Clay and Humus Contents Have the Key Impact on Physical Properties of Croatian Pseudogleys

Vedran RUBINIĆ (✉)
Stjepan HUSNJAK

Summary

Pseudogleys (Stagnosols according to WRB-2014) represent the second most widespread soil type in Croatia, developed almost exclusively in its Pannonian region. Although most Croatian Pseudogleys are found on agricultural land or in agro-ecosystems, they usually have numerous constraints for agricultural production. Primarily, this is due to their unfavorable water/air regime (precipitation water periodically stagnates on/in the poorly permeable subsoil horizon). The aim of this study was to determine which significant differences in physical properties and humus content exist between the eluvial horizon (Eg) and the illuvial horizon (Btg) in Croatian Pseudogleys. Total of 33 Pseudogley profiles were investigated at 11 forest sites across the Pannonian region of Croatia. Properties of Eg horizon significantly differed from the properties of Btg horizon. Compared with the Eg horizon, the Btg horizon had more clay, higher bulk density, less pores, and lower capacity for air. However, the stability of microaggregates was higher in the Btg horizon than in the Eg horizon. Contents of clay and humus have the key impact on most soil physical properties. These results should be borne in mind, both when converting natural Pseudogleys into arable soils and when ameliorating arable Pseudogleys that contain the Eg horizon below the Ap horizon.

Key words

stagnosols, Pannonian region of Croatia, forest soils, soil physical properties, humus

University of Zagreb Faculty of Agriculture, Svetošimunska 25, 10000 Zagreb, Croatia
✉ e-mail: vrubinic@agr.hr

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Introduction

Pseudogley is the second most widespread soil type in Croatia, developed almost exclusively in its Pannonian region (Bogunović et al., 1998; Husnjak, 2014; Rubinić et al., 2015b) (Figure 1). It is formed largely on loess-derived parent materials (Rubinić et al., 2014; 2015a; 2015b). Most Croatian Pseudogleys correlate with Stagnosols (IUSS Working Group WRB, 2014), and their natural profile may be designated principally as Oi-A-Eg-Btg-Cg (FAO, 2006) (Figure 2a). According to Husnjak (2014), these Pseudogleys should be designated as O-A-Et/S-Bt/S-C/S. Husnjak (2014) does not use the suffix "g" to designate stagnic conditions (i.e., pseudogleization process) within the master horizon, but rather the letter "S". Using the slash symbol (/), the "S" designation is then combined with the designation for another master horizon, forming a compound soil horizon. Given that they developed in relief and climate conditions that are generally favorable for agriculture, about 55% of Croatian Pseudogleys are found on agricultural land or in agro-ecosystems (Husnjak et al., 2011). Therefore, such Pseudogleys may be generally designated as Ap-Btg-Cg (FAO, 2006). According to Husnjak (2014), arable Pseudogleys are rarely designated as Ap-Et/S-Bt/S-C/S, and more commonly as P-Bt/S-C/S. This is because deep tillage in Croatian Pseudogleys commonly results in mixing ("disappearance") of the A horizon, the Et/S horizon, and the upper part of the Bt/S horizon (Husnjak, 2014). Further in the text, we use only the FAO (2006) designations for soil horizons, as they are internationally accepted.

Although they are commonly used as arable soils, most Pseudogleys have numerous constraints for agricultural production (Husnjak, 2014). Primarily, this is due to the unfavorable soil water/air regime, which is regularly present in Pseudogleys. Namely, precipitation water periodically stagnates on/in the poorly permeable Btg horizon(s), causing the formation of stagnic properties *sensu* IUSS Working Group WRB (2014).

In Croatian Pseudogleys, the poorly permeable subsoil is largely developed pedogenetically, due to pronounced processes of acidification, lessivage (downward translocation, i.e., eluviation and illuviation of fine clay particles), and compaction (Rubinić et al., 2014; 2015a). Rubinić et al. (2015b) observed an increase in the average clay content of natural Croatian Pseudogleys from 11.5% in the A horizon to 27.6% in the Cg horizon. On arable land, compaction of subsoil layer(s) may be also due to the formation of a plough pan (e.g., Birkás, 2008). Namely, most Croatian farmers repeat the same tillage procedures, which are dominated by mouldboard plowing (Bogunović et al., 2014; 2015). Both the naturally formed poorly permeable subsoil and the plough pan may severely restrict rooting depth. Increased penetration resistance and/or water stagnation in/on the poorly permeable soil layer force the roots to grow horizontally (e.g., Birkás, 2008; Rubinić et al., 2015a).

Croatian Pseudogleys that are not limed are acid or very acid (Husnjak, 2014). Hence, the amount of exchangeable calcium ions (as well as other basic cations) is often low in these soils. Accordingly, topsoil structure is usually very unstable (Husnjak, 2014). This is even more prominent if the humus content is low (e.g., Kisić, 2002). In such cases, crust may form at the soil surface, significantly inhibiting the emergence of seedlings (e.g., Vučić, 1987).

Obviously, Pseudogleys are soils that are marked by distinct depth-related changes in their properties. This is particularly true concerning their physical characteristics. Hence, the aim of this study was to determine which significant differences in particle size distribution (PSD), bulk density (BD), water holding capacity (WHC), air capacity (AC), microaggregates stability (MS), porosity (P), and humus content exist between the eluvial horizon (Eg) and the illuvial horizon (Btg) of these soils. Total of 33 Pseudogley profiles were investigated at 11 forest sites across the Pannonian region of Croatia (Figure 1). Chemical properties and PSD of A, Eg, Btg, and Cg horizons of these 33 soil profiles were previously analyzed by Rubinić et al. (2015b) in relation to mean annual precipitation and relief position.

All Pseudogleys profiles in this paper were found in forests, and not on arable land. However, only by fully understanding properties and processes in natural soils, one can successfully ameliorate arable soils. Therefore, we think that our research will be useful not only for the sector of forestry, but also for the agricultural production in the study area.

Materials and methods

Pannonian region of Croatia covers about 46% of the country (Bašić, 2013). Climate in this region is moderate continental and humid (semihumid to semiarid only in the most eastern part of the region). Pseudogleys formed on the Pleistocene terraces that are built largely from loess derivates, and sporadically from brown loess (Rubinić et al., 2015b). Forest community of sessile oak and hornbeam (*Epimedio-carpinetum betuli*) is the prevailing natural vegetation on these terraces (Bašić, 2013) and the climax vegetation on Pseudogley soils (Škorić, 1986).

Total of 11 locations were investigated across the Pannonian region of Croatia (Figure 1). All locations featured well-established sessile oak and hornbeam forests (Figure 2b). Six locations were on plateaus and five were on slopes. The locations on slopes were uniform in terms of inclination (5%) and soil profile position (middle slope, about 50 m from the slope summit). At each investigated location, three replicate soil pits were dug within a circle of about 50 m radius. Therefore, 33 Pseudogley profiles were investigated across the study region. Each soil pit was dug to the depth of about 1 m. Soils were described and sampled according to FAO (2006). Soil samples were collected from each mineral horizon of each soil profile (only the results for Eg and Btg horizons are presented in this paper). Core samples were taken as triplicates.

Disturbed soil samples were air-dried and sieved through the 2 mm sieve. Soil analyses were conducted according to Škorić (1985). Soil PSD was determined by pipette-method with wet sieving and sedimentation after dispersion with sodium-pyrophosphate ($Na_4P_2O_7$, c=0.4M). Soil MS was determined using the *Vageler's structure factor*. Humus content was determined by acid-dichromate ($K_2Cr_2O_7$, c=0.4 M) digestion. Core samples were used to determine soil BD, particle density (PD), and WHC. Soil P was calculated, as follows: P=(1-BD/PD)*100. Soil AC was also calculated, as follows: AC=P-WHC.

Data were statistically analyzed using the *Mixed Procedure* and the *Corr Procedure* of the SAS® 9.2 statistical package (SAS

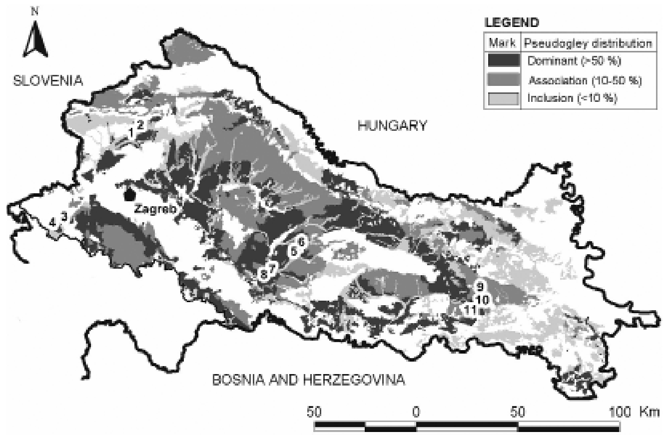

Figure 1. Map of Pseudogley distribution in the Pannonian region of Croatia (modified according to Bogunović et al., 1998). Numbers from 1 to 11 mark the approximate positions of the 11 investigated locations. At each location, three replicate Pseudogley profiles were investigated.

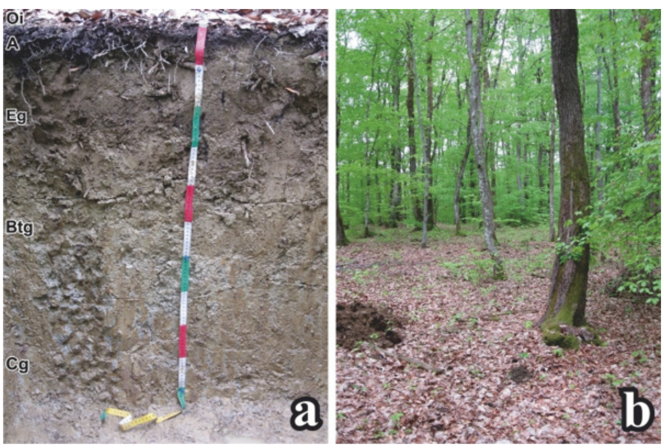

Figure 2. a: Example of the typical natural Pseudogley profile in the Pannonian region of Croatia; O, A, Eg, Btg, and Cg are soil horizon designations according to FAO (2006). b: Example of the typical landscape on natural Pseudogleys in the Pannonian region of Croatia.

Institutes, Cary, NC). After performing the analysis of variance, we compared the means for each soil property using the Tukey's Honestly Significant Difference (HSD) test. Finally, Pearson correlation coefficients ("R coefficients") were computed and tested for significance.

Results and discussion

Although both soil horizons were silt loams (FAO, 2006), the Eg horizon clay content was lower (17.3%) than the Btg horizon clay content (25.1%) (Table 1). Accordingly, the content of silt was higher in the Eg horizon (77.7%) than in the Btg horizon (70.8%) (Table 1). Contents of clay and silt showed almost perfect linear relationship, i.e., they were very strongly negatively correlated (Table 2). In Croatian Pseudogleys, the vertical increase in clay content is due to clay eluviation/illuviation, rather than deposition of coarser-textured layer over a finer-textured layer (see Rubinić et al., 2014; 2015a; 2015b). Results of the here presented study confirm this. Namely, the ratio between the clay content in the Btg horizon and the clay content in the Eg horizon, which was as high as 1.45 (see Table 1), confirms that, generally, Btg horizon of Croatian Pseudogleys is an illuvial (argic) horizon (IUSS Working Group WRB, 2014). Furthermore, the difference in the sand content between the Eg horizon and the Btg horizon (Table 1) was not high enough to point to lithic discontinuity between the two horizons (IUSS Working Group WRB, 2014). In any case, the content of sand in the investigated soil profiles was negligible (4.9% in the Eg horizon and 4.1% in the Btg horizon).

Typically, biological activity decreases and soil compaction increases with soil depth. In most Pseudogleys, this is distinctly pronounced (e.g., Vučić, 1987; Škorić, 1991). Accordingly, the Btg horizon featured higher BD, lower P, and lower AC, compared with the Eg horizon (Table 1). This is in line with the lower humus content and the higher clay content in the Btg horizon than in the Eg horizon (Table 1). Namely, BD was strongly correlated with both the clay content and the humus content (Table 2). It increased from 1.30 g cm^{-3} in the Eg horizon to 1.47 g cm^{-3} in the Btg horizon (Table 1). However, one should not ignore the effect of soil structure and soil compaction on soil BD (see Vučić, 1987; Škorić, 1991). Therefore, the increased BD of the Btg horizon should be regarded as also due to massive structure and increased compaction of this soil horizon.

Table 1. Comparison of means (with the ± values of the double standard error of the mean) of the selected properties of eluvial (Eg) and illuvial (Btg) soil horizons in 33 Pseudogleys studied across the Pannonian region of Croatia.

Soil horizon	PSD (%)			BD	WHC	P	AC	MS	Humus
	Sand 2-0.063 mm	Silt 0.063-0.020 mm	Clay <0.002 mm	g cm^{-3}	% vol	% vol	% vol	%	%
Eg	4.9 ^{a} (±0.3)	77.7 ^{a} (±0.6)	17.3 ^{a} (±0.8)	1.30 ^{a} (±0.01)	39.7 ^{a} (±0.4)	49.9 ^{a} (±0.6)	10.2 ^{a} (±0.4)	61.3 ^{a} (±2.6)	1.8 ^{a} (±0.1)
Btg	4.1 ^{b} (±0.3)	70.8 ^{b} (±0.6)	25.1 ^{b} (±0.8)	1.47 ^{b} (±0.01)	38.3 ^{b} (±0.2)	43.8 ^{b} (±0.4)	5.5 ^{b} (±0.4)	67.0 ^{b} (±2.5)	0.8 ^{b} (±0.1)

PSD – particle size distribution, BD – bulk density, WHC – water holding capacity, P – porosity, AC – air capacity, MS – microaggregates stability. Different superscript letters (^{a}, ^{b}) denote significant differences between mean values of the investigated properties ($P<0.05$ for WHC, $P<0.01$ for all other properties).

Table 2. Correlation coefficients for the selected properties of eluvial (Eg) and illuvial (Btg) soil horizons in 33 Pseudogleys studied across the Pannonian region of Croatia.

Soil property	Sand content	Silt content	Clay content	BD	WHC	P	AC	MS	Humus content
Sand content	–	0.45**	−0.63**	$−0.17^{ns}$	0.08^{ns}	0.13^{ns}	0.11^{ns}	−0.34**	0.31*
Silt content	–	–	−0.98**	−0.66**	0.46**	0.67**	0.55**	−0.34**	0.72**
Clay content	–	–	–	0.61**	−0.42**	−0.62**	−0.51**	0.38**	−0.70**
BD	–	–	–	–	−0.63**	−0.98**	−0.83**	0.25**	−0.67**
WHC	–	–	–	–	–	0.65**	0.14^{ns}	0.08^{ns}	0.42**
P	–	–	–	–	–	–	0.84**	$−0.20^{ns}$	0.67**
AC	–	–	–	–	–	–	–	$−0.32^{ns}$	$−0.17^{ns}$
MS	–	–	–	–	–	–	–	–	$−0.17^{ns}$
Humus content	–	–	–	–	–	–	–	–	–

BD – bulk density, WHC – water holding capacity, P – porosity, AC – air capacity, MS – microaggregates stability; ^{ns} - not significant, * - significant with P<0.05, ** - significant with P<0.01.

Soil P decreased from moderate (49.9% vol) in the Eg horizon to low (43.8% vol) in the Btg horizon (Table 1). It was strongly correlated with both the clay content (negatively) and the humus content (positively) (Table 2). However, statistical correlation does not necessarily imply causation. Hence, the correlation between P and clay content (r=-0.62, P<0.01) is probably due to the lower humus content, and not to the higher clay content in the Btg horizon, compared with the Eg horizon (Table 1). Namely, P is usually higher in finer-textured soils than in coarser-textured soils, which is why it usually does not decrease with depth in soils with argic horizons (e.g., Vučić, 1987).

Soil microaggregates were moderately stable (Škorić, 1985) in both soil horizons (Table 1). However, compared with the MS in the Eg horizon (61.3%), MS in the Btg horizon (67.0%) was higher (Table 1). This is the result primarily of the averagely higher pH in the Btg horizon than in the Eg horizon. Namely, as the result of decalcification during top-down pedogenesis, pH in forest Pseudogleys typically increases with soil depth (Rubinić et al., 2015b). Thereby, peptization of clay particles and dispersion of soil microaggregates is most pronounced in the Eg horizon. Additionally, MS usually increases with the increase in clay content (Vučić, 1987). This is confirmed by weak positive correlation between the two soil properties (Table 2).

Although increase in clay content usually increases WHC, this was not the case in the analyzed soil horizons. Namely, WHC in both soil horizons was moderate and very similar. However, it was slightly higher in the Eg horizon (39.7% vol) than in the Btg horizon (38.3% vol) (Table 1), and the correlation between the two properties was moderately negative (Table 2). It may be that the depth-related decrease in the humus content influenced the decrease of WHC from the Eg horizon to the Btg horizon (Table 1 and Table 2). In any case, the decrease of WHC with soil depth was accompanied with the decrease in soil P and the increase in soil BD (Table 1 and Table 2).

As expected, soil AC was higher in the Eg horizon (10.2% vol) than in the Btg horizon (5.5% vol) (Table 1). Hence, AC is interpreted as moderate in the Eg horizon and low in the Btg horizon. Although soil AC usually depends directly on P and WHC (e.g., Škorić, 1991), the correlation coefficient for AC and WHC was not significant (Table 2). However, the correlation coefficient for AC and P was strongly positive (Table 2). These results imply that the Eg horizon has a higher share of macropores within the total soil P, compared with the Btg horizon. This agrees with the increase in both the clay content and the BD from the Eg horizon to the Btg horizon (Table 1 and Table 2).

Conclusions

We analyzed physical properties of Eg and Btg horizons in 33 forest Pseudogleys across the Pannonian region of Croatia. We found that, generally, the properties of Eg horizon significantly differ from the properties of Btg horizon. Compared with the Eg horizon, the Btg horizon has more clay, higher bulk density, less pores, and lower capacity for air. However, the stability of microaggregates is higher in the Btg horizon than in the Eg horizon. Along with the clay content, humus content has the key impact on most soil physical properties.

The obtained results should be borne in mind, both when converting natural Pseudogleys into arable soils and when ameliorating arable Pseudogleys that contain the Eg horizon below the Ap horizon.

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