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ASSESSMENT OF SOIL PHYSICAL CHARACTERISTICS OF LUVISOLS UNDER MONOCULTURE OF VINES

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The physical properties of Luvisols under vineyards of the Nitra wine-growing area (Slovakia) were evaluated in the paper. Soil samples were taken from two selected localities (Nitra – Dražovce, Vrábľa). The obtained results showed that in the soil profile of Dražovce, the average contents of non-capillary pores, capillary pores and semi-capillary pores to the total porosity were equal to 26.1, 64.4 and 9.4%, respectively, and in the soil profile of Vrábľa – 22.3, 75.6 and 2.1%, respectively. In the Dražovce locality, the average content of aggregate stability index (S_w) decreased in the following order: abandoned vineyard > grassy strip between the vineyard rows > intensively cultivated rows of vineyard. In contrast, in the Vrábľa locality, higher average contents of S_w were determined in intensively cultivated rows of vineyard in comparison to grassy strip between the vineyard rows. The lowest average value of vulnerability coefficient (K_v) was observed in abandoned vineyard (Dražovce locality) and in both localities in grassy strip between the vineyard rows. Intensive cultivation of the vineyard rows resulted in higher vulnerability of soil structure. The values of maximum capillary capacity were almost the same in both soil profiles of Luvisols. A higher content of soil moisture was observed in the soil profile in the Vrábľa locality (33.6 ± 2.50) in comparison to the Dražovce locality (30.6 ± 5.44). Higher content of storage moisture was determined in the Vrábľa locality ($2,684 \text{ l m}^{-2}$) in comparison to the Dražovce locality ($2,450 \text{ l m}^{-2}$).

Keywords: porosity, soil structure parameters, the Nitra viticulture region, vineyards

In viticulture, attaining high quality grapes for winemaking is a priority for growers. Quality can also be related to the effects of “terroir”, a term first established for French wines (Wilson, 1998). In the “Old World” wine industry, the concept of “terroir”, is used to describe all aspects of the environment, geography, geology, and cultural practices that influence grape production. A key factor for economical and sustainable vine growing is to ensure the optimal soil conditions; therefore, the soil for vine growing has to be ideal. White (2009) identified the following key properties, with respect to the ideal soil for vine growing: soil depth, soil structure and water, soil strength, soil chemistry, and nutrient supply and soil organism. Viticulture is unusual in that it is often conducted on sites considered as unsuitable for most crops. Before the foundation of a future vineyard, winemakers have to proceed in a preventive manner and assess the suitability of the area. They highlighted in addition to chemistry mainly the physical properties of soils. For example, in this regard, it is important that vines have sufficient water to allow for adequate vine and berry growth, but excess amounts of water can lead to excess vigour and poor fruit composition and vine quality. At present, Slovakia is prone to droughts and soil droughts, which negatively affect crop production, including major field crops (Mati et al., 2011).

As mentioned above, the successful cultivation of the vine is related to the selection of appropriate soil and climatic conditions before the establishment of the vineyard. Not all

soil types are suitable for cultivation of each grape variety. At present, Slovakia has 11,199 hectares of vineyards and only 8,856 hectares of them are productive (ŠÚ SR, 2014). In Slovakia, vineyards are now growing on a range of soils including Chernozems, Cambisols, Luvisols, Fluvisols, and Leptosols (Šimanský, 2011). Very suitable soils for the vine growing are also Luvisols which occupy the area of 286 182 ha, accounting for 11.7% of agricultural land in Slovakia (Zaujec et al., 2009), but these soils have a range of growing conditions for plants due to their different physical, physico-chemical and biological properties.

The objectives of the present study were:

1. to compare the physical properties of Luvisols in the Nitra vine region,
2. to evaluate the effect of different soil management practices on the structural condition of Luvisols under monoculture of vine.

Material and methods

During the year 2011, the soil surveys were carried out to determine the soil properties of several vineyards soils in Nitra-Dražovce and Vrábľa. These localities are located in the Nitra wine-growing region (Slovakia) and there are different parent materials and climate conditions. Mean annual temperatures in the studied area ranged from 9.3 to 9.7 °C and mean annual precipitation varied from 564 to 580 mm.

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Both localities are categorized into the area of Podunajská nížina (also called the Danube Lowland, Slovakia) and has nature divided into finger like bays (Rybár et al., 2015). From geomorphological point of view, Dražovce belongs to the Nitra Upland. This locality (Dražovce) is tectonically divided from the right side on the Tribeč Mts. which is situated to the Western Carpathian Core Mountains with their Mesozoic formation (sequences) along to the Nitra Upland (Rišnovce Depression) on the left side (Pristáš et al., 2000). General orientation of these complex structures is N – S direction. Geological background (Dražovce locality) is situated on intersect of these two entities and called Stredonitrianska field. Gradual origin and development of this locality was concentrated on formation of various erosion-accumulation structures e.g. multiple river terraces, alluvial cone coming from the Tribeč Mts. (Stankoviansky et al., 2012). Geomorphological design has been recently developed because of extensive anthropogenic performance mainly associated with agricultural "vineyard" activity. For development of material compositions of soil, considerable influence is posed by the fluvial terrace accumulation and their lateral movements or gravitationally transported materials from Mesozoic sequences (many carbonates components from the Tribeč Mts.) (Pristáš et al., 2000). The Vrábľa locality belongs to the geomorphological region of the Nitra and Žitava Uplands with the most typical of north-eastern part of the Danube Lowland (Šujan and Rybár, 2014). For the soil development of this locality, the Western Carpathian Core Mountain (the Tribeč Mts.) has no extensive impact on material composition as compared to the Dražovce area but specific development of multiple river terraces materials was detected. At this locality, the development with different intensity of subsidence and certain lateral migration of rivers was observed (channel networks) (Stankoviansky et al., 2012; Šujan and Rybár, 2014). Due to this reason, the Vrábľa locality underlines erosion-accumulation formations (river/fluvial sediments) with typical development such as multiple river terraces (Harčár et al., 1988; Šujan and Rybár, 2014).

In each locality, before soil sampling a pit was excavated (in grassy strip between the vineyard rows) and the soils were classified according to the World Reference Base for Soil Resources (WRB, 2006) based on the whole-profile soil morphology. Soils in the Dražovce and Vrábľa locality were classified as Haplic Luvisol and Stagni-Haplic Luvisol, respectively. In the soil pits, the soil samples were collected (in triplicate) after 10 cm layers to a depth of 80 cm to cylinders with an inner diameter of 5 cm and height of 5 cm. Determination of physical (pore size distributions), hydrophysical properties (soil moisture, storage moisture, maximum capillary water capacity, available water capacity, and retention water capacity) was then conducted using standard methods (Fiala et al., 1999).

The total porosity (P) in percentage was calculated according to equation 1:

$$P = \frac{\rho_s - \rho_d}{\rho_s} \cdot 100 \quad (1)$$

where:

- ρ_s – particle density (g cm^{-3})
- ρ_d – bulk density (g cm^{-3})

Volume of non-capillary pores (P_n) in percentage was calculated according to the equation 2:

$$P_n = P - \Theta_{30} \quad (2)$$

where:

- P – total porosity (%)
- Θ_{30} – soil moisture after 30 min of suction (%)

Volume of the capillary pores (P_k) is identical to the water holding capacity (Θ_{RVK}) and volume of semi-capillary pores (P_s) in percentage was calculated according to the equation 3:

$$P_s = \Theta_{30} - \Theta_{RVK} \quad (3)$$

Soil moisture was assessed as gravimetric soil moisture expressed in percentage (%) and then recalculated on volume percentage according to equation (4):

$$\theta = w \times \rho \quad (4)$$

where:

- θ – soil moisture by volume (%)
- w – soil moisture by weight (%)
- ρ – bulk density (g cm^{-3})

The storage moisture (Ws) in percentage was calculated according to equation (5):

$$Ws = \theta \times h \quad (5)$$

where:

- h – thickness of the soil layer (dm)

The available water capacity (AWC) in percentage was calculated according to equation (6):

$$AWC = \theta_{FC} - \theta_{wp} \quad (6)$$

where:

- θ_{FC} – field capacity (%)
- θ_{wp} – wilting point (%)

The available water storage (AWs) in percentage was calculated according to equation (7):

$$AWs = \theta - \theta_{wp} \quad (7)$$

The soil samples for determination soil structure parameters (vulnerability coefficient, index of aggregate stability and crust index) were taken from a depth of 0–30 cm:

A/ In the Dražovce locality from three plots:

1. abandoned vineyard,
2. grassy strip between the vineyard rows,
3. intensive cultivated rows of the vine.

B/ In the Vrábľa locality from two plots:

1. grassy strip between the vineyard rows,
2. intensive cultivated rows of the vine.

The vulnerability coefficient (K_v) was calculated according to following equation (8).

$$K_v = \frac{MWD_d}{MWD_w} \quad (8)$$

where:

MWD_d –the mean weight diameter of aggregates for dry sieving (mm)

MWD_w –the mean weight diameter of WSA (mm)

The index of crusting (I_c) as well as the indexes of aggregate stability (S_w) were calculated according to following equations (9–10):

$$I_c = \frac{1.5S_f + 0.75S_c}{Cl + (10 \cdot SOM)} \quad (9)$$

where:

S_f – % fine silt

S_c – % coarse silt

Cl – % clay

SOM – % soil organic matter content

$$S_w = \frac{WSA - 0.09 \text{ sand}}{\text{silt} + \text{clay}} \quad (10)$$

where:

WSA – is content of water-stable aggregates (%)

For both localities, soil mineralogical composition was identified using X-ray diffraction analysis methodology according to González et al. (2007). In order to visualize physical quantities of clay minerals VESTA programme was evaluated (Momma and Izumi, 2011).

A simple t -test was carried out to test the significance between the physical properties in different soil profiles in the same soil type. The interrelations between pore size distributions and soil water parameters in soil profiles of Luvisols were determined through correlation matrix. Above-mentioned statistical analysis was performed using the computer program Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA).

Results and discussion

In both soil profiles, the pore size distributions are shown in Figure 1 A, B. Overall, in soil profiles of Luvisols to the depth 80 cm the values of total porosity (P), capillary pores (P_k) as well as non-capillary pores (P_n) were on average the same, however, within each of studied soil profiles, porosity distribution was different across the depth. The average

vineyard soils of Slovakia (Šimanský et al., 2013; Šimanský et al., 2016) but also abroad (Ruiz-Colmenero et al., 2013; Navel et al. 2014). In the Dražovce locality, the average content of aggregate stability index (S_w) decreased in the following order: abandoned vineyard > grassy strip between the vineyard rows > and intensively cultivated rows of vineyard. The better structural state is often determined in-between

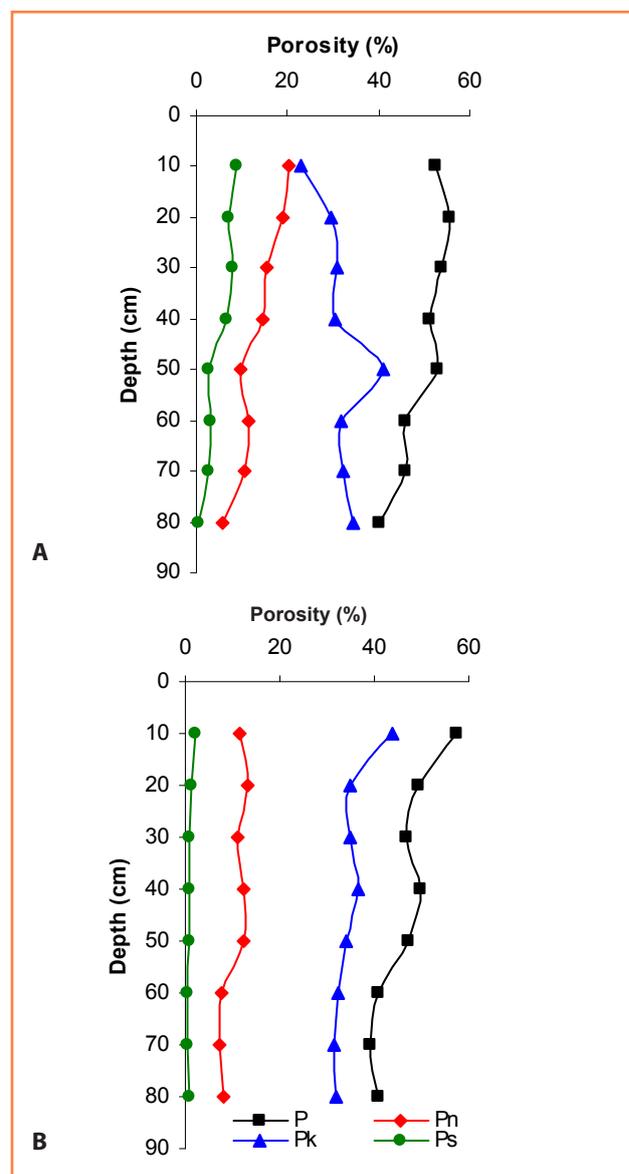


Figure 1 Pore size distributions in profiles of Luvisols A) in Dražovce locality and, B) in Vrábľa locality P – total porosity, P_n – non-capillary pores, P_k – capillary pores, P_s – semi-capillary pores

Table 1 Statistical evaluation of physical properties of Luvisols (comparison between two soil profiles of Luvisols, based on t -test)

	P	P_n	P_k	P_s	θ	AWC	AWs	θ_{KMK}
t-test	1.157	1.444	-1.520	3.518	-1.383	-0.496	-0.370	-0.036
Probability	0.267	0.171	0.151	0.003	0.188	0.628	0.717	0.972

P – total porosity, P_n – non-capillary pores, P_k – capillary pores, P_s – semi-capillary pores, θ – soil moisture, AWC – available water capacity, AWs – available water storage, θ_{KMK} – maximum capillary capacity

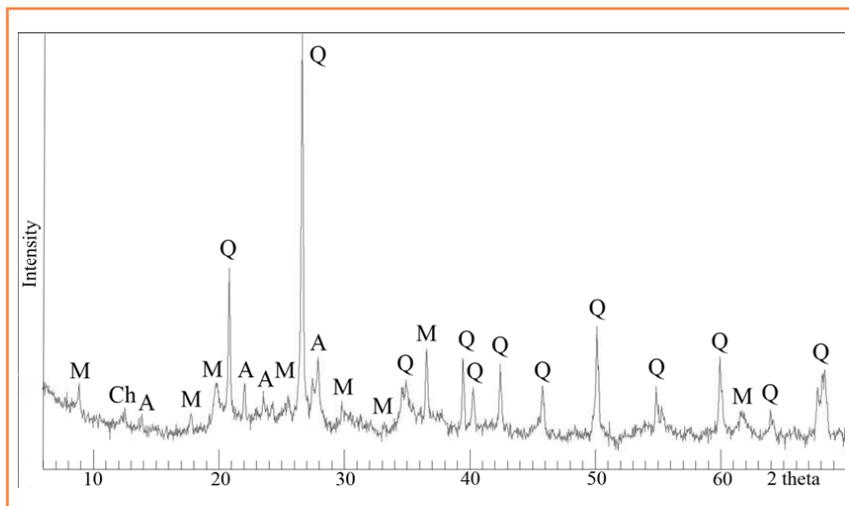


Figure 3 X-ray diffraction analysis of soil minerals in Vrábale locality: Q – quartz (SiO_2), A – albite-anortite ($\text{NaCaAlSi}_3\text{O}_8$), M – muscovite ($\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$), and Ch – clinochlore ($(\text{Mg}, \text{Fe}^{2+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$) there was also detected low content of kaolinite ($\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$)

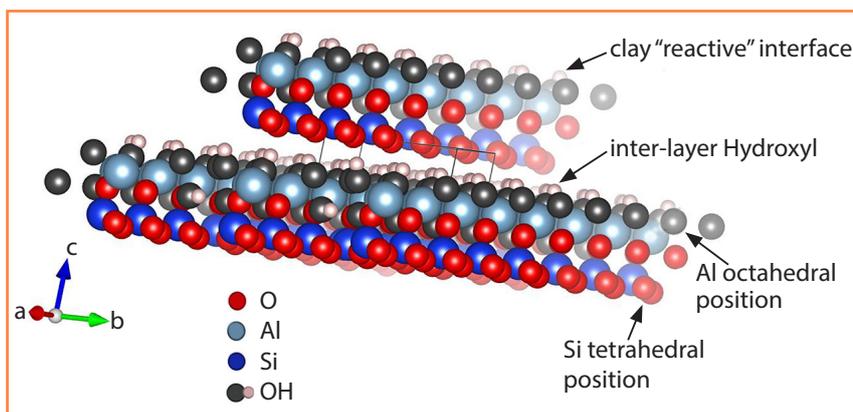


Figure 4 Model of phyllosilicate structure (multi-layered clay mineral) e.g. kaolinite (type of 1 : 1) with visualised octahedral and tetrahedral sheets, interlayered dimension along with active surface determined different charge, water supply, and etc. in clay structures; a, b, c – axes shown main vectors integrity

with quartz which predominantly has positive charge it is most likely mineral-mineral bonding (Denef et al., 2004). Generally, soils which contain 2 : 1 clay minerals (two octahedral and one tetrahedron layers) play a key role to develop the aggregates with long-term stability because of higher cation exchange capacity and specific surface area. These properties have tendency to strong interactions with organic substances and more clays minerals (Vitro, et al. 2013). The parameters of SOM from studied localities are mentioned by Šimanský et al. (2016). In the Dražovce locality, the total SOC content was the lowest in cultivated rows of vine (0.98%) then follows grass in the rows of vine

(1.43%) and abandoned vineyard (1.76%). On this locality we identified mineral soil association with dominant content of quartz (SiO_2), albite-anortite ($\text{NaCaAlSi}_3\text{O}_8$), muscovite ($\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$) and calcite (Figure 2). From clays like minerals was identified kaolinite ($\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$) (Figure 4) as a major component associated with insignificant amount of clinochlore ($(\text{Mg}, \text{Fe}^{2+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$).

There is some evidence that kaolinite belongs to the group of multi-layered phyllosilicates with characteristic octahedral vs. tetrahedral relation which poses structural integrity ratio 1 : 1 (Figure 4). On the other hand, clinochlore is a typical member of chloride multi-layered

phyllosilicate with extensive element substitution (the same or different element valence substitutions) ability with strong impact on soil structure and other soil characteristics (Denef et al., 2004; Vitro et al. 2013). It is most probable that the existence of other layered phyllosilicates (clay), and other minerals in the system could play a role contributing to a gradual aggregate formation and stability (Denef et al. 2004). In the Vrábale locality, the SOC content was more than two times higher under grasses (2.17%) than without grasses (0.88%). This locality has almost similar association of soil minerals (as compared to the Dražovce locality) such as quartz, albite-anortite, muscovite without a higher content of calcite but with a great content of mixed clay minerals (multi-layered phyllosilicates) that was detected from chloride group – clinochlore (Figures 3, phyllosilicate type 2 : 1). This result suggested that clay minerals with variable charge such as kaolinite (1 : 1) type (Dražovce locality) along with quartz has higher aggregate stability by lower SOC (0.98%), than soils in the Vrábale locality with mixed clay minerals such as clinochlore (2 : 1 type) that needed higher SOC (2.17%) to aggregate formation. Similar results of clay like minerals were also confirmed in soils by Denef et al. (2004), and Vitro et al. (2013).

The retention capacity of soils was assessed on the basis of capillary pores. In all cases, the results of *Pk* content showed a high capacity of the soils to retain water within the soil profiles. The values of maximum capillary capacity were almost the same in both profiles of Luvisols. On average, the values were 35.2% and 35.3% in the Dražovce locality and the Vrábale locality, respectively. Based on the *t*-test results, statistically significant differences in the soil moisture content between both soil profiles of Luvisols were not observed (Table 1), however, on average, a higher content of soil moisture by 10% was observed in soil profile in the Vrábale locality ($33.6 \pm 2.50\%$) in comparison to the Dražovce locality ($30.6 \pm 5.44\%$). Values of storage moisture (*Ws*) showed similar differences. *Ws* values reflect the soil water content in the soil layer at the time of collection (Fulajtár, 2006). A higher content of *Ws* was

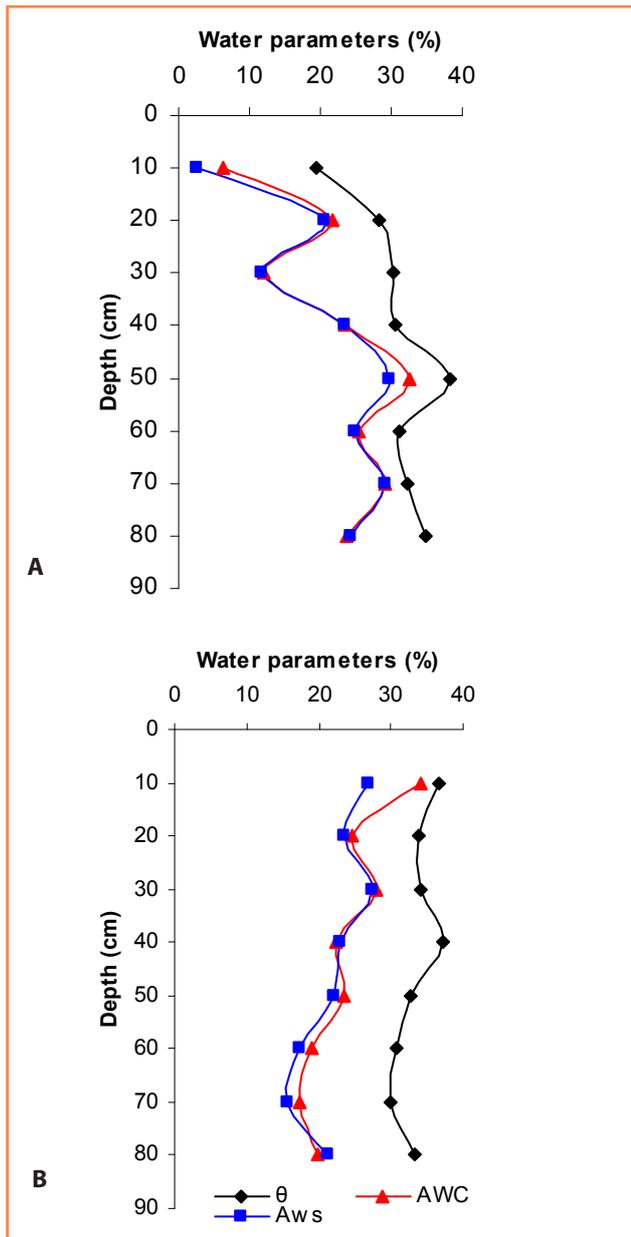


Figure 5 Water parameters in profiles of Luvisols A) in Dražovce locality and, B) Vrábě locality
 θ – soil moisture, AWC – available water capacity, AWs – available water storage

determined in the Vrábě locality ($2,684 \text{ l m}^{-2}$) in comparison to the Dražovce locality ($2,450 \text{ l m}^{-2}$), however, the trends of changes due to the soil depth were different (Figure 5 A, B). The same effects in linear trends were observed in available water capacity (AWC) in both soil profiles of Luvisols. In the Dražovce locality, the values of AWC linearly increased within the soil depth ($y = 1.99x + 1.67$; $R^2 = 0.493$) and opposite, in the Vrábě locality, the values of AWC linearly decreased within the soil depth ($y = -3.91x + 137.23$; $R^2 = 0.751$). Statistically significant differences in the AWC ($t = -0.496$, $P = 0.628$) in both soil profiles of Luvisols were not observed. The AWC can be influenced by field water capacity and by wilting point (Fulajtár, 2006). The retention water capacity and wilting point are influenced by particle-size distribution. Soils with higher clay content have a higher retention capacity

than sandy soils. The mentioned soils had been evaluated according to WRB classification as medium (WRB, 2006) with average clay content of 20% to the soil depth of 30 cm. The clay particles are able to be located nearby plant roots (Tisdall and Oades, 1982) and the root system of plants has a higher amount of available water. On the other hand, plants with a higher ground biomass have more requirements in water and AWC can be limited. Šimanský and Bajčan (2013) showed that soil management practices in a productive vineyard had a statistically significant influence on values of AWC. Statistically significant differences in the available water storage (AWs) ($t = -0.370$, $P = 0.717$) in both soil profiles of Luvisols were not observed, however, the changes due to the soil depth in both profiles were significant. In the Dražovce locality, the values of AWs linearly increased within the soil depth ($y = 2.02x + 3.03$; $R^2 = 0.577$) and, in contrast, in the locality the values of AWs linearly decreased within the soil depth ($y = -4.71x + 149.3$; $R^2 = 0.615$).

Table 3 shows the coefficients of correlations between porosity and water availability. In the locality Vrábě, we determined statistically significant correlations between total porosity and other water parameters. An opposite situation was observed in the Dražovce locality. The negative significant correlations were observed between the P_n and θ , W_s and AW_s , but only in soil profile of the Dražovce locality. It means that the higher of P_n in soil was, the lesser was the decrease in soil water parameters. In both soil profiles, the higher P_k contents resulted in higher values of soil water parameters. The higher content of P_s in soil there was the higher values of θ , W_s and AWC were but only in the Vrábě locality. On the other hand, content of P_s in soil resulted in lower values of soil water parameters in the Dražovce locality.

Conclusion

Even though both soil profiles of Luvisols differed in physical characteristics mainly across the depth, they had high capacity to retain water within the soil profiles on average. The same, the values of maximum capillary capacity, storage moisture, available water capacity and available water storage were almost the same on average in both profiles of Luvisols. The lowest vulnerability of soil structure was observed in abandoned vineyards and in both localities in grassy strip between the vineyard rows. Intensive cultivation of the vineyard rows resulted in higher vulnerability of soil structure. The same effect was observed in the crusting index values. The highest formation of soil crust was determined in intensive cultivated rows of vineyards. Soil management practices significantly influenced soil structure and our results supported the importance of optimization of soil management practices in productive vineyards to avoid the environmental degradation and to maintain the sustainable land management of Luvisols which are suitable soils for growing vines.

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