

Correlation between aggregate stability and microbiological activity in two Russian soil types

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Abstract

Two Russian soil type, soddy-podzolic soil from Vladimierskaya region and dark-gray forest soil from Korskya region were taken. Some microbiological parameters were assayed as basal respiration, substrate induced respiration, microbial biomass, microbial metabolic coefficient and correlated with soil aggregate stability concerning soil organic matter, soil texture and soil bulk density. The result shown a positive correlation between all microbiological parameters with soil aggregate stability at this rank, microbial metabolic coefficient > microbial biomass = substrate induced respiration > basal respiration. Microbiological parameters and soil aggregate stability in dark-gray forest soil are greater than soddy-podzolic soil except basal respiration as a result of high organic content in this soil as well as the biomass as a percent of soil total organic matter. aggregate disintegration coefficient of dark-gray forest soil is 0.0028 with R^2 0.927 and need 85 rain drop (equivalent to an energy of 83385 J Kg⁻¹) greater than soddy-podzolic which had disintegration coefficient 0.0039 with R^2 0.849 and needed only 40 rain drop (equivalent to an energy of 39240 J Kg⁻¹).

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Introduction

Microorganisms are the primary agents of aggregate stabilization. Both fungi and bacteria contribute to stabilization of soil aggregates through deposition of extracellular polysaccharides and formation of degraded, aromatic humic materials that form clay-polyvalent metal-organic matter complexes. Though not as persistent, fungi also contribute to aggregate stabilization through hyphal anchoring of particles. The influence of fungi and bacteria on aggregate stabilization varies widely among species and depends considerably on the nature of the available substrates (Aspiras et al. 1971) and on the products of rhizode positions (Reid and Goss, 1981). Furthermore, the type of land-use management can influence both the composition of microbial communities and their contribution to aggregate stabilization (Beare et al. 1994).

Soil microbial biomass is one of the most important soil biological properties. It regulates many critical processes in ecosystems, such as the biophysical integration of organic matter with soil solid, aqueous and gaseous phases. It also becomes vital in regulating the quantity and quality of components in the hydrologic

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cycle and in greenhouse gas emissions. The measurement of microbial biomass is useful for describing biomass turnover in different ecosystems.

Aggregation is a product of interactions of the soil microbial community, mineral and organic components, the composition of the above-ground plant community, and what has happened to the ecosystem in the past (ŽKemper and Koch, 1966; Tisdall and Oades, 1982; Goldberg et al., 1988). In addition to an indirect role in aggregation and soil structure via their contribution to humification, soil microorganisms also act directly. Bacteria and fungi exude colloidal polysaccharides that can glue soil particles. Soil fungi, for example, produce glomalin, which has been demonstrated to represent a high proportion of soil organic matter promoting aggregate formation (Rillig et al. 2002). The mechanical role of microorganisms is also considerable, given their biomass of 40–200 gm⁻² and their hyphal structure (Dighton and Kooistra 1993; Thorn, 1997) that contributes to anchoring soil components to each other. The fungal mycelium has been described as a 'sticky string bag' because it entangles particles within the hyphae network and cements particles together through extracellular polysaccharide production (Oades and Waters, 1991).

Decomposition rates of organic matter (OM) in soil aggregates are reduced compared with OM not associated with aggregates (Besnard et al., 1996; Angers et al., 1997). This has been attributed to factors such as a reduced oxygen diffusion rate within aggregates (Sexstone et al., 1985) and the physical separation of SOM from microflora and fauna (Hattori, 1988).

Soil aggregate stability is the result of complex interactions among biological, chemical, and physical processes in the soil (Tisdall and Oades, 1982). Factors affecting aggregate stability can be grouped as abiotic (clay minerals, sesquioxides, exchangeable cations), biotic (soil organic matter, activities of plant roots, soil fauna and microorganisms), and environmental (soil temperature and moisture) (Chen et al., 1998). The aim of recent scientific work is to determine the most effective microbiological parameters correlated with soil aggregate stability and to link with the soil organic matter.

Material and Method

Bulk soil samples were taken from two Russian soil type soddy-podzolic soil from Vladimskaya region and dark-gray forest soil from Korsky region, soil aggregate in 10 -20 mm diameter are taken for microbiological and physical analysis from previous soils.

Substrate-induced respiration (SIR) method are used to determine microbial biomass C in soils, the theory behind this method is that the initial rate of microbial CO₂ production in response to a soluble energy-yielding substrate would be proportional to the mass of organisms. This method was initially developed to distinguish bacterial and fungal biomass, 100 g (oven-dry weight) are weighted and placed in to bags and treated with 55-60% water holding capacity then incubated at 22 C° for 7 days, 1 g soil from incubated soil putted in vials by five replicates and 0.1 ml of 10% glucose solution were added to each replicates and capped with a septum. Time recorded and incubated at 22 C° for 3 hours, sample the headspace of the vial with a syringe and inject the 1 ml of gas into the Gas Chromatography to determine the ISR, where 1 g soil putted in vials by 5 replicates are incubated for 24 hours at 22 C° without adding glucose solution and measured by same way for basal respiration, five vials are incubated without adding soil and glucose as control (BS) (Anderson and Domsch, 1978; Domsch et al., 1979)

Basal Respiration and Substrate Induced Respiration of soil are calculated:

$$\text{SIR } (\mu\text{g C-CO}_2 / \text{g soil.h}) = (\% \text{ volume CO}_2 \text{ sample} - \% \text{ volume CO}_2 \text{ air}) \cdot V \text{ vial (ml)} \cdot 12 \mu\text{g /mole} \cdot 60 \cdot 10/22 \\ \text{mmole}/\mu\text{l} \cdot m \text{ dry weight} \cdot \Delta t \text{ (minute)}$$

Soil microbial biomass calculated from SIR velocity by this function:

$$\text{C microbial } (\mu\text{g} / \text{g soil}) = (\mu\text{l C-CO}_2 / \text{g soil. h}) \cdot 40,04 + 0,37$$

Microbial Metabolic Coefficient calculated from the relation between basal and substrate induced respiration

$$\text{QR} = \text{BR/SIR}$$

The rate of soil aggregate disintegration were determined by two ways A/ wet sieving technique were used to estimate the rate of soil aggregate disintegration using air dried samples of 4-8 mm in diameter which obtained by sieving, 20 g of oven dried soil aggregate transferred to a sieve having 0.25 mm diameter apertures. The water level was adjusted so that the aggregate on the sieve were just submerged at the highest point of oscillation. The oscillation rates were 40 cycles in minute, the amplitude of the sieving action was 40 mm and the period of sieving ranged from 2- 90 minutes. The weight of soil aggregate retained was monitored after different shaking times (0, 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90 minutes) according to (Yoder, 1936) B/ measuring the energy required for aggregate disintegration using raindrop simulator which consists of 50-ml burette installed at 1-m height to form raindrops of 0.1 ml in volume .the number of simulated raindrops required to disintegrate an individual aggregate 0.50-0.52 g in weight and to pass through the 2.8 mm sieve was recorded. This test is known as counting the number of drop impacts (CND) (Imeson and Vis, 1984) .The particle size distribution analysis was performed by sieving and pipette method and bulk density was determined by clod method as outlined by (Klute,1986). The organic matter was determined by modified Walkley- Black method (Allison, 1965)

Statistical analyses were done by Microsoft Excel Software (2003) to determine the correlation between selected response physical variables and microbiological activity parameters in the soil.

Results and Discussion

The microbiological activity parameters which shown in table 1 are compared between each other's to determine which of them is most correlated with aggregate stability (rate of soil aggregate disintegration) as shown in table 2.

Table 1: Some of microbiological activity parameters (substrate induced respiration, basal respiration, microbial biomass, and microbial metabolic coefficient) in studied soils.

Soil type	SIR	S.D	BR	S.D	Cmic	S.D	QR	S.D
	$\mu\text{g C-CO}_2/\text{g. h}$		$\mu\text{g C-CO}_2/\text{g h}$		$\mu\text{g /g}$			
Dark-gray forest	19.091	± 2.207	1.066	± 0.107	1413	± 163	0.056	± 0.0034
Soddy-podzolic	18.057	± 1.711	1.784	± 0.150	1169	± 111	0.099	± 0.0136

The results are declared that the all microbiological parameters have a positive correlation with aggregate stability however the microbial metabolic coefficient (QR) is more correlated with aggregate stability than the others soil microbiological parameters in both soils, the correlation coefficient is more closed to dark-gray forest soil than the soddy-podzolic soil as a result of high organic content of dark-gray forest soil than soddy-podzolic soil as shown in table 2 and 3. This result is similar to (Machulla, 2003) who reported that the best indicator of the whole metabolic activity of soil microbial populations is soil respiration, a robust parameter that can be rapidly and reproducibly determined. It allows gross comparisons of soils and reflects soil management changes, or the impact of elevated atmospheric CO₂ on soil microorganisms (Machulla 2003).

Table 2: Some of important soil properties related with aggregate stability.

Soil type	Bulk density gm/cm^3	Particle size distribution g.Kg^{-1}			O.M Texture g.Kg^{-1}	Biomass as a percent of soil organic C	Kinetic Energy J Kg^{-1}	No.of rain drop	Rate of soil aggregate disintegration g.min^{-1}	
		Clay	Silt	Sand						
Dark-gray forest	1.248	266	605	129	SiL	62.1	3.92	83385	85	0.003
Soddy-podzolic	1.255	251	645	104	SiL	43.8	4.60	39240	40	0.002

While the soil biomass (microbial carbon) Cmic $\mu\text{g/g}$ soil and Induced soil respiration SIR $\mu\text{g C-CO}_2/\text{g}$ soil h are seemed to be in the second of rank and have approximately the same level of correlation with soil

aggregate stability as shown in table 3 because the varying degrees of correlation between aggregation and microbial biomass or microbial products are related to: (1) the different scales (i.e. macro versus microaggregate scale) of influence of fungi versus bacteria; (2) soil texture; and (3) soil mineralogy. The link between microorganisms and aggregation is pertinent, microbial biomass and water-extractable carbohydrates have been correlated to varying degrees with aggregation (Degens, 1997)

Table 3: Correlation coefficient between microbiological activity parameters and the rate of soil aggregate disintegration

Soil type	SIR $\mu\text{g C-CO}_2 / \text{g} \cdot \text{h}$	BR $\mu\text{g C-CO}_2 / \text{g} \cdot \text{h}$	C.mic $\mu\text{g} / \text{g}$	QR
Dark-gray forest	0.25853	0.10268	0.258442	0.44525
Soddy-podzolic	0.102921	0.26096	0.10268	0.30636

The different organic fractions contribute to aggregate stabilization, including microbial biomass in particular fungi (Degens, 1997), microbial-derived polysaccharides (Haynes and Francis, 1993), humic substances (Piccolo and Mbagwu, 1999), and lipids (Dinel et al., 1991).

The basal respiration in soddy-podzolic soil has a greater positive correlation with aggregate stability than dark-gray forest soil which may be the result of that this soil contain high amount of microbial carbon (biomass) as a percent of total organic carbon in soil as shown in table (2) as reported that soil microbial biomass responds much more quickly than most other soil fractions to changing environmental conditions, such as variations in substrate input (Powlson et al. 1987) Linked parameters (e.g., biomass-specific respiration or biomass as a percentage of soil organic C) are also useful because they possess “internal controls” (Barajas Aceves et al. 1999).

The two soils particularly have the same texture with little amount of clay and high amount of silt and have the same bulk density as shown in table (1) and (2) so the major role here for binding soil aggregate are the SOM and microbiological activity which explain the high correlation coefficient with microbiological parameters in dark-gray soil which contain high amount of SOM than soddy-podzolic, as reported that the contribution of soil microorganisms to aggregation is most apparent in soils of lower clay content and low shrink-swell capacities, where the abiotic effects of wet-dry and freeze-thaw cycles are reduced (Oades 1993).

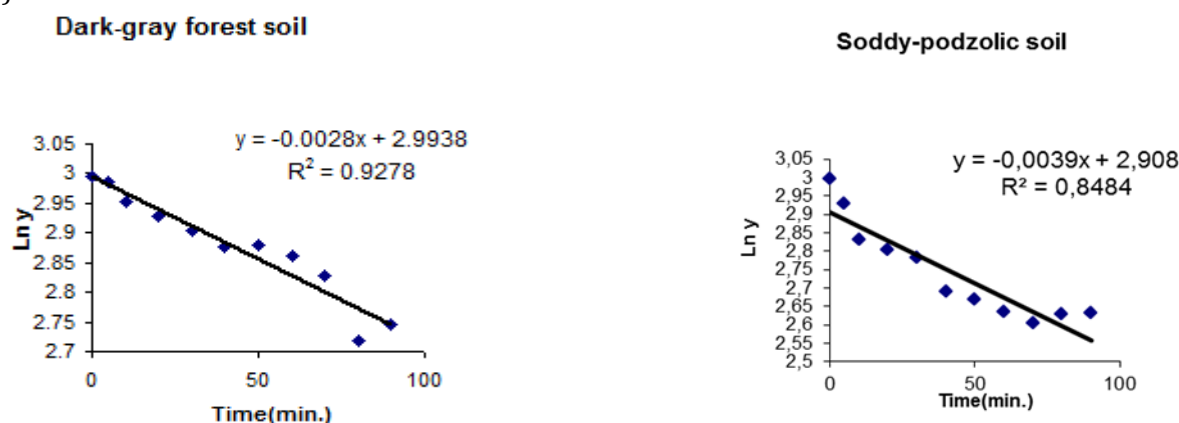


Figure 1. Change in soil mass of aggregate retained on 0.25mm sieve over time due to shaking during wet sieving

In fig 1 presents the mass of soil aggregates retained on 0.25 mm sieve as a function of shaking time in minutes for two soils from two locations. The soils from each location encompassed two different land use cropland and forestland. It can be noticed from these figure that there was a continuous decrease in mass of soil retained on the 0.25mm sieve over the entire range of shaking time which lasted 100 minutes. Further, it can be observed that the majority of disintegration occurred gradually during the whole time of sieving due to the resistance to break down upon wetting, however the dark-gray forest soil shown greater resistance against resistance as a result of high SOM content. Figure 1 also reveals that the slope of straight line (coefficient of determination) ranged from as low as 0.0028 for the dark-gray forest soil for Vladimerskaya region to as high as 0.0039 soddy-podzolic soil in Korskya region due to the same reason.

Water drop impact test as illustrated in table 2 exhibits the number of drop impacts required to disrupt the aggregate sufficiently for it to pass through the 2.8mm sieve and kinetic energy required to break up the aggregate. Dark-gray forest soil need 85 rain drop (equivalent to an energy of 83385 J Kg⁻¹) greater than soddy-podzolic more than twice which needed only 40 rain drop (equivalent to an energy of 39240 J Kg⁻¹), close examination of this data reveal that the resistance of aggregates to disruption by rain drop was mainly related to soil organic matter content. [Canton et al. \(2009\)](#) found a significant correlation between the number of drop impacts and soil organic matter content under wet conditions.

Conclusion

Soil aggregate stability is more governed by SOM than microbiological activities in the soils which have a proportional same texture and bulk density. All microbiological activity parameters have a positive relation with aggregate stability in both dark-gray forest and soddy-podzolic soil. Microbial metabolic coefficient which is a proportion between soil basal respiration and substrate induced soil respiration considered a good index to determine the soil aggregate stability which is directly proportional to the decrease in QR values. While the biomass-specific respiration or biomass as a percentage of soil organic C is inversely proportional with aggregate stability. Water drop impact test gives is more proper, simple and gives distinct clear result than the wet sieving technique to determine the aggregate stability in soils particularly have high SOM.

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