the region and not all vegetation types were represented under similar management conditions, a balanced design could not be achieved. In total 13 river red gum, 16 coolibah, 16 grassland, 6 myall, 3 black box and 2 tree plantings were sampled. Management at individual sites ranged from light native macropod grazing only to continuous grazing by sheep or cattle. Some grasslands had been cultivated 15 years previous to the current study, and the tree and shrub plantings had been cropping fields (predominantly cereal crops) more than 10 years prior to sampling.

Nine soil core samples were taken (minimum internal core diameter of 5.5 cm) from a 25 × 25-m plot stratified by cover at each site. Cores were subdivided into depth increments of 0–5 cm and 20–30 cm and stored in sealed containers (in the dark) until they could be returned to the lab. Samples were air-dried and returned to sealed containers until chemical, textural and physical analyses could be conducted. Use of air-dry aggregates was considered acceptable for analysis of aggregate stability as prevailing field conditions in the study region during summer yield aggregates of similar water content (Chan et al., 1988), and air drying provides a more standardised and repeatable measure than non-air drying.

Herbaceous vegetation and litter biomass were measured using a modified BOTANAL technique (Tothill et al., 1978). Twenty 50 × 50-cm quadrats located at 4-m intervals around the perimeter of a 20 × 20-m cell nested within the soil sampling quadrat were used to measure biomass and ground cover. Canopy cover was estimated visually over a 1-ha area encompassing the soil plot. Surveys were conducted in April–May and again in October–November 2008 as the weather leading up to these sampling periods was favourable for maximum vegetation growth. Hence, the vegetation survey recorded the maximum seasonal vegetation cover and biomass potential under prevailing management at each site.

2.3. Soil analyses

Soil chemical analyses were undertaken to characterise the soils of the different vegetation types following the laboratory methods of Rayment and Higginson (1992). A bulked sample from the two depth increments at each site was passed through a 2-mm sieve using a mechanical soil mill after leaves, sticks and other macro-organic matter were removed. Samples were mixed thoroughly and subsampled for further analyses. Electrical conductivity (EC) and pH were determined in a 1:5 soil:water extract. For soils with pH < 7.5, exchangeable cation concentration (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) was determined using atomic absorption spectroscopy following extraction using 1 M NH_4Cl at the University of New England. For soils with pH ≥ 7.5, exchangeable cations were determined at an external commercial laboratory (Victorian Department of Primary Industries, Werribee, Vic.) using the alcoholic 1 M NH_4Cl method (Tucker, 1954) after pre-treatment