Effect of soil organic matter, electrical conductivity and sodium adsorption ratio on tensile strength of aggregates

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Abstract

The properties of soils affected by salinity and processes involving degradation of soil structure have been partly recognized. However, the effects of saline and sodic conditions on mechanical and physical properties of soils have been studied to a lesser extent. In this research, the effects of electrical conductivity (EC) and sodium adsorption ratio (SAR) on soils possessing various amounts of organic matter were assessed under laboratory conditions. The soils contained a uniform clay type, predominantly Illite. The major difference of the soils was their amount of organic matter content. The treatments consisted of solutions with definite EC and SAR (two levels of EC: 0.5 and 4 dS/m and three levels of SAR: 0, 5 and 15). The amount of tensile strength was dependent on organic matter, EC, and SAR in a way that with the increase of SAR, the tensile strength decreased. In similar SAR, treatments with higher EC exhibited greater tensile strength. Also, the soils with higher organic matter showed greater tensile strength. The analysis of variance showed the significant difference (at 1%) between the mean of parameters analyzed (soil type, sampling depth, EC, and SAR). The order of averages of tensile strength were: permanent pasture (\textit{Agropyron elongatum})<intensive cultivation<permanent pasture (\textit{Festuca arusdinaceae})<virgin soil. The differences were also significant for the SAR factor. The order of averages were: SAR\textsuperscript{15}<SAR\textsuperscript{5}<SAR\textsuperscript{0}.

Keywords: Soil tensile strength; Organic matter; Electrical conductivity (EC); Sodium adsorption ratio (SAR)

1. Introduction

Tensile strength is a sensitive indicator of the physical condition of a soil. In diverse ways (like energy for ploughing operations, penetration of roots and germination) it is effective in the efficient manipulation of field soils. The tensile strength depends on the amount of cations, dispersible clay, type and size of clay, aggregates stability, concentration and composition of soil solution, soil organic matter and wetting/drying cycles (Barzegar et al., 1994, 1995). The tensile strength of soil is defined as a capacity to endure the applied forces without being disrupted. From a quantitative point of view, tensile strength is equal to maximum stress which can be applied on a soil without undergoing any disruption (Hillel, 1980).
Soils, in particular agricultural soils, exhibit little stability against applied tensile stresses. Nevertheless, the tensile linkages in soils are most effective factors in soil resistance against cultivation operations, execution of horizontal load (in tensile processes), and vertical load (in displacement process) under field conditions (Chancellor, 1994). Soils which possess aggregates with greater tensile strength are more resistant to mechanical dispersion when subjected to soil preparation.

Kay and Dexter (1992) suggested that failure zones in soil are the determinant factor in its interaction with applied stresses (i.e., cultivation, impacts of rain drops, root growth, etc.). According to Braunack et al. (1979) tensile strength also should be considered as an indication of resistance in the weakest failure zones. Utomo and Dexter (1981) suggested that the distribution of strength could also be utilized as an index of soil friability.

Tensile strength is a dynamic characteristic of soils. The resistance of failure zones at any time depends on air filled pores, small cracks, and bonds between particles inside or between small cracks. Moreover, the tensile strength of soils is interrelated with the amount of water and processes responsible for changing porosity or linkage between soil aggregates (Kay and Dexter, 1992). Hillel (1980) defined the tensile strength of soil as the force required for soil particles rupture or separation. In other words, tensile strength is described as the amount of force per unit area required to separate a portion of soil from another.

Dexter and Kroesbergen (1985) also explained that probably tensile strength is the most useful measure of strength of individual soil aggregates. This can be determined from simple tests under wide range of aggregate sizes. It can finally be considered as a very sensitive indicator of soil conditions.

Causarano (1993) investigated the effective factors on tensile strength of soil aggregates in two soil types. He found that within the moisture ranges studied (field capacity to air dry conditions) the tensile strength of sandy loam (with small range of variation of organic matter) was dependent on the quantity of water. However, in the case of clay soil (with 1.3–10.4% organic matter) it appears that organic matter increases the strength of moist soil aggregates, and decreases the tensile strength of dry soil aggregates.

The tensile strength of the smallest soil aggregates was approximately 50% greater than biggest soil aggregates. Kay and Dexter (1992) explained that wetting and drying cycles could decrease tensile strength during the season. Decrease of strength is the sum of effects of entrapped air and localized swelling in the soil aggregates. During the process of wetting, the spreading of failure zones increased in proportion with the wetting intensity and number of drying and wetting cycles. It can be deduced that seasonal changes of tensile strength of soils is controlled by farm management practices. These changes are the result of the interacting processes of an increasing amount of cementing materials between particles (like dispersed clay) from one side and the development of weak failure zones during wetting/drying cycles from the other. The climatic conditions could cause an increase in the dispersion of clay which results an increase in the tensile strength of dry soil aggregates. From the other side, the wetting/drying cycles could decrease the tensile strength. Moreover, increase of strength in the failure zones (due to joining of particles) and decrease of strength due to weakening of failure zones (because of repeated periods of wetting and drying) is dependent on farm management and crop rotation. The converse effect of crop rotation on tensile strength is also dependent on the post climatic conditions (Kay and Dexter, 1992).

Barzegar et al. (1995) explained that soil strength is influenced by several factors associated with the soil clay fraction such as exchangeable cations, clay content, clay type, and the amount of dispersible clay. Clay particles are involved in binding or cementing soil particles but when clay particles are flocculated and aggregated by calcium ions and organic matter, they may not be extensively involved in binding or cementing other particles and therefore, total clay may not reflect the soil strength.

Clay mineralogy, in addition to its influence on dispersion, may also affect the nature of individual contact points and the strength of bonding between soil particles (Barzegar et al., 1995). Hardsetting soils in Australia are dominated by Illite and these minerals are highly susceptible to dispersion (Emerson, 1984).

Barzegar et al. (1995) suggested that the amounts of dispersed clay and cation exchange capacity (CEC) of clay were highly related to the strength of the soils ($R^2 = 0.86$). Dexter and Chan (1991) suggested that
cations which give rise to the greatest clay dispersion in water (i.e., sodium) are also those which give rise to the greatest strength of the dried soil.

Utomo and Dexter (1981) reported the Becher (1978) explanation that showed the decrease of soil strength with increasing organic matter content over a range of water content. In drier soils the increase in organic matter content did not give a consistent effect. Kay et al. (1994) suggested that tensile strength of air-dried aggregates increased with depth which appeared to be due to reduced severity of wetting. The increase in tensile strength could not be correlated with changes in soil properties such as clay, sand, organic matter contents, and bulk density.

Irrigation water or underground water has a direct effect on soil solution in arid and semi-arid regions. This in turn affects the dynamics of soil structure (Bybordi, 1989). An understanding of the processes of disaggregation and the resultant tensile strength of soils as a consequence of using saline and sodic water might provide a key to improving soil structure and plant establishment in several arid and semi-arid regions of the world (Barzegar et al., 1994).

The process of soil aggregation decreases considerably (particularly during wetting) as result of clay dispersion or disintegration of aggregates. Both the phenomena are results of crusting and hardening of soil surface. This increases the strength of soil and then decreases the infiltration rate, porosity, and germination (Barzegar et al., 1994).

Churchman et al. (1993) concluded that organic matter may not even have a positive effect on aggregation under certain circumstances. Organic matter can disperse particles when present in small amounts, when it comprises high concentrations of low molecular weight acids and when the negative charge on the clay/metal oxide/organic matter conglomerate is expressed at relatively large distances from particles because there is sodium on exchange sites.

The hydraulic conductivity of sodic soils can decrease with leaching as a result of organic matter and clay dispersing together. Organic matter can prevent loss of permeability when SAR is low but not at high SAR. Dispersion ratios were strongly inversely correlated with organic matter contents in sodic soils with relatively low exchangeable sodium percentage (ESP) values. However, additions of organic matter increased the dispersion of soils at high SAR, while its removal decreased the dispersion of sodium-saturated soils (Churchman et al., 1993).

Barzegar et al. (1994) suggested that the dispersive effects due to SAR in increasing soil strength are modified by electrolyte concentration. They concluded that by improving the organic matter status of a soil, the effect due to sodicity on soil strength can be modified.

The objective of this study is to investigate the effect of SAR and EC on tensile strength of soils under different cultivation management with varying organic matter content. This study is a basic laboratory research. It provides appropriate methods of investigating the effect of variables such as EC, SAR and organic matter and will pave the way to implement comprehensive follow-up studies done on regional and national levels in Iran.

2. Materials and methods

2.1. Soil sampling

The soil sampling sites were located between the cities of Sari and Neka and were about 20 km from the Caspian sea. The soil samples possessed uniform characteristics (regarding clay content and type) and varied in organic matter content. The prevailing texture were loam or clay loam and clay type was predominantly Illite. The difference was mainly a result of cropping history. The soils were classified as Typic Xerochrepts (ISWRI, 1977) and Typic Calcixerolls (ISWRI, 1981). The EC in the majority of soils was less than 1 dS/m. However, in the east and west of the sampling areas, marginal and saline lands exist (ISWRI, 1995). Before 1966, soils of the region were covered by natural forests. Later on, the forests were cut and put under cultivation. Soil sampling was conducted on July 1996.

The soil sampling sites include the following:

- The wild life park at Dasht-e-Naz (code P). It had remained uncultivated for 100 years. It has been set aside as a protected region for the grazing of yellow stags since 1966.
- Farms cultivated under intensive agriculture with systematic crop rotations (code W). The crop rotation was: wheat–corn–soybean–corn–wheat–
soybean/bressem. At the time of soil sampling, the relevant plot was under wheat cultivation.

- Two plots at the forage seed breeding station of Dolemarz. One of the plots was under Tall fescue (Festuca arusdinaceae) planted under rain-fed conditions (code F). The other site was under rain-fed cultivation of Tall wheat grass (Agropyron elongatum) with E code. During the latter 10 years the plots were not tilled and only seed propagation was accomplished.

Composite soil samples were collected from 0–10 and 10–20 cm depth (0–5 and 5–10 cm in the case of soil P) from at least 10 different points at each sampling site. The soil samples were transferred to the laboratory and air dried and 2–4 mm aggregates were separated for treatments preparation. Soil particles less than 2 mm were utilized for the chemical and physical analysis.

2.2. Determination of physical and chemical characteristics of soils

Soil characteristics determined on soil particles less than 2 mm were: EC, pH, SAR in soil extracts; calcium carbonate; sand, silt and clay content; clay mineralogy by X-ray procedure; and organic carbon percentage by Walkley–Black method. Table 1 shows the physical and chemical characteristics of the soil studied.

2.3. Treatments

The 2–4 mm aggregates of each sample were treated with fixed EC and SAR solutions. Solutions with specified EC and SAR (EC in two concentrations of 0.5 and 4 dS/m and SAR in three levels 0, 5 and 15) were prepared in the laboratory with pure salts of sodium chloride, calcium chloride, and magnesium chloride on a calculated basis with Ca/Mg = 1. In order to prevent the slaking of samples while preparing the treatments, sintered glass funnels were used. Preparation of each treatment consisted of five wetting/drying cycles with a 48 h duration. During each cycle, the samples were subjected to wetting with a respective solution under submerged conditions for 7 h. Then it was subjected to a 30 cm (3 kPa) suction for 17 h. The samples were drained and kept for another 24 h. The EC and SAR of the equilibrated solutions of each funnel were determined after five wetting and drying cycles. After the end of fifth cycle the samples were air-dried and saved for the necessary analysis.

2.4. Determination of tensile strength of the aggregates

The determination of the tensile strength of aggregates has been performed in an indirect method (Dexter and Kroesbergen, 1985). The principal of this procedure is based on testing the force needed for crushing one aggregate between two flat and parallel plates. For this purpose a device was made in the Iranian Agricultural Engineering Research Institute (IAERI). It is shown in Fig. 1. While using this device, the part which lies directly over sample exerts the necessary pressure on the sample through a crow-bar. A basin of water is placed at the base. Water is gradually added until it attains the tensile strength of the aggregate. When this is reached, the crow-bar suddenly becomes loose and the aggregate is crushed.

<table>
<thead>
<tr>
<th>Variables soils</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>EC (dS/m)</th>
<th>SAR</th>
<th>OC (%)</th>
<th>CaCO₃ (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>0–10</td>
<td>8.04</td>
<td>0.47</td>
<td>1.4</td>
<td>2.18</td>
<td>18.9</td>
<td>37</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>W2</td>
<td>10–20</td>
<td>8.06</td>
<td>0.47</td>
<td>1.7</td>
<td>2.17</td>
<td>17.4</td>
<td>38</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>E1</td>
<td>0–10</td>
<td>7.75</td>
<td>0.54</td>
<td>0.7</td>
<td>2.38</td>
<td>26.38</td>
<td>23</td>
<td>38.6</td>
<td>38.4</td>
</tr>
<tr>
<td>E2</td>
<td>10–20</td>
<td>7.80</td>
<td>0.43</td>
<td>0.6</td>
<td>2.13</td>
<td>30.13</td>
<td>20</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>F1</td>
<td>0–10</td>
<td>7.43</td>
<td>0.84</td>
<td>0.6</td>
<td>3.42</td>
<td>24.25</td>
<td>27</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td>F2</td>
<td>10–20</td>
<td>7.55</td>
<td>0.63</td>
<td>0.5</td>
<td>2.89</td>
<td>27.63</td>
<td>32</td>
<td>31</td>
<td>37</td>
</tr>
<tr>
<td>P1</td>
<td>0–5</td>
<td>7.27</td>
<td>0.97</td>
<td>0.3</td>
<td>10.32</td>
<td>3.63</td>
<td>28</td>
<td>30</td>
<td>42</td>
</tr>
<tr>
<td>P2</td>
<td>5–10</td>
<td>7.55</td>
<td>0.60</td>
<td>0.5</td>
<td>7.19</td>
<td>7.38</td>
<td>33</td>
<td>29</td>
<td>38</td>
</tr>
</tbody>
</table>
At this stage, the flow of water is cut-off and the mass of water in the basin is determined. The force required to crush the aggregate \((F)\) is obtained on the basis of Newton by the equation:

\[
F = \left( \frac{M_c X_1}{X_2} \right) + Mu g
\]  

(1)

where \(Mu\) is the sum mass (kg) of the part which lies directly over sample, \(g\) acceleration due to gravity and is equal to 9.807 m/s\(^2\), \(M_c\) the mass of water (kg), and \(X_1/X_2\) the ratio related to the length of the crow-bar (Dexter and Kroesbergen, 1985).

Rogowski (1964) by assumption of 0.5 for the Poison ratio presented Eq. (2) for the tensile strength

\[
Y = \frac{0.576F}{d^2}
\]  

(2)

where \(F\) (N) is calculated from Eq. (1), and \(d\) (m) is the mean aggregate diameter, which is estimated from sieving (Dexter and Kroesbergen, 1985). The amount of tensile strength is usually reported on the basis of kPa.

3. Results

The aggregate tensile strength for each treatment of soils are presented in Table 2. Each data is the average of 15 measurement of 2–4 mm aggregates. Fig. 2 shows the soil tensile strength relevant to their organic carbon content. As observed, the increase of tensile strength in each treatment directly depends on the amount of organic carbon in soils. The tensile strength in all soils is related to the pertinent treatment. It proportionately decreases with the increase of SAR and it is greater in treatments with higher EC.

Fig. 3 shows the effect of treatments. As shown, the amount of SAR, in all soils, is inversely proportional to the with tensile strength while in similar SAR, the treatments with higher EC have higher tensile strength. The analysis of variance was executed in a factorial experiment (with four levels of soil factor, two levels of soil sampling depths, two levels of EC, three levels of SAR, and two replicates) in a completely randomized block design.

Table 3 shows the summary of analysis of variance of data. The Duncan test for the tensile strength variable has shown that the differences were significant at 1% for four levels of soil factor. The order of

![Fig. 1. A device for determination of aggregate tensile strength.](image)

Table 2

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P1</td>
</tr>
<tr>
<td>EC=0.5 dS/m SAR=0</td>
<td>51.63</td>
</tr>
<tr>
<td>EC=0.5 dS/m SAR=5</td>
<td>39.88</td>
</tr>
<tr>
<td>EC=0.5 dS/m SAR=15</td>
<td>42.13</td>
</tr>
<tr>
<td>EC=4 dS/m SAR=0</td>
<td>52.22</td>
</tr>
<tr>
<td>EC=4 dS/m SAR=5</td>
<td>42.61</td>
</tr>
<tr>
<td>EC=4 dS/m SAR=15</td>
<td>38.17</td>
</tr>
</tbody>
</table>

* The organic carbon of soils were decreased from P1 to E2.
averages were: E<W<F<P. The differences were also significant at 1% for three levels of the SAR factor. The order of averages were: SAR=15<SAR=5 <SAR=0.

4. Discussion

The amount and type of organic matter (during the various stages of decomposition) were considered the most important factor in the stability of soil structure. The complex soil system makes it very difficult to explain the mechanism involved in the soil structure stability. The dual role of organic matter (Emerson, 1984) can be explained in two processes:

1. Increase of repulsive forces between particles and increase in negative charges of pure clay which intensify the colloidal condition of soil particles, and increase the clay dispersion.

2. The formation of bonds with adsorbed cations increase the physical resistance of soil aggregates against dispersion, and therefore increase the aggregate stability.

The crop rotation and land management, due to its effect on the amount and type of organic matter, affect the strength of soil. This effect is caused by physical and chemical effect of plant roots. Organic matter can also adjust the negative effect of sodic conditions in soils. The strength is also influenced
Fig. 3. The effect of treatments on the soils tensile strength.
by the presence of cations such as calcium, magnesium, aluminum, etc. in soil solution. The negative effect of sodic conditions decreases with the increase of salt concentration, which was in agreement with our data. Interaction between EC and SAR was significant at 5%.

The amount of soil moisture and wetting/drying cycles are also important factors on the physical and mechanical properties of soils. However, its quantitative effect depends on experimental conditions which are not assessed here.

In this study, higher tensile strength is obtained with increase of organic matter. Increase of SAR was also indirectly proportional to tensile strength. In similar SAR, treatments with higher EC had greater tensile strength. This shows the adjusting effect of EC on the soil sodic conditions.

In a previous study (Barzegar et al., 1994) it had been shown that the amount of clay dispersion increased with the increase of SAR. Increase in surface area due to clay dispersion causes higher tensile strength of the dry soil aggregates. However, in this study, an opposite trend was observed. Such differences could be attributed to the different rate of wetting and drying cycles. These cycles cause a reduction in the stability of soil aggregates because of slaking. Another reason was due to the higher content (between 2 and 10%) of organic carbon. The results obtained by Causarano (1993) also confirm our data. Observation of soil aggregates during treatment preparation did confirm the reciprocal relationship of tensile strength with the SAR.

The analysis of variance also showed a significant difference between soils, depth of sampling, and levels of EC and SAR treatments. The differences between soils in view of the amount of organic matter and its management were expected. However, one interesting conclusion was that the samples E and F planted under rain-fed pasture in one location showed significant differences in their tensile strength. This could be attributed to the difference in the amount of clay, calcium carbonate, and soil organic carbon content (Table 1). Soil E had a lower content of organic carbon and clay, and higher content of calcium carbonate. Furthermore, Festuca (in soil F) compared to Agropyron (in soil E) possesses deeper and denser roots (Sheidaie and Nemati, 1978).

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References


