SOIL FRIABILITY ASSESSMENT OF SOME AGRICULTURAL SOILS IN ROMANIA

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Abstract

Tensile strength is a dynamic property and is sensitive to soil structure because it is related to the presence of air-filled pores, the occurrence of micro-cracks and the strength of inter-granular bonds within and between micro-cracks. Moreover, the tensile strength of soil is much affected by the soil water content and processes which change pore characteristics and/or the cementation between structural units. A friability index has been proposed that is based on measurements of tensile strength of different sized aggregates. The main objectives of the present paper were to measure the mechanical properties (tensile strength and friability) of soil aggregates collected from three agricultural soils, and to explore the relationships between mechanical and basic physical properties of the investigated soils. Soils used in these investigations can be described as “friable” according to the classification used for friability index, \( F_1 \), values. Soil aggregates of the sandy soil from Grădiștea had the smallest values of tensile strength. The highest values of tensile strength were recorded in case of clayey soil, whereas the loamy soil had values between the sandy and clayey soils. Increasing organic matter content decreased the values of tensile strength for soil aggregates from all soils. High values of clay content in case of loamy and clayey soils increased the values of tensile strength. Increasing amount of clay in sandy soil has been shown to increase the tensile strength of this soil. This may be due to clay particles acting as cementing materials between large particles. Higher amounts of clay in sandy soils provide more opportunities for interparticle contact. Small size classes of aggregates presented higher values of tensile strength as compared with larger size classes of aggregates when the volume dependence method was used. In case of sandy and clayey soils were found underestimates and respectively overestimates of \( F_1 \) values. As for the loamy soil, the volume dependence method (\( F_1 \)) gave similar values when compared to the coefficient of variation method (\( F_2 \)). The coefficient of variation method is recommended as standard method for measuring soil friability.

Key words: friability index, tensile strength, soil aggregates, aggregate size.

INTRODUCTION

The term “tensile strength”, \( Y \), was defined by Dexter and Watts (2001) as the stress (force per unit area) required to breakdown the soil aggregates.

Tensile strength is an indicator which describes the minimum force required during seedbed preparation when large clods are fragmented without disturbing soil microstructure (Munkholm and Kay, 2002).

Tensile strength is a dynamic property (Kay and Dexter, 1992) and is sensitive to soil structure (Watts and Dexter, 1998) because it is related to the presence of air-filled pores, the occurrence of micro-cracks and the strength of inter-granular bonds within and between micro-cracks.

Moreover, the tensile strength of soil is much affected by the soil water content and processes which change pore characteristics and/or the cementation between structural units (Kay and Dexter, 1992).

A friability index has been proposed that is based on measurements of tensile strength of different sized aggregates (Utomo and Dexter, 1981b). Friability, \( F \), is defined as ‘the tendency of large clods or aggregates to breakdown and crumble under an applied stress into a certain size range of smaller fragments (aggregates)’ (Utomo and Dexter, 1981b). This property is one of the objectives of tillage because a friable soil is much easier to till and large clods are relatively weak whereas the smaller aggregates are relatively strong and resistant to further breakdown (Dexter, 1997).
Theory

Determination of aggregate tensile strength, $Y$, has been widely applied to characterize the ease of aggregate fracture in tillage (Munkholm and Kay, 2002). As it is difficult to measure $Y$ directly in a direct tension test (Dexter and Watts, 2001), most authors have used indirect tension tests to determine $Y$. For a spherical aggregate, $Y$ can be determined from the equation (Dexter and Kroesbergen, 1985):

$$ Y = q \frac{P}{D^2} \tag{1} $$

where: $q$ is the proportionality constant, $P$ is the applied compressive force at breakdown (N), and $D$ is the effective diameter (m). The coefficient, $q$, depends on the relationship between the compressive and tensile stress in the centre of the aggregate and has been used ranging from 0.576 (Braunack et al., 1979) to 1.860 (Dexter, 1988b).

Utomo and Dexter (1981b) proposed the scale factor between aggregate size and the aggregate tensile strength as an index of friability, $k$:

$$ \log e Y = -k \cdot \log e V + B \tag{2} $$

where: $V$ (m$^3$) is the aggregate volume, and $B$ (kPa) is the predicted log strength of 1m$^3$ of soil. The intercept $B$ can be written as:

$$ B = \log e \left( \frac{Y_0 V_0^k}{\Gamma(1+k)} \right) \tag{3} $$

where: $Y_0$ and $V_0$ are the strength and volume respectively of the basic soil elements, which comprise the bulk aggregates, and $\Gamma$ is the tabulated Gamma function.

Three methods for quantifying friability were described by Watts and Dexter (1998) and Dexter and Watts (2001), and are based on the statistical theory of brittle fracture. Briefly, this theory can be described by the “weakest link” concept: the strength of the total solid is determined by the local strength of the weakest volume element, in the same way as the strength of a chain is determined by its weakest link (Dexter and Watts, 2001). The methods for quantifying friability are as follows:

1. The first method is based upon the coefficient of variation of the tensile strength and is derived from Dexter and Watts (2001, Eq. 14). Only one size class of soil aggregates is needed for calculation of friability index using this method. The index $F_I$, is given by:

$$ F_I = \frac{\sigma_Y}{Y} \pm \frac{\sigma_Y}{Y \sqrt{2x}} \tag{4} $$

where: $\sigma_Y$ is the standard deviation of measured values of tensile strength, $\bar{Y}$ is the mean of the tensile strength measurements and $x$ is the number of replicates. The second term is the standard error of the coefficient of variation or friability.

2. The volume dependence method is based on Dexter and Watts (2001, Eq. 18), and leads to:

$$ F_2 = \frac{I}{\beta} \tag{5} $$

where: $\beta$ is obtained from the slope of a plot of

$$ log e Y = -\frac{I}{\beta} log e V + E \tag{6} $$

where: $Y_V$ is the tensile strength of volume $V$, and $E$ is the intercept, the value of which is given in Dexter and Watts (2001, Eq. 18). Because the aggregate strength is size dependent, for this method at least 3 – 4 size classes of aggregates are needed for calculation of $F_2$.

Chan et al. (1999) found that for an Australian clayey soil:

$$ F_I \approx 2F_2 \tag{7} $$

Dexter and Watts (2001) recommended the first method as the standard method for measuring soil friability because it is easy to calculate and because it requires fewer measurements than the second method.

The main objectives of the present paper were to measure the mechanical properties (tensile strength and friability) of soil aggregates collected from three agricultural soils, and to explore the relationships between mechanical and basic physical properties of the investigated soils.

MATERIALS AND METHODS

Sample collection and preparation

For soil tensile strength measurements samples were collected from the field. Two sampling points were located in Giurgiu county (Grădiștea, Brăniștari) and one point in Teleorman county (Drăgănești-Vlașca) so that three different textured soils were covered, namely: sandy soil, loamy soil and clayey soil. At the time of sampling the plots had been cropped with winter wheat and alfalfa. The soils were characterized using standard methods and the results are given in Table 1.
Soil aggregates from the plough layer were collected from two depth intervals (5-10 cm and 15-20 cm), and soil aggregates from the subsoil were collected from the 35-40 cm depth interval.

Table 1. Physical characterization of the soil profiles

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (cm)</th>
<th>Clay content (%)</th>
<th>Organic matter (%)</th>
<th>Bulk density (Mg m(^{-3}))</th>
<th>Texture class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grădiștea</td>
<td>5-10</td>
<td>11.7</td>
<td>1.55</td>
<td>1.46</td>
<td>sandy loam</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>11.2</td>
<td>1.22</td>
<td>1.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>8.3</td>
<td>0.49</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td>Brăniștari</td>
<td>5-10</td>
<td>28.5</td>
<td>2.71</td>
<td>1.48</td>
<td>clayey loam</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>30.1</td>
<td>2.37</td>
<td>1.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>31.2</td>
<td>1.88</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>Drăgănești - Vlașca</td>
<td>5-10</td>
<td>36.5</td>
<td>6.39</td>
<td>1.20</td>
<td>clay</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>39.0</td>
<td>5.10</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>44.4</td>
<td>3.53</td>
<td>1.41</td>
<td></td>
</tr>
</tbody>
</table>

To obtain aggregates of the desired size range, a set of two sieves was used. The soil mass was carefully passed through these sieves and the remaining aggregates on each sieve were placed in airtight containers in order to avoid any further mechanical disturbance of the aggregates. After completing this operation three size classes of aggregates were obtained: aggregates of diameter larger than 2 cm, between 1-2 cm, and smaller than 1 cm.

In the laboratory, the soil aggregates were allowed to air dry at room temperature. After air-drying the aggregates, an additional sieving of the aggregates smaller than 1 cm in diameter was performed so that two more size classes of aggregates were obtained, namely: aggregates of diameter between 0.5-1 cm, and between 0.25-0.5 cm. These two size classes of aggregates together with aggregates of diameter larger than 2 cm and between 1 and 2 cm, were then used for determination of the friability index \(F_1\) using the second method. In total, four classes of aggregate sizes were obtained and subsequently subjected to the crushing tests.

Indirect tension tests for measurement of soil tensile strength

For the size classes of aggregates larger than 1 cm a loading frame was used. The loading frame consists of two parallel plates between which the aggregates are crushed by raising the lower plate with the help of a handle. The force acting across the soil sample is measured by a load ring.

The force which is applied to the aggregates is measured by a load-ring of 0-1 kN range placed between the upper plate and the cross beam of the loading frame. In this work, 40 replicate aggregates were measured for each size class, depth and soil texture.

For the size classes of aggregates smaller than 1 cm a digital balance was inserted into the loading frame and acted as a load sensor. The force \(P\) (N) applied to the aggregate is the product of the balance output in kg, and \(g = 9.807\, m/s^2\), which is the acceleration of gravity (Dexter and Watts, 2001).

Before crushing the aggregates, the size of each aggregate was measured by using callipers and then calculated as described below. To provide a standard sample orientation, the aggregates were then placed with the flattest side downwards on the lower plate as suggested by Dexter and Watts (2001) so that the aggregates would be crushed across their shortest axis.

When the load was applied to the aggregate, the force measured increased up to the point of breakdown and a vertical crack appeared into the aggregate when a rapid drop in force was recorded. The peak force, \(P\) (N), at breakdown was recorded and then used in calculating the aggregate tensile strength \(Y\) using Eq. (1) with \(q = 0.576\) and \(D\) was calculated from Eq. (8) from below.

**Measurement of aggregate size**

Aggregate diameter \(D\) had to be estimated before the aggregates were crushed. For the size classes of aggregates larger than 1 cm, the diameter was estimated from “Method 2” described by Dexter and Watts (2001):

\[
D = \frac{D_x + D_y + D_z}{3}
\]  

(8)

where: \(D_x\), \(D_y\) and \(D_z\) represent the longest, intermediate and smallest diameters respectively of each aggregate. Also the mass \((M)\) of individual aggregates and the mean mass \((\bar{M})\) of the aggregates in the population were recorded.

To determine the friability index \(F_1\), a single size class of aggregates was used, which was
the size class of aggregates with diameter between 1 and 2 cm.
For determining the friability index $F_2$, four size classes of aggregates were used, namely: aggregates of diameter larger than 2 cm, between 1-2 cm, 0.5-1 cm, and 0.25-0.5 cm.

In order to obtain the friability index $F_2$, it was necessary to calculate firstly the effective density and the effective volume of each aggregate.

For each aggregate that was measured from each size class of aggregates, the effective density ($\rho_e$) was calculated using Dexter and Watts (2001, Eq. 27, “Method 4”): 
\[ \rho_e = \frac{6 \cdot M}{\pi \cdot D_1^3} \]  
(9)
where: $M$ is the aggregate mass (kg) and $D_1$ is aggregate size (m) calculated using Eq. (10) described above and then corrected to the mass weight of each aggregate separately from the following equation:
\[ D_1 = D \cdot \left( \frac{M}{\overline{M}} \right)^{1/3} \]  
(10)
where the terms $D$, $M$ and $\overline{M}$ are as described above.

Then, for each depth at the three locations, the mean effective density ($\overline{\rho_e}$) was calculated.
To obtain the effective aggregate volume ($V$), firstly the effective diameter ($D_2$) for each aggregate separately was calculated, using from Dexter and Watts (2001, Eq. 29, “Method 5”):
\[ D_2 = \left[ \frac{6 \cdot M}{\pi \cdot \rho_e} \right]^{1/3} \]  
(11)
where the terms in this equation are as described above, and secondly, the effective aggregate volume ($V$) was calculated using $V = \pi \cdot D_2^2 / 6$, which is the same as:
\[ V = \frac{M}{\rho} \]  
(12)
For each aggregate size class, the mean aggregate volume ($\overline{V}$) for each depth at each of the three locations was calculated.

Quantification of soil friability
The methods for quantifying friability, $F$, which were used in this paper, were described in the Introduction section.

Statistical analysis of the soil mechanical properties was done by using the OriginLab software.

RESULTS AND DISCUSSIONS

Aggregate tensile strength and friability index, $F_I$
The values of tensile strength of aggregates 1-2 cm in diameter and of friability index $F_I$ are summarized in Table 2. According to the soil friability classification used by Imhoff et al. (2002), the soils used in these investigations may be classified as “friable”. Out of 9 obtained values, 1 was “very friable” and 8 were “friable”. High values of friability ($F_I$) indicate that the larger clods have lower values of tensile strength than smaller aggregates and can be more easily crushed into small strong fragments. This is of particular interest when tillage operations are performed in the field because one of the aims of tillage is to produce a suitable aggregate-size distribution for an optimum seedbed with a few passes of tillage implements (Imhoff et al., 2002).

Table 2. Mean values of tensile strength and friability index, $F_I$

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (cm)</th>
<th>Tensile strength (kPa) ± s.d. (kPa)</th>
<th>Friability index $F_I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grădiștea</td>
<td>5-10</td>
<td>50.07 ± 25.13</td>
<td>0.504</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>121.04 ± 59.16</td>
<td>0.498</td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>160.86 ± 80.68</td>
<td>0.490</td>
</tr>
<tr>
<td>Brăniștari</td>
<td>5-10</td>
<td>75.39 ± 21.54</td>
<td>0.285</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>206.65 ± 67.31</td>
<td>0.326</td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>252.54 ± 91.63</td>
<td>0.363</td>
</tr>
<tr>
<td>Drăgănești - Vlașca</td>
<td>5-10</td>
<td>156.77 ± 35.41</td>
<td>0.226</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>238.15 ± 58.61</td>
<td>0.247</td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>281.03 ± 72.09</td>
<td>0.257</td>
</tr>
</tbody>
</table>

From mean aggregate tensile strength ($\overline{Y}$) for each of the three soil textures and for the sampling depths (Figure 1) it can be seen that the aggregates collected from sandy soil were weakest, followed by the aggregates from loamy and clayey soils respectively.
Analysis of variance showed that there are statistically significant differences between the soil profiles at the 95% confidence level ($F$-
Where:
The methods for quantifying friability, quantification of soil friability aggregate volume (for each aggregate size class, the mean effective density (\( V_{mean} \)), effective density (\( \rho_{eff} \)) was calculated using Dexter and Watts (2001, Eq. 29, following equation:

\[
MDD = \frac{1}{g_{152}} g_{172} g_{170} \frac{1}{g_{152}} g_{32} g_{83} g_{85}
\]

where the terms in this equation are as above.

Then, for each depth at the three locations, the weight of each aggregate separately was calculated, using from implementing (Imhoff et al., 2002).

Out of 9 statistical significant differences between the loamy and clayey soils respectively.

Weakest, followed by the aggregates from the aggregates collected from sandy soil were the greatest effect on tensile strength is by the following equations:

- for sandy soil:
  \[
  Y = 297.16 - 17.95 C \quad r^2 = 0.32 \quad (\pm 103.47) (\pm 9.84) \quad p = 0.111
  \]

- for loamy soil:
  \[
  Y = -1125.60 + 43.51 C \quad r^2 = 0.64 \quad (\pm 369.63) (\pm 12.32) \quad p = 0.0096
  \]

- for clayey soil:
  \[
  Y = -320.87 + 13.67 C \quad r^2 = 0.75 \quad (\pm 120.87) (\pm 3.01) \quad p = 0.0027
  \]

Increasing amount of clay in sandy soil has determined an increase of the soil tensile strength values (Figure 3). This may be due to clay particles acting as cementing materials between large particles, high amounts of clay providing more opportunities for interparticle contact and also adsorb more water, causing higher tensions in soil water at a specific water content (Kemper et al., 1987). Dispersion of cementing materials (e.g. clay) can cause migration of those to lower energy positions, and the greatest effect on tensile strength is recorded when the bonding occurs at contact.
points within or at the ends of microcracks (Kay and Dexter, 1992).

**Friability index, F\textsubscript{2}\)**

In Table 3 are presented the values of friability index, \(F_2\), and Figure 4 a, b and c show some examples of the volume dependence of the tensile strength.

As expected from the work of Dexter and Watts (2001), the values of friability index, \(F_2\), obtained using Eqs. (5) and (6) from the volume dependence method described in the introduction section, are smaller than the values of friability index, \(F_1\), obtained using Eq. (4) from the coefficient of variation method.

Table 3. Values of friability index, \(F_2\)

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (cm)</th>
<th>Friability index (F_2)</th>
<th>Ratio between (F_1/F_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grădiștea</td>
<td>5-10</td>
<td>0.314</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>0.217</td>
<td>2.29</td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>0.202</td>
<td>2.43</td>
</tr>
<tr>
<td>Brâniștari</td>
<td>5-10</td>
<td>0.370</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>0.289</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>0.291</td>
<td>1.25</td>
</tr>
<tr>
<td>Drăgănești - Vlașca</td>
<td>5-10</td>
<td>0.335</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>0.286</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>35-40</td>
<td>0.381</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Measurement of the tensile strength of soil aggregates as functions of volume is based on the assumption that small aggregates are fragments of larger aggregates (Watts and Dexter, 1998).

It is desirable that the material of the smaller aggregates, which initially comprised the larger clods, has a relatively greater strength than that of the larger clods, otherwise, the soil mass could break down into individual mineral particles or dust (Utomo and Dexter, 1981). Statistical analysis of the friability \((F_2)\) results showed that \(F_2\) was not correlated with organic matter content and clay content.

One possible explanation could be that soil aggregates of different size may have been formed by different mechanisms (Dexter, 1988b), may be of different ages, and may have weathered differently (Watts and Dexter, 1998), and these can affect the subsequent strength behavior of the aggregates.

Amongst the main factors which can affect friability index, \(F_2\), is the water content. Utomo and Dexter (1981) found maximum friability at around the soil plastic limit when assessed the friability using the volume dependence method. Similar results were reported by Shanmuganathan and Oades (1982), Munkholm and Kay (2002) and Munkholm et al. (2002).

In these investigations, we looked also for a correlation between \(F_1\) and \(F_2\), and the results are shown in Figure 5. The regression line in Figure 5 show a small linear correlation...
between $F_1$ and $F_2$, and the equation of regression is as follows:

$$F_1 = 0.67 - 1.115 F_2 \quad r^2 = 0.45$$

$(\pm 0.076) \quad (\pm 0.251) \quad p = 0.0002$

When the results for each soil profile were compared separately, these have shown different trends. Whereas for the sandy and clayey soils were found underestimates and respectively overestimates of $F_2$ values, for the other loamy soil the volume dependence method ($F_2$) gave similar values when compared to the coefficient of variation method ($F_1$). The ratio $F_1/F_2$ is as follows: 2.11 for the sandy soil, 1.05 for the loamy soil and respectively 0.74 for the clayey soil.

**CONCLUSIONS**

Soils used in these investigations can be described as “friable” according to the classification used for $F_1$ values.

Soil aggregates of the sandy soil from Grădiștea had the smallest values of tensile strength. The highest values of tensile strength were recorded in case of clayey soil, whereas the loamy soil had values between the sandy and clayey soils.

Increasing organic matter content decreased the values of tensile strength for soil aggregates from all soils.

High values of clay content in case of loamy and clayey soils increased the values of tensile strength.

Increasing amount of clay in sandy soil has been shown to increase the tensile strength of this soil. This may be due to clay particles acting as cementing materials between large particles. Higher amounts of clay in sandy soils provide more opportunities for interparticle contact.

Small size classes of aggregates presented higher values of tensile strength as compared with larger size classes of aggregates when the volume dependence method was used.

In case of sandy and clayey soils were found underestimates and respectively overestimates of $F_2$ values. As for the loamy soil, the volume dependence method ($F_2$) gave similar values when compared to the coefficient of variation method ($F_1$).

The coefficient of variation method ($F_1$) is recommended as standard method for measuring soil friability.

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**REFERENCES**


