Friability and its relationship with clay and organic carbon in soils cultivated with sugar cane

Friabilidad y su relación con la arcilla y el carbono orgánico en suelos cultivados con caña de azúcar

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ABSTRACT

Friability is a property related to the brittle fracture of soil aggregates and, therefore, is considered a key to the physical quality of soils and the consumption of energy during farming. This paper contains the preliminary results of research that aimed to quantitatively determine the friability index (FI) and its relationship with other soil properties; in particular, this research focused on the relationship between the FI and the clay content and organic carbon percentage (OC) of soils with a different dominance in the fine fraction (1:1 and 2:1 clay) that were cultivated with sugar cane in the southwest region of Colombia. The FI was determined by the compressive strength method using aggregates with diameters between 9.5 and 19.0 mm taken from the surface horizon, which were air air-dried and then dried at a low-temperature in an oven. The clay type content and OC content were determined in these samples. A 98.6% of the studied samples had FI values between 0.24 and 0.80, thus, classifying them as friable (especially those having a 1:1 type clay dominance) and very friable (especially those having a 2:1 type clay dominance), suggesting a structural condition of low to moderate energy requirements for farming, low greenhouse gas emissions (GHG) and a reduced risk of damage on the physical quality if a suitable soil moisture content exists during the tilling. This study found correlations between the texture, OC, and FI of the soils, indicating that the two first properties affected the friability. However, this effect depended on the clay dominance type.

Key words: soil physics, friability index, aggregates, tensile strength, tillage, sugar crops.

RESUMEN

La friabilidad es una propiedad relacionada con la fractura frágil de los agregados del suelo y por lo tanto considerada clave en la calidad física de los suelos y en el consumo de energía durante la labranza. En este artículo se reportan resultados preliminares de una investigación que busca determinar cuantitativamente el índice de friabilidad (IF) y su relación con otras propiedades del suelo; en particular, se centra en la relación del IF con el contenido de arcilla y el porcentaje de carbono orgánico (CO) en suelos con dominio diferente en su fracción fina (arcillas 1:1 y 2:1), cultivados con caña de azúcar en el suroeste colombiano. El IF se determinó por el método de resistencia a la compresión, usando agregados con diámetros entre 9.5 y 19 mm, tomados del horizonte superficial, secados al aire y en horno a baja temperatura. A estas muestras igualmente se les determinó el tipo y contenido de arcilla y CO. El 98.6% de los suelos estudiados reportaron valores de IF entre 0,24 y 0,80 que los clasifica como friables (particularmente aquellos con dominio de arcillas tipo 1:1) y muy friables (particularmente aquellos con dominio de arcillas tipo 2:1), sugiriendo una condición estructural con bajos a moderados requerimientos de energía para la labranza, bajas emisiones de gases efecto invernadero (GEI) y riesgo reducido de daño en su calidad física si se trabajan en condición adecuada de contenido de agua en el suelo. Se encontraron correlaciones entre la textura, el CO y el IF de los suelos, indicando que las dos primeras afectan la friabilidad, pero este efecto depende del tipo de arcilla dominante.

Palabras clave: física de suelos, índice de friabilidad, resistencia a la compresión, labranza, plantaciones azucareras.

Introduction

The use of fossil fuels in agriculture generates CO_2, a powerful greenhouse gas (GHG) (Filipovic *et al.*, 2006; Soni *et al.*, 2013); specifically, tilling the soil is usually the operation that results in the largest consumption of fuel in agricultural production (Robertson *et al.*, 2000). Energy requirements for this task depend, to a large degree, on the physico-mechanical state of the top soil and, in particular, on the friability (Munkholm, 2011), defined as the tendency of an unconfined soil mass to break down under an applied tensile or compressive force on a particular group of

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small-sized aggregates (Utomo and Dexter, 1981; Dexter and Watts, 2000). Soils with a suitable friability require less energy for tilling and, therefore, result in savings in terms of fuel and costs and reduced GHG emissions(Soni *et al.*, 2013). Friability is synonymous with quality in terms of the physical condition of the soil and is a desirable characteristic when preparing a medium for sowing (Watts and Dexter, 1998).

The physical quality of a soil is important for the suitable rooting of plants, especially in the first 10 cm of the soil, where many environmental and agronomic processes that are vital to the suitable germination of seeds are carried out (Reynolds *et al.*, 2007). A good medium for sowing is the principal objective of tilling, an activity that is more easily carried out in friable soils with large, relatively weak clods and small, relatively strong aggregates that are resistant to breaking down (Dexter, 1997). Friability is crucial for producing a suitable aggregate size that favors the germination of seeds and radical development of plants (Karlen *et al.*, 1990; Dexter and Watts, 2000).

Friability is an indicator of the structural stability of the soil (Watts and Dexter, 1998). Macks *et al.* (1996) suggested friability as an indicator of the physical condition for the direct establishment of crops. Snyder *et al.* (1995) reported that friability is a dynamic property and varies as a function of the moisture content of soils. Furthermore, soils must be prepared when they have the optimal conditions for the moisture content in order to achieve higher fragmentation during tilling. Intensive farming and the use of machines on soil with unsuitable moisture contents affect friability and lead to compaction and a vicious cycle, needing more and more energy in order to obtain a suitable medium for sowing crops (Munkholm, 2011).

Qualitative, semi-quantitative and quantitative methods have been used to estimate friability (Munkholm, 2011). The qualitative methods were based on the morphological description, the degree of structural development, the soil strength, and the consistency of the soil moisture (Schoeneberger, 2002; Ball *et al.*, 2007; FAO, 2009). The semi-quantitative methods applied the drop impact needed for fragmenting a soil sample and established characteristics such as the distribution of the aggregate size, the mean geometric diameter or the weight of the mean diameter (Hadas and Wolf, 1984). For the quantitative determination, laboratory tests that measured the tensile and compressive strengths of the soils were used jointly (Utomo and Dexter, 1981; Watts and Dexter, 1998; Dexter and Watts, 2000), using stress that led to soil sample break down; subsequently, the friability index (FI) was determined using the theory of material strength. In addition, indirect quantitative methods were used, based on the relationship of friability with the moisture retention curve (Dexter and Watts, 2000) and the porosity structure (Guérif, 1994).

The strength of the soil and, therefore, the friability depended on various factors that were associated with the clay fraction, as well as the exchangeable cations, their content and type, and quantity of dispersible clay (Barzegar *et al.*, 1995a). The type and quantity of the clay fraction performed an important function in the dynamic of the physical and chemical properties of soils, influencing several soil fertility aspects, such as moisture content, water movement and water retention percentage, carbon capture, erosion, aggregation, and deformation resistance (Graham and O'Geen, 2010). Different experiments have demonstrated that soil strength increases when clay content increases, confirming the role of this fraction in the binding and consolidation of aggregates (Barzegar *et al.*, 1995b). These authors reported that the compressive strength increases at a higher proportion in soils with a smectite dominance in the clay fraction, as compared to soils with a dominance of illite and kaolinite. Likewise, Spoor *et al.* (1982) reported that highly expansive clays, such as smectite, generate a higher soil strength.

The organic carbon percentage (OC) also acts as a hardening agent in the formation of the structure (Oades, 1984), affecting the friability and strength of the aggregates (Watts and Dexter, 1998). OC can be found in small pores, creating connections between the particles and increasing the soil strength (Guérif, 1994). Watts and Dexter (1998) and Macks *et al.* (1996) reported positive correlations between friability and OC; however, other researchers have found a negative correlation between these properties (Imhoff *et al.*, 2002; Guimarães *et al.*, 2009).

The objective of this study was to present results from the quantitative determination of the FI and its relationship with the clay fraction and the OC in soils with a different dominance in the fine fraction (1:1 and 2:1 clay) that were dedicated to the cultivation of sugar cane in Valle del Cauca, Colombia.

Materials and methods

This study was carried out on soils of 18 farms dedicated to the cultivation of sugar cane, located in the central and southern regions of the Valle del Cauca Department and the northern region of the Cauca Department, Colombia.

According to the Holdrige life zone classification system, the study area is composed of a dry tropical forest and, based on the Köppen climate classification system, it corresponds to a Tropical Wet Savanna (Awi). The environmental climate is warm and dry and the dominant edaphic climate isustic and isohyperthermic. The studied soils included Inceptisol, Vertisol, Mollisol, Alfisol and Ultisolorders (Tab. 1).

The soils were selected based on the mineralogy of the fine fraction and classified into a group with a 1:1 clay dominance, principally kaolinite, or with a 2:1 clay dominance, principally smectite and vermiculite (Tab. 1), relying on a detailed study of the research area (IGAC, 2006a). On each of the 18 farms, a specific soil type was located, in which five observation sites was positioned at a distance of 80 m and 120 m between them. The first horizon (Ap) was defined and sampled in each site, whose thickness varied between 10 and 24 cm. For the sampling, a block was taken from each observation site with the approximate dimensions of 30 cm length x 18 cm width x 12 cm thickness. These blocks were individually wrapped in adhesive plastic and subsequently transported in wood boxes to the laboratory for the mentioned tests in order to avoid disturbing the samples.

The aggregates of each block were manually separated along the natural plains of weakness in the soil and then separated by size, between 9.5 and 19 mm, using sieves. Ten aggregates were selected from each of the 90 collected soil blocks, for a total of 900 aggregates, which were dried in a greenhouse with an average daily temperature between 27 and 32°C for 5 d. Afterwards, they were placed in an oven with a temperature of 40°C for 48 h (Guimarães *et al.*, 2009). In order to prevent the samples from obtaining moisture from the environment, once the aggregates were dried in the oven, they were packaged and placed in an hermetic container until they were weighed and subjected to the compression test. The FI was determined with the indirect compressive strength test proposed by Utomo and Dexter (1981) and Dexter and Watts (2000), using a CBR mechanical press (Soiltext - CF410) with two speeds. In the tests, the weighed aggregates were placed between two parallel plates and a load was added at a constant deformation speed of 0.07 mm s^{-1}, until the aggregates broke apart.

The mean diameter (D_m) of the aggregates (mm) was determined with the equation proposed by Dexter and Kroesbergen (1985):

$$D_m = \frac{d_1 + d_2}{2} \tag{1}$$

where, d_1 was the size of the mesh opening in the upper screen (mm) and d_2 was the size of the mesh opening in the lower mesh (mm).

The effective diameter (D_e) (mm)was calculated using the individual mass of the aggregates and the following equation (Dexter and Watts, 2000):

TABLE 1. Geographic location of the farms. Mineralogical dominance and taxonomy of the clay fraction in soils cultivated with sugar cane (southwest region of Colombia).

Farm	Coordinates of the central sampling site	Soil taxonomy	Number of sampling sites	Weighted clay content (%)	Dominant minerals in the clay fraction
1	3°17´32.9”/76°30´39.2”	Udertic Haplustalfs	5	55.28	Kaolinite
2	3°16´03.4”/76°30´20.2”	Vertic Endoaqualfs	5	56.64	Kaolinite-quartz
3	3°37´31.6”/76°19´50.2”	Vertic Haplustolls	5	31.32	Smectite-mica
4	3°46´52.1”/76°22´20.1”	Typic Calciusterts	5	50.29	Smectite
5	3°7´42.5”/76°24´42.2”	Typic Palehumults	5	56.44	Metahalloysite-Kaolinite
6	3°5´30.4”/76°28´03.2”	Typic Palehumults	5	69.27	Kaolinite
7	3°4´4.5”/76°25´54.9”	Vertic Haplustalfs	5	48.21	Kaolinite
8	3°13´6.2”/76°30´23.1”	Udertic Haplustalfs	5	66.34	Kaolinite-quartz
9	3°38´11.5”/76°18´23.4”	Typic Haplustolls	5	31.13	Smectite-Kaolinite
10	3°40´12”/76°24´31”	Typic Haplustepts	5	27.78	Kaolinite-chlorite
11	3°47´45.2”/76°17´19.6”	Vertic Haplustolls	5	43.29	Smectite-vermiculite
12	3°42´24.7”/76°23´8”	Petrocalcic Haplusterts	5	35.55	Smectite-vermiculite
13	3°55´35.8”/76°18´26.8”	Entic Haplusterts	5	64.10	Smectite
14	3°42´6.11”/76°17´49.1”	Entic Haplustolls	5	34.08	Vermiculite-Smectite
15	4°4´38.3”/76°14´12.5”	Entic Haplusterts	5	33.70	Vermiculite-Smectite
16	4°4´59”/76°17´16”	Typic Endoaquerts	5	40.49	Smectite-integrated
17	3°31´37.8”/76°28´21.7”	Entic Haplustolls	5	30.02	Kaolinite-mica
18	3°3´1”/76°30´43.2”	Typic Palehumults	5	49.77	Kaolinite-integrated

$$D_e = D_m \left(\frac{M}{M_0} \right)^{1/3} \tag{2}$$

where, M was the mass of each aggregate (g) and M_0 was the mean mass of one lot of aggregates (g).

For the quantification of the FI, first, the compressive strength of the soil samples was calculated (Y) (kPa) from the value of the peak strength registered at the moment the aggregates broke apart (P) (N) using the equation proposed by Utomo and Dexter (1981) and Dexter and Watts (2000):

$$Y = 0.576\ (P/D_e^2) \tag{3}$$

In this equation, 0.576 is a constant of proportionality.

Using the Y (kPa) of each aggregate, the FI was determined with the equation proposed by Dexter and Watts (2000), which related the standard deviation of the measured values of compressive strengthand average of the compressive strength measures in replicas . The present study used 10 aggregates per soil sample in each test:

$$IF = \frac{\sigma_y}{\bar{Y}} \pm \frac{\sigma_y}{\bar{Y}\sqrt{2n}} \tag{4}$$

The second term of the equation corresponds to the standard error of the coefficient of variation.

The classification of the FI of the soil that was used in this study was based on the proposals of Imhoff *et al.* (2002): not friable (<0.1), slightly friable (0.1-0.2), friable (0.2-0.5), very friable (0.5-0.8) and mechanically unstable (>0.8). These ranges involve certain characteristics in the soils (Tab. 2).

TABLE 2. Classification of the soils according to the friability index (FI) (using the considerations proposed by Imhoff *et al*., 2002; Macks *et al.*, 1996).

FI	Classification	Characteristics
<0.1	Not friable	Soils with high strength, requiring a lot of energy during tilling and resulting in considerable emissions of GHG. Soils with very low physical quality.
0.1-0.2	Slightly friable	Soils with high strength, requiring a lot of energy during tilling and resulting in considerable emissions of GHG. Soils with very low physical quality.
>0.2-0.5	Friable	Soils with moderate strength, requiring moderate energy during tilling. Soils with moderate to high physical quality.
>0.5-0.8	Very friable	Soils with low strength, requiring low energy during tilling. Soils with moderate physical quality.
>0.8	Mechanically unstable	Soils with very low strength, requiring very little energy during tilling. The physical quality may be considered low, but this depends on the management since they could be suitable for direct sowing.

The mineralogy of the clay fraction of the soils was determined using the x-ray diffraction technique (DRX) (IGAC, 2006b, Soil Survey Staff, 2014). This analysis was carried out with the saturation of the clay with potassium, magnesium, ethylene glycol, and heating at 550°C; then, oriented clay slabs were mounted and subjected to x-ray radiation. Furthermore, the OC was determined for each of the samples with the Walkley & Black method (IGAC, 2006b). Based on the DRX analysis, the studied soils were divided into two groups: one with a predominance of clay type 1:1 (kaolinite) and the other with a predominance of clay type 2:1 (smectite and vermiculite). Due to the fact that it was not possible to classify some of the samples because there was not a predominance of either group, the results reported herein were based on 840 aggregates.

The SPSS software, version 22 (IBM, 2013), was used for the descriptive statistical analysis, which was used to determine the central tendency measurements (arithmetic mean and median), dispersion measurements (statistical range, standard deviation, and coefficient of variation) and form measurement (skewness and kurtosis). In addition, Kolmogorov-Smirnov and Shapiro-Wilk normality tests were applied. Also, the Pearson correlations were analyzed between the FI, clay and OC, considering all of the soils with subsequent considerations of the two groups: one with a 1:1 clay dominance and the other with a 2:1 clay dominance.

Results and discussion

The studied soils had different degrees of evolution and were found in medium-height and high terraces on the flood plain of the Cauca River. Sugar cane has been cultivated in these soils for more than 20 years, and two main mineral groups can be observed in the dominance of the fine fraction of the first horizon (Tab. 1): clay type 1:1 (kaolinite), associated with low and high evolution (inceptisols, alfisolsand ultisols), and clay type 2:1 (smectite and vermiculite),which is abundant in soils with moderate evolution (molisols and vertisols). The textural class of the soils varied from silty to clay, with clay contents between 20.14 and 78.58% and sand contents between 2.71 and 41.40%.

98.6% of the studied soils had a FI that classified the soils as friable (0.20 - 0.50) and very friable (>0.5 – 0.8), (Tab. 3 and Fig. 1), with a range of friable (0.24) to mechanically unstable (0.83). This indicated that most of them had a suitable structure that would facilitate tilling, with low to moderate energy requirements and a low risk of damage to the physical quality when the farming is conducted with suitable conditions of soil moisture content. Only one of the samples presented an FI of 0.83 (mechanically unstable), with a low strength, which indicated a fragile soil, in terms of the structural condition, that was susceptible to physico-mechanical degradation; nevertheless, it should be noted that, in its natural state, this soil can provide a suitable sowing medium, making it appropriate for direct sowing (Macks *et al.*, 1996).

The variability of the FI was similar in the two soil groups (Tab. 3 and Fig. 1), but the soils with a 1:1 clay dominance (kaolinite) presented a mean that was slightly higher to the mean seen in the soils with a 2:1 clay dominance (smectite and vermiculite). Furthermore, the former was classified as very friable and the latter was classified as friable. The difference can be seen in the fact that friable soils have a more stable structural condition than very friable soils, but friable soils can require more energy for farming.

The variability in the sand was notable, with a CV that was approximately double that of the clay (Tab. 3). The organic material contents had medium variability, which corresponded to the different types of analyzed soils.

For each of the studied variables, the mean and median were compared, the skewness and kurtosis were evaluated in the results, and Kolmogorov-Smirnov and Shapiro-Wilk tests were applied (Tab. 4), with findings that the FI and OC were reasonably assigned to a normal distribution. The Pearson correlation test was used for all of the soils and then for each of the two groups. The analysis for all of the soils showed that there was a significant, positive correlation between the FI and OC, results that were similar to those found by Watts and Dexter (1998) in Alfisol, silty-loam soils in the United Kingdom and by Macks *et al.* (1996) in Alfisol, silty and silty clay soils in Australia. This could be explained by the fact that OC

TABLE 3. Descriptive statistics of the variables analyzed in soils cultivated with sugar cane (southwest region of Colombia).

Variable	horizon	No. of data	Mean	Median	Range	Skewness	Kurtosis	Standard deviation	Coefficient of variation (CV, %)
					All of the soils				
FI	Ap	84	0.50	0.49	0.59	0.44	-0.44	0.13	26.0
Clay	Ap	84	46.24	43.04	58.44	0.31	-0.97	15.32	33.1
Sand	Ap	84	17.77	16.03	38.69	0.60	-0.62	10.88	61.2
OC	Ap	84	1.81	1.81	2.47	0.53	0.72	0.49	27.1
					Soils with 1:1 clay dominance				
FI	Ap	42	0.53	0.49	0.54	0.36	-0.93	0.14	26.4
Clay	Ap	42	51.36	52.55	58.44	-0.22	-1.04	16.60	32.3
Sand	Ap	42	14.47	13.13	38.68	0.95	0.36	9.90	68.4
OC	Ap	42	1.91	1.90	2.35	0.56	0.59	0.50	26.2
					Soils with 2:1 clay dominance				
FI	Ap	42	0.47	0.47	0.56	0.51	0.28	0.13	27.7
Clay	Ap	42	41.06	36.90	48.33	0.75	0.24	12.47	30.4
Sand	Ap	42	21.35	20.21	38.07	0.28	-1.04	11.02	51.6
OC	Ap	42	1.71	1.71	2.33	0.54	1.20	0.48	28.1

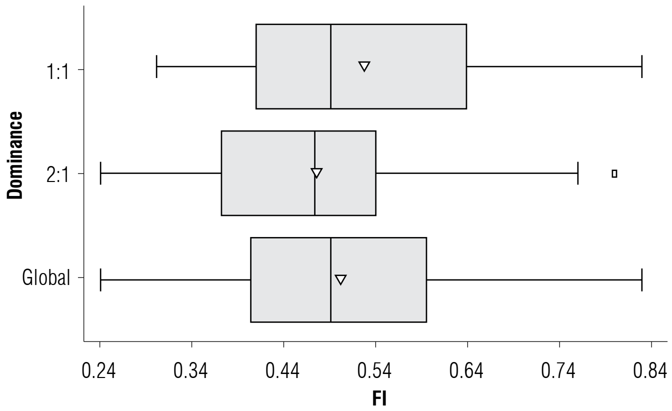

FIGURE 1. Box plot of the FI for all of the soils (global) and for the soils with a dominance of clay 1:1 and clay 2:1 in soils cultivated with sugar cane (southwest region of Colombia).

favors the structure and stability of aggregates, making a soil resistant to physical damage from tilling and rapid wetting (Watts and Dexter, 1998). Macks *et al.* (1996) confirmed that soils with a suitable structural condition are characterized by having a combination of high friability, high OC content, high levels of aggregate stability and low apparent density.

The analysis of all of the studied soils also showed that the sand fraction had a highly significant, negative correlation with the FI, clay, and OC (Tab. 5). On the other hand, a highly significant, positive correlation was observed between the clay content and OC, which indicated the accumulation of organic material in soils with fine textures.

In the soils with a kaolinite dominance (1:1 clay), the FI did not present a correlation with any of the analyzed variables, probably due to the low specific surface area that is seen in this clay type. Nevertheless, similar to the above description, a highly significant, positive correlation was observed between the clay and OC and a highly significant, negative correlation was observed between the sand and OC for all of the soils (Tab. 5).

In the soils with a 2:1 clay dominance (smectite and vermiculite), there was a highly significant, positive correlation between the FI and OC (Tab. 5), similar to the results of the analysis with all of the soils and in agreement with reports from Watts and Dexter (1998) and Macks *et al.* (1996). This indicated that the 2:1 clay dominance, with a large specific surface area, can generate larger unified plains with the OC, which form micro- and macroaggregates that are more stable and have a higher FI. Other authors have found a negative correlation between the FO and OC, attributable to the low range of OC contents in the evaluated soils (2.0 to 4.4%), but the FI presented a highly significant, positive correlation with the clay content (Imhoff *et al.*, 2002).

In the present study, the soils with a 2:1 clay dominance demonstrated a highly significant, negative correlation

TABLE 4. Kolmogorov-Smirnov and Shapiro-Wilk normality tests of the variables considered in soils cultivated with sugar cane (southwest region of Colombia).

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Degrees of freedom	Significance	Statistic	Degrees of freedom	Significance
FI	0.080	82	0.200*	0.975	82	0.110
Sand	0.088	82	0.183	0.936	82	0.000
Clay	0.114	82	0.011	0.956	82	0.007
OC	0.068	82	0.200*	0.977	82	0.139

*Lower limit of the true significance.

TABLE 5. Pearson correlation for the FI of all of the studied soils and for the 1:1 and 2:1 clay dominance in soils cultivated with sugar cane (southwest region of Colombia).

	All of the soils			
	FI	Clay (%)	Sand (%)	OC (%)
FI	1	0.176	-0.358**	0.266*
Clay (%)	0.176	1	-0.771**	0.548**
Sand (%)	-0.358**	-0.771**	1	-0.611**
OC (%)	0.266*	0.548**	-0.611**	1
	Soils with 1:1 clay dominance			
	FI	**Clay (%)**	**Sand (%)**	**OC (%)**
FI	1	-0.109	-0.003	-0.068
Clay (%)	-0.109	1	-0.782**	0.602**
Sand (%)	-0.003	-0.782**	1	-0.620**
OC (%)	-0.068	0.602**	-0.620**	1
	Soils with 2:1 clay dominance			
	FI	**Clay (%)**	**Sand (%)**	**OC (%)**
FI	1	0.455**	-0.628**	0.566**
Clay (%)	0.455**	1	-0.735**	0.414**
Sand (%)	-0.628**	-0.735**	1	-0.561**
OC (%)	0.566**	0.414**	-0.561**	1

* significant at $P \leq 0.05$; ** significant at $P \leq 0.01$.

between the FI and sand (Tab. 5), which can be explained by the dominance of particles between 0.05 and 0.1 mm (very fine sand) and 0.1 and 0.25 mm (fine sand) in this fraction. Furthermore, similar to the results in the analysis of all of the soils and the analysis of the soils with a 1:1 clay dominance, there was a highly significant, positive correlation between the total clay and OC.

Conclusions

Most of the studied soils (98.6%), which were cultivated with sugar cane, had FI values that classified them as friable (particularly those with a 1:1 clay dominance) and very friable (particularly those with a 2:1 clay dominance), indicating a structural condition that is suitable for farming, with low to moderate energy requirements, low GHG emissions and a reduced risk of damage to the physical quality when the task is carried out in suitable soil moisture content conditions.

The soils with the two clay dominance types presented a stable structural condition; however, the soils with a 1:1 clay dominance tended to produce a better distribution of aggregate size for sowing, requiring less energy for tilling, but were relatively susceptible to structural deterioration.

The analysis of all of the studied soils demonstrated a significant, positive correlation between the FI and OC and a highly significant, positive correlation between the clay and OC, confirming the importance of texture and organic material content for the friability of soils. Furthermore, there was a highly significant, positive correlation between the clay and OC, demonstrating an accumulation of organic material in the soils with fine textures.

This study identified a highly significant, positive correlation between the FI and clay in the group of soils with a 2:1 clay dominance, different from those with a 1:1 dominance, where there was no correlation. This suggested a better association between the OC and 2:1 clay that favored the soil structure and possibly resulted in a reduction in the requirements of tilling for the consumption of energy and for the emissions of GHG.

Contrary to the observations for the soils with a 1:1 clay dominance, the sand fraction had a highly significant, negative correlation with the FI in the soils with a 2:1 clay dominance. However, in the two soil groups, there was a highly significant, negative correlation between the sand fraction and OC.

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