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Stability of soil aggregates in Latosols and Cambisols via standard method and sonification

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The results of determining the stability of aggregates in water are sometimes contrasting, and do not permit a definition of the energy level or force involved in this analysis. The objective of this study was to compare two methods to determine the geometric mean diameter (GMD) and the percentage of aggregates > 2 mm in Latosol and Cambisol submitted to management under coffee. To conduct this study we collected soil blocks with preserved structure at the following depths, having gypsum as the soil surface reference: Hilled layer (soil above the gypsum layer) and depths of 0.0-0.20 m and 0.20-0.40 m below the gypsum line, with three repetitions, in two soil classes: Latosol and Cambisol. The aggregate stability was determined via wet sieving (standard method) and sonification. For the sonification, 5 g of aggregate were subjected to increasing levels of ultrasonic energy, 2.2, 6.4, 12.8 and 25.5 J mL^{-1}. After sonification at each energy level, samples were passed through the same set of sieves used in the standard method. Geometric mean diameter of the aggregates and the percentage of aggregates > 2 mm was calculated. The data were submitted to variance analysis and the averages were compared by the Scott-Knott test ($p < 0.05$). In Cambisol, the GMD and percentage of aggregates > 2.0 mm were higher when these aggregation indices were determined by the standard method, and sonification demonstrated a difference in depth regarding aggregate stability, the 0.20 to 0.40 m depth being more susceptible to breakdown. sonification methods S15 and S30, which respectively correspond to ultrasonic energy levels 6.4 and 12.8 J mL^{-1}, were more sensitive in detecting differences in depth in the GMD aggregation index of the soil used.

Key words: Ultrasonic energy, wet sieving, aggregation.

INTRODUCTION

In general, in research laboratories the measurement of aggregate stability of a soil aims to reproduce some mechanism that causes the breakdown of these aggregates, and then evaluates their resistance degree. There are at least four mechanisms responsible for soil aggregate breakdown: 1- hydration processes: In which

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breakdown would occur by compression of the air entrapped within the aggregate due to the sudden entry of water; 2- breakdown by raindrop impact; 3- microcracks during wetting and drying cycles; 4- dispersion by physicochemical processes (Le Bissonnais, 1996; Amezketa, 1999). Thus there are different methods to measure the aggregate stability of a soil, but all simulate a single mechanism (Beare and Bruce, 1993).

The wet sieving (WS) of Yoder (1936) is considered the standard recommended procedure to determine the aggregate stability for all soil types, and it has been used as a predictor of water erosion effects on soil structure for many years. However, this method has some limitations, such as the lack of standardization in the water content of the aggregates under analysis, and even regarding the pre-wetting procedures (Castro et al., 1998).

Nevertheless, this method requires control of the aggregate wetting, in order to better manage hydration energy with the slow expulsion of air trapped inside the aggregates, since these are the forces responsible for aggregate breakdown in the weakness zones. It is noted that the slower the aggregate moistening speed, the lower the disintegrating effects generated by the saturation of the samples by the occupation of the water within the voids. The pressure buildup within the matrix is lower and, consequently, the clay expansion rate is reduced and lower still is the aggregates breakdown rate (Lado et al., 2004).

Moreover, according to Castro et al. (1998), direct immersion of the air-dried aggregates in water simulates the soil disintegration under natural flood conditions (Kemper and Chepil, 1965) and pre-wetting of the aggregates allows for wetting by capillary action, improving simulation of field conditions during rain, when considering that a flood is formed gradually and only an initial water depth flows slowly towards the slope.

On the other hand, the ultrasound or sonification method is based on the phenomenon of cavitation (Chen and Zhu, 2011), where ultrasonic waves are irradiated in a suspension of water and soil aggregates. This phenomenon only occurs if the acoustics of the ultrasound pressure is enough to stimulate cavitation (Mayer et al., 2002), which is characterized by the formation, growth and implosion of air bubbles in the suspension (Pilli et al., 2011), responsible for disintegration of the soil material (Norte, 1976).

The main advantage of sonification is in the control of the energy level used to promote the breakdown of aggregates, allowing comparison of the results obtained in different soil types (Raine and So, 1993, 1994). However, several experimental conditions may influence the results: (I) The output energy can be different from the actual energy applied, which leads to the previous calibration of the actual power emitted (Sá et al., 2000); (II) The immersion depth and geometric shape of the ultrasonic probe can interfere with the energy spread (Mayer et al., 2002; Schmidt et al., 1999), and the deeper the probe, the higher the energy distribution in the medium, and as such, the immersion depth of the rod should be the same for all samples; (ii) The water:aggregate ratio affects the effectiveness of the ultrasonic energy dispersion, due to the water:aggregate proportion being identical in the analyzes (Schomakers et al, 2011.); (iii) The cavitation phenomenon is reduced, the temperature of the soil suspension exceeds 40°C (Roscoe et al., 2000), thus the temperature during the test procedure must be monitored and the equipment always cooled when reaching this temperature; (iv) The probe vibration amplitude is influenced by the polishing state of the tip, therefore, the tips must be replaced when worn (Mayer et al., 2002).

Although with distinct analytical principles, both methods, wet sieving and sonification, allow to obtain soil aggregation indices such as geometric mean diameter (GMD) and percentage of aggregates > 2 mm (Kemper and Chepil, 1965). Therefore, this study aimed to compare the methods for determining these aggregation indices in a Latosol and Cambisol in a coffee (*Coffea arabica* L.) plantation.

MATERIALS AND METHODS

Description of the study area and soil sampling

The soil samples were collected in areas of five-year-old commercial coffee field, implanted under a conservationist soil management system that has been used in the cities of São Roque de Minas and Vargem Bonita in the upper São Francisco river basin, Minas Gerais, Brazil (Serafim et al., 2013). The climate is Cwa, according to the Köppen classification, with average annual rainfall of 1,344 mm, and a well-defined dry season from May to September (Menegasse et al., 2002).

We sampled two crops: Both stands are ca. two hectare in size and rectangular in shape. The soils of these areas originating from pelitic rocks (siltstones of the Canastra formation) were classified according to the Brazilian Classification System (Embrapa, 2013), as dystrophic Red Latosol and typic dystrophic Tb Haplic Cambisol. Physical and chemical characterization of the soils were conducted and the calculation of kaolinite and gibbsite content (Table 1) carried out by means of stoichiometric ratios derived from their ideal chemical formulas as proposed by Resende et al. (1987).

The same conservation soil management system was used in both soil classes. This system employs the use of soil and water conservation practices that seek to improve or maintain physical quality in different soil classes. To implement the primary soil tillage (plowing + two diskings) in the total area, dolomitic limestone (4 Mg ha^{-1}) and gypsum (1.92 Mg ha^{-1}) incorporated up to 0.20 m deep were applied. Subsequently, the planting furrows were opened to a depth of 0.60 and 0.50 m wide, by means of a subsoiler coupled to a fertilizer spreader that allows, besides furrow opening, soil mixing and homogenization of lime and fertilizer to the depth of 0.40 m (2 kg gypsum m^{-1} and formula 08-44-00 + 1.5% Zn and 0.5% B). Three months after the planting of the coffee seedlings, which is held in the first half of November, 7 kg m^{-1} of agricultural gypsum was surface-applied distributed along the row (Serafim et al., 2011; Serafim et al., 2013).

Thereafter, the application of gypsum is performed via the hiling process in the crop row. In this practice, brachiaria that was established before the coffee planting, after reaching 50 cm, is

Table 1. Physical, chemical and mineralogical characterisation of the diagnostic horizons “Bi” and “Bw” of the typic dystrophic Tb Haplic Cambisol and dystrophic Red Latosol, respectively.

Horizon/Prof	Clay	Silt	Sand	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	Ki(1)	Kr	Ct(2)	Gb(3)
m				g kg^{-1}						%	
Bi (0.1-0.31)	518	432	50	233	285	122	1.1	1.45	1.14	50.08	13.29
Bw (0.65-1.23)	848	118	32	127	364	158	1.2	0.59	0.46	27.29	39.16

(1) Index weathering; (2) Ct, kaolinite; (3)Gb, gibbsite. Ki, SiO_2: Al_2O_3 molecular ratio, Kr: SiO_2, (Al_2O_3 + Fe_2O_3) molecular ratio. Fonte: Carducci et al. (2014) and Serafim (2011).

barred to 10 cm and the resulting plant material mixed in the soil is applied around the coffee trunk. Thus, the soil piled up along the crop row covers all the gypsum applied to the surface, forming a layer of 0.5 m of soil mixed with brachiaria waste from the interrows. This hilling over the gypsum reduces its solubilization rate, allowing a gradual release of the calcium sulfate throughout the years (Serafim, 2011).

The chemical characterization of the soil before and after five years of management system implementation is in Table 2.

To conduct this study blocks of soil (0.15 m × 0.10 m × 0.05 m) were collected in the hilled layer, in addition to the 0.20-0.40 and 0.0 to 0.20 m depths, in three repetitions, in both soil classes.

It is highlighted that the hilled layer was chosen for evaluation as it contributes to the increase of soil organic matter on the soil surface and this may promote the aggregation of mineral particles as observed by Silva et al. (2013). The layers of 0.0-0.20 m and 0.20-0.40 m are located in a row below the gypsum line that was applied to the surface, so the aggregation of these layers can be influenced by the gypsum.

Subsequently, the blocks were gently broken down and sieved manually through sets of sieves at intervals of 4.76 to 8 mm mesh widths, wherein the aggregates retained in the 4 mm sieve were packaged in open plastic containers to be air-dried and used for the physical analyzes.

Wet sieving method

25 g of aggregates were weighed with 4.76 to 8 mm of diameter. These were placed on filter paper and put into a tray with a thin layer of distilled water for pre-wetting for 12 h. The wet sieving of the samples was then performed using of a set of sieves of 2.00, 1.00, 0.50, 0.25 and 0.105 mm in diameter, as described in Yoder (1936). The aggregates were agitated in the equipment with an oscillating movement of 32 rpm (revolutions per minute) for 15 min. Portions of aggregates retained in each sieve were transferred to aluminum containers with the aid of water jets and dried in an oven at 105 to 110°C for 24 h with subsequent weighing and obtaining of moisture content and aggregation indices, as described by Kemper and Chepil (1965): (1) Percentage of aggregates larger than 2 mm; and (2) Geometric mean diameter (GMD).

Sonification methods

5 g of aggregates were used (dry weight, oven-dried at 105°C) and placed on a base with adjustable inclination (45°C) with the aid of a volumetric burette and subjected to slow pre-wetting by drip. The pre-moistened aggregates were then transferred to a 200 mL beaker, where the final volume of the beaker was completed with distilled water (soil:distilled water 1:40).

Sonifications were carried out with a Qsonica Q500 apparatus operating at 20 kHz, whose output was calibrated by the method described in Sá et al. (2000), for 5, 15, 30 and 60 s. In this work, the sonification times will be refered to as S5, S15, S30 and S60

The material sonification exposure times correspond to specific energies applied (EA) of 2.2, 6.4, 12.8 and 25.5 J mL^{-1}, respectively, calculated from Sá et al. (2000) according to Equation 1:

$$E = \frac{P * T}{V} \qquad (1)$$

Where: EA is the energy applied to the suspension (J mL^{-1}); P is the power emitted by the apparatus (85 kW) obtained by means of calibration described in Sa et al. (2000); T is the sonification time (seconds) and v is the suspension volume (mL).

We highlight that the shaft of the apparatus was introduced in the beaker with the sample (aggregate + water) to a depth of 20 mm and the temperature was controlled during the tests remaining at 35°C.

After sonification at each of the energies (one sample per energy level) the samples were passed through a series of sieves (2.00, 1.00, 0.50, 0.25 and 0.105 mm) equivalent to the standard method, and then GMD indices and percentage of aggregates larger than 2 mm were calculated for each sonification time, based on the initial sample.

Statistical analysis

The experimental design was completely randomized in a factorial arrangement (2 × 3 × 5), as follows: 2 soils (LVd and CXbd), 3 soil layers (hilled layer; 0.0 - 0.20 and 0.20 - 0.40 m) and 5 methods (WS, S5, S15, S30 and S60). The data were submitted to the Shapiro-Wilk normality test and then the analysis of variance. When significant, data were compared using the mean test of Scott-Knott at a significance level of 5% probability with the aid of the Sisvar program (Ferreira, 2011). Correlation analyzes were performed using the R and Sigma programs.

RESULTS AND DISCUSSION

For Latosol, that has a strong microgranular structure largely favored by its oxidic mineralogy (Table 1), it became clear that a lot of energy would be necessary to breakdown the aggregates, in both methods (Table 3), independent of depth evaluated, to determine the aggregation indices; the opposite of that in Cambisol that has a kaolinitic mineralogy (Table 1), and therefore low aggregate resistance when wet (Ferreira et al., 1999).

Thus, for Cambisol, we found significant differences

Table 2. Chemical characterization of Cambisol and Latosol before and after five years of coffee emplantation.

Soil	**Before planting**		**After five years from planting**		
	Soil layers (m)				
	0.0-0.20 m	**0.20-0.40 m**	**hilled**	**0.0-0.20 m**	**0.20-0.40 m**
Cambisol	4.9	5.2	3.8	4.23	4.57
Latosol	4.4	4.7	4	4.23	4.33
			K^+ (mg dm^{-3})		
Cambisol	162.6	41.3	100.67	206	104.67
Latosol	73.33	38.67	84.67	37.33	35.33
			P (mg dm^{-3})		
Cambisol	1.71	0.65	18.25	7.58	0.75
Latosol	1.91	1.13	10.65	3.74	3.22
			Ca^{2+} (cmol$_c$ dm^{-3})		
Cambisol	0.5	0.1	6.23	4.33	2.3
Latosol	0.1	0.1	3.5	5.73	4.8
			Mg^{2+}(cmol$_c$ dm^{-3})		
Cambisol	0.47	0.1	0.1	0.2	0.1
Latosol	0.1	0.1	0.1	0.1	0.2
			Al^{3+} (cmol$_c$ dm^{-3})		
Cambisol	1.4	1.37	2.3	0.77	0.63
Latosol	1.37	0.87	2.63	1.5	1.13
			H+Al (cmol$_c$ dm^{-3})		
Cambisol	7.87	4.87	13.24	8.8	4.7
Latosol	9.83	7.87	15.39	11.46	10.22
			SB(cmol$_c$ dm^{-3})		
Cambisol	1.38	0.3	6.59	5.06	2.67
Latosol	0.38	0.3	3.82	5.93	5.09
			t (cmol$_c$ dm^{-3})		
Cambisol	2.78	1.67	8.89	5.83	3.3
Latosol	1.75	1.17	6.45	7.43	6.22
			T(cmol$_c$ dm^{-3})		
Cambisol	9.25	5.18	19.83	13.86	7.37
Latosol	10.21	8.17	19.21	17.39	15.31
			V (%)		
Cambisol	14.95	5.93	31.97	36.41	36.25
Latosol	3.8	3.66	19.76	34.24	33.27
			m (%)		
Cambisol	50.31	81.82	28.41	12.95	19.17
Latosol	78.08	74.23	41.17	20.2	18.24
			SOM (%)		
Cambisol	3.89	1	3.18	3.56	1.29
Latosol	3.89	2.96	3.7	3.32	3.24
			P-REM (mg L^{-1})		
Cambisol	12.95	5.26	10.5	11.54	5.3
Latosol	6.42	4.76	5.48	5.32	5.26

SB, Sum of bases; t, effective cation exchange capacity; T, cation exchange capacity at pH7; V, base saturation; m, aluminum saturation; SOM, soil organic matter; P-REM, remaining phosphorus. Source: The authors.

between the WS (WS) and the S15 to S60 energies applied (Table 3). The aggregates of this soil disintegrated under these applied energies. There was a significant reduction of aggregates larger than 2 mm, decreased geometric diameter (Table 3), increased percentage of aggregates retained in smaller diameters

Table 3. Aggregate stability indexes, aggregate class > 2 mm and geometric mean diameter in Latossolo and Cambisol submitted to the standard method (wet sieving -WS) and the modern method (sonification- S5, S15, S30, S60) at different depths.

Soil	Aggregate stability determination methods				
	WS	**S5**	**S15**	**S30**	**S60**
			% of aggregates > 2.00 mm		
Cambisol	$97^{A\alpha}$	$87^{A\beta}$	$85^{A\beta}$	$79^{A\beta}$	$70^{A\beta}$
Latosol	$98^{A\alpha}$	$87^{A\beta}$	$84^{A\beta}$	$80^{A\beta}$	$69^{A\gamma}$
			0.0-0.20 m		
Cambisol	$96^{A\alpha}$	$73^{A\beta}$	$57^{B\gamma}$	$57^{B\gamma}$	$34^{B\delta}$
Latosol	$90^{A\alpha}$	$81^{A\alpha}$	$70^{A\beta}$	$66^{B\beta}$	$53^{B\gamma}$
			0.20-0.40 m		
Cambisol	$89^{A\alpha}$	$30^{B\beta}$	$29^{C\beta}$	$17^{C\beta}$	$3^{C\gamma}$
Latosol	$86^{A\alpha}$	$90^{A\alpha}$	$88^{A\alpha}$	$87^{A\alpha}$	$77^{B\beta}$
			Geometric mean diameter (mm)		
			Hilled layer		
Cambisol	$4.7^{A\alpha}$	$3.0^{A\beta}$	$3.2^{A\beta}$	$2.6^{A\beta}$	$1.7^{A\gamma}$
Latosol	$4.8^{A\alpha}$	$3.6^{A\beta}$	$3.2^{B\beta}$	$2.8^{B\beta}$	$1.9^{A\gamma}$
			0.0-0.20m		
Cambisol	$4.6^{A\alpha}$	$2.0^{B\beta}$	$1.1^{B\gamma}$	$1.0^{B\gamma}$	$0.33^{B\delta}$
Latosol	$4.6^{B\alpha}$	$3.0^{A\beta}$	$2.1^{C\gamma}$	$1.8^{C\gamma}$	$1.2^{A\delta}$
			0.20-0.40m		
Cambisol	$3.8^{B\alpha}$	$0.7^{C\beta}$	$0.4^{C\beta}$	$0.18^{C\beta}$	$0.07^{B\beta}$
Latosol	$4.2^{B\alpha}$	$3.6^{A\alpha}$	$3.6^{A\alpha}$	$3.5^{A\alpha}$	$1.6^{A\beta}$

Means followed by the same letter do not differ by the Scott-Knott test ($p < 0.05$): Greek letters compare methods within each depth (within each soil) and uppercase compare the depths of the same soil.

classes (< 0.105 mm) (Figure 1).

The highest breakdown resistance of Cambisol in both the WS as well as at the lowest power, especially within the first depth (hilled layer and from 0.0 to 0.20 m) may be due to the soil management effects, that favored high organic matter and calcium content in that depth region (Table 2). As already pointed out, in this management system, Brachiaria grown in the rows is managed through periodic cuts with subsequent distribution of residue near the coffee plants in the crop row (Serafim et al., 2011; Silva et al., 2013). Thus, the decomposition of plant residue, on releasing low molecular weight organic acids capable of forming organic complexes with aluminum, calcium and magnesium, has positive effects on aggregation, favoring the formation of macroaggregates in the surface layers (Amaral et al., 2004).

Calcium is a crucial element for the stabilization of soil organic matter and aggregates through its role in the formation of complexes with clay and organic matter via the cation bridge (Matkin and Smart, 1987; Muneer and Oades, 1989; Six et al., 2004; Bronick and Lal, 2005). This bond is a way to stabilize and increase the carbon residence time in the soil, due to the physical protection derived from the formation of microaggregates (Edwards and Bremner, 1967; Six et al., 2004; Bayer et al., 2011). Thus, it is suggested that the higher organic matter content found in the management systems with high gypsum doses, such as that studied here (Table 2), are related to higher Ca^{2+} content and that the calcium and organic matter interaction favor improvements in soil aggregation properties (Silva et al., 2013).

In Latosol there was a macroaggregate reduction and a more homogenous redistribution of aggregates in the other size classes (Figure 1). In the 0.20 to 0.40 m depth of this soil it was found that the sonification methods S5, S15 and S30 used promoted the same breakdown as prmoted by the WS (Table 3), confirming that low energy levels (2.2 to 12.8 J mL^{-1}) are insufficient to rupture the aggregates of very weathered soils rich in iron and aluminum oxides (Vitorino et al., 2003; Indiá Júnior et al., 2007; Silva et al., 2015).

Sá et al. (1999) found that in the A horizon of a distroferric Red Latosol total dispersion occurred at an energy level near 476.53 J mL^{-1}, while in Horizon A the aggregates of a Red Nitosol reached the maximum dispersion at an energy level near 238.27 mL^{-1}, which proves the greater aggregate stability of Latosols. Silva et al. (2015) studying the dispersion of oxidic soils derived from volcanic ash from Hawaii observed that for more weathered soils, like the Latosols of the present study, rich in carbon, aluminum oxides and crystalline and non-crystalline iron, and positively charged, power levels of approximately 1600 J mL^{-1} are required to cause total dispersion.

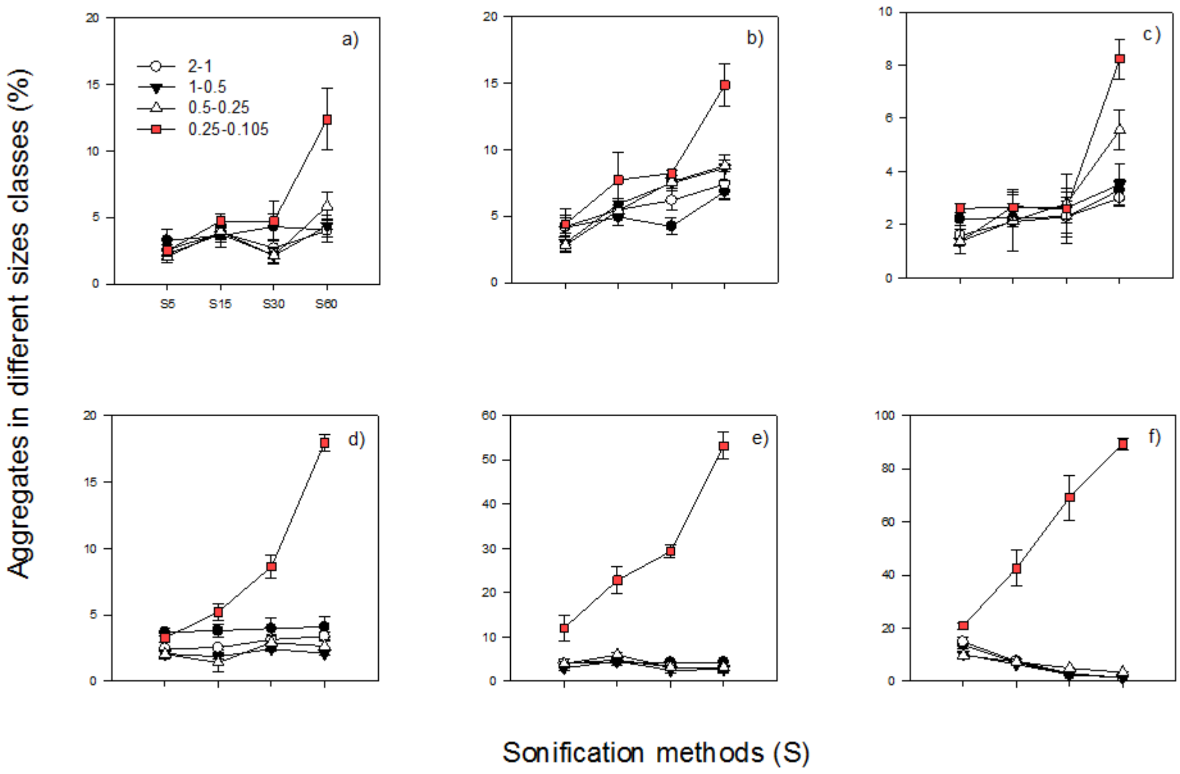

Figure 1. Aggregates distribution in different size classes obtained by the sonification method for the following soil layers: Hilled layer, from 0.0 to 0.20 and 0.20-0.40 m for Red Latosol (a, b, c) and a Cambisol (d, e, f), respectively.

Particularly at a depth of 0.20 to 0.40 m in Cambisol, which coincides with the Bi horizon where the organic matter content is reduced (Table 2), the sonification promoted strong breakdown even at lower energy levels (Table 3 and Figure 1). It should be noted that this horizon presents a weak structure, combined with high silt content (Table 1) which makes this soil more likely to breakdown (Ribeiro et al., 2009). The energy applied of 25.5 J mL^{-1} (U60), for example, left the soil completely dispersed, thus not being a good choice in the evaluation of the stability of these aggregates (North, 1979; Tippkötter, 1994). This value is much lower than those found by Sá et al. (1999), that is, energy higher than 127 J mL^{-1} leads fragile soils, like Cambisols, to total dispersion.

Ribeiro et al. (2009) also observed that due to low structure and low organic matter content, the maximum dispersion of aggregates in Horizons Bi and C of Haplic Cambisol typical tb was achieved with the application of only 9.4 J mL^{-1}. These findings highlight the need for more detailed studies with the lowest possible energy levels to improve understanding of the flocculation-dispersion phenomena in young soils.

The results of GMD for the Latosol profile showed that the S15 and S30 methods, which correspond, respectively, to the energy levels 6.4 and 12.8 J mL^{-1}, detected the soil management and mineralogy influences on the aggregation. At these energy levels a higher GMD at the 0.20 to 0.40 m depth was observed, followed by the hilled layer, and finally the of 0.0 0.20 m depth (Table 3).

This fact may be related to the primary importance of mineralogy and secondary importance of organic matter in the aggregation processes of very weathered soils (Silva et al., 2015), since it is observed that a higher correlation coefficient (r = 0.71, P <0.001) was found between GDM and soil organic matter when the aggregation rate was determined by the S5 sonification method (Figure 2), that is, organic bonds are ruptured with ease at the first energy levels applied, and aggregate stability would possibly be maintained via more resistant bonds (covalent) from the minerals.

These results agree with those of Inda Junior et al. (2007), who when evaluating the organomineral complex stability in Brazilian tropical soils, found that the sonification energy required for complete dispersion of soils is related to clay mineralogy, particularly the levels of low crystalline iron oxide (hematite, goethite, maghemite, lepidocrocite and ferrihidrita) and kaolinite, and gibbsite ratios. Organomineral complexes and non-crystalline aluminum oxides (gibbsite) increase the aggregate stability, requiring application of higher energy levels to soils rich in these elements when using ultrasonic energy (Asano and Wagai, 2014; Candan and

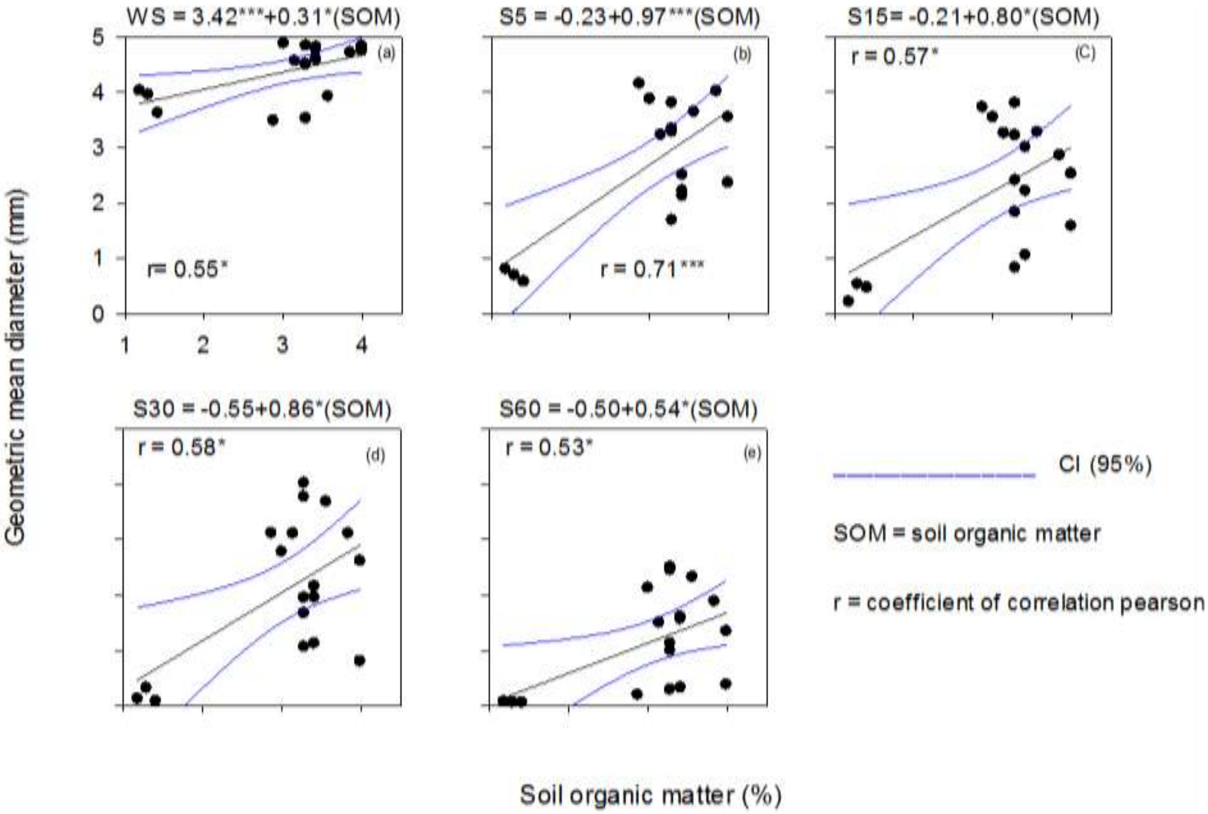

Figure 2. Correlations between soil organic matter content and geometric mean of aggregate diameters, obtained by different stability methods. WS (a) = Wet sieving method; S = Sonification methods: S5 (b), S15 (c), S30 (d) and S60 (e), respectively correspond to energy levels of 2.2, 6.4, 12.8 and 25.5 J mL^{-1}. IC = confidence interval. The whole database was considered.

Broquen, 2009; Igwe et al., 2013; Silva et al., 2015).

For each soil type, correlations were made between the GMD obtained by the WS and sonification (Figures 3 and 4). In general, in Cambisol high correlation coefficients were found between the methods (Figure 3), which indicates that there may be, for this soil class, a relationship between the ultrasonic energy levels and the energy applied by the WS.

In the Cambisol it was observed that the correlation coefficients of the equations decrease with the increase of the applied energy level, which is consistent since high energy levels tend to completely disintegrate the aggregates of this soil class (Table 3 and Figure 1) (Ribeiro et al., 2009).

Sá et al. (2000b) evaluated the stability of aggregates in the A horizon of a Red Nitosol and found that sonification energy levels from 1.32 to 15.8 J mL^{-1} were equivalent to the energy imposed by the WS, however, when assessing the aggregate stability of the Bt horizon of this soil class no relationship was observed between the sonification and the WS, especially by the fact that low ultrasonic energy levels were sufficient to cause a strong breakdown of soil, while in the WS, aggregates remained stable.

For the aggregates of the A horizon of a distroferric Red Latosol, Sá et al. (2000b) observed the GMD, average weight diameter and aggregate class > 2 mm, and the ultrasonic energy of 1.32 J mL^{-1} promoted the same breakdown as the WS. In our study, in Latosol, by the GMD and aggregates retained in the class > 2 mm (Table 3), we observed that only in the 0.20 - 0.40 m layer did the WS promote the same breakdown as sonification methods S5, S15 and S30 (2.2, 6.4 and 12.8 J mL^{-1}) and only by the results of aggregates retained in the > 2 mm class were the methods equivalent in the 0.0 to 0.20 m layer, wherein the WS promoted the same breakdown as the S5 sonification method.

Furthermore, for Latossol positive relationships were not found between the GMD results obtained by WS and sonification (Figure 4) at low energy levels (up to S30 = 12.8 J mL^{-1}), possibly because the energy band used to promote the soil breakdown was not enough to disperse the microaggregates of this very weathered soil (Table 1).

It was found that at the energy level of 25.5 J mL^{-1} (S60), the correlation coefficient (r = 0.11) becomes positive, confirming, for Latosol, that there is a relationship between the methods at higher energy levels (Figure 4). In dispersion curve analysis, seeking to verify

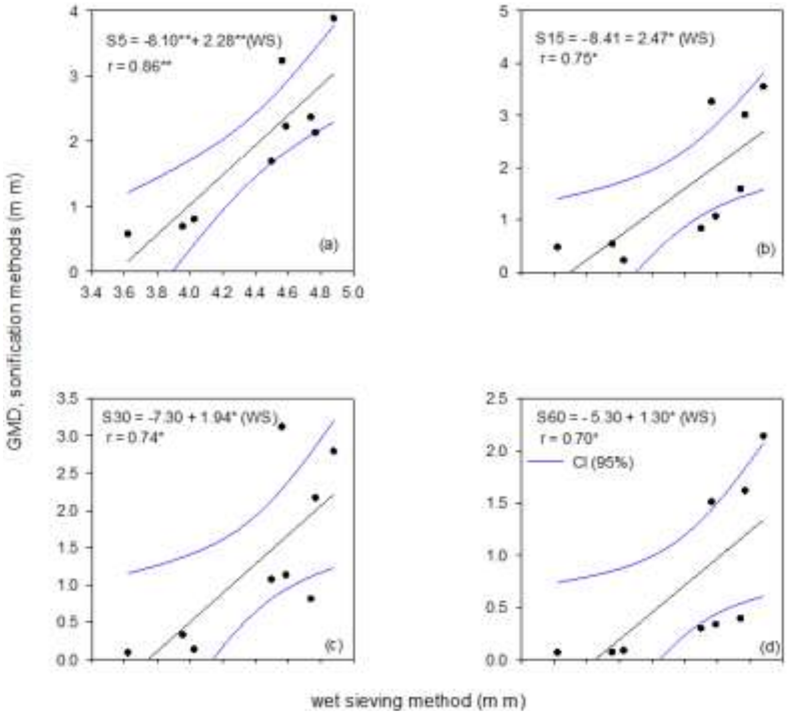

Figure 3. Correlation of geometric mean of aggregate diameters (GMD) between wet sieving (WS) and sonification methods (S) in Cambisol. S5 (a), S15 (b), S30 (c) and S60 (d), respectively correspond to energy levels of 2.2; 6.4; 12.8 and 25.5 J mL^{-1}. IC = confidence interval.* P < 0.05; ** p < 0.01.

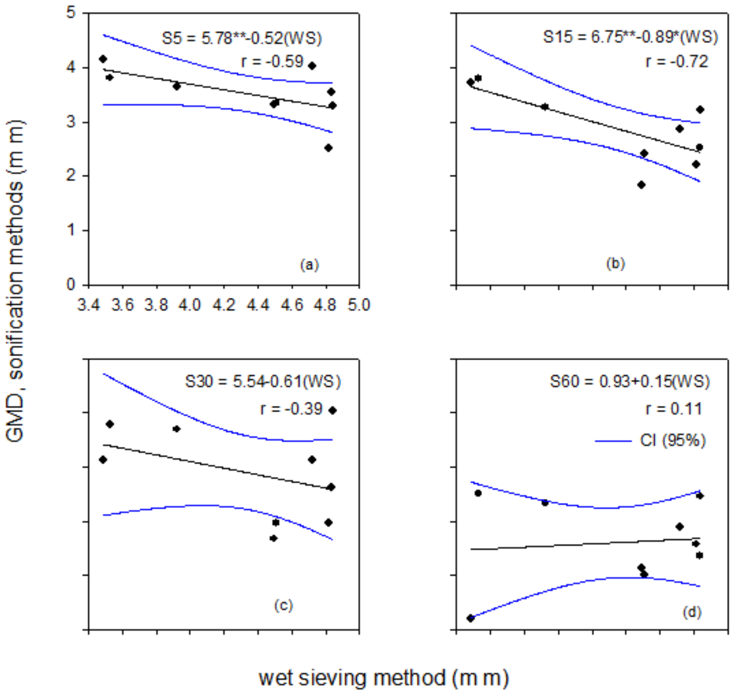

Figure 4. Correlation of geometric mean of aggregate diameters (GMD) between wet sieving (WS) and sonification methods (S) in Latosol. S5 (a), S15 (b), S30 (c) and S60 (d), respectively correspond to energy levels of 2.2, 6.4, 12.8 and 25.5 J mL^{-1}. IC = confidence interval.

differences in the aggregate stability of a eutro eutroferric Red Latosol under different uses (*Eucalyptus* sp, *Pinus* sp, forest, pasture, 13-year-old coffee plantation, 2-year-old coffee plantation and annual crops), Sá et al. (2002) noted that the best range for detecting differences in aggregate stability of the soil was 30 to 90 J mL^{-1}.

The results of this study corroborate Sá et al. (2000), demonstrating that the stability of the aggregates depends on the characteristics of each soil and the type of disruptive forces applied. Thus, differences in the aggregate stability can be related to the type and amount of energy applied, and the methodological procedures involved in each type of analysis.

Conclusion

Sonification methods S15 and S30, which respectively correspond to ultrasonic energy levels J 6.4 and 12.8 mL^{-1}, were more sensitive in detecting differences in depth in the GMD aggregation index of the soil used.

Conflict of Interests

The authors have not declared any conflict of interests.

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