DYNAMICS OF SOIL STRUCTURE PARAMETERS IN LOAMY SOILS OF SLOVAKIA

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Abstract

Studies on the structure of loamy soils were carried out in several fields located on loamy calcareous Chernozem, loamy haplic and mollic Fluvisols in the north-west part of the Danube lowland (Slovakia). The aims of the studies were to evaluate: (1) the overall and dynamics of the soil structure parameters with dependence on soil types, and (2) the relationships between soil parameters and soil structure parameters. The results showed that soil structure parameters varied in time and soil types. Overall, the best soil structure according to vulnerability coefficient (Kv), index of aggregate stability (Sw) and crusting index (Ic) was in mollic Fluvisol > haplic Fluvisol > calcareous Chernozem. The results of the dynamics of structural parameters such as: Kv, Sw and Ic were very similar. The most favourable soil structure evaluated according to the percentage of aggregate destruction (PAD) was in mollic Fluvisol > calcareous Chernozem > haplic Fluvisol. When all soils were assessed together, the negative significant correlations were observed between the Kv and contents of soil organic carbon (r = -0.634, P ≤ 0.01, n = 18), hot- (r = -0.732, P ≤ 0.001, n = 18) and cold-water soluble carbon (r = 0.670, P ≤ 0.01, n = 18) as well as C_HA:C_FA ratio (r = 0.615, P ≤ 0.01, n = 18). The same trend was observed between Ic and soil organic matter (SOM) parameters. Higher stability of SOM positively affected stabilization of macroaggregates (r = 0.520, P ≤ 0.05, n = 18). If all loamy soils were assessed separately, we detected negative significant correlations between Ic and soil organic carbon (calcareous Chernozem: r = -0.998, P ≤ 0.001, n = 6; haplic Fluvisol: r = -0.997, P ≤ 0.001, n = 6; mollic Fluvisol: r = -0.995, P ≤ 0.001, n = 6). In mollic Fluvisol, values of Kv and Ic increased with higher labile carbon contents as well as higher stability of SOM positively affected stabilization of macroaggregates.

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Keywords: vulnerability coefficient, index of aggregate stability, crusting index, percentage of aggregate destruction, Chernozem, Fluvisol

1. INTRODUCTION

Structure refers to the aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from the adjoining aggregates by surfaces of weakness (Millar et al., 1962). Stable aggregates are regarded as an indicator of the soil structure, playing an important role in the maintenance of soil structure and fertility, reducing detachment by
raindrop impact, abrasion in overland flow, and the formation of surface crusts and seals, and facilitating water filtration and root development (Šimanský et al., 2013; Wang et al., 2013). Formation and stability of natural soil aggregates are affected by dozens of different factors and their individual effects are hardly distinguishable (Jozefaciuk and Czachor, 2014). Structure modifies the influence of texture in regard to moisture and air relationships, availability of plant nutrients, action of microorganisms and plant growth (Kögel-Knabner et al., 2008; Grosbellet et al., 2011; Kurakov and Kharin, 2012). Soil structure is a complex system. One of the reasons for the complexity of soil structure is the dynamic nature of soil structure (Lal and Shukla, 2004), and is difficult to characterize (Coughlan et al., 1991).

Since, there are differences in formation of soil structure with dependence soil type (Šimanský and Bajčan, 2014) and soil management practices (Balashov and Bukhina, 2011; Šimanský et al., 2013), the purpose of this study was to evaluate: (1) overall and dynamics of the soil structure parameters with dependence on soil types (2) the relationships between soil parameters and soil structure parameters.

2. MATERIALS AND METHODS

The studied areas were located in the north-west part of the Danube lowland, between the cities of Hlohovec and Trnava, in the Slovak Republic. The geological substrates of the investigated region are neogene clays, sands and gravels, which are mostly covered with loess and loess loam. Fluvial sediments are found along the rivers Váh and Dudváh. The first investigation area is situated near the flat area on the river Váh near the village of Šulekovo (48° 26′ 3.72″ N, 17° 46′ 7.88″ E), the second place is located near the flat area on the river Dudváh near the village of Trakovice (48° 26′ 21″ N, 17° 42′ 31″ E) and the last place is situated on slight slopes near the Bučany village (48° 25′ 22.3″ N, 17° 42′ 8.6″ E). The average annual temperature is 9.8°C and the average precipitation per year is 580 mm. In spring 2011, soil surveys of selected sites were conducted. The soils were classified according to the World Reference Base for Soil Resources (WRB, 2006). In the field near Šulekovo the soil was classified as loamy haplic Fluvisol, in Trakovice as loamy mollic Fluvisol and in Bučany as loamy calcic Chernozem. The soils from all sites were analysed. The major characteristics of the soil in the top layer (0–0.2 m) are shown in table 1. In these areas (fields), the soils had been cultivated and in 2011, the sugar beet (Beta vulgaris L. var. altissima) was grown in all fields, always following the crops of spring barley (Hordeum sativum L.). In autumn 2010, the soil was ploughed to the depth of 0.25m and in case of the haplic Fluvisol farmyard manure was applied in the dose of 40 t ha⁻¹. In the first decade of May, the sugar beet was sown in all fields.

Table 1. Soil characteristics in the top layer (0–0.2 m) (Šimanský and Kováčik, 2014)

<table>
<thead>
<tr>
<th>Soil types</th>
<th>pH</th>
<th>Ca²⁺ [mol kg⁻¹]</th>
<th>Mg²⁺ [%]</th>
<th>CO₃⁻ [%]</th>
<th>Corg [g kg⁻¹]</th>
<th>sand [%]</th>
<th>silt [%]</th>
<th>clay [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcic Chernozem</td>
<td>7.8±0.04</td>
<td>9.3±1.5</td>
<td>7.6±2.1</td>
<td>9.28±1.04</td>
<td>11.9±0.08</td>
<td>43±3.95</td>
<td>47±3.17</td>
<td>10±1.48</td>
</tr>
<tr>
<td>haplic Fluvisol</td>
<td>7.6±0.06</td>
<td>10.3±1.1</td>
<td>10.5±2.1</td>
<td>2.12±0.27</td>
<td>21.2±0.11</td>
<td>38±6.13</td>
<td>40±2.85</td>
<td>17±3.94</td>
</tr>
<tr>
<td>mollic Fluvisol</td>
<td>7.8±0.03</td>
<td>8.6±1.4</td>
<td>12.4±3.5</td>
<td>11.6±0.94</td>
<td>19.2±0.12</td>
<td>47±3.69</td>
<td>38±4.29</td>
<td>14±1.83</td>
</tr>
</tbody>
</table>

pH – soil pHH₂O, Ca²⁺ - exchangeable calcium, Mg²⁺ - exchangeable magnesium, CO₃⁻ - content of carbonates, Corg - soil organic carbon content
In each field four different places were chosen randomly (first time) and soil samples were always collected from these areas. The soil samples were taken from a depth of 0–0.2m during the growing season of sugar beet in year 2011 (25 May, 18 Jun, 15 Jul, 14 Aug, 15 Sept, 16 Oct).

The content of soil organic carbon (Corg) was assessed by Tyurin method (Dziadowiec and Gonet, 1999). The labile carbon content (CL) (Loginow et al., 1987), hot- (CHWD) and cold-water soluble carbon (CCWD), (Körschens, 2002) and the composition of humus fractions, humic (HA) and fulvic (FA) acids, was determined according to Belchikova and Kononova (Dziadowiec and Gonet, 1999). The absorbance of humus substances and humic acids was measured at 465 and 650 nm to calculate the colour quotient QHs and QHA. The total nitrogen (Nt) by the Kjeldahl method (Bremner, 1960) and the potentially mineralisable nitrogen (Npot) (Standford and Smith, 1978) were determined. We also determined the contents of exchangeable cations such as: Ca2+ and Mg2 (Fiala et al., 1999). Carbonates were determined by volumetric method using a Jankov calcimeter, based on the CO2 evolution after reacting with HCl (diluted with water in a 1:3 ratio). The vulnerability coefficient (Kv), index of aggregate stability (Sw) crusting index (Ic) as well as the percentage of aggregate destruction (PAD) were calculated according to following equations (1-4):

\[
Kv = \frac{MWD_d}{MWD_w} \quad (1)
\]

where: MWDd is mean weight diameter of aggregates for dry sieving (mm) and MWDw is mean weight diameter of water stable aggregates (mm).

\[
Sw = \frac{WSA - 0.09sand}{silt + clay} \quad (2)
\]

where: WSA is content of water-stable aggregates (%)

\[
Ic = \frac{1.5S_f + 0.75S_c}{Cl + (10 \cdot SOM)} \quad (3)
\]

where: \(S_f\) is % fine silt, \(S_c\) is % coarse silt, \(Cl\) is % clay, and \(SOM\) is % soil organic matter content.

\[
PAD = \frac{md - mw}{md} \times 100 \quad (4)
\]

where: \(md\) is mass fraction of aggregates >0.25 mm after dry sieving, and \(mw\) is mass fraction of aggregates >0.25 mm after wet sieving.

All analyses were undertaken in the Statgraphics Centurion XV.I programme (Statpoint Technologies, Inc., USA). A one-way ANOVA model was used to test the effects of soil type on soil structure parameters, with separation of the means by the LSD test. Relationships between soil organic matter, soil parameters such as carbonates, calcium, magnesium and parameters of soil structure were then determined through correlation matrix. To evaluate the trends of soil structure parameters during the vegetation season of sugar beet in 2011, the Mann-Kendall test was used.

3. RESULTS AND DISCUSSION

Figure 1 provides a summary and dynamics of the soil structure parameters with dependence on soil type. The vulnerability coefficient is very important indicator of soil structure and it shows how many times is aggregate size at the beginning decreasing with dependence on degradation mechanisms (Valla et al., 2000). The highest average value of Kv was observed in the calcareic Chernozem (5.95). Based on LSD-test, this was significantly higher than the Kv in the haplic
Fluvisol (3.07) as well as in the mollic Fluvisol (2.43). In the calcaric Chernozem, Kv value increased the most from 25.5 to 14.8 by 3.22 (damage of soil structure) and then decreased from 14.8 to 16.10 by 4.39 (improve of soil structure). During the vegetation season of sugar beet, in the haplic Fluvisol the values of Kv decreased, but in the mollic Fluvisol it has been relatively balanced (fig. 1A). Our data confirmed the fact that formation and stabilization of soil structure is dynamic processes (Lal and Shukla, 2004), which depend on soil type. Kv values closely mirrored the aggregate stability values (Sw) in all investigated soil types. It means that the most favorable soil structure (the highest Sw) was observed in the mollic Fluvisol and the worst (the lowest Sw) in the calcaric Chernozem. Even dynamic changes of Sw values were consistent with the dynamics of Kv in individual soil types (fig. 1B). The same trend has been confirmed by the value of crusting index (Ic), which is very important parameters for evaluation of soil structure. Generally, Ic values are influences by the soil texture and SOM concentration (Lal and Shukla, 2004) and tillage systems and fertilization (Šimanský et al., 2008). Each soil type has different genesis, and hence morphological features and different soil properties (Duchafour, 1982). Therefore, we hypothesized that properties of selected soil types will be also crucial for the formation of soil crust. According to the susceptibility to crust formation, studied soils were ranged in a decreasing order: calcaric Chernozem > haplic Fluvisol > mollic Fluvisol. In Slovakia, Chernozems (Bielek et al., 1998; Zaujec and Šimanský, 2008) and mollic Fluvisols (Bielek et al., 1998) are the most fertile soils. These soils have a favourable range of growing conditions for plants due to their optimal physical, physico-chemical and biological properties. In our case, in calcaric Chernozem, worse soil structure will have relation with internal factors (nearly half the content of SOM compared to mollic Fluvisols – table 1). During the vegetation season of sugar beet, in all soil types the Ic values were relatively stable without significant fluctuation (fig. 1C). The results showed that if we assessed soil structure according to Kv, Sw and Ic in individual soil types the trends and overall results were the same. Different results were observed when we evaluated soil structure by the percentage of aggregate destruction (PAD). The PAD (average values) decreased, but without statistical significance in the following order: haplic Fluvisol > calcaric Chernozem > mollic Fluvisol (fig. 1D). During the vegetation season of sugar beet, the dynamics of PAD according to the results of the Mann-Kendall test found no trend in all soil types, except the haplic Fluvisol, the content of PAD decreased with time (fig. 2).

Table 2 shows the correlation coefficient results for soil structure parameters and soil parameters. In general, the most important internal factor affecting the binding soil mineral particles together is SOM (Krol et al., 2013; Šimanský and Bajčan, 2014). García and Orenes et al. (2005) presented very strong positive linear relationships between aggregate stability and organic carbon concentration. When all soils were assessed together, the negative significant correlations were observed between the Kv and contents of soil organic carbon, hot- and cold-water soluble carbon as well as CHA:CFA ratio. It means, the higher content and quality of SOM in soils were, the lesser were the decrease in soil structure vulnerability values. Vulnerability coefficient can be influenced by soil moisture, calcium content and SOM content (Zaujec and Šimanský, 2006). The same trend was observed between Ic and SOM parameters. The higher quantity and quality of SOM in soils were, the lesser was formation of soil crust in mentioned soil types. Above-mentioned results are consisted with the results of Šimanský et al. (2014). In addition, the values of Ic negative correlated with total and potentially mineralisable nitrogen and exchangeable magnesium. In contrast to our results, Zhang and Norton (2002) reported that Ca2+ is more effective than Mg2+ in improving soil structure, because Mg2+ may have deleterious effect on aggregate stability by increasing clay dispersion. The extent of negative effect of Mg2+ compared with Ca2+ may depend on clay type (Bronick and Lal, 2005) and electrolyte concentration in the soil (Tisdall 1996). In this study, the higher content of Mg2+ in comparison to Ca2+ on average was determined (table 1).
Figure 1. Dynamics of the soil structure parameters during the vegetation season of sugar beet: A) vulnerability coefficient, B) index of aggregate stability, C) crusting index, D) percentage of aggregate destruction.

cCh - calcric Chernozem, hF - haplic Fluvisol, mF - mollic Fluvisol.

Different letters between columns (a, b, c) indicate that means are significantly different at $P \leq 0.05$ according to LSD-test.

Figure 2. Dynamics of the percentage of aggregate destruction according to the results of the Mann-Kendall test

PAD - percentage of aggregate destruction.

Higher content of hot-water soluble carbon and higher CHA:CFA ratio was reflected in higher aggregate stability. When all soils were assessed together, higher stability of SOM positively affected stabilization of macroaggregates because of negative correlation between PAD and QHA (table 2). If all loamy soils were assessed separately, we detected negative significant correlations between Ic and Corg in all soil types. Higher content of SOM of rather stable than labile form resulted to reduction of crust, which is consistent with the results of Šimanský et al. (2014). In calcric Chernozem, positive correlations between PAD and Nt and Npot were determined (table 2),...
it means that higher content of nitrogen in calcaric Chernozems can be responsible for brake down of macroaggregates. Nitrogen mainly in ammonium form has negative effect on soil structure (Haynes and Naidu, 1998). This trend was not confirmed in other soil types. In mollic Fluvisol, values of $K_v$ and $I_c$ increased with higher labile carbon contents as well as higher stability of SOM positively affected stabilization of macroaggregates.

Table 2. Correlation coefficients between some soil properties and soil structure parameters (all soils together).

<table>
<thead>
<tr>
<th>Corg</th>
<th>Cl</th>
<th>CCWD</th>
<th>CHWD</th>
<th>CHA:CFA</th>
<th>QHS</th>
<th>QHA</th>
<th>Nt</th>
<th>Npot</th>
<th>CO3-</th>
<th>Ca2+</th>
<th>Mg2+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kv</td>
<td>-0.634** n.s.</td>
<td>-0.670**</td>
<td>-0.732***</td>
<td>-0.615** n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sw</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.700**</td>
<td>0.552* n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Ic</td>
<td>-0.883*** n.s.</td>
<td>-0.659**</td>
<td>-0.917***</td>
<td>-0.880*** n.s.</td>
<td>n.s.</td>
<td>-0.522* -0.522* n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>-0.694**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAD</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Corg - soil organic carbon, Cl - labile carbon, CHWD - hot-water soluble carbon, CCWD - cold-water soluble carbon, CHA:CFA - the carbon of humic acids to carbon of fulvic acids ratio, QHS - colour quotient of humic substances, QHA - colour quotient of humic acids, Nt - total nitrogen, Npot - potentially mineralizable nitrogen, CO3- - carbonates, Ca2+ - exchangeable calcium, Mg2+ - exchangeable magnesium, Kv - vulnerability coefficient, Sw - index of aggregate stability, Ic - crusting index, PAD - percentage of aggregate destruction, sum of samples = 18, *P ≤ 0.05; **P ≤ 0.01; ***P ≤ 0.001; n.s. - non-significant.

4. CONCLUSIONS

Soil structure parameters varied in time and soil types and the attributes observed at any given time reflect the next net effect of numerous interacting factors which can change at any moment. Even though the overall but also the results of the dynamics of structural parameters were identical for the vulnerability coefficient, index of aggregate stability and crusting index, but different for the percentage of aggregate destruction, the soil structure cannot be evaluated only on the base of a one parameter, but it must always be assessed comprehensively using multiple indicators. Our results show the fact that the key factor controlling structure of loamy soils (their stability and vulnerability) is the quality and quality of soil organic matter. In calcaric Chernozem, haplic and mollic Fluvisols, higher soil organic matter content of rather stable than labile form resulted to reduction of crust.

References


