Geoderma 183–184 (2012) 19–24

Contents lists available at SciVerse ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Synergistic impacts of clay and organic matter on structural and biological properties of a sandy soil

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ARTICLE INFO

Article history:
Received 26 January 2011
Received in revised form 1 March 2012
Accepted 4 March 2012
Available online 5 May 2012

Keywords:
Aggregate stability
Soil strength
Microbial biomass carbon
Kaolin
Lucerne hay

ABSTRACT

Clay and organic matter, when incorporated together in a sandy soil, improved soil aggregation in association with both microbial activity and soil strength. Incorporation of clay into sandy agricultural soils in south-western Australia is a practice used to overcome water repellence, but the addition of high levels of clay can cause hardsetting. We investigated the extent to which addition of clay and organic matter would improve aggregate stability of a sandy agricultural soil from Meckering, Western Australia without negatively affecting soil strength. Four levels of subsoil clay and three levels of lucerne hay were compared in topsoil incubated for up to 42 days at two temperatures. Addition of both clay and lucerne hay together increased stable aggregation and the longer the period of incubation, the greater the macroaggregate stability. A decrease in soil respiration associated with increasing level of clay added may be related to protection of organic matter. Soil strength increased when the amount of clay alone was increased, but addition of both clay and organic matter decreased soil strength. Soil amelioration with 5% clay and 0.8% organic matter was most effective at improving the stability of macroaggregates without hardsetting. The non-linear relationships observed demonstrate the importance of understanding interactions between biological and physical components of soil fertility in relation to the sustainability of land management practices.

1. Introduction

Sandy soils in Western Australia typically have low proportions of macroaggregates, are highly water repellent (Carter et al., 1997), and are prone to wind erosion (McFarlane and Carter, 1990; Select Committee into Land Conservation, 1990). These soils are widespread, occupying about 5 million hectares of agricultural land in Western Australia (Nulsen, 1993). When managing such soils, two physical constraints need consideration: water repellence and hardsetting. Water repellence caused by organic substances requires astute amendments of organic matter in order to prevent water repellence becoming persistent. The application of clay has been used to ameliorate water repellence in the field (Nulsen, 1993), but if it is added in excess, surface crust formation and hardsetting can occur (Harper and Gilkes, 2004). Clay sourced below the sandy surface layers often consists of kaolinite that tends to disperse easily (even at very low exchangeable sodium percentages) to form surface crusts or dense subsurface horizons (Mullins et al., 1990). These adverse effects of soil management on physical fertility can neutralise each other. For example, water repellent soils can be ameliorated with clay addition and dispersive clays can be stabilized with organic matter. Furthermore, both clay and organic matter can influence microbial processes, and these interactions can change aggregate formation and soil cohesiveness.

This investigation sought to improve understanding of the effects of adding clay and organic matter to a sandy soil, and to clarify how this relates to cohesiveness of sand particles which is mediated by microbial activity. We focused on the change in soil cohesiveness at the laboratory scale using a simple and well-defined model system. Hardsetting properties can influence choice of cultivation time because the formation of a poor seedbed or crusting after sowing can impede root growth (Mullins et al., 1990). However, it was not our intention to derive specific recommendations for soil amendments applicable to field situations.

The beneficial effects of clay on soil aggregate stability depend on microbial activity in sandy soil (Boix-Fayos et al., 2001; Kiem and Kandeler, 1997). For example, Kiem and Kandeler (1997) used field observations to show that aggregate stability associated with microbial biomass was greatest in sandy soils (<15% clay) and least in clay soils (>35% clay). In contrast, the abundance of aggregates <0.105 mm from soils along a climatological transect in south-east Spain was positively related to both clay and organic matter content (Boix-Fayos et al., 2001). Although increasing concentrations of both clay and organic matter are associated with higher levels of soil

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doi:10.1016/j.geoderma.2012.03.012

aggregation in field soils (see Edwards and Bremner, 1967; Tisdall and Oades, 1982), clay can also stabilize soil organic matter by providing a protective coating on soil particles which inhibits or retards microbial decomposition (Bronick and Lal, 2005; Sollins et al., 1996). Moreover, organic matter can stabilize dispersive clays and improve physical fertility (Tisdall and Oades, 1982).

Despite the appreciation of effects of clay and organic matter on soil aggregation, there is little experimental evidence for combined effects of clay and organic matter on stabilising macroaggregates in relation to hardsetting properties of sandy soil. We investigated how clay (primarily kaolin) and organic matter (lucerne hay) applied to a sandy soil affected soil aggregate stability, soil strength and microbial processes. Our intention was to determine whether there was a particular combination of clay and organic matter that most optimally enhanced the physical characteristics of this sandy soil. We used kaolin subsoil clay because (i) kaolin is the predominant clay mineral in these soils, (ii) it is readily available on the farm where the soil was collected, and (iii) it has been applied in this region to overcome water-repellence (McFarlane and Carter, 1990). Lucerne hay was selected as the organic matter source because it can increase soil aggregation (Chantigny et al., 1997) and has high calcium content (Smethurst et al., 2005) which stabilizes clay minerals. Seasonal variation was simulated by incubating the soil at two temperatures.

We hypothesised that application of clay and organic matter would benefit the physical fertility of this sandy soil. Based on previous studies of field soils, addition of clay to sandy soil may induce hardsetting properties, and addition of organic matter may interfere with soil aggregation. We sought to determine appropriate amounts of clay and organic matter that would stabilise soil aggregates but avoid hardsetting properties. We expected changes in biological processes such as mineralisation and accumulation of microbial biomass.

2. Materials and methods

2.1. Soil sampling and preparation

Soil was collected from agricultural land near Meckering (31 46′S, 117 42E; 135 km east-north-east of Perth) Western Australia. The site was chosen because the farmer had previously applied subsoil clay to ameliorate the water-repellence at this location, as has been done elsewhere in Western Australia (Nulsen, 1993). The experimental soil used was adjacent topsoil (0–10 cm deep) which had not been treated with subsoil clay in the field. A bulk sample of topsoil was collected and passed through a 2000 μm sieve to remove large gravel and coarse plant material. Subsoil (at about 1 m depth) was collected as the source of clay (kaolin was the only clay mineral present as determined using X-ray diffraction). Particle size distribution in the topsoil (89% sand, 3% silt and 8% clay) was analysed using a pipette method (Gilkes et al., 2003). Field capacity was 16% w/w under suction at 10 kPa.

2.2. Experimental design

The soil incubation experiment had the following three treatments: (i) 4 rates of clay (0, 2, 5 and 10% w/w), (ii) 3 rates of organic matter (0, 0.4 and 0.8% w/w) and (iii) 2 temperatures (4 and 23 °C). There were 3 replicates of each treatment. Aggregate stability and microbial biomass C were assessed after 3 periods of incubation (14, 28, and 42 days). Plastic containers containing soil treatments were arranged as a split-split-plot design with variables of temperature (main plots), clay (subplots), and organic matter (sub-subplots).

2.3. Addition of clay and lucerne hay

Subsoil (46% clay) was passed through a 250 μm sieve to collect soil microaggregates <250 μm. This fraction was added to the topsoil at the rate of 0, 2, 5 and 10% (equivalent to 0, 26, 65, 130 t/ha) respectively. Dried lucerne hay was ground to fractions of about 0.5 mm and added to the topsoil at rates of 0, 0.4 and 0.8% w/w (equivalent to 0, 10 and 20 t/ha).

Subsoil clay was added to the topsoil at either 4.30 g (2% clay), 10.75 g (5% clay) or 21.50 g (10% clay) to obtain a 1000 g mixture. The topsoil and subsoil were air-dry at the time of mixing. Lucerne hay was added as described above and the soil was mixed thoroughly on an end-over-end shaker for 200 cycles then transferred to a non-draining plastic container (100 mm height × 150 mm diameter). After mixing, the moisture content was established at field capacity and the soil was incubated for 42 days either in a glasshouse (daily temperature average was 23 °C) or a cool room (constant temperature was 4 °C). Before incubation, the treated sandy soil was stored overnight to equilibrate at 4 °C. Throughout the incubation period, soil was maintained at field capacity by addition of water to maintain a constant weight.

After incubation, soil samples from each of the three replicates were divided into two sub-samples. One sub-sample was dried using fan-forced air at 25 °C. Dried samples were gently broken up by hand and passed through an 8 mm sieve to measure cohesiveness and through a 2 mm sieve in preparation for measuring soil strength. Another sub-sample from each replicate was stored in its moist state at 4 °C for about 5 days prior to microbial biomass measurements.

2.4. Aggregate size distribution

Measurement of aggregate stability was based on the concept of macro- and microaggregates described by Edwards and Bremner (1967). The threshold between macro- and microaggregates was set at 250 μm (Cambardella and Elliot, 1993). Cohesiveness of soil particles or the formation of aggregates was measured on 3 replicates of each of the 24 treatments by non-destructive sampling on day 14, 28, and 42 for samples incubated at either 23 and 4 °C. Aggregate distribution was determined by wet sieving soil samples (Cambardella and Elliot, 1993) with the following modifications: a series of 4 sieves was used to obtain 4 aggregate size fractions: (i) >2000 μm (large macroaggregates), (ii) 250–2000 μm (small macroaggregates), (iii) 53–250 μm (microaggregates), and (iv) <53 μm (silt and clay fraction). Sieved soil samples of approximately 100 g were moistened slowly on filter papers, arranged on ceramic plates and stored overnight at 4 °C before measuring aggregate distribution.

2.5. Soil microbial biomass C

Soil microbial biomass C (MBC) was determined by the fumigation-extraction method (Vance et al., 1987). This entailed fumigation of 22 g of samples (F) under vacuum at room temperature for 48 h in desiccators containing 30 mL volumes of ethanol-free chloroform. Non-fumigated (NF) samples (22 g) were also kept at room temperature for 48 h. After fumigation, chloroform was removed by repeated flushing of the desiccators. Samples were transferred to plastic vials (300 mL volume) and 0.5 M K_2SO_4 was added. The suspensions were placed in a rotary shaker for 1 h then transferred to 30 mL vials through 42 Whatman filter papers that had been pre-washed with deionised water. The amount of CO_2-C in the filtrate was determined by automated combustion analysis (Shimadzu TOC-5000A, Kyoto, Japan). MBC was calculated from the difference between CO_2-C from the F and NF samples multiplied by a conversion factor ($k_{EC} = 2.64$; Vance et al., 1987).