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Soil organic carbon mineralization rates in aggregates under contrasting land uses

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ABSTRACT

Measuring soil organic carbon (SOC) mineralization in macro-aggregates (250–2000 μm), micro-aggregates (250–53 μm) and the <53 μm fraction helps to understand how spatial separation of SOC inside soil aggregates regulates its dynamics. We hypothesized that (i) compared with macro-aggregates SOC mineralization rate of micro-aggregates would be slower, (ii) adsorption of SOC on <53 μm fraction decreases the SOC mineralization rate, and (iii) land use has a significant influence on SOC decomposition rate. To test these hypotheses we collected topsoil from Dermosol (Acrisols in FAO Soil Classification) sites under three contrasting land uses namely native pasture (NP), crop–pasture rotation (CP) and woodland (WL). Macro-aggregates, micro-aggregates and the <53 μm fraction were separated from bulk soil by wet sieving. The three aggregate size ranges were then incubated for six months and CO_2 evolution was measured at different time intervals. The chemically stable SOC of <53 μm fraction of macro-aggregates, micro-aggregates and the <53 μm fraction (separated by wet sieving) was measured by oxidation of SOC with 10% H_2O_2. On average, cumulative mineralization, C_{min} (g CO_2–C kg^{-1} aggregate) of the <53 μm fraction, was 28% lower than that of macro-aggregates and micro-aggregates. However, SOC mineralized (SOC_{min}) was similar in all size fractions. The size of slow SOC pool (percent of SOC concentration in aggregates) was also significantly higher in the <53 μm fraction and ranged from 58 to 96%, across aggregate sizes. However, the chemically stable SOC (percent of SOC concentration in aggregates) was significantly higher in macro-aggregates and micro-aggregates than that of the <53 μm fraction. Mean residence time (MRT) of slow SOC pool (MRT_s) was higher in the <53 μm fraction than for either macro-aggregates or micro-aggregates. Among the land uses NP had higher SOC_{min} compared with CP and WL. In conclusion, the insignificant difference in SOC_{min}, slow SOC pool sizes and MRT_s between macro-aggregates and micro-aggregates indicated that SOC mineralization rate and thus the protection of SOC was similar in both macro-aggregates and micro-aggregates.

1. Introduction

Soil aggregates are conventionally sub-divided into macro-aggregates (>250 μm) and micro-aggregates (<250 μm) and these can be readily separated by wet sieving procedures in the laboratory. Using the "aggregate hierarchy" and "porosity exclusion" hypotheses, it is typically postulated that soil organic carbon (SOC) concentration and porosity will decline with decreasing aggregate size (Dexter, 1988; Tisdall and Oades, 1982) but that SOC in micro-aggregates will be more stable and resistant to degradation. This stabilization of SOC in soil aggregates is believed to result principally from aggregate architecture and the protection of SOC from microbial decomposition through formation of clay–organic carbon complex (Sollins et al., 1996). Several investigations have found that the turnover of SOC is more rapid in macro-aggregates compared with micro-aggregates (e.g. Besnard et al., 1996; Six et al., 2002). Franzluebbers and Arshad (1997) concluded that microbial biomass and basal soil respiration (BSR) were also both higher in macro- compared with micro-aggregates in Alfisols and Fernandez et al. (2010) and Noellemeyer et al. (2008) further reported that 1–4 mm aggregates had higher respiration than <1 mm aggregates in Mollisols. Other investigations have however, reported that micro-aggregates can also have a large amount of unprotected SOC in Ultisols (Beare et al., 1994a, 1994b; Bossuyt et al., 2002) and Razafimbelo et al. (2008) found no significant difference in the amount of carbon mineralized in macro-aggregates and micro-aggregates in Oxisols.

A strong relationship between land use practice and the amount of SOC stored in macro- and micro-aggregates has also been reported (Jastrow, 1996; Jastrow and Miller, 1998; John et al., 2005; Paul et al., 2008a; Six et al., 1998, 1999). The carbon turnover rate is one of the factors that influences the amount of SOC stored under different land uses. Less intensive management practices (e.g. minimum- or no-tillage) result in slower turnover of macro-aggregates, allowing the development of stable micro-aggregates inside these while more intensive soil disturbance exposes micro-aggregates and the SOC they contain to more rapid decomposition (Beare et al., 1994a, b; Elliott, 1986; Gale et al., 2000; Oades, 1993; Six et al., 2000a).

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To fully understand the dynamics of SOC within and between aggregate size classes, it is also necessary to separate SOC into its active, slow and stable pools (Denef et al., 2009). Using the aggregate hierarchy approach it would be expected that micro-aggregates would contain more slow and stable carbon that macro-aggregates. The active SOC pool is typically dominated by soil microbes and microbial products, while the slow SOC pool includes resistant plant materials and physically and chemically protected SOC. The stable pool is comprised of chemically protected and inert SOC such as charcoal (e.g. Parton, 1996).

Understanding the way in which soil organic carbon becomes stabilized in soil aggregates is key to understand the mechanisms of long term SOC storage in soil but a consensus regarding the quantity and mechanisms of SOC protection in different aggregate sizes and in the <53 μm fraction is still lacking. In the work reported here we examined the amount of carbon mineralized over 6 months in macro-aggregates, micro-aggregates and <53 fraction using a laboratory incubation experiment. The carbon mineralization rates and sizes of active and slow SOC pools in different aggregate sizes and <53 μm fraction were also estimated using a curve-fitting approach on CO_2-C evolution data during 6 months of incubation. We hypothesized that (i) compared with macro-aggregates, SOC mineralization rate of micro-aggregates would be slower, (ii) adsorption of SOC on <53 μm fraction would decrease the SOC mineralization rate, and (iii) that land use has a significant influence on SOC decomposition rate.

2. Materials and methods

2.1. Study area and soil sampling

The study was conducted in Armidale and Guyra on the Northern Tablelands of NSW, Australia (elevation: 980–1275 m) (Fig. 1). In Armidale mean annual maximum and minimum temperatures are 20.3 °C and 7.1 °C, respectively with January the warmest and July the coldest. Mean maximum and minimum temperatures are 12.2 °C and 0.3 °C in July and 27.1 °C and 13.4 °C, respectively in January. Rainfall is summer dominant with a mean annual total of 791.2 mm. In Guyra, mean annual maximum and minimum temperatures are 17.9 °C and 5.3 °C, respectively. Mean maximum and minimum temperatures are 10.2 °C and −0.6 °C in July and 24.5 °C and 10.8 °C, respectively, in January (Bureau of Meteorology, 2011). Rainfall is summer dominant with a mean annual total of 880.6 mm. Frosts are common from mid April to September in both areas (Lodge and Whalley, 1989).

Soil samples were collected between October, 2009 and April, 2010, from the surface (0–10 cm) of Dermosols (equivalent to Acrisols in FAO Soil Classification) with three contrasting land uses (i) native pasture, NP (ii) crop–pasture rotation, CP and (iii) woodland, WL. Soil sampling sites were Kirby, Clarkes, Powalgarh and Black Mountain. Kirby and Clarkes sites were experimental farms of the University of New England, Armidale. Powalgarh and Black Mountain sites were privately owned farms located near the township of Guyra. Parent material of soils at the 4 sites was Tertiary basalt. The native pasture sites were composed solely of native perennial grasses such as Red Grass (*Bothriochloa macra*), Wire Grass (*Aristida ramosa*), Wallaby Grass (*Austrodanthonia* spp.), etc. Recently sown crops at Kirby, Clarkes, Powalgarh and Black Mountain sites were fescue (*Festuca arundinace*), ryegrass (*Lolium perenne*), triticale (*Triticale hexaploide*) and millets, respectively. The woodlands at all sites consisted of *Eucalyptus* spp. dominated by Blakely's red Gum (*Eucalyptus blakelyi*) and Yellow Box (*Eucalyptus melliodora*). Descriptions of the management history of the sites and chemical characteristics of the soils are given in Table 1. Soil samples were collected from each land use by selecting 3 separate blocks (50 × 50 m) of each paddock. In each block 7 random soil cores (0–10 cm) were collected with a metal corer (5 cm in diameter). The soil samples were collected when the moisture content of soil was ~25–35%, and a wooden mallet was used to drive the corer carefully into soil to avoid strong impact that might break the macro-aggregates.

Soil samples were broken by hand along the fractures of peds (>10 mm) and then composited into one in a laboratory. The plant residues that were not incorporated in soil, visible soil fauna, stones and concretions were removed from the soil samples. Bulk density of soil was determined by collecting 3 additional soil cores from each paddock. The percentage of sand, silt and clay in soil samples were determined by pipette method after dispersing with 5% sodium hexametaphosphate (Bowman and Hutka, 2002). A 1:5 soil to water ratio was used to

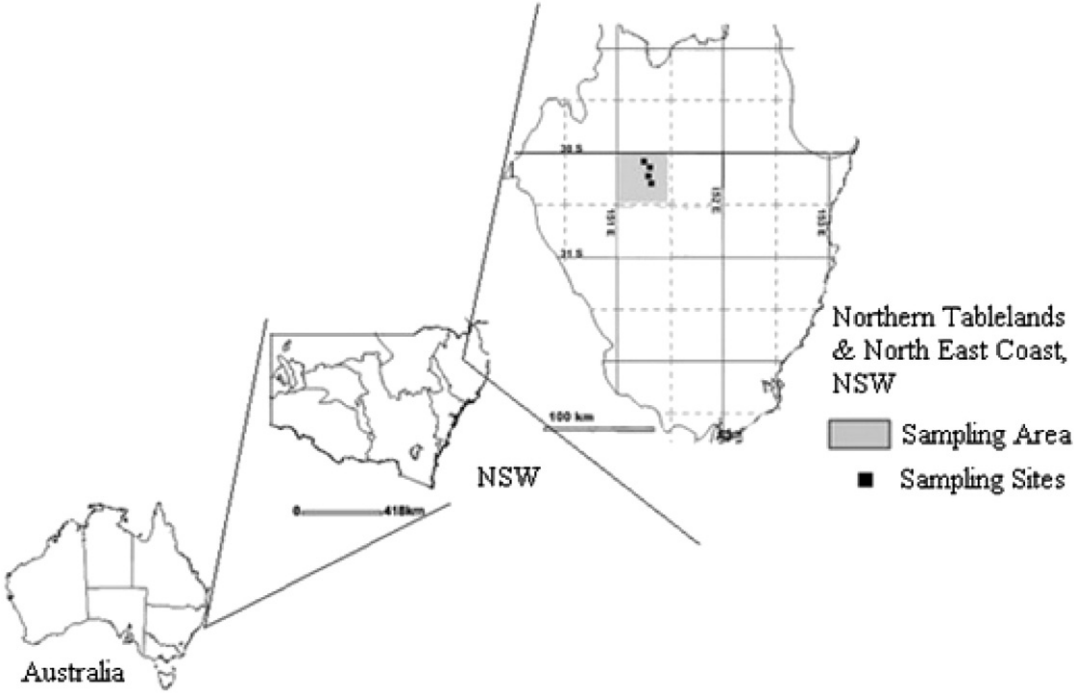

Fig. 1. Location map of study area, NSW, Australia.