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EFFECTS OF CLAY FRACTION MINERALOGY ON PHYSICAL ATTRIBUTES OF A YELLOW ULTISOL TREATED WITH CHISELING

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KEYWORDS

iron oxides, kaolinite, soil bulk density, soil penetration resistance.

ABSTRACT

The objective of this study was to evaluate the influence of minerals in the clay fraction on physical attributes of Yellow Ultisol cultivated with sugarcane and prepared with two different treatments: chiseling across the entire area and chiseling only in planting rows. The samples were collected from four layers of soil at eight months after planting. We assessed the texture of the soil, levels of iron extracted by dithionite-citrate-bicarbonate (DCB) and ammonium acid oxalate (AAO), ratio of kaolinite/(kaolinite + gibbsite), soil bulk density, and soil penetration resistance. The first area showed a higher ratio of kaolinite/(kaolinite + gibbsite) and the second area had greater levels of iron extracted by DCB. Levels of iron extracted by DCB were inversely correlated with soil bulk density and penetration resistance, while the kaolinite/(kaolinite + gibbsite) ratio was directly correlated with soil bulk density and penetration resistance. The area with a greater kaolinite/(kaolinite + gibbsite) ratio had higher values of soil bulk density and soil penetration resistance and the area with higher levels of iron showed lower values of soil bulk density and soil penetration resistance. The mineralogy influenced the soil's physical attributes, while soil preparation treatments did not.

INTRODUCTION

Sugarcane cultivation is economically significant in São Paulo, Brazil, owing to its use in the production of ethanol and sugar. Despite its central role in Brazilian agribusiness, sugarcane cultivation has brought about changes in soil bulk density (BD) and soil penetration resistance (SPR) due to compaction. Conventional sugarcane cultivation systems cause soil degradation through disaggregation, leading to soil compaction.

To minimize the effects caused by compaction, farmers have adopted less aggressive soil preparation practices in agricultural areas, such as chiseling only along planting rows. This practice improves the soil's physical qualities (Calonego et al., 2017) by increasing soil porosity and reducing soil bulk density (Nunes et al., 2014). As such, the effects of soil preparation on the physical attributes are also influenced by the mineralogy of the clay fraction.

The mineralogical composition of Brazilian Ultisols include varying proportions of iron oxides, gibbsite, and kaolinite, which in turn are related to the soil's physical attributes (Lu et al., 2014; Bonetti et al., 2017). Furthermore, Camargo et al. (2013) and Ramos et al. (2015) found high values of soil bulk density and penetration resistance in kaolinitic soils. Meanwhile, Manyala et al. (2015) and Wu et al. (2016) showed a correlation between BD and iron extracted by dithionite-citrate-bicarbonate (DCB) in Ultisols.

Know the mineral composition of the clay fraction will improve our understanding of the physical attributes of the soil. The objective of the current study was to assess the influence of minerals in the clay fraction on the physical attributes in a Yellow Ultisol cultivated with sugarcane and treated with two different preparation methods: chiseling across the entire area and chiseling only in planting rows.

MATERIAL AND METHODS

The study was undertaken in the municipality of Monte Alto, southwest São Paulo, Brazil (geographic

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coordinates: 21º17′24″ S and 48º25′48″ W; altitude of 735 m). We identified an area of 9 hectares with a slope of 1.1% for the collection of 64 soil samples spaced approximately 132 m apart. Within the study area, a section at higher altitude (Area I, 648 m) and a section at lower altitude (Area II, 640 m) were identified and 32 samples were collected from each section to capture the greatest variability of the soil's clay fraction mineralogy (Camargo et al., 2014).

The climate of the region was classified as mesothermal (Thornthwaite B2rB'4^a), with dry winters and temperatures in the hottest month greater than 22 ºC and in the coldest month greater than 18 ºC. Annual average precipitation is 1,400 mm, with rain concentrated in the period from October to March, and a relatively dry period from April to September.

The soil in the area is Yellow Ultisol and the parent material is identified as Vale do Rio do Peixe sandstone, formerly Bauru Adamantina Formation (IPT, 1981). Sugarcane has been cultivated in the study area for more than 20 years and mechanical harvesting has been used since 2004.

In half of the study area, the soil was prepared as follows: chiseling along the planting rows with tilling of the soil only in the sugarcane planting rows, thus preserving the soil between rows. In the other half of the study area, the entire area was subjected to chiseling and tilling was conducted along and between planting rows.

The sugarcane was planted using a planter with a potential of 220 hp and weight of 10.540 kg. Earthing-up, or ridging, was conducted one month after planting using a cultivator coupled to a tractor with a potential of 182 hp.

We collected disturbed and undisturbed soil samples along planting rows (at 0.20 m from the ridge) and between rows (at 0.75 m from the ridge) from the following layers: 0.00–0.10 m, 0.10–0.20 m, 0.20–0.40 m, and 0.40–0.60 m. The disturbed samples were collected with the help of a Dutch auger and used to examine soil texture (Claessen, 1997) and clay fraction minerals. The identification of clay fraction minerals began with clay separation using a centrifuge (Jackson, 1958) and removal of iron oxides was done using the method described by Mehra & Jackson (1960). The levels of iron extracted using ammonium acid oxalate (Fe_{AAO}) were determined based on the methodology proposed by Camargo et al. (1986). To assess the kaolinite (Kt) and gibbsite (Gb) surface areas, we used a Rigaku Mini-Flex II x-ray diffractometer with a copper cathode that had a nickel filter and kα radiation (20 mA, 30 Kv) on slides of powdered material. The procedure used was 2° 2Θ/minute for the characterization of Kt and Gb. The ratio of kaolinite/(kaolinite+gibbsite) [Kt/(Kt+Gb)] was calculated based on the reflection areas of Ct (001) and Gb (002) of the diffractograms.

The undisturbed samples were collected using an Uhland sampler with volumetric rings (0.05 × 0.05 m). From these samples, we determined soil BD (Embrapa, 1997) and SPR (Tormena et al., 1998).

Firstly, descriptive statistics were calculated, including mean, standard error, standard deviation, minimum, maximum, and coefficient of variation to determine the variability of the studied attributes. Subsequently, we conducted explorative multivariate analyses with hierarchical grouping (data not shown) and principal component analysis (PCA). For these analyses, we selected only the variables that were not collinear. After selection, variables were standardized (null mean and unit variance). Hotelling's T^2 test was conducted to check for significant differences ($p<0.05$) between the groups observed in the analysis.

We only considered the principal components whose eigenvalues were greater than unity according to the criteria established by Kaiser (1958). The coefficients of the linear functions that define the main component were used in their interpretation, with the sign and relative size of the coefficients as an indication of the weight to be assigned to each variable. Only coefficients with high values (absolute value greater than or equal to 0.60) were considered for interpretation. The multivariate analysis was conducted using the program Statistica 7.0.

RESULTS AND DISCUSSION

We found that the higher altitude (Area I) section was characterized by a greater ratio of kaolinite/(kaolinite+gibbsite) [Kt/(Kt+Gb)] and lower levels of iron extracted by dithionite-citrate-bicarbonate (Fe_{DCB}) and by ammonium acid oxalate (Fe_{AAO}) compared to the lower altitude (Area II) section (Table 1). This mineralogical difference in the two areas can be attributed to the effect of relief on the formation of soil characteristics (Camargo et al., 2014). Due to its impact on the flow of water, relief influences chemical reactions and the transport of materials through soil with different mineralogical compositions (Ghidin et al., 2006). Thus, variations in topography produce internal drainage conditions that affect the movement and redistribution of clay minerals (Campos et al., 2012).

TABLE 1. Descriptive statistics, including Standard Error (SE), Standard Deviation (SD), Minimum (Min), Maximum (Max), Coefficient of Variation (CV), of the studied attributes.

Attribute	Mean	SE	SD	Min	Max	CV (%)	Mean	SE	SD	Min	Max	CV (%)
	Area I						Area II					
	Depth 0.00-0.10 m						Depth 0.00-0.10 m					
Clay (g kg^{-}	117	2	7	110	129	6	145	3	10	129	157	7
Silt (g kg^{-1})	76	5	14	48	91	19	57	4	12	37	68	21
Sand (g kg^{-}	807	5	13	790	836	2	798	4	10	781	810	1
Fe$_{DCB}$ (g kg^{-}	17	0.22	0.61	16	18	4	20	1	3	16	23	14
Fe$_{AAO}$ (g kg^{-}	0.71	0.13	0.36	0.43	1	51	0.92	0.11	0.31	0.64	2	33
Kt/Kt+Gb	0.74	0.03	0.07	0.62	0.83	10	0.56	0.02	0.06	0.46	0.65	11
	Depth 0.10-0.20 m						Depth 0.10-0.20 m					
Clay (g kg^{-}	138	5	14	116	161	10	157	5	14	136	176	9
Silt (g kg^{-1})	92	10	27	48	122	30	86	5	14	67	108	16
Sand (g kg^{-}	770	12	35	741	836	5	757	3	9	746	770	1
Fe$_{DCB}$ (g kg^{-}	18	0.73	2	14	20	12	20	1	3	16	25	17
Fe$_{AAO}$ (g kg^{-}	0.64	0.07	0.18	0.40	0.91	28	0.87	0.09	0.25	0.50	1	28
Kt/Kt+Gb	0.79	0.01	0.03	0.74	0.84	4	0.60	0.02	0.06	0.54	0.73	10
	Depth 0.20-0.40 m						Depth 0.20-0.40 m					
Clay (g kg^{-}	186	6	16	160	205	9	189	5	14	161	206	8
Silt (g kg^{-1})	75	10	28	43	119	37	80	8	22	62	120	28
Sand (g kg^{-}	738	5	15	710	758	2	731	6	17	694	748	2
Fe$_{DCB}$ (g	19	0.60	2	16	22	9	22	1	3	19	27	13
Fe$_{AAO}$ (g kg^{-}	0.58	0.04	0.12	0.38	0.74	20	0.84	0.14	0.38	0.33	2	45
Kt/Kt+Gb	0.81	0.02	0.05	0.74	0.87	7	0.61	0.04	0.12	0.43	0.84	19
	Depth 0.40-0.60 m						Depth 0.40-0.60 m					
Clay (g kg^{-}	262	7	19	231	290	7	249	6	17	222	272	7
Silt (g kg^{-1})	53	9	26	11	96	49	58	8	23	30	97	39
Sand (g kg^{-}	685	8	24	644	707	3	693	6	16	661	709	2
Fe$_{DCB}$ (g kg^{-}	24	1	4	19	29	15	24	0.96	3	21	28	11
Fe$_{AAO}$ (g kg^{-}	0.56	0.63	0.18	0.40	0.84	32	0.69	0.09	0.25	0.38	1	36
Kt/Kt+Gb	0.77	0.02	0.06	0.68	0.86	8	0.55	0.03	0.08	0.40	0.65	15

In Area I, we found a mean clay content of 262 g kg^{-1} and mean sand content of 807 g kg^{-1}. In Area II, the clay content was on average 249 g kg^{-1} and a similar mean of 798 g kg^{-1} was found for sand (Table 1). The levels of sand observed can be attributed to the parent material of the study area. Montanari et al. (2010) showed similar variations in Latosols with parent material comparable to the current study.

In the two study areas, we found an increase in the clay content and a decrease in the sand content with increasing depth (Table 1). These results are consistent with past observations of increased clay with depth that occurs in Ultisols and is attributed to the mobilization and loss of clay from superior to inferior layers (Campos et al., 2012; Suzuki et al., 2014).

The soil bulk density (BD) (Table 2) and soil penetration resistance (SPR) (Table 3) were greater in Area I than Area II. It is important to highlight that the two study areas received the same soil preparation treatment, localized chiseling and chiseling across the entire area; the collection of soil samples were also carried out during the same period for the two areas, at eight months after soil preparation. As such, differences in physical attributes are a reflection of differences in mineralogy in the two areas.

TABLE 2. Descriptive statistics, including Standard Error (SE), Standard Deviation (SD), Minimum (Min), Maximum (Max), Coefficient of Variation (CV), of soil bulk density (Mg m^{-3}).

Depth (m)	Mean	SE	SD	Min	Max	CV (%)	Mean	SE	SD	Min	Max	CV (%)
	Area I						Area II					
	Chiseling in planting rows						Chiseling in planting rows					
	Sample from row						Sample from row					
0.00-0.10	1.64	0.09	0.12	1.56	1.73	7.34	1.49	0.03	0.04	1.47	1.52	2.42
0.10-0.20	1.84	0.08	0.11	1.76	1.92	6.15	1.64	0.02	0.03	1.62	1.66	1.80
0.20-0.40	1.80	0.09	0.14	1.70	1.90	7.70	1.67	0.04	0.06	1.63	1.71	3.69
0.40-0.60	1.77	0.10	0.14	1.67	1.87	8.06	1.75	0.07	0.09	1.69	1.82	5.26
	Sample from between rows						Sample from between rows					
0.00-0.10	1.67	0.09	0.13	1.58	1.77	7.88	1.30	0.34	0.48	0.96	1.63	36.64
0.10-0.20	1.88	0.04	0.05	1.84	1.92	2.91	1.76	0.08	0.12	1.68	1.84	6.54
0.20-0.40	1.85	0.04	0.06	1.81	1.89	3.25	1.84	0.03	0.05	1.81	1.87	2.49
0.40-0.60	1.72	0.09	0.14	1.62	1.82	8.17	1.72	0.02	0.03	1.70	1.74	1.72
	Chiseling in total area						Chiseling in total area					
	Sample from row						Sample from row					
0.00-0.10	1.71	0.01	0.02	1.70	1.72	1.02	1.77	0.00	0.00	1.76	1.77	0.28
0.10-0.20	1.84	0.00	0.00	1.83	1.84	0.20	1.82	0.07	0.10	1.75	1.89	5.51
0.20-0.40	1.77	0.00	0.00	1.77	1.78	0.17	1.78	0.10	0.14	1.68	1.87	7.63
0.40-0.60	1.82	0.07	0.10	1.75	1.89	5.28	1.80	0.05	0.07	1.75	1.85	4.04
	Sample from between rows						Sample from between rows					
0.00-0.10	1.68	0.03	0.04	1.65	1.71	2.28	1.71	0.00	0.01	1.71	1.71	0.30
0.10-0.20	1.89	0.00	0.00	1.89	1.89	0.05	1.86	0.02	0.03	1.84	1.88	1.79
0.20-0.40	1.89	0.03	0.05	1.86	1.93	2.59	1.74	0.10	0.14	1.64	1.84	8.06
0.40-0.60	1.86	0.08	0.11	1.78	1.94	6.11	1.79	0.07	0.10	1.72	1.87	5.64

TABLE 3. Descriptive statistics, including Standard Error (SE), Standard Deviation (SD), Minimum (Min), Maximum (Max), Coefficient of Variation (CV), of soil penetration resistance (MPa).

Depth(cm)	Mean	EPM	DP	Mínnnn.	Máx.	CV (%)	Mean	EPM	DP	Mín.	Máx.	CV (%)
	Area I						Area II					
	Chiseling in planting rows						Chiseling in planting rows					
	Sample from row						Sample from row					
0.0-0.10	1.66	0.16	0.23	1.50	1.82	13.63	0.79	0.33	0.47	0.46	1.12	59.07
0.10-0.20	3.09	0.89	1.26	2.20	3.98	40.73	1.28	0.05	0.07	1.23	1.33	5.52
0.20-0.40	2.69	0.96	1.36	1.73	3.65	50.47	1.36	0.16	0.23	1.20	1.52	16.64
0.40-0.60	2.00	0.68	0.96	1.33	2.68	47.61	2.19	0.96	1.36	1.23	3.15	61.99
	Sample from between rows						Sample from between rows					
0.0-0.10	2.30	0.21	0.29	2.10	2.51	12.74	1.46	0.42	0.59	1.04	1.87	40.34
0.10-0.20	3.98	0.89	1.26	3.09	4.87	31.57	2.68	0.38	0.54	2.30	3.06	20.05
0.20-0.40	3.08	0.04	0.05	3.05	3.12	1.63	3.61	0.60	0.85	3.01	4.21	23.50
0.40-0.60	1.78	0.74	1.05	1.04	2.52	59.10	2.27	0.46	0.64	1.81	2.72	28.41
	Chiseling in total area						Chiseling in total area					
	Sample from row						Sample from row					
0.0-0.10	1.97	0.11	0.16	1.86	2.08	7.90	1.96	0.72	1.02	1.24	2.68	51.95
0.10-0.20	2.96	0.18	0.25	2.78	3.13	8.38	2.30	0.75	1.06	1.55	3.05	46.12
0.20-0.40	1.65	0.59	0.83	1.06	2.23	50.29	1.93	0.34	0.48	1.59	2.27	24.91
0.40-0.60	1.96	0.58	0.81	1.38	2.53	41.59	1.90	0.25	0.35	1.65	2.14	18.28
	Sample from between rows						Sample from between rows					
0.0-0.10	2.15	0.03	0.04	2.12	2.18	1.97	2.30	0.45	0.64	1.85	2.75	27.67
0.10-0.20	3.66	0.51	0.72	3.15	4.17	19.71	2.80	0.43	0.61	2.37	3.23	21.72
0.20-0.40	2.79	0.59	0.83	2.20	3.38	29.91	2.13	0.02	0.02	2.11	2.14	1.00
0.40-0.60	4.13	1.11	1.56	3.03	5.24	37.79	2.08	0.53	0.74	1.55	2.60	35.78

Area I showed a greater presence of kaolinite (Table 1), which can influence BD and SPR. The higher values of BD and SPR have been observed in a kaolinitic soil by Souza et al., 2009. According to Ajayi et al. (2009) kaolinitic soils have higher BD as a consequence of the face to face arrangement of microscopic kaolinite plates in soil, which consequently had higher values of SPR. On the contrary, in Area II, we found lower levels of BD (Table 2) and SPR (Table 3) in comparison to those in Area I. This behavior could be the result of increased levels of iron oxides in this area (Table 1). Iron oxides are cementing agents that are important in the process of soil aggregation (Inda et al., 2013; Bahia et al., 2014); therefore, greater levels of these minerals in the soil result in a more random arrangement of the particles, which is reflected in a more granular structure (Resende et al., 2005). This granular structure produced soils with lower BD and SPR when compared with soils with a higher presence of kaolinite (Ajayi et al., 2009).

We found that the coefficient of variation (CV) of the SPR in Area I was greater in comparison to that in Area II (Table 3). These results suggest a relationship between the minerals of the clay fraction and the variation in of SPR, since the greater CV observed in Area I compared to that in Area II can be attributed to the kaolinitic mineralogy found in this area, consistent with the results above.

Multivariate Analysis

When we conducted the hierarchical grouping analysis, we found two distinct groups: Group 1 is composed of Area I (with a predominance of Kt/(Kt+Gb) ratio), and Group 2 composed of Area II (with a predominance of Fe_{DCB}). After the exploratory analysis, we conducted a Hotelling's T^2 test to confirm the difference between the two groups as a function of the depths studied. We found significant effects for Area I and Area II at depth 1 ($F = 7.32$; $p = 0.0004$), depth 2 ($F = 3.609$; $p = 0.041$), depth 3 ($F = 6.47$; $p = 0.0006$), and depth 4 ($F= 6.09$; $p= 0.008$). These results support the separation of the areas based on the mineralogy of the soil as discussed above.

For the principal component analysis in layer 0.00–0.10 m, the principal components 1 and 2 explained 79% of the variability contained in the original variables (PC1 49% and PC2 30 %) (Table 4). We found that PC1, involved a combination of variables Kt/(Kt+Gb) ratio, Fe_{DCB}, clay, and sand content. The variables sand content and Kt/(Kt+Gb) ratio showed a direct correlation, while an inverse correlation of these variables was found with clay content and Fe_{DCB} (Table 4).

TABLE 4. Correlations of the variables soil penetration resistance (SPR), kaolinite/(kaolinite+gibbsite) ratio [Kt/(Kt+Gb)], iron extracted by dithionite-citrate-bicarbonate (Fe_{DCB}), clay content, sand content, and soil bulk density (BD) with the principal components for four depths.

Variables	PC1 (49%)*	PC2 (30%)*
	Depth 0.00-0.10 m	
SPR	-0.17	**-0.85**
[Kt/(Kt+Gb)]	**0.67**	-0.44
Fe_{DCB}	**-0.95**	0.11
Clay	**-0.85**	-0.09
Sand	**0.91**	0.23
BD	0.03	**-0.89**
	Depth 0.10-0.20 m	
	PC1 (66 %)	PC2 (15%)
SPR	**-0.87**	-0.32
[Kt/(Kt+Gb)]	**-0.65**	-0.53
Fe_{DCB}	**0.87**	-0.29
Clay	**0.89**	-0.30
Sand	**-0.74**	0.49
BD	**-0.83**	-0.32
	Depth 0.20-0.40 m	
	PC1 (50%)*	PC2 (26%)*
SPR	-0.30	**-0.85**
[Kt/(Kt+Gb)]	-0.53	0.49
Fe_{DCB}	**0.85**	-0.03
Clay	**0.87**	-0.14
Sand	**-0.86**	0.33
BD	**-0.65**	**-0.69**
	Depth 0.40-0.60 m	
	PC1 (52%)*	PC2 (20%)*
SPR	**-0.75**	-0.36
[Kt/(Kt+Gb)]	-0.31	**-0.77**
Fe_{DCB}	**0.81**	-0.11
Clay	**0.70**	**-0.63**
Sand	**-0.81**	0.18
BD	**-0.81**	-0.20

*Value refers to the percent of variation of the original group of data taken for the respective principal components. Correlations in bold (>0.60 of absolute value) are considered in the interpretation.

The biplot (Figure 1) enabled us to identify the variables that contributed the most to the characterization of both study areas. The sand content and Kt/(Kt+Gb) ratio helped to characterize Area I, indicating that the area consisted of higher levels of these attributes. On the contrary, the variables Fe_{DCB} and clay content characterized Area II, which had higher levels of these attributes and lower levels of sand content and Kt/(Kt+Gb) ratio. The dispersion of the variables for the two areas were located in opposite directions in the biplot. We found that the variables sand content and Kt/(Kt+Gb) ratio had inverse correlations with the clay content and Fe_{DCB}. These inverse correlations can be attributed to the environments ability to form kaolinite, which is complicated by the presence of iron oxides. A higher level of iron oxide in the clay fraction caused disorganization in the kaolinite structure as the iron impedes the crystallization of the mineral (Mestdagh et al., 1980; Camargo et al., 2014). In other words, it disrupts the face to face adjustment of microscopic kaolinite plates, thus explaining the inverse relationship observed between Fe_{DCB} and Kt/(Kt+Gb) ratio in the present study. The direct correlation between the sand content and Kt/(Kt+Gb) ratio is due to the fact that soils with high levels of sand liberate silica and contribute to the formation of kaolinite. According to Drees et al. (1989), the presence of mineral quartz in the clay fraction is common. Through weathering, the silicate minerals facilitate the recombination of Si with Al results in kaolinite formation (Ryan & Huertas 2013).

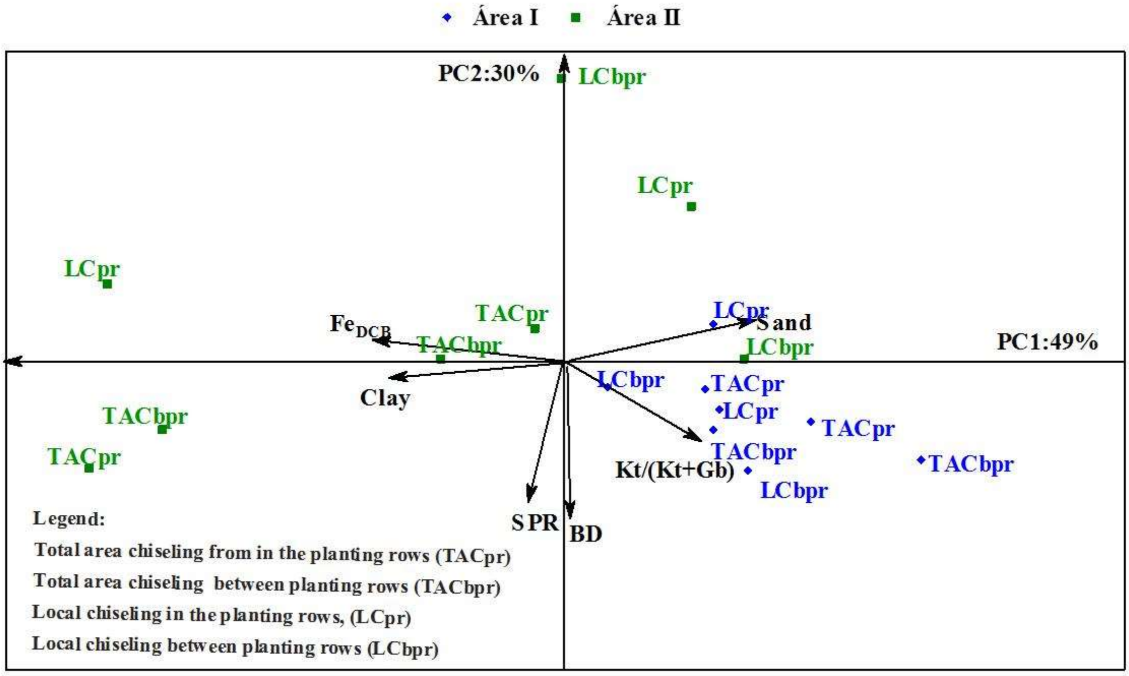

FIGURE 1. Graph showing the principal components PC1 and PC2 for the layer 0.0 – 0.10 m, with the variables: soil penetration resistance (SPR), soil bulk density (BD), clay content, sand content, Kt/(Kt+Gb) ratio and iron extracted by dithionite-citrate-bicarbonate (Fe_{DCB}).

The relationship between the level of Fe_{DCB} and the clay content observed herein supports the results found between these variables in the study by Camargo et al. (2014).

Considering the results presented in Table 4, in layer 0.10–0.20 m, the principal components explained 81% of the total variability in the data (PC1 66% and PC2 15%). In this layer, PC1 included the participation of SPR, Kt/(Kt+Gb) ratio, Fe_{DCB}, clay content, sand content, and BD, as these variables provided greater discriminatory power (Table 4). The BD and SPR showed a direct correlation with Kt/(Kt+Gb) ratio and sand content; however, BD and SPR were inversely correlated with the clay content and Fe_{DCB}. Area I can be characterized mineralogically by kaolinite (Figure 2) and the plate structure that it is associated with it was reflected in soils with greater levels of BD and SPR. Camargo et al. (2013) and Ramos et al. (2015) also observed higher levels of BD and SPR in kaolinitic soils. The increase of BD and SPR were evidences of soil compaction because it makes the movement of air and water through soil profile very difficult (Chen et al., 2014). As such, owing to its highly kaolinitic mineralogy, the soil of Area I is more susceptible to compaction.

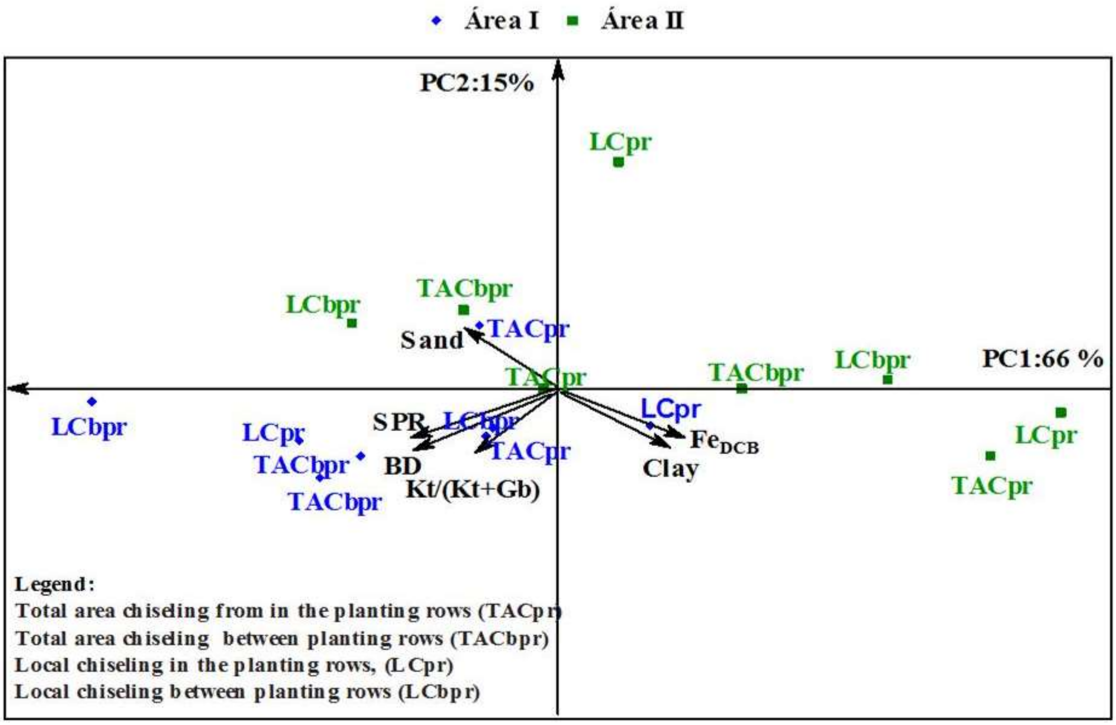

FIGURE 2. Graph of the principal components PC1 and PC2 in 0.10 – 0.20 m layer, with the variables: soil penetration resistance (SPR), soil bulk density (BD), clay content, sand content, Kt/(Kt+Gb) ratio and iron extracted by dithionite-citrate-bicarbonate (Fe$_{DCB}$).

Area II had an oxidic mineralogy owing to its characterization by Fe$_{DCB}$ (Figure 2). The iron oxides improved aggregation due to their cementing activity among soil particles (Regelink et al., 2015), resulting in improved soil porosity that produced lower values of BD (Camargo et al., 2014), and consequently SPR. Camargo et al. (2013) and Manyala et al. (2015) also observed a direct correlation between Fe$_{DCB}$ and BD and SPR. The oxidic mineralogy of Area II reduced BD and SPR, and therefore improved the soil's physical quality (Pezarico et al., 2013) which was reflected in soils that were less susceptible to the processes of compaction.

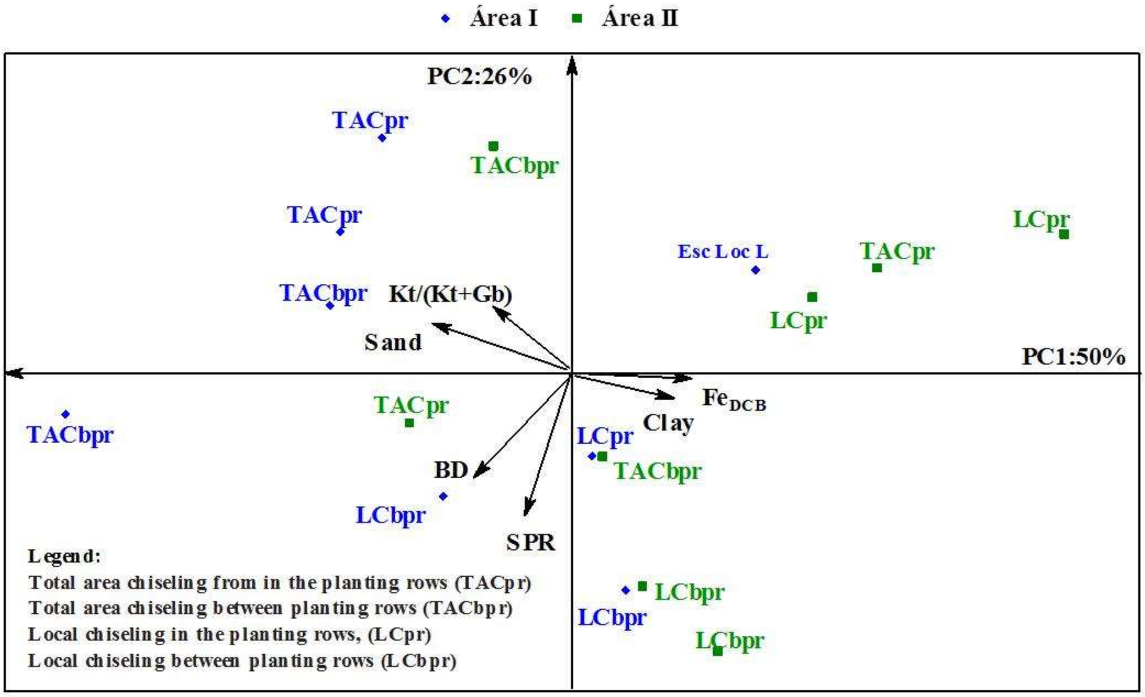

FIGURE 3. Graph of the principal components PC1 and PC2 in 0.20 – 0.40 m layer, with the variables: soil penetration resistance (SPR), soil bulk density (BD), clay content, sand content, Kt/(Kt+Gb) ratio and iron extracted by dithionite-citrate-bicarbonate (Fe$_{DCB}$).

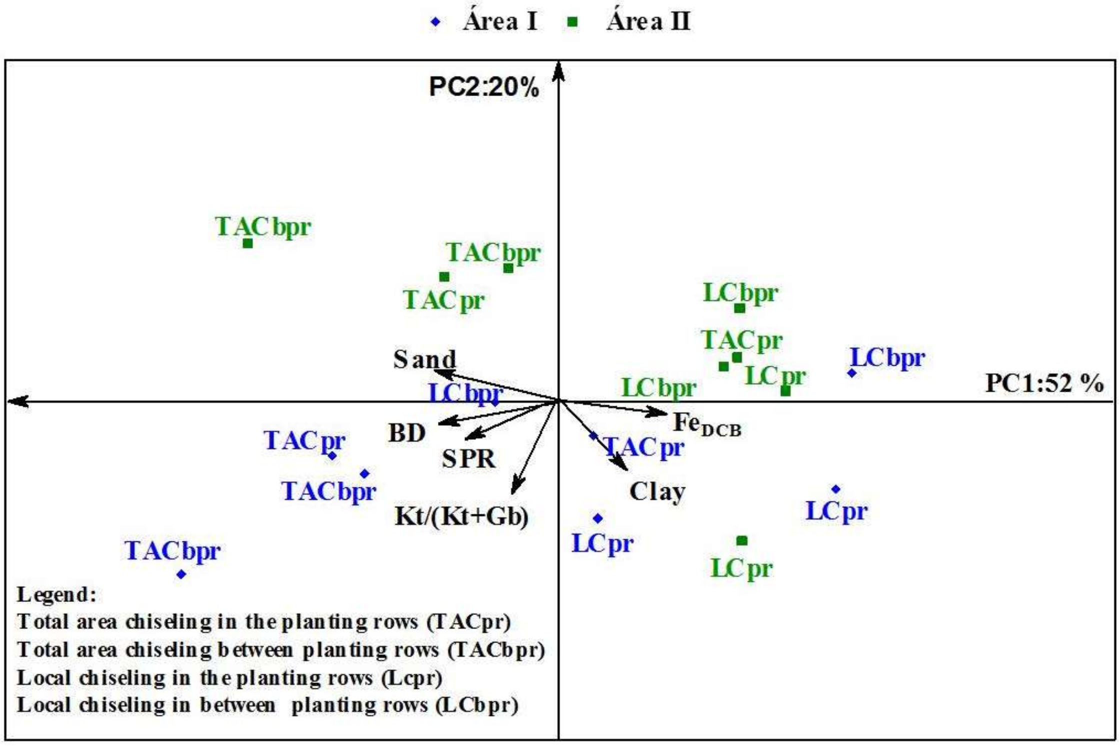

FIGURE 4. Graph of the principal components PC1 and PC2 in layer 0.40 – 0.60 m, with the variables: soil penetration resistance (SPR), soil bulk density (BD), clay content, sand content, Kt/(Kt+Gb) ratio and iron extracted by dithionite-citrate-bicarbonate (Fe$_{DCB}$).

In layer 0.20–0.40 m, the principal components PC1 and PC2 explained 76% (PC1 50% and PC2 26%) of the variability of original variables (Figure 3 and Table 4). For PC1, the variables Fe$_{DCB}$, clay content, sand content, and BD were involved. As with the previous layer, the BD had an inverse correlation with clay content and Fe$_{DCB}$, while we observed a direct correlation with sand content.

In layer 0.40–0.60 m, the principal components explained 72% (PC1 52% and PC2 20%) of the variability among original variables (Figure 4 and Table 4). There was the observation that BD and SPR were inversely correlated with Fe$_{DCB}$, as noted in previous layers (Table 4).

The graphs presented in Figures 1–4 showed no separation of areas with chiseling in the planting rows, and total area chiseling, as well as no divergence among samples taken from within and between rows. Thus, we suggest that the separation of the areas could be attributed to the mineralogical differences found between them.

The mineralogy of areas influenced the levels of BD and SPR, yet these attributes were not affected by soil preparation treatments. These results suggest that changes in physical attributes are not always correlated exclusively to soil management; in the current study these alterations appear to be the result of the mineralogy of the clay fraction.

Based on these results, the mineralogical assessment of soils should be adopted to better understand the variations in physical attributes. Furthermore, agricultural practices that look to improve the physical condition of soils and consequently their quality, should also be implemented. In this context, Area I, which had a greater Kt/(Kt+Gb) ratio requires more frequent monitoring and the adoption of practices to improve the physical quality of the soil as this area showed a predisposition for compaction processes due to its mineralogy.

Therefore, management practices that are more conservative and cheaper, such as localized scarification, can be adopted, as we did not observe differences in the physical attributes of the soil when non-conservative management practices were used.

CONCLUSIONS

Both chiseling in the planting row and chiseling in the total area did not influence the physical attributes in the study areas. Soil attributes were associated with soil mineralogy; BD and SPR decreased in areas with elevated levels of iron oxide. On the contrary, the value of soil BD and SPR increased as kaolinite content increased.

Mineralogy could be adopted as an important tool to support soil management decisions in specific areas, thereby avoiding unnecessary management that could degrade the soil.

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