The Effect of Different Soil Management Practices on the Structure of Vineyard Soil

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ABSTRACT
The effect of different soil management practices on soil structure was studied in a vineyard. In 2006, an experiment of the different management practices in a productive vineyard (Leptosol) was established in Nitra-Dražovce (Slovakia). The following treatments were established: 1. control (grass without fertilization), 2. T (tillage), 3. T+FM (tillage+farmyard manure), 4. G+NPK3 (grass+NPK 120-55-195 kg ha⁻¹), 5. G+NPK1 (grass+NPK 80-35-135 kg ha⁻¹). The results showed that the highest value of the critical level of soil organic matter was seen in the G+NPK3 treatment. In the tilled treatment (T), the highest vulnerability of the soil structure was observed. The application of nutrients in G+NPK1 had a negative influence on the content of water-stable micro-aggregates. However, higher doses of fertilization (NPK 120-55-195 kg ha⁻¹) had a positive effect on the decrease in water-stable micro-aggregates. Overall, G+NPK3 (NPK 120-55-195 kg ha⁻¹) gave the best improvement in the structure of the soil.

Keywords: Crusting index, Leptosol, soil management, soil structure, vineyard.

INTRODUCTION
The European Union currently assigns to Slovakia 22,200 hectares of vineyard. This allocation is not final, and it can change depending on market demand. The mentioned area is not used at present, although viticulture is an important component of agricultural production in Slovakia.

Vineyards are grown as a monoculture for many years in the same place and this causes changes to the soil environment. In general, the vine does not make demands on the soil. At present time, farmers are directing more attention to physical properties of the soil than its chemical composition. A key factor of soil quality is the structural state (Jackson et al. 2003; Karlen 2004). Agro-technical operations and environmental changes modify the soil structure (Bronick and Lal 2005) and organic matter content. For example, added farmyard manure (organic composts) (Tisdall and Oades 1982; Šimanský 2011b), fertilizers (Šimanský et al. 2006), and crop residues (Triberti et al. 2008) to soils can positively affect soil
structure stability and decrease the erosion processes. In productive vineyards, soil structure can be influenced by mulching (Glab and Kulig 2008) or grass sown in rows or between rows of vine (Cellète et al. 2008; White 2009). The relationship between soil organic matter and soil structure has been studied in different climatic conditions, soil types, and soil managements (Elliot 1986; Oades and Waters 1991; Šimanský et al. 2008), but its relationships in Rendzic Leptosols, which are used for vineyards, is not well understood as yet. Leptosols are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony. Leptosols are azonal soils which are particularly common in mountainous regions. Leptosols are the most extensive soils on earth, extending over about 1.7 billion ha (WRB 2006). In Slovakia, Leptosols cover 3.5% of the agricultural land. The total area of Slovak Republic is 4.9 mil. ha, of which agricultural land constitutes 2.4 mil. ha.

The aim of this work is to evaluate effects of different soil management practices on the soil structure of a vineyard as well as to assess the effects of soil chemical properties and soil organic matter on soil structure in Rendzic Leptosols.

METHODOLOGY

In 2006, an experiment on the different management practices in a vineyard was carried out in Nitra-Dražovce (48°21'6.16"N; 18°3'37.33"E), Slovakia. It is located in the Nitra wine-growing area. The area has a temperate climate with an annual average rainfall of 550 mm and an annual mean temperature of ≥ 10 °C. The soil was developed on limestone and magnesian limestone. The soil type was classified according to WRB classification as a Rendzic Leptosol (WRB 2006). The soil samples (depth 0-0.3 m) contained 17.0±1.6 g kg⁻¹ of organic carbon, 1867±103 mg kg⁻¹ of total N, 99±8 mg kg⁻¹ of total P, 262±15 mg kg⁻¹ of total K, and base saturation percentage was 99.3±0.01 % with an initial pH of 7.18±0.08 (in 2000). Rock fragments were observed in the soil profile to a depth of 0.3 m = 8%.

In 2000, the vines (Vitis vinifera L. cv. Chardonnay) were planted in rows (3 m x 1 m; 3300 plants ha⁻¹) and were trained using a rheinish-hessian system. A variety of grasses were used in the inter-rows of the vines, which were sown in 2003. The vines were protected against the detrimental effects of diseases and pests. The experiment was conducted on a randomized complete block design with four replicates. It included the following treatments:

1. Co – control - grass sown in the rows and between vine rows (minimal human impact to the soil in comparison to other treatments);
2. T – tillage - yearly medium tilth to a depth of 0.25 m and intensive cultivation between vine rows during the growing season with hoes (an average of 3 times per vegetation season of vine - depending on climatic conditions);
3. T+FYM – tillage+farmyard manure - medium tilth to a depth of 0.25 m with ploughed farmyard manure at a rate of 40 t ha⁻¹ (organic carbon content 10.2%, total nitrogen content 0.45%) and intensive cultivation.
between vine rows during the growing season. First application of FYM was released in autumn 2005 and next in autumn 2009;

4. G+NPK3 – doses of NPK fertilizers in 3rd intensity for vineyards, that is, 120 N kg ha\(^{-1}\), 55 P kg ha\(^{-1}\) and 195 K kg ha\(^{-1}\). The dose of nutrients was divided: 2/3 applied into the soil in the spring (bud burst - on March) and 1/3 during flowering (in May). The grass was sown in and between the vine rows;

5. G+NPK1 – doses of NPK fertilizers in 1st intensity for vineyards, that is, 80 N kg ha\(^{-1}\), 35 P kg ha\(^{-1}\) and 135 K kg ha\(^{-1}\). The dose of nutrients was divided: 1/2 applied into the soil in the spring (bud burst - on March) and 1/2 during flowering (on May). The grass was sown in and between the vine rows.

Soil samples were collected from all treatments from a depth of 0–0.3 m, during the spring of 2008-2011. In each location, soil samples were collected and mixed to homogenise the sample. Soil samples were dried at laboratory temperature and standard soil analyses were used for determination: soil pH (1:2.5 - soil: water), sorptive parameters (Fiala et al. 1999), total organic carbon content (Dziadowiec and Gonet 1999) and optical parameters of humus substances and humic acids in soil samples, labile carbon content (C\(_L\)) (Loginov et al. 1987) and hot water soluble carbon (C\(_{HWD}\)) (Körschens 2002). Soil samples for the determination of the structure parameters were taken with the aid of a spade to maintain the soil aggregates. Soil samples were dried at laboratory temperature and divided by sieve (dry and wet sieve) to 7 size fractions. We calculated the vulnerability coefficient (K\(_v\)) according to Valla et al. (2000), as well as the stability index of water-stable aggregates (Sw) and values of sum of mean weight diameters (MWD) in fractions of aggregates. The index of crusting (I\(_c\)) (Lal and Shukla 2004) and critical soil organic matter content (S\(_t\)) according to Pieri (1991) as one of the most important parameters of soil structure stability were calculated as well.

The obtained results were statistically evaluated. Analysis of variance (ANOVA) was performed by using the Statgraphics Centurion XVI (Statpoint Technologies, Inc., USA). Treatment differences were considered significant at \(P\) values < 0.05 by the LSD multiple-range test. Correlations between soil organic matter and soil structure stability were determined.

**RESULTS AND DISCUSSION**

**Stability, Water Resistance and Vulnerability Parameters of Soil Structure**

The results of the effects of different soil management practices in a vineyard on stability, water resistance and vulnerability parameters of soil structure are shown in Table 1. In comparison to all soil management practices in a vineyard, a higher stability index value of water-stable aggregates (1.64±0.17), but without statistical significance was seen during the treatment with ploughed farmyard manure. Added organic manures can positively affect physical properties and
especially the structure of soil (Pagliai et al. 1987; Mbagwu 1992; Obi and Ebo, 1995). In G+NPK3 (6.99±0.33), the most favourable values of the critical level of soil organic matter (statistically significant in comparison to all treatments) were observed during the period (2008-2011). Similarly, the values of crust index were the most favourable in G+NPK3. Index of crusting (Ic) is a very important parameter of soil structure based on textural composition and soil organic matter content (Lal and Shukla 2004). Soil crust formation is dependent on soil tillage and fertilization as presented by Šimanský et al. (2008). In our case, the effect of soil texture was eliminated because the experiment was based on one soil type with a defined particle size distribution (569 g kg\(^{-1}\) of sand, 330 g kg\(^{-1}\) of silt and 101 g kg\(^{-1}\) of clay). This means the values of Ic have been affected by soil organic matter content (SOM). SOM is an important agent responsible for binding soil mineral particles together (Oades and Waters 1991) and it decreases the amount of soil crust formed (Šimanský et al. 2008). The application of NPK fertilizers (in 1\(^{st}\) and 3\(^{rd}\) intensities) as well as application of farmyard manure increased the content of SOM (Šimanský 2011a), which led to a decrease (positive effect) in Ic, but without statistical significance (Table 1). Agbede (2010) states that adding a combination of organic manures together with NPK fertilizers to the soil can improve the physical properties of soils. For control, between values of mean weight diameters of structure aggregates (MWDs - dry pre-sieved) and mean weight diameters of water-stable aggregates (MWDm), the lowest differences were determined. In this case, this means that the vulnerability of soil structure (Kv) was the lowest. In comparison to all soil management practices in a vineyard, a higher value of Kv was seen in the T treatment. Tillage disrupts soil aggregates and decreases SOM (Elliot 1986; Plante and McGill 2002).

### Table 1

<table>
<thead>
<tr>
<th>Parameters( \text{S_t})</th>
<th>Soil management</th>
<th>Co</th>
<th>T</th>
<th>T+FM</th>
<th>G+NPK3</th>
<th>G+NPK1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sw (1.51±0.24a)</td>
<td>Co</td>
<td>1.63±0.15a</td>
<td>1.64±0.17a</td>
<td>1.58±0.11a</td>
<td>1.37±0.09a</td>
<td></td>
</tr>
<tr>
<td>S_t (6.67±0.58b)</td>
<td>T</td>
<td>5.69±0.72a</td>
<td>6.68±0.85b</td>
<td>6.99±0.33b</td>
<td>6.64±0.45b</td>
<td></td>
</tr>
<tr>
<td>I_c (0.88±0.14a)</td>
<td>T+FM</td>
<td>0.99±0.11b</td>
<td>0.87±0.19a</td>
<td>0.84±0.04a</td>
<td>0.88±0.06a</td>
<td></td>
</tr>
<tr>
<td>MWDs (2.17±0.11a)</td>
<td>G+NPK3</td>
<td>2.57±0.16b</td>
<td>2.36±0.21ab</td>
<td>2.38±0.19ab</td>
<td>2.30±0.14ab</td>
<td></td>
</tr>
<tr>
<td>MWDm (1.20±0.05a)</td>
<td>G+NPK1</td>
<td>0.98±0.05a</td>
<td>1.11±0.08a</td>
<td>1.28±0.02a</td>
<td>1.04±0.04a</td>
<td></td>
</tr>
<tr>
<td>Kv (1.87±0.18a)</td>
<td></td>
<td>3.14±0.38b</td>
<td>2.27±0.45a</td>
<td>2.05±0.28a</td>
<td>2.30±0.16a</td>
<td></td>
</tr>
</tbody>
</table>

Co – control, T – tillage, T+FM – tillage+farmyard manure, G+NPK3 – grass+NPK 120-55-195 kg ha\(^{-1}\), G+NPK1 – grass+NPK 80-35-135 kg ha\(^{-1}\). Different letters in the same column indicate that treatment means are significantly different at \(P<0.05\) according to LSD. 

\(\text{S_t}\) – critical level of soil organic matter, \(\text{I_c}\) – index of crusting, \(\text{K_v}\) – vulnerability coefficient, \(\text{S_w}\) – index of stability, \(\text{MWDs}\) – mean weight diameter –dried sieve, \(\text{MWDm}\) - mean weight diameter of water-stable aggregates.
Soil management practices had a statistically significant influence on the content of water-stable micro-aggregates (WSAmi) during the 2008-2011 period. In T (25.15±6.24), the lowest content of WSAmi was determined; however, in G+NPK1 (35.81±11.9) the highest content of WSAmi was detected (Table 2). In T, the content of WSAmi was lowered by 18 % in comparison to the control. The main cause of decreased WSAmi could be the lower content of the SOM in WSAmi, just as in the study of Scott (1998), as well as the disruption of soil macro-aggregates (Six et al. 2002). However, in G+NPK3 (almost twice the dose of nutrients), WSAmi content was lower by 25% in comparison to G+NPK1 (Table 2).

Correlations between Soil Chemical Properties, Soil Organic Matter and Soil Structure Parameters

In the soil solution, the concentration of hydrogen cations had a significant effect on the soil crust. The higher values of pH as well as the lower values of hydrolytic acidity where the lower vulnerability of soil was used to create the soil crust were observed in all soil management practices in the vineyard (Table 3). Stability of the soil structure is connected with acid soils (Scott 2000; Huffman et al. 2001). Roberts and Carbon (1971) recorded that water resistance does not develop under alkaline conditions due to the higher solubility of humic substances. There are very important factors for the formation of a favourable structure of soil for the right quantity and quality of SOM (Fortun et al. 1989; Šimanský et al. 2007) which confirmed our results (Table 3). The higher content of total organic carbon in soil positively affected K, S, S and I. The quality and stability of SOM also had a positive influence on S.

A very important factor for forming of individual size fractions of aggregates is soil organic matter (Šimanský et al. 2007); on the other hand, it is not important for all size fractions of aggregates because some aggregates are formed by chemical factors (Six et al. 2004). Correlations between chemical properties,
organic matter and size fractions of water-stable aggregates are shown in Table 4. An important negative correlation was detected between pH and WSA 0.25-1 mm content. A 0.25-1 mm size fraction of WSA was formed in acid pH with a higher portion of basic cations in sorptive complex. Highly negative correlations between WSA_{0.25} (r=-0.509, P<0.05), WSA 2-3 mm (r=-0.465, P<0.05) and exchangeable Na\(^+\) were found. These facts have been confirmed by several studies (Levy and Torrento 1995; Amézketa 1999; Bronick and Lal 2005). At the same time, we found a positive correlation between WSA 2-3 mm and C_{HA}. A positive correlation between WSA_{0.25} and Q_{HS} was also found.

**CONCLUSION**

The highest value of the critical level of soil organic matter was seen in the treatment with higher doses of fertilization (3\(^{rd}\) intensity). In the tilled treatment,
the highest vulnerability of the soil structure was observed. The application of nutrients in 1st intensity of fertilisation of the vineyard had a negative influence on the content of water-stable micro-aggregates; however, higher doses of fertilization (3rd intensity) had a positive effect on the decrease of water-stable micro-aggregates. Overall, in the treatment of the application of nutrients in 3rd intensity of fertilization of the vineyard, the best structure state of soil was observed.

The quantity and quality of the soil organic matter as well as its stability are very important factors of stability, water resistance and vulnerability of soil structure in all soil management practices in a vineyard.

Soil structure cannot be evaluated only on the base of a one parameter, but it must always be assessed comprehensively using multiple indicators.

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