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Methodological aspects of the quantification of dispersible clay and its relationship with soil properties along a catena under no-till management

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Abstract. Continuous no-till management of sloping cultivated areas can promote soil property transformations, causing changes in aggregation and dispersion. The objective of this work was (i) to quantify the readily and mechanically dispersible clays using different methods and (ii) to examine their relationships with soil properties along a catena under no-till management. For this study, the catena was divided into three distinct parts: crest, upper-slope and mid-slope positions. Undisturbed soil cores were sampled at each slope position to determine the following soil properties: organic carbon, Ca^{2+}, Mg^{2+}, K^+, Al^{3+}, P, pH, cation exchange capacity and total clay content. Additionally, the levels of readily dispersible clay were measured using turbidimeter and hydrometer methods, whereas mechanically dispersible clay was quantified using the turbidimeter method. We observed high influence of total clay content and organic carbon on soil flocculation; P, Mg^{2+} and cation exchange capacity were positively related to clay dispersion. Soil management and water transport downslope are probably influencing changes in soil properties and determining the distribution of dispersible clay contents along the catena. No relationships were observed between readily dispersible clay measured using turbidimeter and hydrometer in terms of quantity. Hydrometer and turbidimeter measurements can deliver significantly different results regarding dispersible clay quantification, potentially leading to misinterpretations concerning the amount of clay dispersed in water.

Keywords: soil structure, erodibility, aggregation

INTRODUCTION

Cropping system management plays an important role in the construction and modification of the geomorphology and soil structure of sloping agricultural landscapes (De Alba *et al*., 2004; Arnáez *et al*., 2015). Inadequate conservation practices can promote a continuous degradation of soil structure (Nunes *et al*., 2017), resulting in the dispersion of particles as a result of the presence of unstable aggregates, impeding the retention of rainwater and favouring the displacement of these particles, thereby facilitating erosion (Beutler *et al*., 2001; Farahani *et al*., 2018a).

For a considerable length of time, the no-tillage system (NT) has been considered to be an efficient management system for soil structure maintenance (Reichert *et al*., 2009; Derpsch *et al*., 2014). Many studies emphasize its benefits to chemical, physical and biological soil functions, but these benefits have propagated the idea that NT does not require any complementary practices and that further investigations with the aim of avoiding soil structure degradation are unnecessary. However, over the years of continuous NT practices, the transformations in the chemical state of the soil can alter the pH of the soil, causing changes in aggregation and structure (*e.g.* Reichert *et al*., 2009; Giarola *et al*., 2013; Silva *et al*., 2014; Nunes *et al*., 2015; Tormena *et al*., 2017). Nunes *et al*. (2017) explains that soil management practices can induce high concentrations of mono- (*e.g.* K^+) and bivalent salts (*e.g.* Ca^{2+} and Mg^{2+}), which have the ability to remove Al^{3+} from negatively charged sites within the soil, causing clay dispersion. Chemical transformations may be more evident in superficial layers along cultivated lands on a sloping field (Rosemary *et al*., 2017), such as those which occur within a farm field in a soil catena, which naturally have different soil characteristics due to

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topographic aspects (De Alba *et al*., 2004). According to Rosemary *et al*. (2017) the term 'catena' refers to a toposequence of soils derived from a similar parent material and climatic conditions, but with different characteristics due to variations in relief.

A knowledge of physical processes that occur in a catena may be an important tool for the purpose of proposing management strategies to avoid soil degradation (*e.g*. erosion) (Arnáez *et al*., 2015; Rosemary *et al*., 2017). The indicators of structural stability can be used to contribute to the monitoring of possible modifications, indicating improvements or deteriorations in the structure of the soil (Arshad and Martin, 2002; Nunes *et al*., 2017). Dispersible clay represents the portion of the total clay which has the ability to disperse easily in the presence of water (Dexter and Czyż, 2000; Dexter *et al*., 2011); it is an important indicator of structural stability (Igwe and Udegbunam, 2008; Nunes *et al*., 2017) in catena soils which have been influenced by intensive fertilization, constant soil tillage and the absence of organic carbon (Azevedo and Bonumá, 2004; Dexter *et al*., 2011; Czyż and Dexter, 2015).

Clay particles can either flocculate or disperse in aqueous solution, and this is related to two principal designations in clay content: total clay (T_{clay}) and readily dispersible clay (*RDC*) (Czyż and Dexter, 2015). While T_{clay} is the same value as that measured in the determination of soil particle-size distribution, which is required for soil classification, the readily dispersed clay (*RDC*) value represents the portion of T_{clay} that becomes dispersible after a small input of mechanical energy. *RDC* is the portion of the mechanically dispersible clay (*MDC*), which receives greater and continuous inputs of energy to the dispersion (Czyż and Dexter, 2015).

Clay dispersion has a significant impact on the environment (Azevedo and Bonumá, 2004) and is influenced by a wide range of soil attributes (*e.g*. see Igwe and Udegbunam, 2008; Nunes *et al*., 2017). Clay content, water dynamics in soil and organic matter, cation exchange and mineralogical composition (*e.g*. Farahani *et al*., 2018a; Nunes *et al*., 2017; Farahani *et al*., 2018b) exert a significant influence on the soil structure. However, the determination of dispersible clay content, with and without energy (*i.e*. mechanical dispersion) input for dispersion, as well as the methodological and instrumental aspects (*e.g*. hydrometer and turbidimeter techniques), limits the potential precision in the quantification of its relationship with other soil properties. The use of turbidimeter techniques for clay determination is common (*e.g*. Czyż and Dexter, 2015; Nunes *et al*., 2017), but as yet, the results have not been compared or associated with the results obtained *via* traditional methods, such as the hydrometer method.

In this context, under the hypothesis that methodological aspects can influence the quantification of the dispersible clay and affect our understanding of its relationship with soil properties in sloping agricultural soils (*e.g*. catena), the objective of this work was to quantify the readily and mechanically dispersible clays using different methods and to examine their relationship with soil properties along a catena under no-till management.

MATERIAL AND METHODS

The study was carried out at an experimental site of Ponta Grossa State University (UEPG), Paraná State, Brazil (25° 05′ 52″ S and 50° 02′ 43″ W). The predominant climate in the region, according to the classification of Köppen, is humid subtropical mesothermal (Cfb), with an annual rainfall and temperature averages of 1,545 mm and 18°C, respectively (IAPAR, 2000). The soil in the study area is classified as a Rhodic Hapludox (Soil Survey Staff, 2010) and had been cultivated under a no-till system for 25 consecutive years at the time of the experiment, with the following crop rotation over the years: maize (*Zea mays* L.) soybean (*Glycine max* L.) and bean (*Phaseolus vulgaris* L.) in spring/summer and wheat (*Triticum aestivum* L.) intercropped with black oat (*Avena strigosa* Schreb) + vetch (*Vicia sativa* L.) in autumn/winter.

The experimental field selected for this study had a varied soil texture (Table 1) that are located in close vicinity; the soil was derived from a similar parent material and subjected to similar climatic conditions, but presented different characteristics. Taking into account the textural and topographical aspects of the experimental area, a sampling scheme was designed to cover a distance of 700 m (Fig. 1) under a catena. The catena was divided into three distinct sections: crest (CR), upper-slope (UP) and mid-slope (MD), with different elevations. The positions were georeferenced with a Trimble R4 Topographic GPS Receiver.

A sampling scheme was designated for each slope position, where a regular mesh of 5 x 4 m was established at 1 m intervals. At 20 points, undisturbed soil cores of approximately 5 cm in height and 7.3 cm in diameter were sampled at a depth of 0.0-0.05 m at each slope position (CR, UP and MD). Prior to sampling, straw (common in no-till systems) was removed from the soil surface to avoid mechanical disturbance. In total, 60 cores were obtained (*i.e*., 20 cores *x* 3 slope positions). The soil cores were placed in containers and transported to the laboratory.

Chemical properties were determined following the methodology of EMBRAPA (2017). Organic carbon (OC) was determined using the Walkley-Black method; phosphorus (P) was extracted using Mehlich-1 extraction and determined using colourimetry. Calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) were extracted with ammonium acetate and determined using atomic absorption spectrophotometry. Potential acidity (H^++Al^{3+}) was determined by extraction with calcium acetate and titration. Aluminium (Al^{3+}) was extracted with potassium chloride (1 M) and determined using titration. The base sum ($BS = K^+ + Ca^{2+} + Mg^{2+}$) and the cation exchange capacity ($CEC = H^+$

Table 1. Soil physical-chemical characterisation in a catena sectioned into crest (CR), upper-slope (UP) and mid-slope (MD) positions (Fig. 1) at the depth of 0.0-0.05 m under no-till management

Soil properties	Slope position		
	CR	UP	MD
Clay (%)	38.1 ± 1.5	27.8 ± 0.65	23.5 ± 1.56
Sand (%)	54.4 ± 0.36	65.5 ± 2.03	70.1 ± 1.94
Silt (%)	7.5 ± 1.45	6.7 ± 2.28	6.4 ± 1.85
Texture (USDA)	Sandy clay	Sandy clay loam	Sandy clay loam
OC (g kg^{-1})	25.0 ± 3.33	25.0 ± 3.51	20.2 ± 3.45
P (mg kg^{-1})	38.1 ± 9.05	58.7 ± 19.60	55.4 ± 13.53
K^+ ($mmol_c$ kg^{-1})	2.8 ± 0.92	6.7 ± 2.1	1.6 ± 0.49
Ca^{2+} ($mmol_c$ kg^{-1})	34.3 ± 12.23	54.2 ± 11.88	60.6 ± 22.73
Mg^{2+} ($mmol_c$ kg^{-1})	9.1 ± 2.23	18.9 ± 2.68	12.3 ± 2.63
Al^{3+} ($mmol_c$ kg^{-1})	1.0 ± 0.48	1.3 ± 0.75	1.2 ± 51.30.64
H^++Al^{3+} ($mmol_c$ kg^{-1})	70.4 ± 18.5	56.2 ± 22.9	51.3 ± 10.5
$CEC_{pH=7.0}$ ($mmol_c$ kg^{-1})	116.6 ± 11.92	135.9 ± 28.23	125.8 ± 20.34
pH	5.9 ± 0.48	6.0 ± 0.39	6.3 ± 0.33

Data represent mean values and standard deviations. OC – organic carbon, CEC – cation exchange capacity, n = 20.

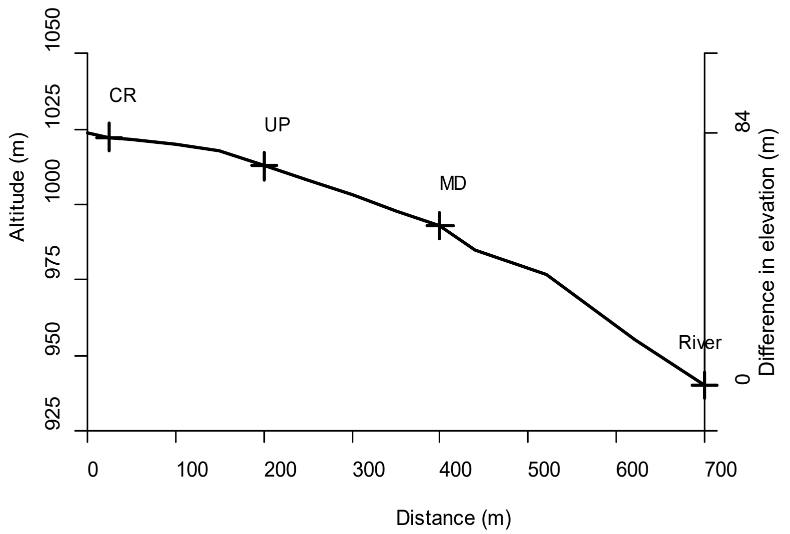

Fig. 1. Slope positions along a catena. Crest (CR), upper-slope (UP) and mid-slope (MD) positions with different clay contents (Table 1) used for soil sampling.

+ Al^{3+} + BS) were calculated. The pH of the water (pH) was determined using the electrochemical measurement of the effective concentration of H^+ ions in the soil solution, using a combined electrode inserted in a soil-water solution (1:2.5).

Clay contents were determined using hydrometer and turbidimeter methods. The total clay (T_{clay}) and readily dispersible clay – hydrometer (RDC_h) were first quantified using the hydrometer method, whereas readily dispersible clay – turbidimeter (RDC_t) and mechanically dispersible clay (MDC_t) were quantified using the turbidimeter apparatus. It should be noted that RDC_h and RDC_t are the same clay type, quantified by different instruments. The procedure (in detail) for the determination of each clay type is given below.

Readily dispersible clay (RDC_h) was determined using the hydrometer method (Day, 1965), albeit without the addition of a chemical dispersant, *i.e.* only soil and water in suspension. Granulometric fractions (clay, silt and sand) for soil characterization (Table 1) were determined using the hydrometer method. Additionally, an aliquot of 30 mL of solution was extracted from the hydrometer test (treated with chemical dispersant) to determine the total clay content using a turbidimeter, it was quantified by measuring the turbidity of a suspension of the soil in water, measured in turbidimeter units, *i.e.* in nephelometric turbidity unit (NTU g L^{-1}). This procedure was adopted in order to relate the T_{clay} to the NTU measurements. The T_{clay} to NTU conversion was performed using Eq. (1):

$$T_{clay}(NTU) = \left(\frac{NTU}{1000\left(\frac{DSM}{1000}\right)} \right), \qquad (1)$$

where: NTU is the nephelometric turbidity unit and DSM is the dry soil mass (g) used for the hydrometer test.

In order to normalize the clay content measured in NTU to the total clay, quantified in g L^{-1}, we used a K factor (Eq. (2)), as suggested by Czyż and Dexter (2008):

$$K = \left(\frac{T_{clay}\left(NTU / gL^{-1}\right)}{T_{clay}\left(gL^{-1}\right)} \right). \qquad (2)$$

RDC_t was determined using the turbidimeter procedure. Initially, 5 g of field-moist soil were weighed into a 200 mL flask, and 125 mL of deionized water was added. The flask was manually inverted four times to achieve homogenization, with each inversion lasting approximately 4 s. In order to obtain the sedimentation of silt and sand particles, and clay in suspension, the flask remained undisturbed for 16 h. After that, a 30 mL aliquot of the suspension was extracted and placed in the turbidimeter cell (*i.e.* turbidimeter flask) in order to measure the turbidity of the suspension. Additionally, the soil moisture level was determined from 5 g of moist soil and used to calculate the DSM, which was used in the Eq. (3) to quantify turbidity. The measured turbidity was normalized to achieve a DSM concentration of 1 g kg^{-1}:

$$RDC_t\left(gL^{-1}\right) = \left(\frac{NTU}{1000\left(\frac{DSM}{125}\right)} \right) K. \qquad (3)$$

In order to examine the effect of mechanical energy on the amount of dispersed soil clay, we determined the amount of mechanically dispersible clay in water, which was also based upon turbidimeter measurements (MDC_t). The MDC_t was quantified using a 30 mL aliquot of the suspension for the quantification of RDC_t. After RDC_t quantification, the turbidimeter cell was turned on a horizontal axis at 120 rpm for 30 min in order to promote the mechanical dispersion of the clay. Subsequently, the samples remained undisturbed for 16 h and were then transferred to the turbidimeter for turbidity measurement, recorded in NTU. The measured turbidity was normalized to a DSM concentration of 1 g kg^{-1}, using Eq. (3).

Data were analysed using regression models and the multivariate approach. Regression models were used to assess the relationships between the different kinds of dispersible clay (*i.e.* RDC_h, RDC_t and MDC_t). Canonical discriminant analysis (CDA) was performed in order to group the total variability of the field experiments on the basis of new variables (*i.e.*, canonical variables). Biplot graphs were created using the first two canonical variables. The means of the canonical variables for each treatment were compared with the use of 95% confidence spheres. When confidence ellipses overlapped, the differences between the means of the variables were considered to be insignificant. The CDAs were performed using the candisc R package from the R Software (R Core Team, 2016).

RESULTS

The regression models show that the different types of dispersible clays (RDC_t, MDC_t and RDC_h) had different relationships (Fig. 2). While RDC_t and MDC_t presented a positive (0.60) and significant (significant regression parameter, p-value < 0.001) relationship, RDC_t and RDC_h (0.26) as well as MDC_t and RDC_h (0.01) were positively related, although these relationships were not statistically significant (*i.e.* non-significant regression parameters) (Fig. 2). Overall, the types of dispersible clays were more significantly correlated when determined by the same method, regardless of the energy applied to disperse these clays (*i.e.* RDC_t and MDC_t). The hydrometer method produced results different from those obtained *via* the turbidimeter method.

The RDC_h (hydrometer method) did not differ between the slope positions and showed a high degree of variability (Table 2). Also, RDC_t and MDC_t were more concentrated at the upper-slope position, with means that were significantly higher than they were for the crest and the mid-slope positions. However, the values of the dispersible clays obtained using the hydrometer method were considerably higher than those obtained using the turbidimeter method, suggesting an overestimation through the use of the hydrometer method.

Canonical discriminant analysis shows the relationship of the original variables with slope position (CR, UP, MD) and the types of dispersible clays (RDC_t, MDC_t and RDC_h) (Fig. 3). With this analysis, two canonical variables were obtained (CAN_1 and CAN_2); for all scenarios, CAN_1 explained more than 90% of the experimental variation. The dispersion of RDC_t and MDC_t on the space of CAN_1 and CAN_2 shows that these dispersible clays were higher at UP, confirming the result obtained using the unvitiated approach (Table 2). However, Fig. 3 also shows that the higher RDC_t and MDC_t values at UP were related to higher concentrations of Al^{3+}, P, and CEC, but mainly of Mg^{2+} (see the vector of the variables directed to this slope position, Fig. 3). Also, the highest Ca^{2+} and pH values were found

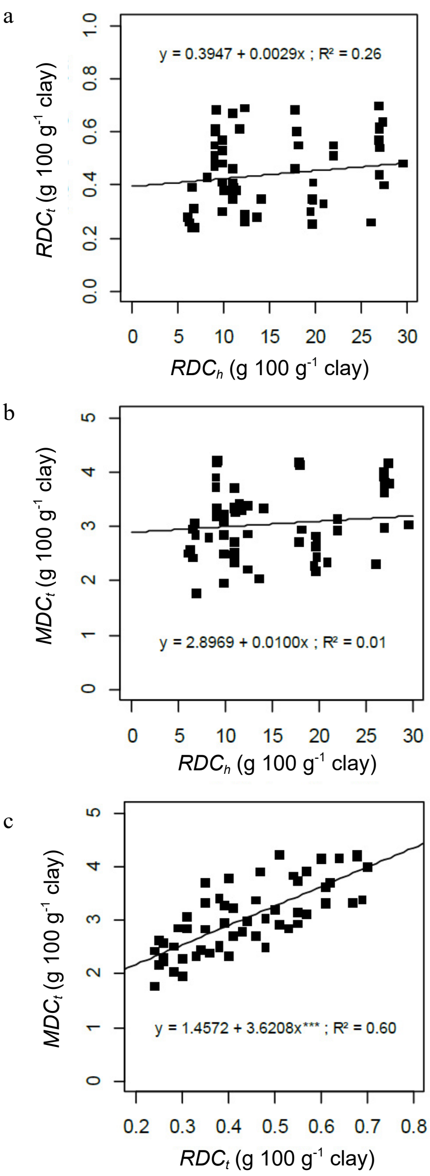

Fig. 2. Dispersible clay relationships: a – RDC_t *versus* RDC_h; b – MDC_t *versus* RDC_h; c – MDC_t *versus* RDC_t. RDC_t – readily dispersible clay – turbidimeter; MDC_t – mechanically dispersible clay in water; RDC_h – readily dispersible clay – hydrometer), *** p-value < 0.01.

Table 2. Mean values and standard deviations (±) of the different kinds of dispersible clays

Dispersible clays	Slope positions		
	CR	UP	MD
RDC	15.13a ± 5.49	18.00a ± 8.33	13.24a ± 8.02
RDC_t	0.29c ± 0.10	0.55a ± 0.08	0.46b ± 0.04
MDC_t	2.51c ± 0.44	3.67a ± 0.50	2.96b ± 0.37

RDC_t – readily dispersible clay – turbidimeter, MDC_t – mechanically dispersible clay in water, RDC_h – readily dispersible clay – hydrometer) in a catena sectioned into crest (CR), upper-slope (UP) and mid-slope (MD) positions. Mean values followed by the same letter do not differ significantly according to Tukey's test ($p < 0.05$).

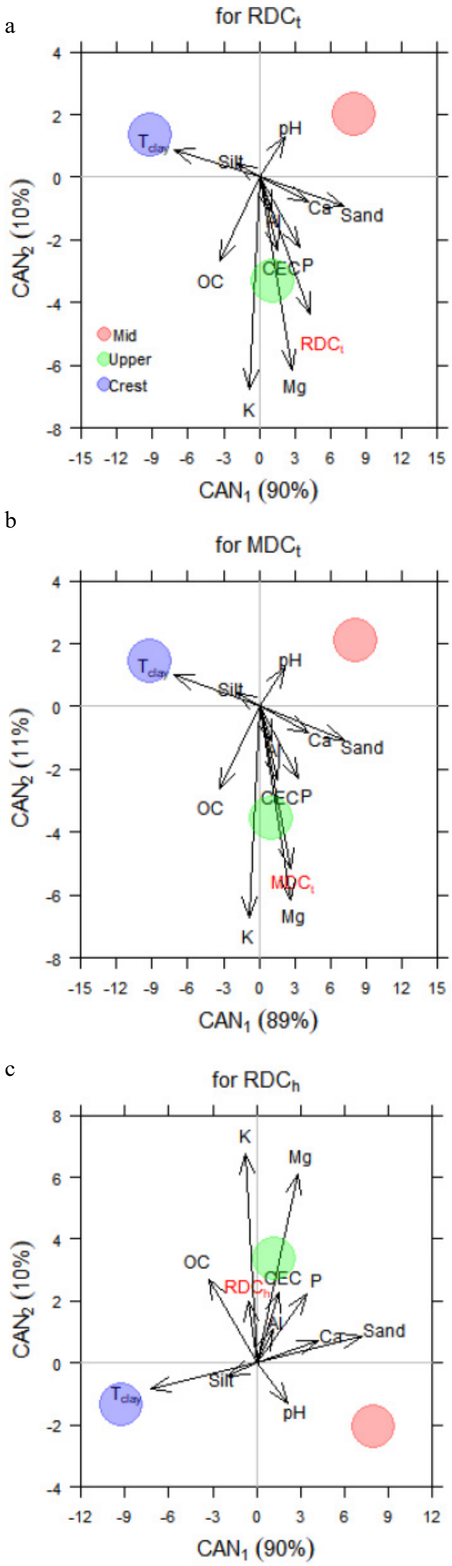

Fig. 3. Dispersion of the scores of the canonical discriminant analysis for chemical and physical variables on: a – readily dispersible clay – turbidimeter (RDC_t), b – mechanically dispersible clay in water (MDC_t) and c – readily dispersible clay – hydrometer (RDC_h) at three slope positions (crest, upper and mid) along a catena under no-till management. OC – organic carbon, CEC – cation exchange capacity.

at UP (see Ca^{2+} and pH in the left direction, the direction which is also observed for the canonical mean of the upper slope position; green circle), but it was in lower proportion than for Al^{3+}, P, CEC and Mg^{2+}. Conversely, we observed the greatest values of T_{clay} and OC (*i.e.* T_{clay} and OC are opposite vectors to UP, Fig. 3). At CR, T_{clay} and OC were highest, with lower values of RDC_t and MDC_t. According to the canonical analyses, RDC_t and MDC_t were more concentrated at UP, followed by MD and CR (Fig. 3).

The RDC_h presented an average of approximately 0 for CAN_1. This means that in approximately 90% of the experimental variation (*i.e.* the variability retained in CAN_1), RDC_h showed a low correlation with the explanatory variables (chemical and physical properties) and hence with the slope position, which explains the non-significant differences obtained for the RDC_h means shown in Table 2. This also corroborates with the low Pearson's correlation found among RDC_h and the other different types of dispersible clay (Fig. 2). In contrast, it seems that RDC_h was independent of soil properties and slope position.

DISCUSSION

The clay types RDC_t and MDC_r were positively related to a significant extent. This means that soil with large amounts of RDC_t may also be more susceptible to mechanical clay dispersion. In other words, the mechanical action of agricultural implements (*i.e.* soil tillage), which can provide significant amounts of energy, can disperse larger amounts of clay when the soil already contains large quantities of readily dispersible clay. This can result in structural soil degradation, making the soil highly susceptible to intense deterioration due to erosive processes, pore obstruction and the loss of nutrients (Dexter *et al.*, 2011).

The RDC_h was expected to correlate to a significant extent with RDC_h. However, the results showed a weak and non-significant relationship. The difference between RDC_t and RDC_h may be derived from the measurement instruments. The RDC_h was determined using a hydrometer, and the RDC_t was quantified using a turbidimeter. Czyż and Dexter (2015) reported that when using a turbidimeter, the measured concentrations may be far below the lower limits of normal gravimetric or hydrometer methods. In other words, the turbidimeter device seems to be more sensitive to small fractions of clay in suspension (*e.g.* Molope *et al.*, 1985) and is therefore more accurate. Due to the weak relationship between RDC_t and RDC_h (Fig. 2), it is possible that this error is large, rendering the hydrometer methods less accurate when small amounts of clay are in suspension.

The physical and chemical properties of the studied soil showed considerable variability along the catenary sequence, which may have been caused by the selective transport of sediment and its deposition during erosion processes (Johnson *et al.*, 2014; Rosemary *et al.*, 2017). The presence of higher levels of RDC_t and MDC_t at UP and MD showed their greater susceptibility to erosion when compared to CR, which is in agreement with Nguetnkam and Dultz (2011), who also observed higher levels of dispersive clay at the midpoint of a toposequence.

The lower values of RDC_t and MDC_t at CR are in accordance with the lower T_{clay} and OC contents. Clay is one of the main components of the soil, and its presence maintains the stability of aggregates, providing greater interaction with polyvalent cations and organic molecules due to its greater specific surface, thereby contributing to aggregation, especially in conditions of intense cultivation and at lower contents of organic carbon (Nguetnkam and Dultz, 2011; Nunes *et al.*, 2017). In weakly structured tropical soils, the clay fraction can act as a consolidating (*i.e.* aggregator) material (Ley *et al.*, 1993), but its effect is more prominent when the soil has a considerable amount of OC. Kay *et al.* (1994) reported that the clay content alone has little effect on soil aggregation, and OC is necessary for good soil structure development.

Greater P, CEC and Mg^{2+} concentrations at UP and MD demonstrated the relationship with RDC_t and MDC_t contents. The increase of P in the soil can cause the dispersion of soil colloids as a function of the adsorption of P in order to increase the negative charges on the surface of the particles (Albuquerque *et al.*, 2003). Martins *et al.* (2011) observed an increase of negative charges on the surface of clay particles, a reduction in the stability of aggregates and increased soil loss via erosion with phosphate fertilization. Soil CEC is related to the stability of aggregates (Dimoyiannis *et al.*, 1998), and its value reflects the negative charge on the surfaces of particles and more repulsive forces that contribute to the separation of particles (Goldberg *et al.*, 1990).

In addition, Mg^{2+}, Ca^{2+} and mainly Al^{3+} are often reported as aggregator elements, and although there is a positive correlation with the dispersed clay (RDC_t and MDC_t, Fig. 3), their effects depend on their concentrations in the soil. We observed that T_{clay} and OC contents were more important for soil aggregation than Mg^{2+}, Ca^{2+} and Al^{3+} concentrations. The contribution of Mg^{2+} to clay dispersion in this study corroborates the findings of Corrêa *et al.* (2003) in his studies with Vertisols. The effects of Mg^{2+}, Ca^{2+} and Al^{3+} on the soil structure may be related to the type of clay and its electrolytic concentration. The phenomena of dispersion and flocculation are influenced by the relationship between $Mg^{2+}$and Ca^{2+}; the Ca^{2+} level is higher than that of Mg^{2+}, it favours the flocculation of clays in the soil as the ionic hydrated radius of Mg^{2+} is higher than that of Ca^{2+}, with a higher degree of interaction with water molecules (Oliveira *et al.*, 2012). Although Al^{3+} contents were related to RDC_t and MDC_t, *i.e.* with clay dispersion, their levels in the soil were too low to have a significant effect on the soil structure (Table 1). The effect of Al^{3+} on soil aggregation may be more evident in highly intemperized soils with no acidity correction, as in the case of Oxisols.

Water movement and nutrient leaching in catena soils can lead base cations (*e.g.* Mg^{2+}, Ca^{2+}) to lower slope positions, resulting in an increase of the gradient and in higher pH levels. In extremely old soils (*e.g.* Oxisols), aggregate formation occurs at low pH levels in the presence of Al^{3+}. However, in this study, nutrients transported downslope (UP and MD) may not have influenced the concentrations of base cations, as there was no significant increase in pH (Table 1). The pH values for all slope positions (CR, U, MD; Table 1) were approximately neutral. Thus, the chemical action of Mg^{2+}, Ca^{2+} and Al^{3+} on aggregation may be limited, thereby increasing the influence of T_{clay} and OC contents on aggregation.

We observed no influence of K^+ on the dispersive clay. The effect of K^+ on the physical properties of the soil is less clear than that of other monovalent cations (*e.g.* Na^+). Monovalent cations (except H^+) are clay dispersants, and their presence or, additionally, the presence of bivalent cations, such as Mg^{2+}, can cause poor flocculation of the clay fraction (Lal and Shukla, 2004). Paradelo *et al.* (2013) observed an increase of the dispersed clay contents in treatments containing K^+ and attributed this effect to the addition of this monovalent cation to the surface of the soil particles. Also, Auerswald *et al.* (1996) argue that K^+ has a direct relationship with soil erodibility. However, De Alba *et al.* (2004) observed that K^+ combined with organic carbon contents contributed to an increase in aggregate stability. Dufranc *et al.* (2004) also observed K^+ as a soil-aggregating agent and concluded that the presence of organic carbon and bacterial polysaccharides may mask the beneficial effects of this element. It is possible that in our measurements, the K^+ content was not high enough to have an effect on clay dispersion, and therefore, T_{clay} and organic carbon did not govern the aggregation process.

CONCLUSIONS

1. This study revealed high degree of influence of the total clay content and organic carbon on soil flocculation.

2. P, Mg^{2+} and cation exchange capacity were positively related to clay dispersion, but due to their low concentrations in the soil, it is probable that the dispersion effect was caused by the lower amount of total clay and organic carbon than by the concentrations of P, Mg^{2+} and cation exchange capacity. We observed no influence of K^+ on clay dispersion or soil aggregation.

3. Soil management and water transport downslope are probably influencing changes in soil properties and determining the distribution of dispersible clay contents along the catena, causing higher concentrations of dispersible clay in upper- and mid-slope positions.

4. The quantification of dispersible clay can be significantly different between hydrometer and turbidimeter measurements, potentially leading to misinterpretations of the amount of clay dispersed in water.

Conflict of interest: The Authors do not declare conflict of interest.

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