



Soil aggregate formation and stability induced by starch and cellulose



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ABSTRACT

Soil aggregate (SA) can be formed and stabilized when soil organic matter (SOM) is decomposed in the soil. However, the relationships between the SA dynamics and SOM with different decomposition rates have not been clarified. Therefore, this study examined the effects of the addition of polysaccharides to soil on SA formation and stability. A Japanese tropical soil was incubated for 99 d at 30 °C in a dark environment following the addition of 0.5% (w/w) starch or cellulose. The decomposition rates of the amendments, and SA formation and stability were evaluated by measuring soil respiration rates, and distribution fractions of soil aggregate sizes and mean weight diameter (MWD) of SA, respectively. The cumulative soil respirations with all treatments rapidly increased until Day 12 of the incubation. The initial slope of the cumulative soil respiration in the soil with starch was significantly higher than that in the soil with cellulose. In either soil with starch or cellulose, the fractions of macro-aggregates (>1000 μm in diameter) significantly increased, respectively, compared with control soil. However, the fractions of meso-aggregates (250–1000 μm) and nano-aggregate (<20 μm) in the soil with starch significantly decreased, while those fractions in the soil with cellulose fluctuated until Day 6. The MWDs reached the maximum on Day 6, indicating the SA formation in the soils with starch or cellulose. The increasing rate of the SA formation in the starch-amended soil was greatly higher than that in the cellulose-amended soil. After Day 6, the MWDs in the soils with either polysaccharide decreased with similar trends with no significant differences between treatments, indicating similar stability of the SA in both treatments. This study showed that the different decomposability of the organic amendments might influence the SA formation differently, but not the SA stability.

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1. Introduction

Soil aggregate (SA) structure plays a significant role in carbon storage in terrestrial regions (Stockmann et al., 2013) because of storage capability within the structure and physical characteristics that regulate microbial decomposition rates (McCarthy et al., 2008). The SA structure can be classified in a hierarchical model based on the size (Tisdall and Oades, 1982). Nano-aggregates (<20 μm in diameter) are formed mainly by combining soil clay particles; aggregates measuring 20–250 μm and >250 μm in diameter are classified as micro- and macro-aggregates, respectively (Edwards and Bremner, 1967; Oades and Waters, 1991). Some studies have separated aggregate sizes into different categories depending on

study designs (Alberts et al., 1983; Jastrow, 1996; Plante and McGill, 2002). However, it appears appropriate to define macro-aggregates (>250 μm) into the specific classes of meso-aggregates (250–1000 μm) and macro-aggregates (>1000 μm) because of the fraction movements within size fractions (Chang et al., 2013; Yoo et al., 2014).

The SA structure can be formed in the soil with binding agents such as decomposed dead organisms and the excretion of living organisms which contain saccharides (Guggenberger et al., 1999). These hydrocarbon compounds in the soil, known as soil organic matter (SOM), may bind the soil particles together with cohesive force, thus creating resistance against outside physical forces such as percolation water (Nimmo and Perkins, 2002). The dynamics of soil aggregation and structural stability induced by SOM may differ depending on the decomposition rates of the SOM present in the system (Bronick and Lal, 2005). Monnier proposed a conceptual scheme for soil aggregate stability using different SOM inputs (translated by Abiven et al., 2009). According to this model, easily decomposable inputs such as green manure would have strong but transient effects on aggregate stability (Kiem and Kandeler, 1997;

Abbreviation: SA, soil aggregate; SOM, soil organic matter; SR, soil respiration; MWD, mean weight diameter; RMSE, root mean square error.

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Liu et al., 2005), while more recalcitrant inputs such as decomposed manures should show weak but long-term effects (Celik et al., 2004).

However, there are some inconsistencies in the collected data on the relationship between the decomposition rates of SOM and soil aggregate stability (Abiven et al., 2009). For example, straw was classified as having fast and transient, intermediate, and recalcitrant agents (Martin and Waksman, 1940; McCalla, 1945; Sonnleitner et al., 2003). The humic substances in the soil were also found in multiple groups (Fortun et al., 1989). Possible reasons for this inconsistency may be related to the methodology and experimental design of the studies such as time scales (Stolt and Bakken, 2014). However, the organic materials may, in fact, contain both easily decomposable and recalcitrant substances; therefore different decomposability of organic materials may make the dynamics of SA formation and stabilization extremely complex.

The measurement of SOM decomposition is not clearly defined. The C:N ratio or molecular weight has been applied as an indicator of decomposition rates (Rousk and Bååth, 2007; Wickland and Neff, 2008). However, those measurements might be unable to clearly distinguish easily decomposable and recalcitrant parts of the SOM and to identify differences in the decomposition among different pure polysaccharides such as starch and cellulose since these compounds contain no nitrogen atoms and structurally have the same molecular weight.

In this study, the effects of organic matter with different decomposition rates on soil aggregate formation and stability over time were investigated by measuring soil aggregate size distribution and mean weight diameters of the SA that was formed. This study focused on two different polysaccharides because they are classified as transient agent factors for soil aggregation (Harris et al., 1966). The two specific objectives were to 1) explore the decomposition rates of the polysaccharides after being applied to soil based on soil respiration measurement and 2) clarify the relationship between the decomposition rates of the polysaccharides and soil aggregate behaviors including formation and stabilization.

2. Materials and methods

2.1. Soil sample preparation

The soil used in this study was collected from a fallow field located in Okinawa Prefecture, Japan, in September 2013, and some basic characteristics for the soils were examined (Table 1). The collected soil was dried in an oven at 45 °C for 24 h and passed through a 2 mm sieve.

2.2. Soil respiration experiment

Nine (9) 125 mL plastic bottles were prepared for the soil respiration experiment. Fifty grams of the soil, in triplicate, were weighed in each bottle, which was placed inside an 1100 mL plastic

bottle. The soil was pre-incubated to stabilize soil microbial activity under the dark condition in an incubator at 30 ± 2 °C for 11 d. At the end of the pre-incubation, 0.5% (w/w) of starch or cellulose dissolved in distilled water was added to the soil. Control treatment without any amendments, in triplicate, was included. All bottles were incubated for 99 d under the same conditions as the pre-incubation. Distilled water was applied to the soil to maintain 50% of the water holding capacity of the soil every 1 d or 7 d throughout the incubation period depending on amounts of water loss. The amounts of water applied to the soil were equivalent to differences of the bottle weights compared to those at the beginning of the pre-incubation. Day 0 was defined as the day before each polysaccharide was added to the soil.

Soil respiration (SR), carbon flux rates from the soil, was measured by using the closed static chamber method of alkali trapping during the main incubation (Nordgren, 1988). The daily amount of CO₂ released from the soil was trapped in a 20 mL of 1 mol L⁻¹ NaOH solution inside a glass vial that was also placed inside each 1100 mL bottle. Every day during the main incubation period, the glass vials were removed from the 1100 mL bottles and replaced by new 20 mL of 1 mol L⁻¹ NaOH solutions.

The alkali solutions were titrated using 0.2 mol L⁻¹ HCl (V_{sample}) and its titer (F , 8.7×10^{-5} mol CO₂ mL⁻¹) to eliminate the inaccuracy caused by unreacted solutions of HCl and NaOH during the titration. In addition, a 1100 mL bottle containing the NaOH solution without the bottle with soil was prepared (V_{blank}). The amount of CO₂ emitted from the soil (SR_{total} , mol CO₂ kg⁻¹ soil d⁻¹) was calculated using the following equation (Luo and Zhou, 2006):

$$SR_{\text{total}} = (V_{\text{sample}} \times F) - (V_{\text{blank}} \times F) \quad (1)$$

After the calculation, the time required for the cumulative soil respiration to reach half of the maximum respiration was calculated based on the cumulative soil respiration generalized by the following logistic equation:

$$Y = a / \{b + \exp(-cX)\} \quad (2)$$

where a , b , and c are empirical constants, and X and Y are time and the SR rates, respectively (Rodeghiero and Cescatti, 2005; Aanderud et al., 2013). The equation can indicate that the steeper the initial slope of the cumulative respiration is from the soil after the amendment addition, the more easily decomposable the amendment is. The accuracy for the equation fitting with the obtained data was performed using coefficient of determination (R^2) and root mean square error (RMSE) (Williams, 1987).

2.3. Soil aggregation experiment

Sixty three (63) 125 mL bottles were prepared for the soil aggregation experiment. Fifty grams of the soil, in triplicate, were weighed in each bottle. The conditions of the pre-incubation and main incubation including periods, temperature, soil water content, and treatments were same as in the soil respiration experiment.

Table 1

Basic analysis results for physical and chemical properties in the soil.

pH ^a	WHC ^b g kg ⁻¹	Sand ^c %	Silt ^c %	Clay ^c %	Total carbon ^d g kg ⁻¹	Total nitrogen ^d g kg ⁻¹	CaCO ₃ equivalent ^e %
5.7	363	69	10	21	4.5	1.0	25

^a Distilled water at 1:2.5 soil:solution ratio.

^b Modified available water-holding capacity (Cassel and Nielsen, 1986).

^c Hydrometer method for soil particle size distribution (Gee and Bauder, 1986).

^d Dumas dry oxidation method measured with CHN recorder (Nielsen and Sommers, 1996).

^e Acetic acid dissolution method (Loeppert and Suarez, 1996).

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