# Tensile strength, friability, aggregation, and soil organic matter physical fractions of an Oxisol cultivated with sugarcane

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Abstract – The objective of this work was to evaluate the tensile strength, friability, aggregation, and the physical fractions of soil organic matter of a Rhodic Hapludox cultivated with sugarcane (*Saccharum officinarum*). The treatments consisted of one, three, and five years of cultivation of sugarcane, in the state of Rio Grande do Sul, Brazil. As a reference, a native forest adjacent to the cultivation area, with soil and relief characteristics similar to those of the cultivation areas, was used. Deformed samples were collected at 0.00–0.05, 0.05–0.10, and 0.10–0.20-m soil depths, for the determination of the soil physical attributes and for the physical fractionation of particle-size and density of the organic matter. The physical attribute evaluations were able to detect changes in the structural quality of the Oxisol, which resulted from the sugarcane cultivation. In comparison with the native forest, the stability and tensile strength of the aggregates decreased with the time of sugarcane cultivation. Tensile strength increased with soil depth, proportionally to the reduction of total soil organic carbon content. Soil preparation and straw burning reduce the input of fresh organic matter into the soil and accelerate the decomposition of the labile organic matter compartment, with negative consequences to soil physical properties over time.

Index terms: *Saccharum officinarum*, organic carbon, organic matter fractionation, soil physical quality.

# Resistência tênsil, friabilidade, agregação e frações físicas da matéria orgânica de um Latossolo Vermelho cultivado com cana-de-açúcar

Resumo – O objetivo deste trabalho foi avaliar a resistência tênsil, a friabilidade, a agregação e as frações físicas da matéria orgânica de um Latossolo Vermelho cultivado com cana-de-açúcar (*Saccharum officinarum*). Os tratamentos consistiram de um, três e cinco anos de cultivo de cana-de-açúcar, no Estado do Rio Grande do Sul. Como referência, utilizou-se uma mata nativa, adjacente à área de cultivo, com características de solo e relevo similares às das áreas de cultivo. Foram coletadas amostras deformadas à profundidade de 0,00–0,05, 0,05–0,10 e 0,10–0,20 m, para determinação dos atributos físicos do solo e para o fracionamento físico densimétrico e granulométrico da matéria orgânica. As avaliações dos atributos físicos foram capazes de detectar alterações da qualidade estrutural do Latossolo resultantes do cultivo de cana-de-açúcar. Em comparação à mata nativa, a estabilidade e a resistência tênsil dos agregados diminuíram com o tempo de cultivo da cana-de-açúcar. A resistência tênsil aumentou com a profundidade no solo, proporcionalmente à redução dos teores de carbono orgânico total. O preparo do solo e a queima da palhada reduzem o aporte de matéria orgânica fresca ao solo e aceleram a decomposição do compartimento lábil da matéria orgânica, com consequências negativas às propriedades físicas do solo ao longo do tempo.

Termos para indexação: *Saccharum officinarum,* carbono orgânico, fracionamento da matéria orgânica, qualidade física do solo.

## Introduction

The world's necessity for alternative sources of energy put Brazil in a leading position, as the country is the world's largest producer of sugarcane (*Saccharum officinarum* L.), with a planted area of 8.6 million hectares, and a production forecast of 691 million tonnes of culms in the 2016/2017 crop year (Acompanhamento…, 2016). The country emerges as the world leader in sugar exports, and in the use of ethanol as a source of renewable energy (Costa, 2009). Currently, the increasing socioeconomic importance of sugarcane cultivation resulted in an increased planted area in the state of Rio Grande do Sul, which

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is mainly due to favorable soil and climatic conditions for cultivation that has led to the geographic expansion of the crop in Brazil. However, negative impacts of this crop establishing on soil properties have been reported as a consequence of inappropriate soil management (Souza et al., 2012b, 2014; Fagundes et al., 2014).

Intensive use of soils with sugarcane modifies their physical and chemical properties, resulting in changes that affect the bulk density, aggregation (Surendran et al., 2016), and organic matter contents (Souza et al., 2012a), with negative consequences on the soil structure. In addition, studies on the soil structural quality, associated with different soil managements, have been postulated for soil tensile strength (TS) and friability (F) (Blanco-Moure et al., 2012; Reis et al., 2014a, 2014b).

Tensile strength (TS) is defined as the force per unit area required to fracture soil aggregate (Dexter & Watts, 2000). According to Dexter & Kroesbergen (1985), it is probably the most useful measurement of individual-resistance aggregates because it can be determined by a simple test, on a wide range of aggregate sizes, consisting of a sensitive indicator of the structural soil condition. Therefore, TS has been used as a soil quality indicator for the management of physical and mechanical processes. Tormena et al. (2008b) evaluated the TS and the friability (F) in an Oxisol under different land use systems, and they found that these attributes expressed a soil quality decrease proportional to the intensity of soil use.

Friability represents another indicator of physical quality, since a friable condition of the soil is desirable for germination, seedling growth, and establishment of the crops. It indicates a tendency of a soil mass to dispose of smaller aggregates with the application of a given amount of stress or load (Watts & Dexter, 1998) due to the weakness planes or fracture zones (Dexter & Watts, 2000).

The soil organic matter (SOM) fractionation have aided with the identification and understanding of carbon accumulation in different soil compartments (Santos et al., 2012; Conceição et al., 2014; Signor et al., 2014). Changes in the proportion of labile SOM fractions, such as carbon of the coarse fraction (CCF), free-light fraction (FLF), and the occluded-light fraction (OLF) can provide information on the environmental sustainability and soil quality in agroecosystems, allowing of corrections for the soil management (Santos et al., 2011).

In Brazil, most of the studies on the effects of soil management under sugarcane cultivation on the soil quality were done in the Southeast and Center-West regions of the country. However, for the southern, and especially for the state of Rio Grande do Sul, these studies are still scarce.

The objective of this work was to evaluate the ensile strength, friability, aggregation, and soil organic matter physical fractions of a Rhodic Hapludox cultivated with sugarcane, with cultivation times of one, three, and five years.

## Materials and Methods

The study was developed in areas belonging to the Grandespe Distillery, located in the municipality of Salto do Jacuí, in the state of Rio Grande do Sul, Brazil (28°59'S; 53°14'W; at 349–369 m altitude). The soil of the experimental area was classified according to Santos et al. (2013) as a Latossolo Vermelho distrófico (Rhodic Hapludox), with a clayey texture (286 g kg$^{-1}$ sand, 233 g kg$^{-1}$ silt, and 478 g kg$^{-1}$ clay). The treatments consisted of different cultivation times of sugarcane: one, three, and five years. As a reference, an adjacent native forest area was used, with soil and landscape properties similar to those of the cultivated areas.

The climate in the experimental area is a humid subtropical type Cfa, according to the Köppen-Geiger's climate classification. The areas have been cultivated with sugarcane (*Saccharum officinarum*) since 1988, after conventional tillage, which consisted of subsoiling down to 0.50 m, two heavy disking, and of opening furrows 0.25 m deep. The fertilization was performed with 500 kg of NPK fertilizer (5% N, 25% $P_2O_5$, and 25% $K_2O$), as recommended by Araújo et al. (2013), with 350 kg applied in the planting line at 0.30-m depth, using a cultivator, and 150 kg broadcasted. The planted varieties were SP 801 842 and RB 835 089, with manual harvest after the burning of straw.

A completely randomized experimental design was carried out, with disturbed soil samples collected randomly at 10 points in the planting line, for each treatment. The samples were taken at 0.00–0.05, 0.05–0.10, and 0.10–0.20 m soil depths, using a cutting shovel, and packed in plastic bags. The soil from the samples was air dried in the shade, until it reached the appropriate moisture for the point of brittleness. A portion of the sampled soil was passed through a 9.52 mm opening sieve for determining the mean weight diameter (MWD), according to the methodology described by Kemper & Rosenau (1986), and Palmeira et al. (1999). Another portion was passed through a 2.00 mm opening sieve to determine the total organic carbon (TOC) content, and particle-size and density of physical fractions of SOM.

The particle-size physical fractionation was carried out according to Cambardella & Elliott (1992), by which the material retained on the sieve with a mesh diameter ≥53 μm corresponded to the carbon of the coarse fraction (CCF), while the carbon associated minerals (CAM) (<53 μm) were obtained by the difference between TOC and CCF.

The density fractionation was performed according to Conceição et al. (2008), using a solution of sodium polytungstate (2.0 Mg $m^{-3}$). The dispersed energy applied by ultrasound was of 408 J $mL^{-1}$, to the samples from the soil collected at 0.00–0.05 and 0.05–0.10 m depths; and of 299 J $mL^{-1}$, to the samples collected at 0.10–0.20 m depth. These energy values were previously determined to ensure the total dispersion of the soil mass (aggregates) into primary particles. The carbon from the heavy fraction (HF) was obtained by the difference between TOC and free-light fraction (FLF), added to the occluded light fraction (OLF).

For the quantification of TS, 175 aggregates were selected from each treatment and layers, resulting in 2.100 aggregates. In the indirect tension test, an electronic linear actuator was used at 4 mm $s^{-1}$ constant speed. Before the application of force, each aggregate was weighted, and measured with a caliper rule to determine their mean diameter for height, width, and length. The aggregates were then dried in kiln, at 105°C for 24 hours, in order to determine the gravimetric moisture (Donagema et al., 2011). On average, the aggregates were 0.11 m height, 0.17 m width, and 0.12 m length, with 3.12% of gravimetric moisture. Each aggregate was accommodated in its more stable position for the evaluations, with a load application of 20 kgf. The value of the applied force (P) for the tensile rupture of the aggregate was recorded with an electronic system of data acquisition. The TS was calculated according to Dexter & Kroesbergen (1985) as $TS = 0.576\ (P/D^2)$, in which: 0.576 is the proportionality constant; P is the applied force (N), and D is the aggregate effective diameter (mm), which was quantified according Watts & Dexter (1998) as $D = D_m\ (M/M_o)$, in which Dm is the average diameter of aggregate (mm); M is the mass of the individual aggregate (g); and $M_o$ is the average mass of aggregates evaluated in the population .

Friability (F) was also estimated with the method proposed by Watts & Dexter (1998), according the equation $F = \sigma y / Y \pm \sigma y / \left[ Y (2n)^{0.5} \right]$, in which: F is the soil friability; σy is the standard deviation of the TS measured values; Y is the average of the TS measured values in all aggregates; and n is the number of replicates. The second term of this equation represents the standard error of the coefficient of variation. The F was classified into classes according to Imhoff et al. (2002): nonfriable, F<0.10; slightly friable, F = 0.10 to 0.20; friable, F = 0.20 to 0.50; very friable, F = 0, 50 to 0.80; and mechanically unstable, F>0.80.

The results were subjected to the analysis of variance, and the mean values were compared by the Tukey's test, at 5% probability, using the statistical software Winstat 2.0 (Machado & Conceição, 2003). Pearson correlation coefficient was used to assess the degree of correlation between variables.

## Results and Discussion

The highest-MWD values were found in the native forest at 0.00–0.05 and 0.05–0.10 m soil depths (Table 1) due to the greater abundance of organic residues in these layers. These residues, decomposed by microbial action, form active compounds that favor cementing and stabilize the aggregates (Salton et al., 2008). The root growth of tree species also contributes to the formation, maintenance, and stabilization of larger aggregates.

The 0.00–0.05 m soil depth showed the lowest-MWD value, mainly after five years (S5) of sugarcane cultivation. According to Góes et al. (2005) and Centurion et al. (2007), these results are related to the most disruptive effect of using the soil revolving. Additionally, Luca et al. (2008) mentioned that this result can be associated with a lower TOC, which contributes to the reduction of the aggregate stability. At 0.10–0.20 m soil depth, the treatments with one year of cultivation (S1) and the native forest showed the highest MWD. In the treatment S1, this result may be related to the soil disturbance during the preparation and planting of sugarcane, compared to other cycles, which did not have the soil prepared after the sugarcane harvest (Souza et al., 2012a).

According to Fontana et al. (2010), lower-MWD values in cultivated areas are related to a conventional soil management with plowing, harrowing, and subsoiling. According to Góes et al. (2005), the intense soil tillage for the cultivation of sugarcane increases the SOM contact with air, accelerating its decomposition, which reflects in its contents in the soil over the crop cycles, with a consequent reduction of MWD.

Góes et al. (2005) observed the highest-MWD values in the native forest, and the smaller in the area cultivated with sugarcane for seven years. Souza et al. (2012a) verified that the highest-MWD values were found in the management involving sugarcane cultivations for just one year, and that the MDW values decrease over cultivation time. Rossetti et al. (2014) reported that the MWD decreases with sugarcane cultivation, in comparison to the native forest. Among the cultivated areas, the authors also reported greater MWD values in the area cultivated for eight years.

The average values of TS were lower in the native forest (Table 1) due to the nonrevolving of the soil, and to the higher concentration of labile SOM in this system. According to Regelink et al. (2015), soil aggregation is related to the organic carbon content in the agricultural soils.

**Table 1.** Mean weight diameter of aggregates (MWD), tensile strength (TS), friability (F), and friability classification at 0.00–0.05, 0.05–0.10, and 0.10–0.20 m soil depths of an Oxisol cultivated with different cultivation times of sugarcane (*Saccharum* sp.), and under a native forest(1).

| Cultivation time | MWD (mm) | TS (KPa) | Friability | Classification |
|---|---|---|---|---|
| | | 0.00–0.05 m | | |
| One year | 1.91b | 84.89a | 0.56a | Very friable |
| Three years | 2.04b | 93.70a | 0.62a | Very friable |
| Five years | 1.18c | 91.66a | 0.56a | Very friable |
| Native forest | 3.29a | 67.19b | 0.53a | Very friable |
| | | 0.05–0.10 m | | |
| One year | 2.39b | 91.57b | 0.62a | Very friable |
| Three years | 2.50b | 118.50a | 0.52ab | Very friable |
| Five years | 1.90b | 126.75a | 0.47ab | Friable |
| Native forest | 3.62a | 69.75c | 0.43b | Friable |
| | | 0.10–0.20 m | | |
| One year | 3.38a | 109.97b | 0.52ab | Very friable |
| Three years | 2.60b | 117.84b | 0.57a | Very friable |
| Five years | 1.98b | 138.61a | 0.46ab | Friable |
| Native forest | 3.55a | 83.60c | 0.43b | Friable |

(1)Means followed by equal letters, for each soil depth, do not differ by Tukey's test, at 5% probability.

Concerning the cultivated areas, the cultivation times had no effect on TS values at 0.00–0.05 m soil depth. However, in the layer 0.05–0.10 m, the highest values were observed with greater cultivation times (S3 and S5), and in the layer 0.10–0.20 m, in the treatment S5.

The average TS values obtained in the present study were higher than those reported by Imhoff et al. (2002), Giarola et al. (2003), Guimarães et al. (2009), and Ferreira et al. (2011). According to Blanco-Canqui et al. (2005), TS values are related to soil management and, in sugarcane production systems, the intense tillage prior to the crop establishing, besides the heavy machinery traffic for fertilization, and sugarcane transportation after manual harvesting, may have increased these values, as a result of increased soil density. Therefore, the faulty zones (pores) inside aggregates reduce, connecting the mineral particles or rearranging them, increasing the resistance of aggregates to breakage, and thus raising TS values.

Bavoso et al. (2010) observed that no-tillage provided larger TS values than other soil management systems. Tormena et al. (2008b) verified that the cultivated areas had higher TS values than those of the fallow and the native forest.

The classification of soil friability depends on its TS values and takes into account the mean diameter of the aggregates. All treatments at 0.00–0.05 m soil depth were classified as very friable (Table 1). In the layers 0.05–0.10 and 0.10–0.20 m, the treatments S5 and were classified as friable, and S1 and S3 were classified as very friable. Higher friability values indicate that larger aggregates have smaller TS than the smaller; being, therefore, more easily broken into smaller units with greater TS, producing a distribution of aggregate sizes more suited to the soil management system (Imhoff et al., 2002).

The treatments significantly affected TOC, CCF, CAM, FLF, OLF, and HF contents (Table 2). In all layers, the highest contents of these variables were found in the native forest, due to greater plant residue inputs in this system, and to the absence of soil disturbance for agricultural use. In the cultivated areas, the exposure of soil carbon to microbial attack and to erosive effects, as a consequence of soil tillage, and the practice of straw burning before harvesting, has a great impact on SOM (Tavares et al., 2010; Müller et al., 2012; Rossetti et al., 2014).

In all evaluated systems, TOC contents were higher on the surface layer and decreased with depth (Table 2). In the native forest, SOM accumulates in the surface layers due to intense addition of organic residues from plant roots and litter to the soil surface (Zschornack, 2007). In the cultivated areas, however, this reduction of TOC contents with depth resulted from SOM oxidation due to soil tillage and straw burning at harvest, at the establishing and reform of the sugarcane crop (Góes et al., 2005).

Galdos et al. (2009) observed that the TOC contents at 0.00–0.10 m soil depth were 36% lower in sugarcane areas where the straw was burnt, in comparison to TOC in the native forest. Furthermore, they observed 30% more TOC in an area cultivated for eight years without burning than in the area where straw was burnt.

The effects of TOC contents on TS are still controversial. Tormena et al. (2008b) observed an inverse linear relation between TS and TOC, in a medium texture Oxisol. Blanco-Canqui et al. (2005) also verified an inverse exponential relation between these parameters. However, Guimarães et al. (2009) reported a direct between these same parameters in an Oxisol, and attributed this result to a cementing effect of TOC on soil mineral particles with humified SOM.

**Table 2.** Soil contents of total organic carbon (TOC), carbon of the coarse fraction (CCF), carbon associated with minerals (CAM), and of the free-light fraction (FLF), occluded light fraction (OLF), and heavy fraction (HF) of soil organic matter, at 0.00–0.05, 0.05–0.10, and 0.10–0.20 m soil depths of an Oxisol cultivated with sugarcane (*Saccharum* sp.), at different cultivation times, and under native forest(1).

| Cultivation time | TOC | CCF | CAM | FLF | OLF | HF |
|---|---|---|---|---|---|---|
| | ----------------------------- | ------------------------- | (g kg$^{-1}$) | ------------------------- | | |
| | | | 0.00–0.05 m | | | |
| One year | 16.40b | 3.35b | 13.05b | 1.20b | 2.41b | 12.79b |
| Three years | 15.88b | 2.70b | 13.18b | 0.98b | 2.39b | 12.51b |
| Five years | 15.50b | 3.21b | 12.29b | 0.99b | 2.71b | 12.80b |
| Native forest | 27.94a | 10.19a | 17.75a | 5.77a | 5.61a | 16.61a |
| | | | 0.05–0.10 m | | | |
| One year | 15.92b | 2.76b | 13.10b | 0.68b | 2.24c | 13.00b |
| Three years | 15.25b | 1.70b | 13.55b | 0.39c | 2.35b | 12.51b |
| Five years | 15.31b | 2.48b | 12.83b | 1.00b | 2.54b | 11.77b |
| Native forest | 25.20a | 6.33a | 18.87a | 2.56a | 4.31a | 18.33a |
| | | | 0.10–0.20 m | | | |
| One year | 15.35b | 2.54b | 12.81b | 0.63b | 2.45b | 12.27b |
| Three years | 14.05b | 1.26c | 12.79b | 0.28c | 1.65c | 12.12b |
| Five years | 14.92b | 2.06b | 12.86b | 0.58b | 2.18b | 12.16b |
| Native forest | 20.23a | 3.18a | 17.05a | 1.24a | 3.77a | 15.22a |

(1)Means followed by equal letters, in each soil layer, do not differ by Tukey's test, at 5% probability.

Zhang (1994) reported that there are two opposite relations between SOM and TS: SOM can increase the number and strength of the connections between soil particles; and it can have a dilution effect, which implies the reduction of soil density, or the increase of the porosity of the aggregates. In the latter case, the decreased number of connections between soil particles, without an expressive increase in the strength of these connections, would reduce TS values.

Significant and negative linear correlations were observed between TS, TOC, and SOM physical fractions (Table 3). The highest correlation was between TS x TOC, and TS x HF. The reduction either of TOC content, or of the physical fractions, increases the TS values. These results corroborate Tormena et al. (2008b), Ferreira et al. (2011), and Reis et al. (2014b), who reported the increased TOC contents reduced the TS values, even in clayey soils.

However, Lehrsch et al. (2012) verified different results, with a significant positive correlation between TOC and TS, a very weak one though (r=0.22). Additionally, Reis et al. (2014a) verified that TS is highly related to TOC and CAM contents, and not to CCF.

**Table 3.** Pearson correlation coefficients (r) between tensile strength (TS) with total organic carbon (TOC), carbon of the coarse fraction (CCF), carbon associated with minerals (CAM), free-light fraction (FLF), the occluded light fraction (OLF), and the heavy fraction (HF) of soil organic matter, at 0.00–0.05, 0.05–0.10, and 0.10–0.20 m soil depths of an Oxisol cultivated with sugarcane (*Saccharum* sp.), at different cultivation times, and under native forest(1).

| | TOC | CCF | CAM | FLF | OLF | HF |
|---|---|---|---|---|---|---|
| | | | 0.00-0.05 m | | | |
| TS | -0.77* | -0.60* | -0.50* | -0.70* | -0.64* | -0.70* |
| | | | 0.05-0.10 m | | | |
| TS | -0.77* | -0.70* | -0.54* | -0.71* | -0.66* | -0.76* |
| | | | 0.10-0.20 m | | | |
| TS | -0.72* | -0.63* | -0.61* | -0.58* | -0.64* | -0.76* |

*Significant at 1% of probability.

## Conclusions

1. All evaluations of the attributes are sensitive to detect changes in the structural quality of an Oxisol cultivated with sugarcane, at different cultivation times.

2. Aggregate stability and tensile strength of the aggregates decrease with the cultivation times, and the tensile strength increases with soil depth proportionally to the reduction of the total soil organic carbon content.

3. Soil preparation and straw burning reduce the supply of fresh organic matter to the soil, and accelerate the decomposition of the labile organic matter compartment, with negative consequences to soil physical properties over time.

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