Acta Scientiarum. Agronomy
ISSN: 1807-8621
Editora da Universidade Estadual de Maringá - EDUEM

Fast immersion to test the stability of aggregates in water: consequences for interpreting results from tropical soil classes

SOILS

Fast immersion to test the stability of aggregates in water: consequences for interpreting results from tropical soil classes

Rodrigo Fonseca da Silva [1*]
Universidade Federal do Piauí, Brazil
ORCID: http://orcid.org/0000-0001-9577-6458
Patriciani Estela Cipriano [2]
Universidade Federal de Lavras, Brazil
Matias Siueia [2]
Universidade Federal de Lavras, Brazil
Geslin Mars [2]
Universidade Federal de Lavras, Brazil
Moacir de Souza Dias [2]
Universidade Federal de Lavras, Brazil

Acta Scientiarum. Agronomy, vol. 42, 2020

Editora da Universidade Estadual de Maringá - EDUEM

Received: 19 April 2018
Accepted: 08 July 2018

DOI: 10.4025/actasciagron.v42i1.42453

ABSTRACT.

Abstract: Aggregates are the primary structural components of soil and have been used as an indicator of soil quality in conservation systems. The objective of this study was to analyse the effect of slow pre-wetting on the results of the aggregate stability test for different classes of tropical soils. Data were arranged in a 2 x 4 factorial design with three replications, in which the first factor comprised the two methods of pre-treatment on soil aggregates: without pre-wetting (WOPW), which considered the moisture of the aggregates in the field, and with pre-wetting (WPW), which considered the slow wetting of aggregates through capillarity on wet filter paper for 24h. The second factor consisted of four soil classes: Typic Dystrustept (Cambissolo Aplico distrófico in Embrapa), Typic Hapludult (Argissolo Amarelo distrófico), Rhodic Kandiudult (Nitossolo Vermelho distrófico), and Anionic Acrudox (Latossolo Vermelho distróferrico) and considered horizons A and B. The pre-wetting significantly increased the values of the weighted average diameter, geometric mean diameter and aggregate stability index. In soils with high organic carbon content, the practice of pre-moistening did not provide variation in aggregation.

Keywords: soil structure++ environmental quality++ geometric mean diameter.

Introduction

The soil is one of the most heavily exploited natural resources (Fernandez, 2006), and the implementation of agricultural systems with inadequately understood effects on the soil can lead to environmental degradation (Roth & Pavan, 1991; Silva Neto, Silva, Inda, Nascimento, & Bortolon, 2010; Lourente et al., 2011; Sabiha, Salim, Rahman, & Rola-Rubzen, 2016; Silva et al., 2017). The demand for appropriate techniques to measure the impact of human actions on soil quality is even more significant when the aim is to obtain a production system that is adapted to the characteristics of each soil class (Barreto, Miranda, Diniz Filho, Lira, & Medeiros, 2014; Shao et al., 2014; Kong, Miao, Wu, & Duan, 2016; Zhang et al., 2016).

In the search for appropriate ways to evaluate the impacts of human practices on soil quality, several researchers have recommended that the evaluation of soil physical indicators should have simple and low-cost methodologies, enabling faster analysis (Mendes, Melloni, & Melloni, 2006; Nesbitt and Adl, 2014; Sun et al., 2014; Faleschini, Zanini, Pellegrino, & Pasinato, 2016), and better reflecting the differences in soil quality (Araújo, Goedert, & Lacerda, 2007; Garcia & Rosolem 2010; Barreto et al., 2014; Desjeux et al., 2015; Duval, Galantini, Martinez, López, & Wall, 2016; Sarathjith, Sankar, Wani, & Sahrawat, 2016). Since aggregates constitute the main structural components of the soil, they have been widely used as quality indicators in conservation systems (Dexter, 1988; Ferreira, 2010; Lourente et al., 2011; Juhos, Szabó, & Ladányi, 2016; Rojas, Prause, Sanzano, Arce, & Sánchez, 2016).

The literature indicates several methodologies to estimate the state of soil aggregation (Kemper & Chepil, 1965; Castro Filho, Muzilli, & Podanoschi, 1998; Ontl, Cambardella, Schulte, & Kolka, 2015). Among these methods, slow pre-wetting by capillarity is a common practice in studies that evaluate aggregate stability (Peng, Yan, Zhou, Zhang, & Sun, 2015). This method aims to minimize aggregate breakdown caused by air compression inside the aggregate (Andrade & Rando, 1981; Wang, Tang, Cu, Shi, & Li, 2016), which may impact the measurement of this soil index.

Although pre-wetting is a widespread practice in studies of soil aggregate stability (Estabragh, Parsaei, & Javadi, 2015; Ma et al., 2015), this practice may overestimate the true value of aggregate stability, since most of the time, the soil moisture condition of the soil in the field is considerably lower than that provided by the wetting. Thus, for a more accurate evaluation of soil aggregate stability, the analysis should be performed by considering the state of vulnerability of the soil to potential breakdown (Sun et al., 2014).

Thus, given the importance of the evaluation of soil aggregation, this study aimed to analyse the effect of slow pre-wetting on the results of aggregate stability measurements on different tropical soil classes.

Material and methods

Characteristics of the study site

The study was carried out from May to July 2015 in the reserve area of the campus of the Federal University of Lavras, Lavras, Minas Gerais State, Brazil (latitude 21°14 '43'' S, longitude 44°59'59'' W; at 919 m above sea level). The climate is subtropical (Cwa type) according to the classification of Köppen, and the vegetation is typical of the Cerrado (Dantas, Carvalho, & Ferreira, 2007).

Soil sampling and treatments

The A and B horizons of different soil classes were sampled. Therefore, in each of the areas, a point was marked in the centre of the plot, and an area equivalent to one hectare was subsequently delimited with the aid of a GPS and a measuring tape. From this area, 25 points spaced 25 meters apart were defined. Afterwards, three points among the 25 were randomly selected to comprise the three replications within each study situation. Once collected, the samples were stored in plastic bags, separated, and properly identified according to the sampling point and were subjected to processing and analysis.

Data were arranged in a 2 x 4 factorial design with three replications, in which the first factor comprised the two methods of pre-treatment on soil aggregates: without pre-wetting (WOPW), which considered the moisture of the aggregates in the field, and with pre-wetting (WPW), which considered the slow wetting via capillarity of aggregates placed on a wet filter paper for 24h. The second factor consisted of the four soil classes classified according to the Soil Survey Staff (2014): Typic Dystrustept (Cambissolo Aplico distrófico in Embrapa, 2013), Typic Hapludult (Argissolo Amarelo distrófico in Embrapa, 2013), Rhodic Kandiudult (Nitossolo Vermelho distrófico in Embrapa, 2013), and Anionic Acrudox (Latossolo Vermelho distróferrico in Embrapa, 2013) (Table 1).

Analysis of organic carbon (OC), texture and flocculation degree (FD)

The pipette method was employed to quantify the distribution unit of particles by adding a chemical dispersant (0.1 mol L-1 NaOH) (Embrapa, 2017). Afterwards, the mixture was shaken using a Wagner shaker for 16 hours (Embrapa, 2017). Flocculation degree (FD) was obtained by the ratio between the total clay dispersed in water and the clay without the chemical dispersant (Equation 1). Particle density was determined by the pycnometer method in a sample dried at 105-110°C (Blake & Hartge, 1986).

$$FD = \frac{Total\ Clay - Clay\ Dispersed\ in\ Water}{Total\ Clay} \quad (1)$$

Organic carbon (OC) was determined by the automated dry combustion method using the Organic Carbon Analyzer, model Vario* TOC Cube (Elementar). Thus, 2 mg soil was weighed, representing each study situation, by means of an analytical scale with 0.0001 g accuracy. Afterwards, samples were ground in a mortar, sieved (0.250 mm mesh) and dried at 65°C for 48h. Next, samples were sealed in tin capsules and incinerated (950°C) for 5 min. After combustion, an infrared sensor detected the amount of CO_2 generated by the combustion, automatically relating it to the amount of carbon (Table 1).

Table 1

Granulometric distribution, flocculation degree (FD), initial moisture (IM), and organic carbon (OC) in the different classes and horizons of the evaluated soils.

Variables (1)	Sand	Silt	Clay	FD	IM	OC
	---------------------------------%					g kg^{-1}
			Horizon A			
Typic Dystrustept	57 a	17 a	26 d	30 a	9 c	16.29 b
Typic Hapludult	52 b	14 b	34 c	25 a	5 d	15.48 b
Rhodic Kandiudult	40 c	13 b	47 b	28 a	16 b	15.37 b
Anionic Acrudox	19 d	18 a	63 a	30 a	24 a	19.54 a
			Horizon B			
Typic Dystrustept	49 a	23 a	28 c	37 b	10 c	10.82 a
Typic Hapludult	24 b	10 c	66 b	38 b	8 d	3.15 c
Rhodic Kandiudult	24 b	8 c	68 a	51 b	18 b	3.12 c
Anionic Acrudox	13 c	20 b	67 a	96 a	28 a	6.37 b

(1)Means followed by the same letter do not differ by the Skott-Knott test at 5% significance level. Lowercase letters compare the soils within the same horizon.

Chemical and mineralogical analysis

The following variables were determined in each soil sample: pH in water (1: 2.5); exchangeable acidity (Al^{3+}), extracted with KCl (1 mol L^{-1}) and quantified by titration with 0.025 mol L^{-1} sodium hydroxide; and potential acidity (H + Al), which was estimated by the SMP method (Shoemaker, McLean, & Fratt, 1961; Embrapa, 2017). Calcium (Ca^{2+}) and magnesium (Mg^{2+}) contents were extracted with KCl (1 mol L^{-1}) and determined by atomic absorption spectrophotometry. Potassium (K^{+}) was extracted with Mehlich and determined by flame photometry (Embrapa, 2017).

Silica (SiO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3) were extracted by sulfuric acid attack according to Resende, Bahia, and Braga (1987) in samples of horizon B of each soil. Molecular relationships Ki and Kr were calculated by the formulas Ki [(% SiO2 / % Al2O3] and Kr [% SiO2 / (% Al2O3 + % Fe2O3)] (Table 2).

Table 2

Chemical characterization and mineralogy of the different soil classes and horizons.

Class	Hz	Depth	pH	K	Ca	Mg	Al	H+Al	SiO_2	Al_2O_3	Fe_2O_3	Ki	Kr
		--cm--			----------$cmol_c$ dm^{-3}----------				------------%----------				
Typic Dystrustept	A	0 - 15	5.30	0.21	2.00	0.50	0.20	4.04	22.20	23.90	3.30	0.93	0.81
	B	15 - 77+	4.90	0.06	0.70	0.10	0.90	3.62					
Typic Hapludult	A	0 - 20	5.30	0.13	1.30	0.60	0.30	3.62	18.97	22.57	5.70	0.84	0.67
	B	22 - 105+	5.60	0.02	0.30	0.30	0.10	2.32					
Rhodic Kandiudult	A	0 - 30	5.90	0.09	1.70	0.80	0.20	2.08	22.70	25.20	20.50	0.90	0.49
	B	30 - 127+	5.40	0.02	1.50	0.20	0.10	3.62					
Anionic Acrudox	A	0 - 26	5.60	0.16	2.50	1.80	0.10	3.62	12.25	29.65	30.34	0.41	0.20
	B	26 - 122+	5.80	0.01	0.10	0.20	0.00	1.66					

Analysis of aggregates stability

Aggregate stability in water was determined according the methodology described by Kemp and Chepil (1965), as modified by Tisdall and Oades

(1979), using a vertical oscillation apparatus similar to Yoder (1936). To perform the analysis, the soil samples were collected with natural moisture and, soon after collection, conditioned in plastic pots that were hermetically sealed and kept in a refrigerator. In the laboratory, the soil samples were selected and, maintaining the field moisture (without drying), were carefully broken up manually until the aggregates could pass through an 8-mm sieve and remain on a 2-mm sieve. After this procedure, the stability of WOPW aggregates was determined. To determine the WPW stability, the aggregates were slowly wetted by capillarity on wet filter paper for 24h. The quantity and size distribution of the aggregates with and without pre-wetting were measured using 2.00-, 1.00-, 0.50-, 0.25-, and 0.105-mm mesh sieves to obtain proportions of the following aggregate classes: 8 - 2; 2 - 1, 1 - 0.5, 0.5 - 0.25, 0.25 - 0.105, and < 0.105 mm in diameter. The soil retained on each sieve, as well as soil that passed through the last sieve (< 0.105 mm), was quantified and associated with 6 aggregates classes, the means diameters of which were, respectively, 5.0, 1.5, 0.75, 0.375, 0.1775, and 0.0525 mm.

The values of mean weight diameter "MWD" (Equation 2) (Kemper & Rosenau, 1986), geometric mean diameter "GMD" (Equation. 3) (Mazurak, 1950) and aggregate stability index "ASI" (Eq. 4) (Castro Filho et al., 1998) were determined according to the following equations:

$$MWD = \sum (w_i \ x_i) \tag{2}$$

$$GMD = \frac{\sum_{i=1}^{n} wp \ \log(x_i)}{\sum_{i=1}^{n} w_i} \tag{3}$$

$$ASI = \left(\frac{P_s - \ wp_{25} - Sand}{P_s - Sand} \right) \ 100 \tag{4}$$

in which w_i is the proportion of each aggregate class in relation to the total; x_i is the mean diameter of the classes (mm), wp is the mass of aggregates of each class (g); Ps is the mass of the dry sample (g); and Wp_{25} is the mass of the aggregates of the < 0.25 mm (g)-size class.

Statistical analysis

After tabulating the data, the assumptions of additivity, normality, homogeneity and independence of errors were verified, and when these assumptions were true, a completely randomized design was used (CRD) (Ferreira, Filho, & Lúcio, 2012). Analyses of variance were separated by soil horizon, in a 2 x 4 factorial arrangement (two types of pre-treatment of aggregates x four soil classes), and the means were compared by the Skott-Knott test ($p \leq 0.05$) (Borges & Ferreira, 2003).

Subsequently, a principal components analysis (PCA) was performed in order to relate treatments and reduce the number of variables to a more significant set. Thus, the initial set of variables was characterized by two new orthogonal latent variables, which allowed locating them in two-dimensional figures, representing the linear combinations of the original variables created with the two highest eigenvalues of the data correlation matrix (Hair Junior, Black, Babin, Anderson, & Tatham, 2009; Silva et al., 2010). The number of components was chosen based on those that presented eigenvalues above 1,0 and cumulative variance values above 70% (Hair Junior et al., 2009). Parametric tests and PCA were performed with the aid of the statistical software R (R Core Team, 2016).

Results and discussion

The pre-wetting was associated with significant interactions between the parameters related to the aggregation of the different soil classes: mean weight diameter (MWD), geometric mean diameter (GMD) and aggregates stability index (ASI) in the different soil classes and horizons evaluated (Table 3). The impact of pre-wetting on the analyses of the structural stability of soil aggregates is important in the evaluation of the soil's vulnerability to erosive processes, especially under farming conditions (Safadoust et al., 2014; Desjeux et al., 2015; Duval et al., 2016).

Table 3

Analysis of variance (F values) for factors related to aggregation in different soil classes for horizons A and B.

Source of variation (1)	MWD	GMD	ASI
		Horizon A	
Soil class (SC)	39.83**	25.84**	39.11**
Pre-wetting (PW)	108.11**	20.32**	94.61**
SC x PW	17.60**	6.25**	16.79**
CV (%) (2)	3.78	3.54	4.60
		Horizon B	
SC	37.58**	23.97**	8.28**
PW	424.41**	383.34**	70.13**
SC x PT	38.54**	12.67**	6.54**
CV (%) (2)	3.63	7.07	5.58

ns: F not significant; *: F significant at 5 %; **: F significant at 1 %; (1) variables analyzed: MWD = Mean Weight Diameter and ASI = Aggregates Stability Index. (2) Coefficient of variation.

In the different horizons and soil classes, except for horizon A of Anionic Acrudox (Figure 1), pre-wetting significantly increased the values of the aggregation indices (MWD, GMD, and ASI). Pre-wetting masked the differences of aggregate stability between the different soil classes, given the different results of the aggregation index for WPW and WOPW samples of the different soil classes.

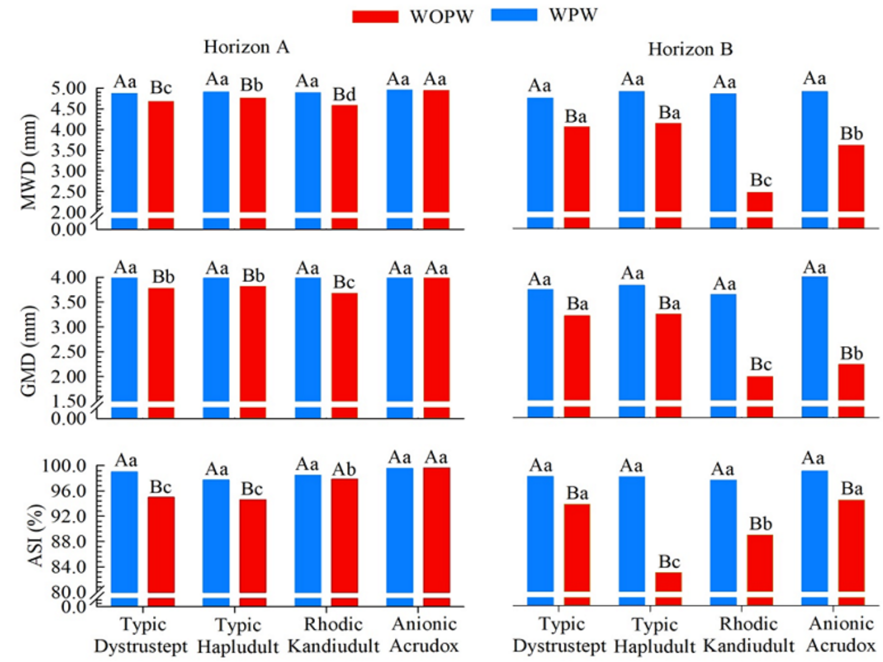

Figure 1

Mean weight diameter (MWD), geometric mean diameter (GMD) and aggregate stability index (ASI) in Horizons A and B, with pre-wetting (WPW) and without pre-wetting (WOPW) in the studied soils: means followed by the same letter do not differ by the Skott-Knott test at the 5% significance level. Uppercase letters compare treatments within the same soil, and lowercase letters compare soils within the same treatment.

Pre-wetting did not influence the values of MWD, GMD, and ASI for horizon A of the Anionic Acrudox soil. This finding may be due to the soil's high content of organic carbon (OC) (Table 1). OC interferes with the formation and stabilization of aggregates, since organic molecules directly affect aggregation and are also an important energy source for microorganisms that assist in the formation and stabilization of soil aggregates (Wohlenberg, Reichert, Reinert, & Blume, 2004; Loss, Pereira, Giácomo, Perin, & Anjos, 2011; Lima Filho, Ambrosano, Rossi, & Carlos, 2014).

The comparison of MWD, GMD, and the ASI among the soil classes showed that the effects of soil characteristics and OC (Table 1) were nullified by pre-wetting. Aggregation indices without pre-wetting (WOPW) indicated that soil with lower OC values were more susceptible to breakdown, whereas aggregation indices with pre-wetting (WPW) presented no significant differences between soil classes (Figure 1). Thus, for horizon B, the WOPW method presented greater variation in MWD, GMD and ASI values, providing a better picture of the relationships among the characteristics of soil, including OC with aggregation, especially under field moisture conditions.

Aggregates that are stable in water are less prone to degradation by water erosion (Kiehl, 1979; Six, Bossuyt, Degryze, & Denef, 2004; Lima Filho et al., 2014), due to their increased resistance to disaggregation and dispersion (Wischmeier & Smith, 1965). Thus, analyses of aggregate stability should be performed to preserve the natural vulnerability of different soils, since soil slow wetting does not occur under field conditions.

The distribution of aggregates larger than 2 mm presented with decreasing percentages in the following order: Anionic Acrudox > Typic Hapludult > Rhodic Kandiudult > Typic Dystrustept, for the WPW method for horizons A and B; and Anionic Acrudox > Typic Hapludult > Typic Dystrustept > Rhodic Kandiudult, for the WOPW method (Figure 2). Using the WPW method resulted in less number of different size class fractions of soil aggregates, keeping most of the aggregates stable in the diameter size class of > 2.00 mm. Conversely, the WOPW method increased the breakdown of aggregates due to the compression of air inside the aggregates (Andrade & Rando, 1981; Wang et al., 2016), and this effect is more evident in soils or horizons with lower OC content (Figure 2 and Table 1).

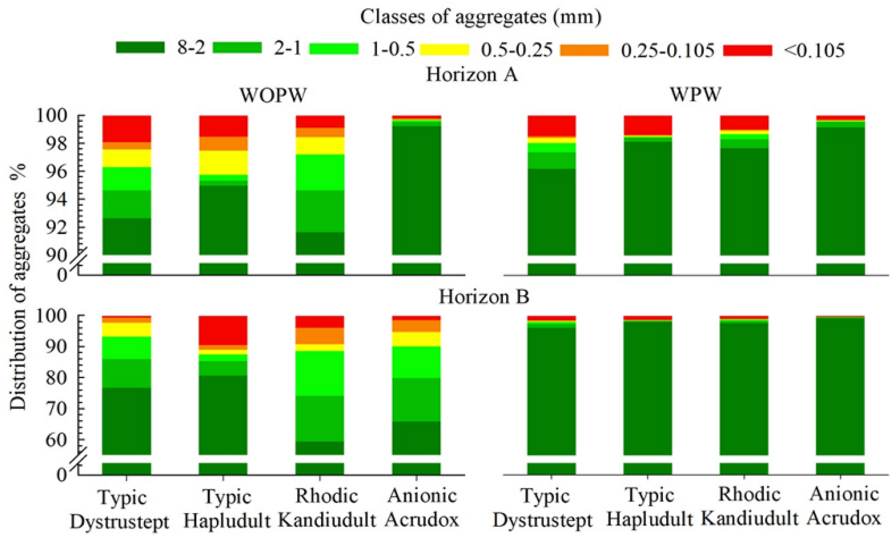

Figure 2

Distribution of aggregates after sieving by the wetting method with pre-wetting (WPW) and without pre-wetting (WOPW) for horizons A and B.

The results demonstrate the influence of pre-wetting on the stability of soil aggregates and has implications on the control of rainfall erosion. Thus, soil that has aggregates with low resistance to fast wetting is easily eroded when exposed to the action of rain and is subject to the surface sealing phenomenon, since disaggregated soil particles may have blocked pores that limit water infiltration (Le Bissonnais & Arrouyas, 1997; Braida & Cassol, 1999), which facilitates the disaggregation and soil transport by runoff (Albuquerque, Cassol, & Reinert, 2000).

The choice of the number of PCs took into account the eigenvalues above one and a cumulative variance higher than 70% (Freddi, Ferraudo, & Centurion, 2008; Hair Junior et al., 2009). Thus, PC1 and PC2 were selected for meeting the established criteria, since they explained 82.68% (PC1 = 63.53% and PC2 = 19.15%) of the variance in horizon A, and 77.65% (PC1 = 45.81% and PC2 = 31.84%) in horizon B. PCA thus reduced the dimensionality of the original variables while losing less than 23% explanatory power. Correlations between the variables and the principal components (PCs) allowed the characterization of the variables that most discriminated the aggregates stability of different soil classes.

From the contribution of the variables associated with the two principal components (Table 4), for horizon A of the different soils classes, PC1 is more correlated with the aggregate classes 8 - 2 mm, 0.5 - 0.25 mm, 0.25 - 0.105 mm and < 0.105 mm (22.71% contribution), with the soil aggregation indices MWD, GMD and ASI (18.33% contribution), with the following soil textures: very fine sand (VFS), fine sand (FS), average sand (AS), coarse sand (CS), very coarse sand (VCS) and clay (40.59%: contribution); with organic carbon (4.85% contribution), and with initial moisture (IM) (6.46% contribution). On the other hand, PC2 correlated better with intermediate aggregates with sizes at 1 - 0.5 mm (3.00% contribution). In horizon B, PC1 presented better correlation with the following aggregate classes: 8 - 2 mm, 2 - 1 mm, 1 - 0.5 mm, 0.5 - 0.25 mm and 0.25 - 0.105 mm (39.80% contribution), with the soil aggregation indices MWD and GMD (16.75% contribution); with the soil textures VCS, CS, MS, and clay (40.51% contribution) and with organic carbon (9.20% contribution).

Table 4

Correlation between each principal component and percentage of variance explained by each variable in relation to the soils studied in the southern region of Minas Gerais, Brazil.

Variables (1)	Eigenvalue				Contribution (%)			
	Horizon A		Horizon B		Horizon A		Horizon B	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
8 - 2 mm	0.82*	0.55	0.83*	-0.55	5.85	8.72	8.40	5.26
2 - 1 mm	-0.52	-0.69	-0.77*	0.59	2.32	10.90	7.15	6.17
1 - 0.5 mm	-0.59	-0.72*	-0.79*	0.56	3.00	19.06	7.51	5.51
0.5 - 0.25 mm	-0.79*	-0.44	-0.77*	0.57	5.44	5.61	7.26	5.70
0.25 - 0.105 mm	-0.70*	-0.44	-0.88*	0.42	4.26	5.67	9.48	3.15
< 0.105 mm	-0.91*	0.35	-0.42	-0.01	7.16	3.53	2.18	0.00
GMD	0.91*	0.35	0.82*	-0.53	7.31	3.51	8.20	4.85
MWD	0.77*	0.63	0.84*	-0.54	5.17	10.45	8.55	5.09
ASI	0.82*	0.04	0.57	-0.32	5.85	0.04	3.88	1.73
Clay	0.87*	-0.41	-0.66	-0.74*	6.66	4.82	5.33	9.44
Silt	0.45	0.13	0.47	0.36	1.74	0.50	2.70	2.25
VFS	-0.90*	0.38	0.69	0.44	7.03	4.09	6.06	3.44
FS	-0.87*	0.46	0.60	0.65	6.62	6.23	4.35	4.29
AS	-0.90*	0.40	0.61	0.75*	7.14	4.59	4.45	9.91
CS	-0.92*	0.35	0.60	0.78*	7.44	3.51	4.31	10.49
VCS	-0.81*	0.26	0.55	0.78*	5.70	2.00	3.65	10.67
IM	0.86*	-0.48	-0.44	-0.40	6.46	6.59	2.32	2.85
OC	0.75*	-0.08	0.59	0.70*	4.85	0.18	4.22	9.20

*More discriminatory values; PC1: principal component 1; PC2: principal component 2. (1) Variables analysed: classes of aggregates (8-2 mm, 2-1 mm, 1-0.5 mm, 0.5-0.25 mm, 0.25-0.105 mm, < 0.105 mm); GMD: geometric mean diameter; MWD: mean weight diameter; ASI: aggregates stability index; clay; silt; VFS: very fine sand; FS: fine sand; AS: average sand; CS: coarse sand; VCS: very coarse sand; IM: initial moisture; OC: organic carbon.

Figure 3 clearly shows a grouping tendency of soil classes and treatments for horizon A, which allows the characterization of the variables that most discriminated the soil properties into groups I, II, and III. However, aggregate indices (MWD, GMD, and ASI), larger aggregates (8 - 2 mm), clay, IM and OC are responsible for the discrimination of group I, which is characterized by the presence of only Anionic Acrudox (WOPW and WPW). In group II, the fractions of sand (VCS, CS, MS, FS, and VFS) and smaller aggregates (less than 2 mm) are the most relevant factors in the formation of the group and are composed of the classes of WOPW soils (Typic Dystrustept and Rhodic Kandiudult). Conversely, group III is relatively close to the central area of the diagram, revealing lower correlation with the variables, and is characterized by WPW soil (Typic Dystrustept, Typic Hapludult, and Rhodic Kandiudult).

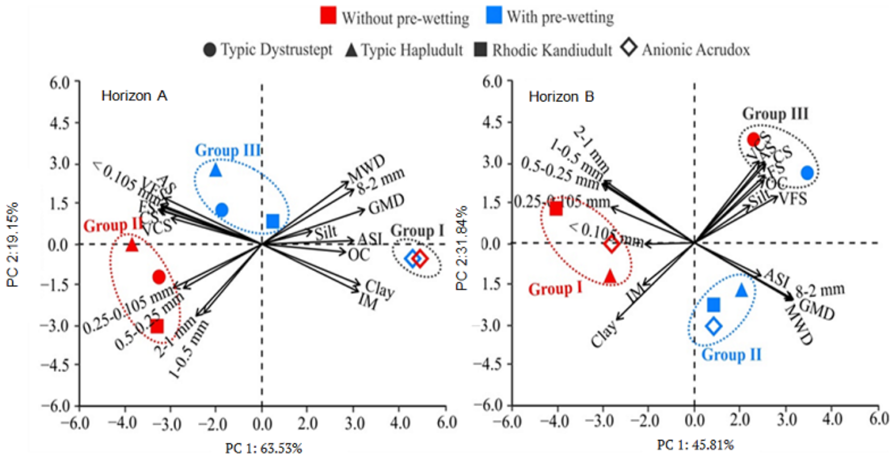

Figure 3

Principal components analysis of the means of the attributes of horizons A and B in different soil classes. Variables: classes of aggregates (8 - 2 mm, 2 - 1 mm, 1 - 0.5 mm, 0.5 - 0.25 mm, 0.25 - 0.105 mm, < 0.105 mm); GMD: geometric mean diameter; MWD: mean weight diameter; ASI: aggregates stability index; clay; silt; VFS: very fine sand; FS: fine sand; AS: average sand; CS: coarse sand; VCS: very coarse sand; IM: initial moisture; OC: organic carbon.

The little influence of the pre-wetting on Anionic Acrudox may be attributed to its higher content of OC and clay (Table 1). Dufranc, Dechen, Freitas, and Camargo (2004) and Gomes et al. (2004) reported that OC and clay contribute to the formation and stabilization of soil aggregates, since OC is an energy source for microorganisms that act as important aggregating agents, directly affecting the aggregate indices.

In horizon B, there was a grouping of soil classes (groups I, II, and III). Thus, the smaller aggregates (AC2, AC3, AC4, and AC5) and clay distinguished group I, which is composed of WOPW soil classes (Typic Hapludult, Rhodic Kandiudult and Anionic Acrudox). In group II, the aggregate indices (MWD, GMD) and larger aggregates (AC1) are the most important variables in the distinction of the group, which is composed of the WPW soil classes (Typic Hapludult, Rhodic Kandiudult, and Anionic Acrudox). Coarse sand (VCS, CS, and MS) and OC are responsible for the discrimination of group III, which is composed of Typic Dystrustept (WOPW and WPW).

OC tended to reduce the difference between treatments (WPW and WOPW) in horizon B of Typic Dystrustept, although with high sand value (Table 1). In addition, studies point to the contribution of OC in soil aggregation (Castro Filho et al., 1998, Fonseca, Carneiro, Costa, Oliveira, & Balbino, 2007), which is even more important in soils with values close to 25% clay (Bayer, Gardner, & Gardner, 1972). Also, it should be emphasized that for more weathered soils, such as Anionic Acrudox, the mineralogical composition of the clay fraction influences aggregation because these soils are composed of resistant microaggregates (Moura Filho & Buol, 1972) that are structurally stable (Ferreira, Fernandes, & Curi 1999).

Results of the PCA for horizons A and B of different soil classes indicate that the pre-wetting process causes considerable reduction in the disruption of the aggregates (Figure 3), interfering with the final result of the analysis and, consequently, in their interpretations. However, in high OC content conditions (Table 1), the influence of trapped air on the disruption of the aggregates (Andrade & Rando, 1981) is very clear, enabling the grouping of the same soil samples (Anionic Acrudox and Typic Dystrustept), regardless of whether pre-wetting was used (Figure 3).

Thus, the relationship between WPW and WOPW aggregates can be used in future studies as a strategy to evaluate the susceptibility of soil to erosive factors, allowing a closer evaluation into what occurs in the field, since different initial moisture contents are taken into account, demonstrating the effect of OC on aggregate stability in different soil classes or treatments in the same soil.

Conclusion

Pre-wetting significantly increases the values of the mean weight diameter, geometric mean diameter and aggregates stability index. However, this practice does not influence the aggregation in soils with high organic carbon content. These associated factors induce misinterpretations of soil vulnerability to erosion processes. Thus, it is advisable to perform this analysis under humidity conditions close to that in the field, since pre-wetting overestimates soil aggregation rates, especially in soils with low organic carbon, which is a condition associated with greater soil vulnerability.

References

Albuquerque, J. A., Cassol, E. A., & Reinert, D. J. (2000). Relação entre a erodibilidade em entressulcos e estabilidade dos agregados. *Revista Brasileia de Ciência do Solo*, *24*(1), 141-151. DOI: 10.1590/S0100-06832000000100016

Andrade, J. C. F. H., & Rando, E. M. Â. (1981). Alterações na consistência e textura de um Latosolo do roxo distrófico ocasionado pelo cultivo convencional. *Revista Ciência e Prática*, 5(1), 4-47.

Araújo, R., Goedert, W. J., & Lacerda, M. P. C. (2007). Qualidade de um solo sob diferentes usos e sob cerrado nativo. *Revista Brasileira de Ciência do Solo*, *31*(5), 1099-1108. DOI: 10.1590/S0100-06832007000500025

Barreto, H. B. F., Miranda, H. O., Lira, J. F. B., Diniz Filho, E. T., & Medeiros, J. F. (2014). Correlação do índice "S" com atributos físico-hídricos em solo aluvial no Rio Grande do Norte. *Global Science and Technology*, 7(3), 87-95. DOI: 10.14688/1984-3801/gst.v7n3p87-95

Bayer, L. D., Gardner, W. H., & Gardner, W. R. (1972). *Soil physics*. (4th ed.). New York, US: J. Wiley.

Blake, G. R., & Hartge, K. H. (1986). Bulk density. (2nd ed.), In A. Klute (Ed.). *Methods of soil analysis* (p. 363-375). Madison, US: American Society of Agronomy.

Borges, L. C., & Ferreira, D. F. (2003). Poder e taxas de erro tipo I dos testes Scott-Knott, Tukey e Student-newmankeuls sob distribuições normal e não normais dos resíduos. *Revista de Matemática e Estatística*, *21*(1), 67-83.

Braida, J. A., & Cassol, E. A. (1999). Relações da erosão em entressulcos com o tipo e com a quantidade de resíduo vegetal na superfície do solo. *Revista Brasileira de Ciência do Solo* , *23*(1), 711-721. DOI: 10.1590/S0100-06831999000300026

Castro Filho, C., Muzilli, O., & Podanoschi, A. L. (1998). Estabilidade dos agregados e sua relação com o teor de carbono orgânico em um Latossolo Roxo Distrófico, em função de sistemas de plantio, rotações de culturas e métodos de preparo das amostras. *Revista Brasileira de Ciência do Solo* , *22*(3), 527-538. DOI: 10.1590/S0100-06831998000300019

Dantas, A. A. A., Carvalho, L. G., & Ferreira, E. (2007). Classificação e tendência climática em Lavras, MG. *Ciência e Agrotecnologia*, *31*(6), 1862-1866. DOI: 10.1590/S1413-70542007000600039

Desjeux, Y., Dupraz, P., Kuhlman, T., Paracchini, M., Michels, R., Maigné, E., & Reinhard, S. (2015). Evaluating the impact of rural development measures on nature value indicators at different spatial levels: Application to France and The Netherlands. *Ecological Indicators*, *59*(1), 41-61. DOI: 10.1016/j.ecolind.2014.12.014

Dexter, A. R. (1988). Advancs in characterization of soil structure. *Soil and Tillage Research*, *11*(3/4), 199-238. DOI: 10.1016/0167-1987(88)90002-5

Dufranc, G., Dechen, S. C. F., Freitas, S. S., & Camargo, O. A. (2004). Atributos físicos, químicos e biológicos relacionados com a estabilidade de agregados de dois Latossolos em plantio direto no estado de São Paulo. *Revista Brasileira de Ciência do Solo* , *28*(3), 505-517. DOI: 10.1590/S0100-06832004000300012

Duval, M. E., Galantini, J. A., Martinez, J. M., López, F. M., & Wall, L. (2016). Sensitivity of different soil quality indicators to assess sustainable land management: Influence of site features and seasonality. *Soil and Tillage Research* , *159*(1), 9-22. DOI: 10.1016/j.still.2016.01.004

Empresa Brasileira de Pesquisa Agropecuária [Embrapa]. (2013). *Sistema brasileiro de classificação de solos*. (3. ed.). Brasília, DF: Embrapa.

Empresa Brasileira de Pesquisa Agropecuária [Embrapa]. (2017). *Manual de métodos de análise de solos*. (3. ed. revista e ampliada). Brasília, DF: Embrapa .

Estabragh, A. R., Parsaei, B., & Javadi, A. A. (2015). Laboratory investigation of the effect of cyclic wetting and drying on the behaviour of an expansive soil. *Soils and Foundations*, *55*(2), 304-314. DOI: 10.1016/j.sandf.2015.02.007

Faleschini, F., Zanini, M. A., Pellegrino, C., & Pasinato, S. (2016). Sustainable management and supply of natural and recycled aggregates in a medium-size integrated plant. *Waste Management*, *49*(1), 146-155. DOI: 10.1016/j.wasman.2016.01.013

Fernandez, L. (2006). Natural resources, agriculture and property rights. *Ecological Economics*, *57*(3), 359-373. DOI: 10.1016/j.ecolecon.2005.04.022

Ferreira, D. F., Filho, A. C., & Lúcio, A. D. (2012). Procedimentos estatísticos em planejamentos experimentais com restrições na casualização. *Boletim informativo da Sociedade Brasileira de Ciência do Solo*, *37*(1), 16-19.

Ferreira, M. M. (2010). Caracterização física do solo. In Q. De Jong Van Lier (Ed.), *Física do solo* (p. 1-28). Viçosa, MG: Sociedade Brasileira de Ciência do Solo.

Ferreira, M. M., Fernandes, B., & Curi, N. (1999). Mineralogia da fração argila e estrutura de latossolos da região sudeste do Brasil. *Revista Brasileira de Ciência do Solo* , *23*(3), 507-514. DOI: 10.1590/S0100-06831999000300003

Fonseca, G. C., Carneiro, M. A. C., Costa, A. R., Oliveira, G. C., & Balbino, L. C. (2007). Atributos físicos, químicos e biológicos de Latossolo Vermelho distrófico de Cerrado sob duas rotações de cultura. *Pesquisa Agropecuária Tropical*, *37*(1), 22-30.

Freddi, O. S., Ferraudo, A. S., & Centurion, J. F. (2008). Análise multivariada na compactação de um latossolo vermelho cultivado com milho. *Revista Brasileira de Ciência do Solo* , *32*(3), 953-961. DOI: 10.1590/S0100-06832008000300005

Garcia, R. A., & Rosolem, C. A. (2010). Agregados em um Latossolo sob sistema plantio direto e rotação de culturas. *Pesquisa Agropecuária Brasileira*, *45*(12), 1489-1498. DOI: 10.1590/S0100-204X2010001200021

Gomes, J. B. V., Curi, N., Motta, P. E. F., Ker, J. C., Marques, J. J. G. S. M., & Schulze, D. G. (2004). Análise de componentes principais de atributos físicos, químicos e mineralógicos de solos do bioma Cerrado. *Revista Brasileira de Ciência do Solo* , *28*(1), 137-153. DOI: 10.1590/S0100-06832004000100014

Hair Junior, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2009). *Análise multivariada de dados*. (6. ed.). Porto Alegre, RS: Bookman.

Juhos, K., Szabó, S., & Ladányi, M. (2016). Explore the influence of soil quality on crop yield using statistically-derived pedological indicators. *Ecological Indicators* , *63*(1), 366-373. DOI: 10.1016/j.ecolind.2015.12.029

Kemper, W. D., & Chepil, W. S. (1965). Size distribution of aggregates. (2nd ed., pt. 1). In C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, & F. E. Clark (Ed.), *Methods of soil analysis*: Physical and mineralogical properties, including statistics of measurement and sampling (p. 499-510). Madison, US: American Society of Agronomy .

Kemper, W. D., & Roseneau, R. C. (1986). Aggregate stability and size distribution. (2nd ed., pt. 1). In A. Klute (Ed.), *Methods of soil analysis* (p. 425-442). Madison, US: American Society of Agronomy , Soil Science Society of America.

Kiehl, E. J. (1979). M*anual de edafologia*: Relação solo-planta. Piracicaba, SP: Ceres.

Kong, D., Miao, C., Wu, J., & Duan, Q. (2016). Impact assessment of climate change and human activities on net runoff in the Yellow River Basin from 1951 to 2012. *Ecological Engineering*, *91*(1), 566-573. DOI: 10.1016/j.ecoleng.2016.02.023

Le Bissonnais, Y., & Arrouyas, D. (1997). Aggregate stability and erodibility: II. Application to humic loamy soils with various organic carbon contents. *European Journal of Soil Science*, *48*(1), 39-49. DOI: 10.1111/j.1365-2389.1997.tb00183.x

Lima Filho, O. F., Ambrosano, E. J., Rossi, F., & Carlos, J. A. D. (2014). *Adubação verde e plantas de cobertura no Brasil*: fundamentos e prática. Brasília, DF: Embrapa .

Loss, A., Pereira, M. G., Giácomo, S. G., Perin, A., & Anjos, L. H. C. (2011). Agregação, carbono e nitrogênio em agregados do solo sob plantio direto com integração lavoura-pecuária. *Pesquisa Agropecuária Brasileira* , *46*(10), 568-76. DOI: 10.1590/S0100-204X2011001000022

Lourente, E. R. P., Mercante, F. M., Alovisi, A. M. T., Gomes, C. F., Gasparini, A. S., & Nunes, C. M. (2011). Atributos microbiológicos, químicos e físicos de solo sob diferentes sistemas de manejo e condições de cerrado. *Pesquisa Agropecuária Tropical* , *41*(1), 20-28. DOI: 10.5216/pat.v41i1.8459

Ma, R., Cai, C., Li, Z., Wang, J., Xiao, T., Peng, G., & Yang, W. (2015). Evaluation of soil aggregate microstructure and stability under wetting and drying cycles in two Ultisols using synchrotron-based X-ray micro-computed tomography. *Soil and Tillage Research* , *149*(1), 1-11. DOI: 10.1016/j.still.2014.12.016

Mazurak, A. P. (1950). Effect of gaseous phase on water-stable syntnetic aggregates. *Soil Science*, *69*(2), 135-148.

Mendes, F. G., Melloni, E. G. P., & Melloni, R. (2006). Aplicação de atributos físicos do solo no estudo da qualidade de áreas impactadas, em Itajubá/MG. *Cerne*, *12*(3), 211-220.

Moura Filho, W., & Buol, S. W. (1972). Studies of a Latossol Roxo (Eutrustox) in Brazil: micromorphology effect on ion release. *Experientiae*, *13*(7), 235-247.

Nesbitt, J. E., & Adl, S. M. (2014). Differences in soil quality indicators between organic and sustainably managed potato fields in Eastern Canada. *Ecological Indicators* , *37*(1), 119-130. DOI: 10.1016/j.ecolind.2013.10.002

Ontl, T. A., Cambardella, C. A., Schulte, L. A., & Kolka, R. K. (2015). Factors influencing soil aggregation and particulate organic matter responses to bioenergy crops across a topographic gradient. *Geoderma*, *255-256*(1), 1-11. DOI: 10.1016/j.geoderma.2015.04.016

Peng, X., Yan, X., Zhou, H., Zhang, Y., & Sun, H. (2015). Assessing the contributions of sesquioxides and soil organic matter to aggregation in an Ultisol under long-term fertilization. *Soil and Tillage Research* , *146*(1), 89-98. DOI: 10.1016/j.still.2014.04.003

R Core Team. (2016). *A language and environment for statistical computing*. Vienna, AU: R Foundation for Statistical Computing.

Resende, M., Bahia F., A. F. C., & Braga, J. M. (1987). Mineralogia da argila de Latossolos estimada por alocação a partir do teor total de óxidos do ataque sulfúrico. *Revista Brasileira de Ciência do Solo* , *11*(1), 17-23.

Rojas, J. M., Prause, J., Sanzano, G. A., Arce, O. E. A., & Sánchez, M. C. (2016). Soil quality indicators selection by mixed models and multivariate techniques in deforested areas for agricultural use in NW of Chaco, Argentina. *Soil and Tillage Research* , *155*(1), 250-262. DOI: 10.1016/j.still.2015.08.010

Roth, C. H., & Pavan, M. A. (1991). Efect of lime and gypsum on clay dispersion and infiltration in samples of a Brazilian Oxisol. *Geoderma* , *48*(3/4), 351-36. DOI: 10.1016/0016-7061(91)90053-V

Sabiha, N. E., Salim, R., Rahman, S., & Rola-Rubzen, M. F. (2016). Measuring environmental sustainability in agriculture: A composite environmental impact index approach. *Journal of Environmental Management*, *166*(1), 84-93. DOI: 10.1016/j.jenvman.2015.10.003

Safadoust, A., Feizee, P., Mahboubi, A. A., Gharabaghi, B., Mosaddeghi, M. R., & Ahrens, B. (2014). Least limiting water range as affected by soil texture and cropping system. *Agricultural Water Management*, *131*(6), 34-41. DOI: 10.1016/j.agwat.2014.01.007

Sarathjith, M. C., Sankar, B., Wani, S. P., & Sahrawat, K. L. (2016). Variable indicators for optimum wavelength selection in diffuse reflectance spectroscopy of soils. *Geoderma* , *267*(1), 1-9. DOI: 10.1016/j.geoderma.2015.12.031

Shao, X., Huang, B., Zhao, Y., Sun, W., Gu, Z., & Qian, W. (2014). Impacts of human activities and sampling strategies on soil heavy metal distribution in a rapidly developing region of China. *Ecotoxicology and Environmental Safety*, *104*(1), 1-8. DOI: 10.1016/j.ecoenv.2014.02.007

Shoemaker, H. E., McLean, E. O., & Fratt, P. F. (1961). Buffer methods for determining lime requirements of soils with appreciable amounts of extractable aluminum. *Proceedings of the Soil Science Society of America*, *25*(1), 274-277. DOI: 10.2136/sssaj1961.03615995002500040014x

Silva Neto, L. F., Silva, I. F., Inda, A. V., Nascimento, P. C., & Bortolon, L. (2010). Atributos físicos e químicos de agregados pedogênicos e de coprólitos de minhocas em diferentes classes de solos da Paraíba. *Ciência e Agrotecnologia* , *34*(6), 1365-1371. DOI: 10.1590/S1413-70542010000600002

Silva, M. O., Freire, M. B. G. S., Mendes, A. M. S., Freire, F. J., Campos, M. C. C., & Amorim, L. B. (2010). Discriminação de diferentes classes de solos irrigados com águas salinas, na região de Mossoró, RN, com o uso de análise multivariada. *Ambiência*, 2(2), 261-270.

Silva, R. F., Santos, G. G., Nobrega, J. C. A., Oliveira, G. C., Dias, B. O., Santos, D. P., & Silva Junior, J. P. (2017). Impacts of land-use and management systems on organic carbon and water-physical properties of a Latossolo Amarelo (Oxisol). *Semina: Ciências Agrárias*, *38*(1), 109-124. DOI: 10.5433/1679-0359.2017v38n1p109

Six, J., Bossuyt, H., Degryze, S., & Denef, K. (2004). A history of research on the link between (micro) agregates, soil biota, and soil organic matter dynamics. *Soil and Tillage Research* , *79*(1), 7-31. DOI: 10.1016/j.still.2004.03.008

Soil Survey Staff. (2014). *Keys to soil taxonomy*. (12th ed.). Washington: D.C.: United States Department of Agriculture; Natural Resources Conservation Service.

Sun, T., Chen, Q. Chen, Y. Cruse, R. M., Li, X. F., Song, C. Y., Kravchenko, Y. S., & Zhang, X. Y. (2014). A novel soil wetting technique for measuring wet stable aggregates. *Soil and Tillage Research* , *141*(1), 19-24. DOI: 10.1016/j.still.2014.03.009

Tisdall, J. M., & Oades, J. M. (1979). Stabilization of soil aggregate by the root systems of ryegrass. *Australian Journal of Soil Research*, *17*(3), 429-441. DOI: 10.1071/SR9790429

Wang, D., Tang, C., Cui, Y., Shi, B., & Li, J. (2016). Effects of wetting - drying cycles on soil strength pro fi le of a silty clay in micro-penetrometer tests. *Engineering Geology*, *206*(1), 60-70. DOI: 10.1016/j.enggeo.2016.04.005

Wischmeier, W. H., & Smith, D. D. (1965). *Predicting rainfall erosion losses from cropland east of the Rocky Mountain*. Washington, D.C.: ARS/USDA.

Wohlenberg, E. V., Reichert, J. M., Reinert, D. J., & Blume, E. (2004). Dinâmica da agregação de um solo franco arenoso em cinco sistemas de culturas em rotação e em sucessão. *Revista Brasileira de Ciência do Solo* , *28*(5), 891-900. DOI: 10.1590/S0100-06832004000500011

Yoder, R. E. A. (1936). Direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Journal of the American Society of Agronomy*, *28*(5), 337-351.

Zhang, Y., Dong, S., Gao, Q., Liu, S., Zhou, H., & Ganjurjav, H., Wang, X. (2016). Climate change and human activities altered the diversity and composition of soil microbial community in alpine grasslands of the Qinghai-Tibetan Plateau. *Science of the Total Environment*, *562*(19), 353-363. DOI: 10.1016/j.scitotenv.2016.03.221

Author notes

*

Author for correspondence. E-mail: rodrigo_silva@ufpi.edu.br