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# Tensile strength and friability of an Alfisol under agricultural management systems

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ABSTRACT: Management systems may influence the structural quality of soils. Tensile strength (TS) and friability (F) are indicators of soil structural quality. The aim of this study was to evaluate the TS and F of an Alfisol under different management systems. The treatments were as follows: (i) soil under conventional system with growing maize after tobacco cultivation, (ii) soil under conventional system with growing maize after use as pasture, (iii) soil under natural pasture, and (iv) a natural area with predominance of spontaneous vegetation. TS and F were evaluated at depths of 0.00-0.05 and 0.05-0.10 m. The water content of soil aggregates, soil particle-size distribution, total organic carbon, carbon in the coarse fraction and carbon associated with minerals were also determined. The increase in clay content and soil organic carbon influences the values of TS. The lowest TS was for the soil under maize cultivation after tobacco in the conventional system. Soil under natural area in the 0.05-0.10 m layer was classified as slightly friable, while other systems were classified as friable. Evaluations of the structural quality of soils under management systems can be performed using TS. However, F was not efficient in detecting changes between the different management systems.

## Introduction

The tensile strength (TS) of aggregates is defined as the force per unit area required to cause the disruption of aggregates, being the most useful measure of individual resistance of soil aggregates consisting of an indicator sensitive to the structural soil condition, that reflects the effects of natural factors, as well as land use and management (Dexter and Kroesbergen, 1985; Dexter and Watts, 2000).

The distribution of TS could be utilized as an index of soil friability (Utomo and Dexter, 1981). The friability (F) of the soil can be defined as the tendency of a soil mass to break into smaller sizes of aggregates under application of stress or load. As a result of its heterogeneous nature, TS responds to the weakness planes or fault zones between aggregates in this way and it can be estimated by the coefficient of variation of TS (Watts and Dexter, 1998).

F is synonymous with soil quality and is indicative of the soil structure being classified by these authors from measurements obtained by the volume of aggregates method from sandy loam soils that produces F values smaller than soils with different textures (Utomo and Dexter, 1981). The volume of aggregates method estimates F values ($F'$) as being the slope of the straight line that relates the logarithm of TS to the logarithm of the sample size (aggregate volume). This method produces F values smaller than those determined from the coefficient of variation method ($F$). Chan et al. (1999) found a mean ratio of $F/F'$ of $\sim 2$ for clayey soils. Imhoff et al. (2002) used the classification of F proposed by Utomo and Dexter (1981) multiplied by 2 to define classes of F for an Oxisol. The F classification proposed by Imhoff et al. (2002) was used for the F values in this work.

Textural class, clay mineralogy and dispersion of these, content of clay and silt, organic matter and their interactions are factors that affect the aggregation and stability of soil aggregates. Furthermore, the greater the concentration of poorly crystalline Fe oxides, conversely, the greater the impact of crystalline Fe forms on the TS of aggregates and soil F (Ley et al., 1993; Imhoff et al., 2002). Thus, the objective of this study was to evaluate the effect of agricultural management systems on the tensile strength and friability of an Alfisol.

## Materials and Methods

The study was conducted on agricultural areas located in Turuçu (31°25'S; 52°15'W) in the Southeastern part of the state of Rio Grande do Sul Brazil. According to Köppen`s classification, the climate is C*f*a (mesothermic humid), with average annual rainfall of 1,400 mm and mean temperature of 17 °C. The study was carried out on eroded granite and granitic sediments from the Rio Grande do Sul Shield. The relief varies from wavy to smooth wavy and all soils are shallow. The soil is a sandy loamy textured Hapludalf (USDA, 2012). The region where the city of Turuçu is located is composed of pioneer vegetation characterized by shrub-herbaceous species, typical of the lagoon, with forest formations and alluvial lowland, typical of the deciduous and semi-deciduous forests, with natural pastures as the primary land use (IBGE, 2004).

The treatments were: (i) soil under conventional system (using the disk plow, followed by two harrowings) (MT), planted with maize - *Zea mays* (L.) after tobacco - *Nicotiana alata* (Link et Otto). This area has been cultivated annually with a succession of crops (strawberry - *Fragaria vesca* (L.), tobacco and maize) for at least five years; (ii) soil under conventional system of maize cultivation after pasture (MNP), used for at least thirty years, 2009 being the first year of cultivation with maize; (iii) soil under natural pasture (NP) used for grazing for at least thirty years, without soil tillage and (iv) soil with a predominance of spontaneous vegetation, herein called natural area (NAT), without soil tillage.

The soil was sampled in Aug 2009 and Mar 2010, to obtain 48 blocks of soil (10 × 20 × 10 cm in height, length and width, respectively) from the layers of 0.00-0.05 and 0.05-0.10 m with the aid of a shovel (six replicates × four treatments × two depths = 48). These layers were chosen taking into consideration the rooting depth of crops and considered the zone most influenced by managements. Soil blocks were wrapped in plastic film immediately after removal to maintain the natural soil water content and the integrity of the samples until their arrival at the laboratory. They were carefully and manually fragmented along their planes of weakness and air dried. Later, 60 soil aggregates were selected per depth in the four areas studied, totaling 480 soil aggregates samples, ranging from 6 to 9 mm in diameter. Each soil aggregate was weighed and the effective diameter was obtained by the arithmetic average of the height, width and length of each aggregate.

The indirect tension test was carried out using an electronic actuator, linear model MA933 at a constant speed of 4 mm $s^{-1}$ until the aggregate failed i.e., until the formation of a continuous tensile crack which ran approximately between the polar diameters. Each soil aggregate was placed in the most stable position and loaded progressively, across a diameter, between a fixed lower plate and an upper parallel mobile plate that was assembled to accept an electronic load cell of 20 kg capacity. The electrical output was recorded by a data acquisition system. After each test, the aggregates of each set were oven dried at 105 °C to calculate the soil water content.

The gravimetric water content and particle size fraction analysis (Embrapa, 1997) are presented in Table 1 and Table 2 respectively. The TS (kPa) was calculated in accordance with the expression formulated by Dexter and Kroesbergen (1985):

$$TS = 0.576\left(\frac{P}{D^2}\right)$$

where the parameter 0.576 is a proportionality constant, P the applied force at failure (N), and D the effective diameter (mm). The equation was elucidated from the theory of loading spherical samples of linearly elastic material. Because of its simplicity it has been used to estimate the TS of aggregates (Chan et al., 1999). On the assumption that aggregate density is constant, the effective diameter of each aggregate (D) was calculated as in Watts and Dexter (1998).

$$D = Dm\left(\frac{M}{M_0}\right)^{\frac{1}{3}}$$

where Dm: is the average diameter of aggregate (mm), M is the mass of the individual aggregate (g), and $M_0$ the average mass of aggregates in the population (g).

Friability was also estimated by the method proposed by Watts and Dexter (1998) according to the equation:

$$F = \frac{\sigma_y}{Y} \pm \frac{\sigma_y}{Y\sqrt{2n}}$$

where F is the soil friability; $\sigma_y$ the standard deviation of measured values of TS, Y the average of the measured values of TS in all aggregates, and n the number of replicates. The second term of this equation represents the standard error of the coefficient of variation. Friability classes used were based on the values of F (dimensionless) proposed by 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).

Disturbed samples were obtained after passing through a sieve (mesh of 2 mm) for the physical fractionation of soil organic matter according to Cambardella and Elliott (1992). The concentration of total organic carbon (TOC) and carbon of the coarse fraction (CCF) in the soil mass were quantified by dry oxidation in an elemental analyzer. The carbon associated with minerals (CAM) was obtained by difference between TOC and CCF.

Data were tested for normality using Shapiro-Wilk statistics. Analysis of variance (Anova) and Duncan test ($p \leq 0.05$) were performed per treatment and per layers. Regression analysis was carried out on the values of TS and TOC, CCF and CAM. These statistical tests were performed using the SAS software (Statistical Analyses System Institute, version 5, 1999).

Table 1 – Gravimetric water content of analyzed aggregates of an Hapludalf under several management systems.

| Treatment[1] | Gravimetric water content (kg $kg^{-1}$) | |
|---|---|---|
| | 0.00 - 0.05 m | 0.05 - 0.10 m |
| MT | 0.55 a | 0.64 a |
| MNP | 0.24 b | 0.19 b |
| NP | 0.40 ab | 0.34 ab |
| NAT | 0.49 ab | 0.52 ab |

[1]MT: soil under maize cultivation after tobacco in conventional system; MNP: soil under maize cultivation after natural pasture in conventional system; NP: natural pasture; NAT: natural area. Numbers followed by the same letters in the column are not different by Duncan test ($p \leq 0.05$).

Table 2 – Particle size fraction of an Hapludalf under several management systems.

| Treatment[1] | Particle-size distribution (g $kg^{-1}$) | | | Soil textural class |
|---|---|---|---|---|
| | Clay | Silt | Sand | |
| | | 0.00 - 0.05 m | | |
| MT | 95 | 205 | 699 | Sandy loam |
| MNP | 133 | 211 | 655 | Sandy loam |
| NP | 152 | 238 | 609 | Sandy loam |
| NAT | 191 | 296 | 512 | Sandy loam |
| | | 0.05 - 0.10 m | | |
| MT | 92 | 208 | 699 | Sandy loam |
| MNP | 135 | 218 | 646 | Sandy loam |
| NP | 151 | 243 | 605 | Sandy loam |
| NAT | 164 | 244 | 591 | Sandy loam |

[1]MT: soil under maize cultivation after tobacco in conventional system; MNP: soil under maize cultivation after natural pasture in conventional system; NP: natural pasture; NAT: natural area.

## Results and Discussion

Statistical moments for tensile strength (TS), total organic carbon (TOC), carbon of the coarse fraction (CCF) and carbon associated with minerals (CAM) are presented in Table 3. The results of the coefficient of variation (CV) for tensile strength are lower than the results of Bartoli et al. (1992) that found CV values ranging from 40 to 73% for Oxisols. Imhoff et al. (2002) and Blanco-Canqui et al. (2005) have reported log-normal distribution, while Dexter and Watts (2000) reported normal distribution, corroborating the findings of this study.

Soil treatments used in conventional systems revealed reduced levels of soil organic matter, a fact that can be attributed to variations of CAM showing the importance of organo-mineral interactions for aggregation and soil structure (Table 4). The reduction of TOC, CCF and CAM values in 0.00-0.05 to 0.05-0.10 m layers for the MNP, NP and NAT treatments can be generally attributed to the time of use of conventional tillage (plowing plus harrowing). Only the MT treatment resulted in an increase of TOC of 14 % in the 0.05-0.10 m layer, which can be imputed to crop rotation.

Imhoff et al. (2002) evaluated the TS in an Oxisol, and found that the mineral fraction of the soil (clay and silt) has a very strong interaction ($p < 0.0001$) with the organic fraction of the soil and that the effects of silt and clay content on the TS depend on the content of organic matter. Czarnes et al. (2000) reported that tensile strength was affected by organic exudates, rooting and plant growth. Accordingly, reductions in organic carbon caused by cropping practices, led to changes in the values of tensile strength of aggregates, making them less resistant to management processes.

Agricultural soils exhibit little stability against applied tensile stresses. Nevertheless, tensile linkages in soils are the most effective factors in soil resistance against cultivation operations, execution of horizontal load (in tensile processes), and vertical load (in displacement processes) under field conditions (Chancellor, 1994). Soils which possess aggregates with greater TS are more resistant to mechanical dispersion when subjected to soil preparation.

Table 3 – Statistic moments of total organic carbon (TOC), carbon of the coarse fraction (CCF), carbon associated with minerals (CAM) and tensile strength (TS) of an Hapludalf under several management systems.

| | TOC | CCF | CAM | TS | TOC | CCF | CAM | TS |
|---|---|---|---|---|---|---|---|---|
| | ——— g dm$^{-3}$ ——— | | | kPa | ——— g dm$^{-3}$ ——— | | | kPa |
| | | | | MT[1] | | | | |
| | 0.00 - 0.05 m | | | | 0.05 - 0.10 m | | | |
| Mean | 9.7 | 4.03 | 5.67 | 111.15 | 11.04 | 3.85 | 7.19 | 131.07 |
| Standard deviation | 1.48 | 1.15 | 1.67 | 34.67 | 4.69 | 1.12 | 4.22 | 24.08 |
| Coefficient of variation (%) | 15.29 | 28.65 | 29.5 | 31.2 | 42.51 | 29.21 | 58.65 | 18.37 |
| Minimum value | 7.61 | 3.18 | 2.01 | 59.17 | 7.22 | 3.02 | 2.9 | 85.71 |
| Maximum value | 12.8 | 7.29 | 8.34 | 155.33 | 22.47 | 6.5 | 17.42 | 167.53 |
| | | | | MNP[2] | | | | |
| | 0.00 - 0.05 m | | | | 0.05 - 0.10 m | | | |
| Mean | 15.95 | 3.95 | 12 | 154.15 | 14.36 | 3.64 | 10.72 | 131.3 |
| Standard deviation | 2.31 | 0.52 | 2.07 | 48.7 | 1.17 | 0.58 | 1.13 | 38.6 |
| Coefficient of variation (%) | 14.51 | 13.04 | 17.3 | 31.59 | 8.16 | 15.95 | 10.56 | 29.4 |
| Minimum value | 12.55 | 3.19 | 8.96 | 108.36 | 11.93 | 3.04 | 8.43 | 94.58 |
| Maximum value | 20.23 | 4.66 | 15.65 | 270.35 | 16 | 4.8 | 12.76 | 218.02 |
| | | | | NP[3] | | | | |
| | 0.00 - 0.05 m | | | | 0.05 - 0.10 m | | | |
| Mean | 29.27 | 5.75 | 23.52 | 166.21 | 19.35 | 4.59 | 14.76 | 155.91 |
| Standard deviation | 2.51 | 2.42 | 2.11 | 46.18 | 2.1 | 2.73 | 3.28 | 61.09 |
| Coefficient of variation (%) | 8.59 | 42.06 | 8.96 | 27.78 | 10.87 | 59.5 | 22.25 | 39.18 |
| Minimum value | 24.82 | 3.43 | 19.2 | 110.95 | 16.87 | 2.84 | 7.71 | 88.76 |
| Maximum value | 33.01 | 10.09 | 27.18 | 246.86 | 21.88 | 11.7 | 18.85 | 316.21 |
| | | | | NAT[4] | | | | |
| | 0.00 - 0.05 m | | | | 0.05- 0.10 m | | | |
| Mean | 31.33 | 7.75 | 23.58 | 169.36 | 19.89 | 3.91 | 15.98 | 165.68 |
| Standard deviation | 6.78 | 2.16 | 5.38 | 45.59 | 6.88 | 0.56 | 6.42 | 55.3 |
| Coefficient of variation (%) | 21.63 | 27.82 | 22.84 | 26.92 | 34.58 | 14.31 | 40.16 | 33.38 |
| Minimum value | 22.42 | 5.72 | 15.86 | 114.28 | 11.79 | 3.14 | 8.63 | 91.53 |
| Maximum value | 43.2 | 13.42 | 32.94 | 281.81 | 31.96 | 4.95 | 27.5 | 261.84 |

[1]MT: soil under maize cultivation after tobacco in conventional system; [2]MNP: soil under maize cultivation after natural pasture in conventional system: [3]NP: natural pasture; [4]NAT: natural area.

Table 4 – Concentration of total organic carbon (TOC), carbon of the coarse fraction (CCF) and carbon associated with minerals (CAM) of an Hapludalf under several management systems.

| Treatment[1] | TOC | CCF | CAM |
|---|---|---|---|
| | g dm$^{-3}$ | | |
| | | 0.00 - 0.05 m | |
| MT | 9.70 c | 4.03 b | 5.67 c |
| MNP | 15.95 b | 3.95 b | 12.00 b |
| NP | 29.27 a | 5.75 b | 23.52 a |
| NAT | 31.33 a | 7.75 a | 23.58 a |
| | | 0.05 - 0.10 m | |
| MT | 11.04 b | 3.85 a | 7.19 c |
| MNP | 14.36 b | 3.64 a | 10.72 bc |
| NP | 19.35 a | 4.59 a | 14.76 ab |
| NAT | 19.89 a | 3.91 a | 15.98 a |

[1]MT: soil under maize cultivation after tobacco in conventional system; MNP: soil under maize cultivation after natural pasture in conventional system: NP: natural pasture; NAT: natural area. Numbers followed by the same letters in the column are not different by Duncan test ($p \leq 0.05$).

Correlations between total organic carbon, carbon of the coarse fraction and carbon associated with minerals suggest increases in TS present a significant linear relationship ($p < 0.01$) (Figure 1). Similar results were obtained by Blanco-Canqui et al. (2005). In addition to organic matter and clay content, silt content and poorly crystalline iron oxides also have a positive effect on TS (Imhoff et al., 2002). The relationships of TS and other soil properties, such as organic carbon, have not been well resolved due to the many factors involved, e.g. soil texture, porosity, water content (Munkholm and Kay, 2002). TS is more strongly related to TOC and CAM than CCF which can be attributed to the formation of stable bonds between soil organic matter and the metal ions and minerals from the soil, that are significantly affected by soil management.

There are two opposing effects of soil organic matter on TS: an increase in the number and strength of linkages between the particles and the effect of dilution that would reduce the bulk density or increase the porosity of aggregates (Zhang, 1994). The increase in soil organic matter results in higher porosity of the aggregate which reduces the number of bonds between particles, in which case the strength of these links is not increased, and there is a consequent reduction in TS.

The predominance of one or another mechanism will determine the direction of correlation between TS of aggregates and soil organic matter, as verified in studies by Rahimi et al. (2000). Zhang (1994) found that there is reduction in TS with increasing organic matter due to the increase the porosity of aggregates. The degree of humidification also influences TS, demonstrating that the more humidified the soil organic matter becomes, the less its effect in reducing TS (Zhang, 1994).

The highest average values of TS were obtained in the 0.00 to 0.05 m layer. This fact can be attributed

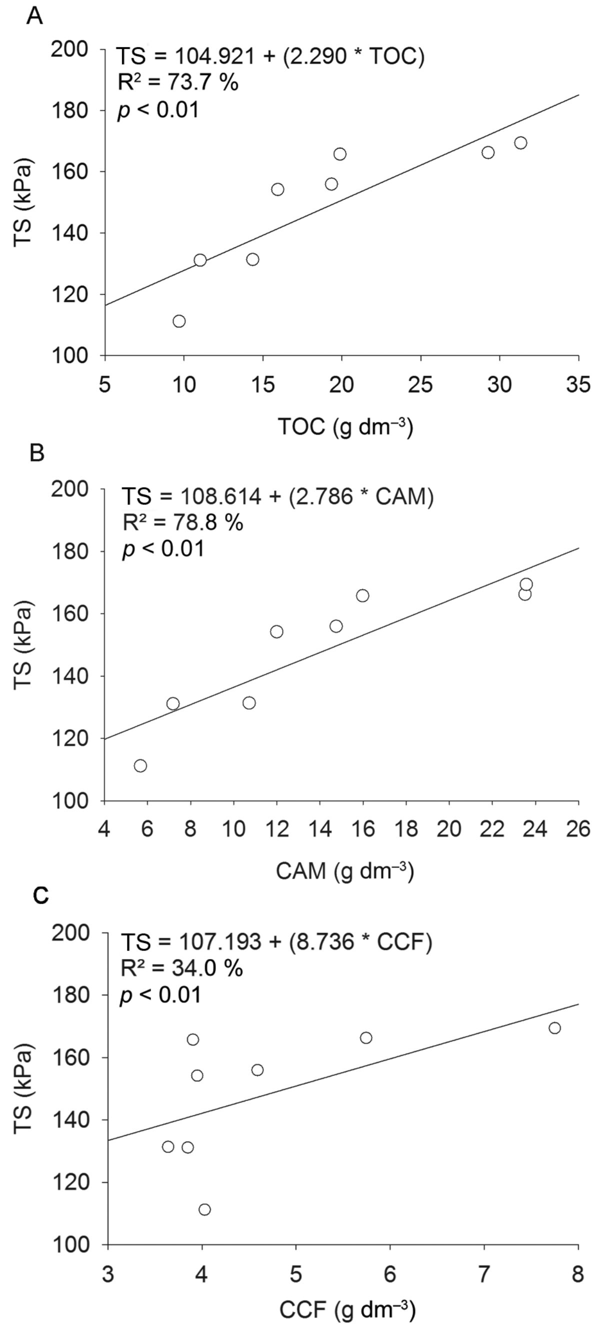


Figure 1 – Correlation between tensile strength (TS) and total organic carbon (TOC) (A), carbon associated with minerals (CAM) (B), carbon of the coarse fraction (CCF) (C) of an Hapludalf under several management systems.

to the content of TOC, which in general was also high in the surface layer. The MT and MNP systems had the lowest TS in the two soil layers (Table 5), probably due to the land use history, in line with the common fact that management systems promote changes in soil physical

Table 5 – Average tensile strength (TS) and friability (F) values of two layers of an Hapludalf under several management systems.

| Treatment[1] | TS, KPa | F | Soil classification as the friability[2] |
|---|---|---|---|
| | 0.00 - 0.05 m | | |
| MT | 111.15 b | 0.27 ± 0.05 | Friable |
| MNP | 154.15 a | 0.28 ± 0.06 | Friable |
| NP | 166.21 a | 0.32 ± 0.06 | Friable |
| NAT | 169.36 a | 0.31 ± 0.06 | Friable |
| | 0.05 - 0.10 m | | |
| MT | 131.07 a | 0.33 ± 0.07 | Friable |
| MNP | 131.30 a | 0.39 ± 0.08 | Friable |
| NP | 155.91 a | 0.29 ± 0.06 | Friable |
| NAT | 165.68 a | 0.18 ± 0.04 | Slightly friable |

[1]MT: soil under maize cultivation after tobacco in conventional system; MNP: soil under maize cultivation after natural pasture in conventional system: NP: natural pasture; NAT: natural area; [2] Based on Imhoff et al. (2002). Same letters in the same column means no difference between values (Duncan test $p \leq 0.05$).

quality and TOC. TS and F are controlled by the distribution of microcracks and weak points within the soil aggregates (Dexter, 2004). The results in MT and MNP may also be associated with variations in intensity and frequency of wetting and drying cycles of soil resulting in mechanically weaker aggregates, and that, under application of a load, they do not produce a broad aggregates size distribution for the larger diameters (Zhang, 1994).

The highest average values of TS were observed in the top layer in different management systems (Table 5), which may be related to TOC, CCF and CAM (Table 4). Imhoff et al. (2002) found an increase in TS due to the increase in the number of electrical charges from clays, which favors the formation of bonds between mineral particles and/or mineral and organic particles.

The highest values of TS in both layers of the NAT and NP treatments suggest that the conditions of soil structure are due to the management system, which allows greater incorporation of organic residues and consequently, a greater aggregation of soil particles, these results confirming that the increase of organic matter favors the increase of TS. However, the values of TS in this study are, in general, higher (Table 3) than those found by Imhoff et al. (2002) evaluating an Oxisol under sugarcane cultivation.

Since the classification of the friability of the soil comes from the values of TS, all management systems, in the two layers, were classified as friable, except for NAT, in the 0.05 to 0.10 m layer, that was classified as slightly friable (Table 5). Levels of friability that fall into the category "slightly friable" indicate that the aggregates are resistant to fracture when subjected to load or pressure. Macks et al. (1996) suggest friability as an indicator of the restriction of the structural condition of the soil for crop establishment in no-tillage. The condition of the soil in the "friable" category requires reduced cropping intensity for the production of small aggregates and, consequently, a planting bed suitable for germination and plant establishment. High values of friability indicate the potential of aggregates to suffer intense fracturing, when minimal force is applied, which is why its use is inappropriate in mechanized agricultural crops (Macks et al., 1996). Considering the historical use based on the classification proposed by Imohff et al. (2002), it appears that for the Hapludalf, the classification does not provide evidence of changes caused by soil management.

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