How the biological activity of Oligochaeta shape soil aggregation and influence the soil functions

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Abstract

This study investigates the effects of biological activity on the formation of soil aggregates. The laboratory experiment consisted of a 12-week soil incubation with macrofauna (Oligochaeta) and grass vegetation (*Brachiaria Decumbens* cv). Soil aggregates were separated into classes according to their morphology, using a stereomicroscope (LEICA M125), and physical, chemical, and biological analyzes were performed on the different aggregates. The results showed that the biological activity contributed significantly to soil structure quality and soil functions, where the biogenic aggregates are more stable, have higher nutrient and organic matter content, thus improving soil functions. The morphological analysis of soil aggregates is a good indicator of soil quality since it encompasses biological, physical, and chemical properties.

Keywords: biogenic aggregates; soil structure, soil quality.

Introduction

The importance of soil organisms is recognized in many processes and functions in soils. It regulates the organic matter accumulation, affects biochemical weathering, promotes soil horizons mixing and nutrient cycling. Soil structure is also enhanced by the activity of soil organisms. For example, the earthworms and the plant root systems increase soil aggregation, which is responsible for the structural soil porosity and also enhances the activity of soil organisms (Lavelle et al., 2006).

In the hierarchical aggregate model (Tisdall and Oades, 1982), aggregates are sequentially formed, i.e., microaggregates are first formed free and then serve as building blocks for the formation of macroaggregates (Six et al., 2004), which constitutes the physiogenic pathway of soil aggregate formation. On the other hand, the biogenic formation pathway describes how biological activity on soil directly promotes the formation of the aggregates, mainly by the activity of earthworms and plant roots (Pulleman et al., 2005) (Figure 1).

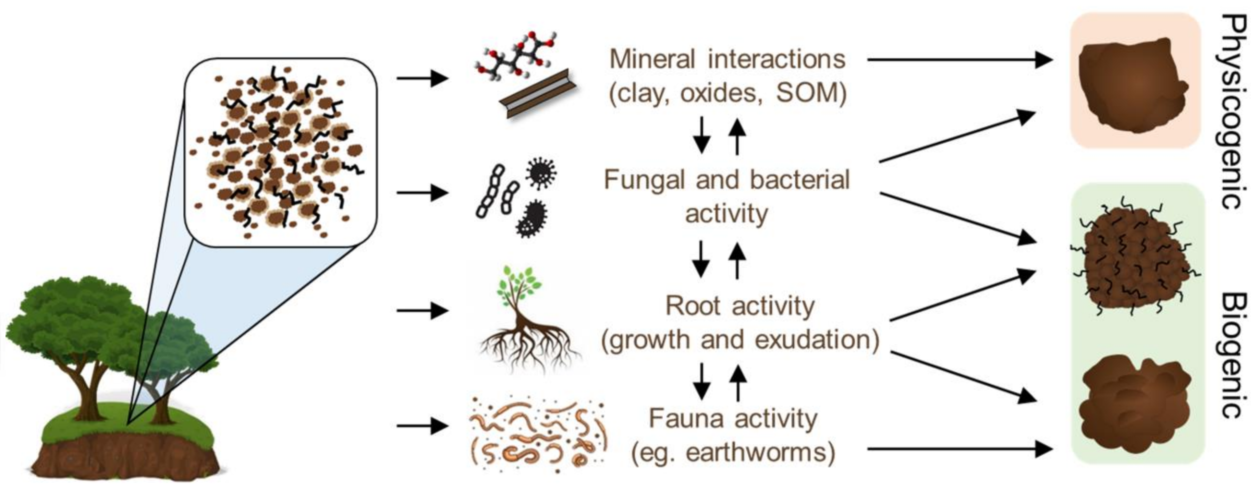

Figure 1. Theoretical framework of the soil aggregates formation pathways, physiogenic and biogenic.
Source: Elaborated by the authors

Several studies clearly indicate that physical and chemical processes influence aggregate formation and stability in soils, but few studies investigate the biogenic pathway (e.g., Silva Neto et al., 2016; Fernandes et al., 2017; Melo et al., 2019; Ferreira et al., 2020). This study aimed to investigate the effects of biological activity on the formation of soil aggregates using incubated soil materials. Considering the influence of roots and plants on soil structure and that earthworms are recognized as typical soil ecosystem engineers, we hypothesized that (1) biological activity contributes significantly to soil structure quality and soil functions; (2) the morphological analysis (identification/quantification) of soil aggregate can be a good indicator of soil quality, as it encompasses biological, physical, and chemical properties.

Methodology

The experiment consisted of a 12-week laboratory soil incubation with macrofauna (Oligochaeta) and grass vegetation (*Brachiaria Decumbens* cv). Soil samples were collected from the surface layer (0-10 cm) of an Inceptisol (Table 1). Samples were air-dried, ground, and sieved over a 2 mm sieve. The soil material was positioned inside plastic tubes and a number of 36 earthworms were dispersed in each cylinder, plus 8g of *Brachiaria Decumbens* cv. seeds.

Table 1. Physical and chemical characteristics of soil material.

Sand	Silt	Clay	pH	Ca	Mg	Na	K	SB	Al	H+Al	T	BS	P	TOC
	$g.kg^{-1}$		H_2O	----------------------			$cmol_c\ kg^{-1}$ soil			----------------------		%	$mg.kg^{-1}$	$g.kg^{-1}$
505	271	223	4.83	3.7	4.3	0.26	0.79	9.03	0.1	8.0	14.65	61	3	21.5

*SB: sum of bases; T: cation exchange capacity; BS: base saturation; TOC: total organic carbon.

After the incubation period, the soil aggregates were separated manually according to morphological fractions (Pulleman et al., 2005), using a stereomicroscope (LEICA M125). Physicogenic aggregates were identified by their angular or prismatic morphology. Biogenic aggregates were distinguished by their rounded shape, a result of root activity or passage through the intestinal tract of soil macrofauna, especially the earthworms. Intermediate aggregates were identified by in-between morphology (Figure 2).

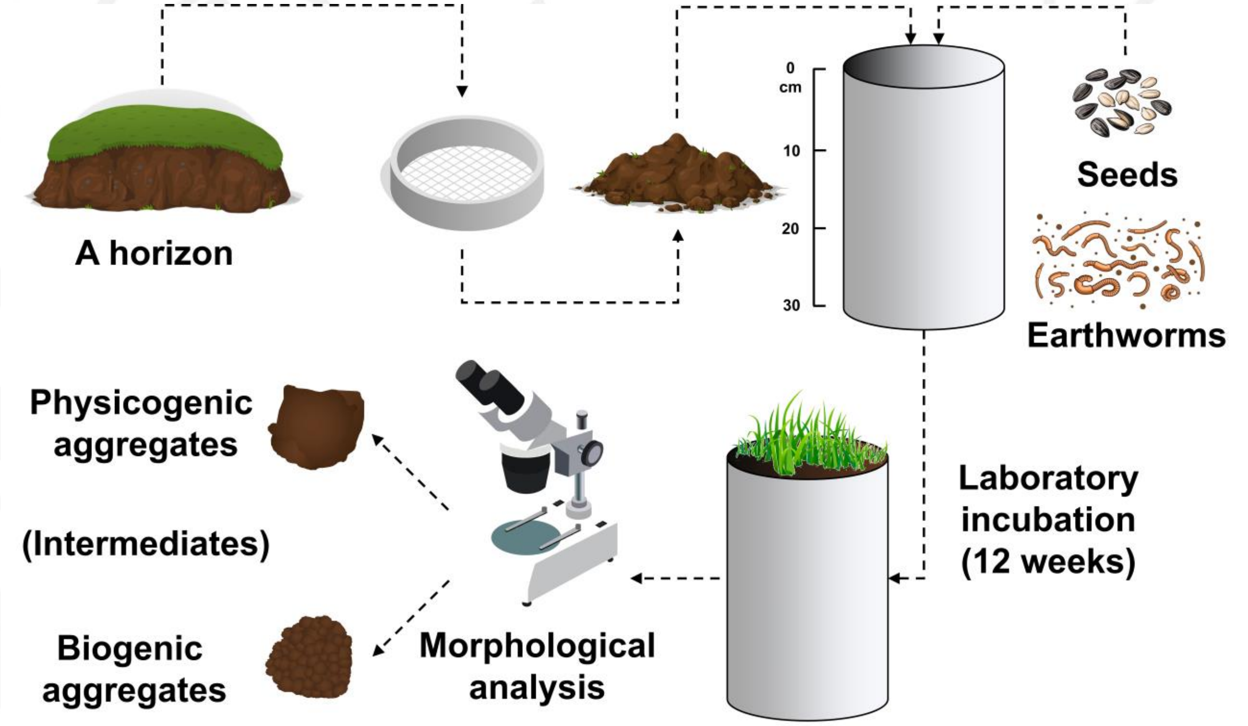

Figure 2. Summary of the experiment design. Source: Elaborated by the authors

The aggregates stability in water was evaluated by the aggregate indices: mean weight diameter (MWD) and geometric mean diameter (GMD). The chemical and physical analytical methods are those described by Teixeira et al. (2017). The biological properties analyzed are the following: microbial biomass carbon (C-MB); microbial biomass nitrogen (N-MB); basal respiration (BR); metabolic quotient (qCO_2) and microbial quotient (qMIC), according to Silva et al. (2012).

The X-ray computed microtomography method was applied in representatives biogenic and physicogenic aggregates to measure distribution of pore size (Melo et al., 2019).

Results

The percentage of aggregates ranged from 30.47 to 32.57% for biogenic, and from 25.70 to 26.78% for physicogenic types. Intermediate aggregates showed the highest percentages at all depths (41.55 to 42.66%). The biogenic aggregates showed the highest aggregate stability values (MWD = 3.98 to 4.06 mm and GMD = 3.56 to 3.83 mm); whereas the physiogenic aggregates were the least stable, with MWD between 3.19 and 3.32 mm, and GMD between 3.04 and 3.13 mm (Figure 3).

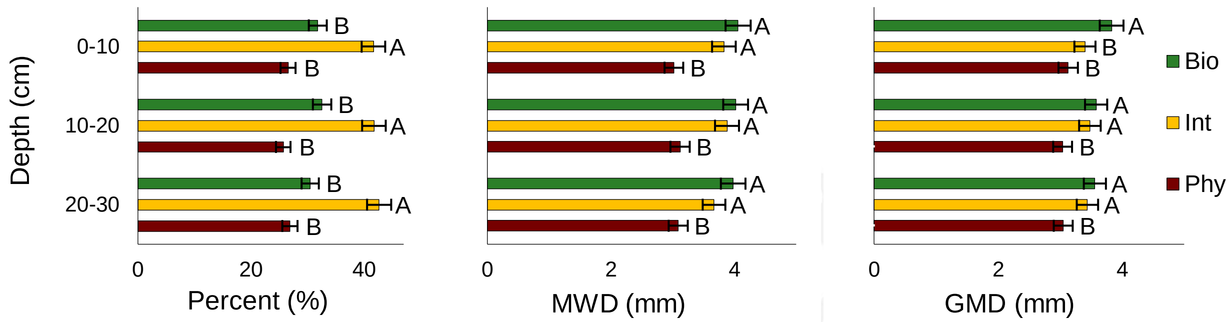

Figure 3. Mean values of soil aggregate fractions, MWD and GMD. *Averages from six replications.

The biogenic aggregates presented highest values of basic cations (Ca, Mg, K), sum of bases (SB), cation exchange capacity (T), base saturation (BS), phosphorus (P) and total organic carbon (TOC) (Table 2) when compared to physicogenic and intermediate types.

Table 2. Chemical attributes of soil aggregates according to the origin types

pH H_2O			Ca			Mg			Na			K			SB		
			cmol$_c$.kg^{-1} soil														
Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio
4,47a	4,47a	4,64a	2,7b	2,5b	3,9a	2,6b	2,6b	2,8a	0,04a	0,04a	0,05a	0,02b	0,02b	0,05a	5,41b	5,41b	6,85a
4,48a	4,43a	4,67a	2,7b	2,7b	4,0a	2,4b	2,6b	3,1a	0,03a	0,04a	0,04a	0,01b	0,01b	0,04a	5,14b	5,30b	7,18a
4,62a	4,57a	4,70a	2,9b	3,1b	4,3a	2,8b	2,7b	3,3a	0,04a	0,04a	0,05a	0,01a	0,01a	0,03a	5,65b	5,95b	6,63a
Al			H+Al			T			BS			P			TOC		
cmol$_c$.kg^{-1} soil									%			mg.kg^{-1}			g.kg^{-1}		
Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio	Phy	Int	Bio
1,8a	1,8a	1,8a	3,3a	3,5a	3,9a	8,68b	8,86b	10,75a	62b	61b	69a	2b	4b	8a	16,6b	17,9b	28,9a
1,7a	1,7a	1,9a	3,0a	3,2a	3,3a	8,09b	8,45b	10,48a	64b	63b	72a	2b	3b	4a	12,4b	13,3b	23,6a
0,2a	0,2a	0,3a	3,2a	3,1a	2,8a	8,85b	9,00b	9,43a	64b	66b	70a	2b	2b	2a	9,2b	10,5b	21,2a

*Averages from six replications. Phy = physicogenic, Int = intermediate, and Bio = biogenic.

When comparing biological properties, the biogenic aggregates present the highest values of C-MB, N-MB and qMIC, and the lowest values of BR and qCO_2 (Figure 4). Higher BR values were observed in the physicogenic and intermediate aggregates, and higher qCO_2 in the physicogenic aggregates.

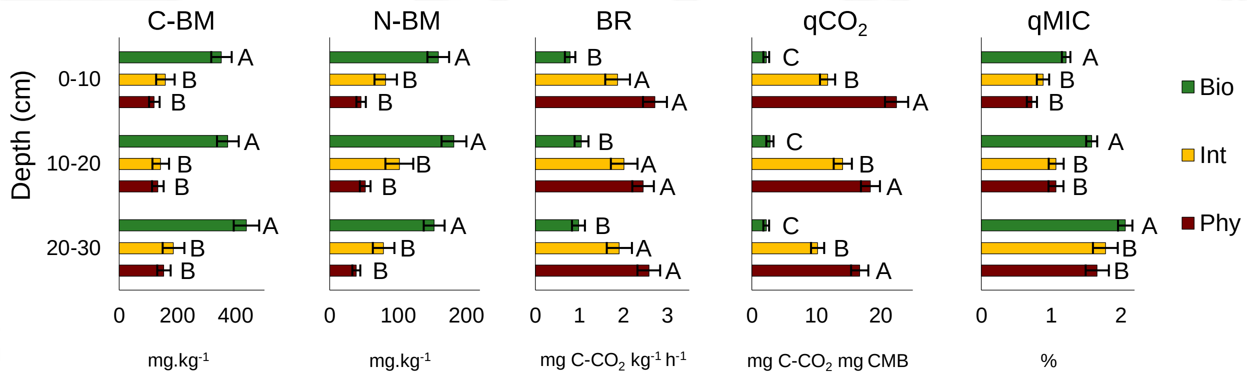

Figure 4. Mean values of soil biological properties. *Averages from six replications

The porosity evaluation using X-ray computed microtomography showed a higher proportion of large pores in the biogenic than for the physicogenic aggregates (Figure 5).

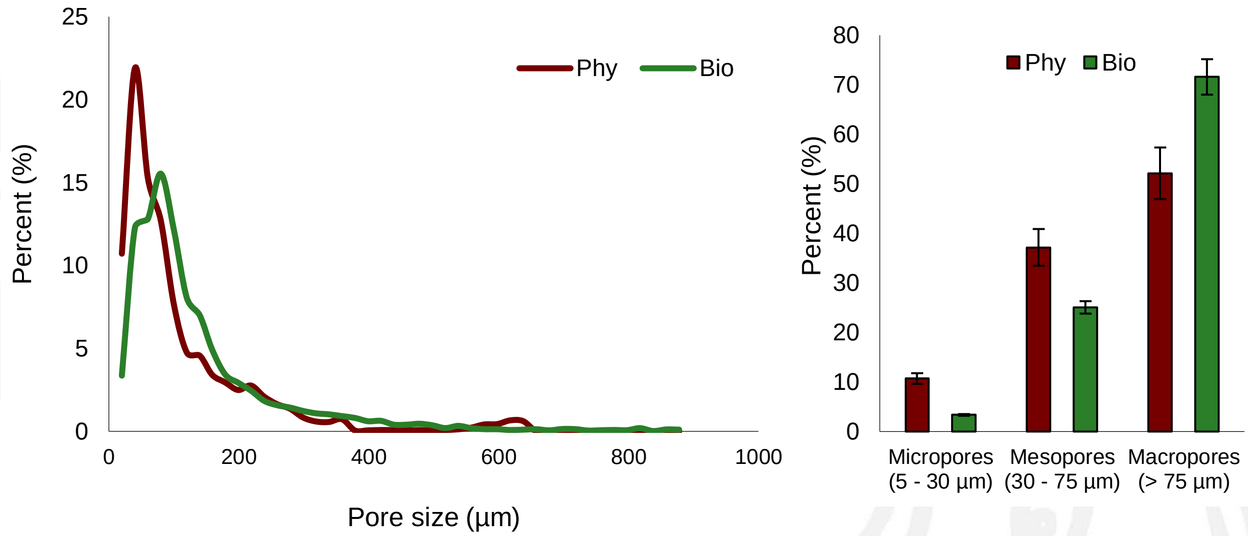

Figure 5. Distribution and mean values of soil aggregates pore sizes.

Discussion

The biogenic formation of soil aggregates represented on average 31.61% of the soil aggregate mass. This shows a relevant contribution of the soil macrofauna (Oligochaeta) and plants (roots) in the aggregate formation. Earthworms move soil particles, ingesting them and forming the biogenic aggregates; they are commonly termed 'ecosystem engineers' (Blouin et al., 2013). Plant roots also move particles forcing the soil particles to come into close contact with each other. Also, they contribute indirectly to soil aggregation through the exudation of polysaccharides and other organic compounds, forming sticky networks that bind together individual soil particles and tiny microaggregates into larger macroaggregates (Six et al., 2004). All these different factors are responsible for binding together the small subunits and giving the higher stability of the biogenic aggregates, as observed from the values of MWD and GMD.

The higher nutrient contents in the biogenic aggregates are associated with their processes of formation. Earthworms accelerate the decomposition of organic materials by increasing the available surface area of organic matter through comminution. When soil and organic materials pass through the earthworm guts, they are ground up physically as well as attacked chemically by the digestive enzymes of the earthworm and the microorganisms inside the gut. After digestion, some organic compounds are released into the environment in the form of small organic compounds and/or mineral nutrients (Blouin et al., 2013).

As for the biological properties, soil structure also creates the habitat for a myriad of soil organisms, consequently driving their diversity and regulating their activity (Rabot et al., 2018). The higher values of C-MB, N-MB, and qMIC found in the biogenic aggregates are associated with the decomposition of organic matter by the earthworms and their effect on nutrient cycling. Models have been used to show the effects of earthworms on the primary production through increased mineralization of organic matter and thus nutrient release (Blouin et al., 2013). Also, the organic matter that is complexed inside the microaggregates becomes inaccessible to the microorganisms and thus is physically more protected from losses (Six et al., 2004).

Aggregate porosity also showed a different pattern between the origin types. In general, the biogenic aggregates presented a higher volume of macropores when compared to the physicogenic aggregates, a result similar to study of Melo et al. (2019). After passing through the earthworm gut, the soil ingested is expelled in the shape of pellets. Most biogenic aggregates are formed by joining these units, thus creating an extensive system of larger pores. This explains the largest amount of macropores observed in the X-ray computed microtomography.

Conclusions

Biological activity undoubtedly contributed significantly to the soil structure quality and soil functions; where the biogenic soil aggregates are more stable, have higher nutrient and organic matter content, thus improving soil biological properties.

The morphological analysis of soil aggregates is a good indicator of soil quality, since it encompasses the biological, physical, and chemical properties. It is a practical, affordable, repeatable, and easily understood and interpreted indicator, which may be used to evaluate if soil conditions are changing according to the adoption of sustainable soil management practices.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, and the Laboratory of Soil Genesis and Classification, Soils Department, UFRRJ.

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