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Impact of varting soil plant cover on soil micromorphology and hydraulic properties

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Abstract Two organic matter horizons developed under a spruce forest and grass vegetation were chosen to demonstrate the impact of a different vegetation cover on the micromorphology, porous system and hydraulic properties of surface soils. Micromorphological studies showed that the decomposed organic material in the organic matter horizon under the grass vegetation was more compact compared to the decomposed organic material in the organic matter horizon under the spruce forest. The detected soil porous system in the organic matter horizon under the spruce forest consisted of two clusters of pores with different diameters that were highly connected within and between both clusters. The soil porous system in the organic matter horizon under the grass vegetation consisted of one cluster of pores with the larger diameters and isolated pores with the smaller diameter. The retention ability of the organic matter horizon under the grass vegetation was higher than the retention ability of the organic matter horizon under the spruce forest.

Key words: *organic matter horizon, spruce forest, grass vegetation, soil micromorphology, organic material decomposition, pore-sizes, soil hydraulic properties*

Introduction

Deforestation and soil degradation are serious problems in the mountains area along the north-west border of the Czech Republic, which arose due to the forest management and acid depositions. One of the highly impacted areas are the Jizera Mountains. Natural stable forest ecosystems were altered in this region by human impact into a spruce monoculture. High concentrations of acidificants in the atmosphere that occurred thirty years ago damaged the soil and forests, and led to the deforestation on the mountain summits. This area was quickly invaded by grass as a natural mechanism of ecosystem restoration. Soils under this grass cover have often better chemical properties than soils covered by forests due to the grass litter quality (Kooijman et al., 2000; Fiala et al., 2001). The various forest covers have a great impact on the water regime and transport of dissolved substances in the soil profile and consequently on the soil degradation processes. The physical and hydraulic properties of mineral soil horizons below the organic matter horizons are usually studied (Bergen and Hagen, 2000; Heiskanen and Häkitalo, 2002; Ellerbrock et al., 2005; Lichner et al., 2007). However, the soil hydraulic properties of the top organic matter horizon considerably control the water flux at the top of the soil profile. Three subhorizons are distinguished within the top organic matter horizon (Green et al., 1993): L subhorizon is the slightly decomposed organic material (leafs or needles), F subhorizon is more decomposed material, and H subhorizon is made from the totally decomposed organic material with a potential mineral addition. While the mineral soil horizons are usually a result of a long time soil genesis, the organic matter horizons of the forest soils may change relatively quickly, depending on the vegetation cover. The comparison of the soil micromorphology and hydraulic properties of the organic H subhorizons developed under the spruce forest and grass vegetation is presented in this study.

Material and methods

The core of the Jizera Mountains is a plutonic area with uniform granite bedrock. The complex soil study of the Jizera Mountains region was previously presented by Mládková et al. (2005) and Borůvka et al. (2005). New representative sampling sites were selected on the base of previous results. Soil samples were collected from five soil pits within each elevation transect, the Paličník mountain, and the Smědava mountain, three soil pits at each location, the former Kristiánov settlement, Protržená přehrada near the Desná village and the Jizerka settlement. The soil pits were placed in a spruce forest (*Picea abies*) of various age, old nature-close beech forest (*Fagus sylvatica*), and a dead forest with young free-growing spruce and with abundant high grass (*Calamagrotis villosa*, *Deschampsia flexuosa*) (referred here as grass vegetation). Prevailing soil types were defined as Haplic Podzols, Entic Podzols and Dystric Cambisols.

Two soil profiles of the Haplic Podzol under the spruce forest (SF) and grass vegetation (GV) with the significantly developed horizon of the top organic matter were selected

for this study. The depths of the SF and GV organic horizons were 9 cm (1 cm of L, 3 cm of F, 5 of the H subhorizons) and 20 cm (6 cm of L, 4 cm of F, 8 cm of the H subhorizons), respectively. The depths of the characteristic mineral horizons were: 0 and 2 cm of the humic horizon, 1 and 12 cm of the albic horizon, 19 and 12 cm of the spodic horizon, and the substrate (IUSS Working Group WRB, 2006). The organic H subhorizons of the selected soil profiles were chosen to demonstrate the impact of the different soil cover (spruce forest versus grass vegetation) on the micromorphology, porous system and hydraulic properties of surface soils. The organic matter content evaluated from the organic carbon, which was obtained using the rapid dichromate oxidation techniques (Sparks, 1996), was 78.0 and 66.5 % in the H subhorizon under the SF and GV, respectively. Undisturbed large soil aggregates and undisturbed 100-cm^3 soil samples were taken from the studied horizons. Micromorphological properties characterizing soil porous structure were studied on thin soil sections prepared from the large soil aggregates (Catt, 1990). The soil porous system was analyzed using the same procedure that was presented by Kodešová et al. (2006). Images were taken at one magnification. To detect pores, image-processing filters were applied. To analyze pore sizes, the ArcGIS raster processing tools were used.

Soil hydraulic properties were studied in the laboratory on the undisturbed 100-cm^3 soil samples placed in Tempe cells. First, the saturated hydraulic conductivity was measured using the constant head method (Dane and Topp, 2002), followed with the multi-step outflow test (van Dam et al, 1994). Soil water retention data points were obtained by calculating water balance in the soil sample at each pressure head step of the experiment. The single-porosity model in HYDRUS-1D (Šimůnek et al., 2005) was used to analyze the multi-step outflow data and to obtain the parameters of both soil hydraulic properties (soil water retention and unsaturated hydraulic conductivity functions) that were described using the van Genuchten (1980) model. Points of the soil water retention curve were also utilized in the inversion. Three scenarios were analyzed in both cases to improve optimization results. All experimental data were used in the inversion for scenarios A and B. The experimental data obtained during the first pressure head step were excluded from the inversion for scenario C. While the saturated soil water content, θ_s, was set to the measured value, the soil hydraulic parameters θ_r (the residual water content), α (reciprocal of the air entry pressure), n (related to the slope of the retention curve at the inflection point), and K_s (the saturated hydraulic conductivity) were optimized in scenario A. A significant weighting factor (WF=10) was assumed for all points of the soil water retention curve. All soil hydraulic parameters (θ_s, θ_r, α , n and K_s) were optimized in scenarios B and C. The high weighting factor (WF=10) was assumed only for one point of the soil water retention curve that was obtained for pressure head -10 (SF) or -8 cm (GV), and low value (WF=0.1) was used for the other points in scenarios B and C. The standard value of the weighting factor (WF=1) was used for the multi-step outflow data in all scenarios.

Results and discussion

Micromorphological images of the H subhorizons developed under the spruce forest (SF) and grass vegetation (GV) are shown in Fig. 1. In both cases soil samples mostly consisted of the organic material with a little fraction of mineral grains. However, depending on the source of the organic matter and its decomposition by a different soil organism images display considerably various micromorphological features. The organic material (residues of spruce needles and roots) in the H subhorizon under the SF was decomposed by the soil organisms of two taxonomy orders (*Acarina*, *Collembola*). The organic material (residues of grass leaves and roots) in the H subhorizon under the GV was mostly decomposed by the soil organisms of at least three taxonomy orders (*Acarina*, *Collembola*, *Oligochaeta*). The organic material in the H subhorizon under the GV was more compact compared to the organic material of the H subhorizon under the SF. The H subhorizon under the GV contained larger fractions of mineral grains (mainly quartz) than the H subhorizon under the SF.

The different composition of the organic matter and mineral grains is reflected in various soil porous systems detected on the micromorphological images (Fig. 2).

Only the pores with a diameter larger than 40 micrometers are visible on the image. Two types of pore clusters were present in the H subhorizon under the SF: the cluster of pores with diameters from 1000 to 200 micrometers and the cluster of pores with diameters smaller than 200 micrometers. Pores of both clusters were highly connected. The pore cluster of pores, with diameters from 1000 to 200 micrometers, was mostly present in the H subhorizon under the GV. Isolated pores with the diameter smaller than 200 micrometers existed in the aggregated organic matter. Total porosities detected on the micromorphological images were 39.20 % and 25.28 % for the H subhorizon under the SF and GV, respectively. The porosities of the aggregated organic matter specified for the sections marked in Fig. 1 were 21.92 % and 1.55 % for the H subhorizon under the SF and GV, respectively.

Soil hydraulic parameters obtained from the numerical inversions of data from the multi-step outflow experiment are shown in Tables 1 and 2 for the SF and GV soil profile, respectively. The simulated outflow data (Fig. 3a) and the soil water retention curves (Fig. 4a) of various scenarios for the SF soil sample are not significantly different. Slightly variable saturated hydraulic conductivities are higher than the measured K_s value (0.748 cm h^{-1}) in scenarios A and B, and lower in scenario C. However, the best correlation between the observed and simulated data was obtained in scenario C. The simulated outflow data (Fig. 3b) and the soil water retention curves (Fig. 4b) of various scenarios for the GV soil sample are significantly different. Highly variable saturated hydraulic conductivities are higher

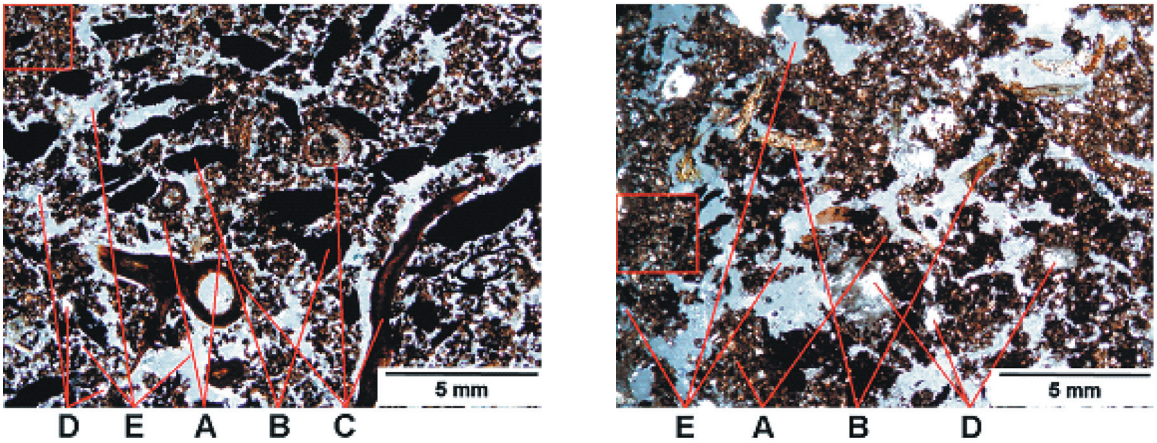

Fig. 1 Micromorphological images of the soil samples characterizing the H subhorizons of the soil profile under the spruce forest (a) and grass vegetation (b). A – decomposed material (organism excrements), B – not decomposed organic material (a – spruce needles, b – grass leaves), C – residues of roots, D – mineral grains, and E – pores.

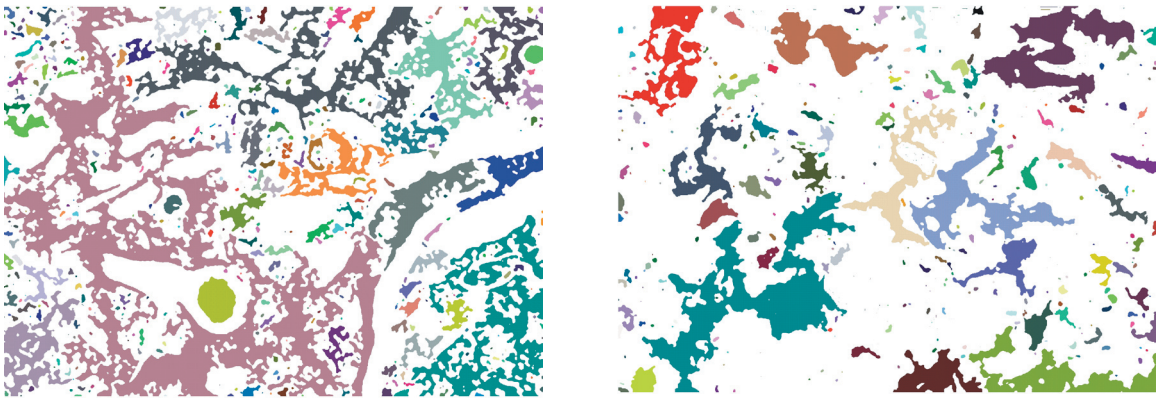

Fig. 2 Detected pores on images of soil samples characterizing the H subhorizons of the soil profile under the spruce forest (a) and grass vegetation (b). Each color represents interconnected pores.

than the measured K_s value (0.571 cm h^{-1}) in scenarios A and B, and lower in scenario C. The best correlation was obtained in scenario C. The parameters obtained from scenario C describe the hydraulic properties of mobile water domains in studied soil samples with exception of the large capillary (corresponding to the pressure heads higher than -10 or -8 cm) and gravitational pores. Their impact is mainly noticeable on the SF soil sample data. The difference between the measured saturated soil water content and the optimized value from scenario C represents a pore fraction potentially available for a preferential water flow under the conditions close to saturation. The difference between the measured hydraulic conductivity and the optimized value from the scenario C indicates flow in this pore fraction. However, this difference does not describe the actual pore fraction permeability due to the different soil water retention properties of the pore fraction and the limitation effect of the porous plate in the Tempe cell. The soil hydraulic properties of the H subhorizon under the GV exhibit the higher retention ability than the H subhorizon under the SF. The high values of the saturated soil water content were in both cases obtained due to the high water contents in the organic matter in both soil samples. In addition the 100-cm^3 soil samples used for the soil hydraulic properties determination contained a significant volume of tree and grass roots in the entire soil sample. The volume of the dry soil sample of the H subhorizon under the SF and GV was 83.09 cm^3 and 57.49 cm^3, respectively. Since the studied soil samples did not display volume changes at the end of the multi-step outflow experiment, the resulting parameters represent the soil hydraulic properties within the pressure head range from -10 (–8) to –1000 cm. Considering the water flow process only in soil pores, the soil water retention and hydraulic conductivity curves may be shifted along the soil water content axis without the impact on the simulated transient flow data.

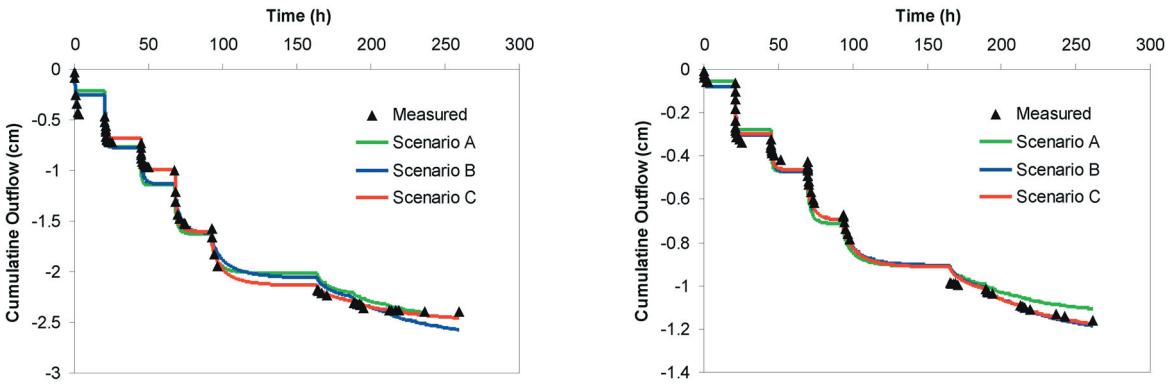

Fig. 3 Multi-step outflow data obtained on the soil sample characterizing the H subhorizons of the soil profile under the spruce forest (a) and grass vegetation (b).

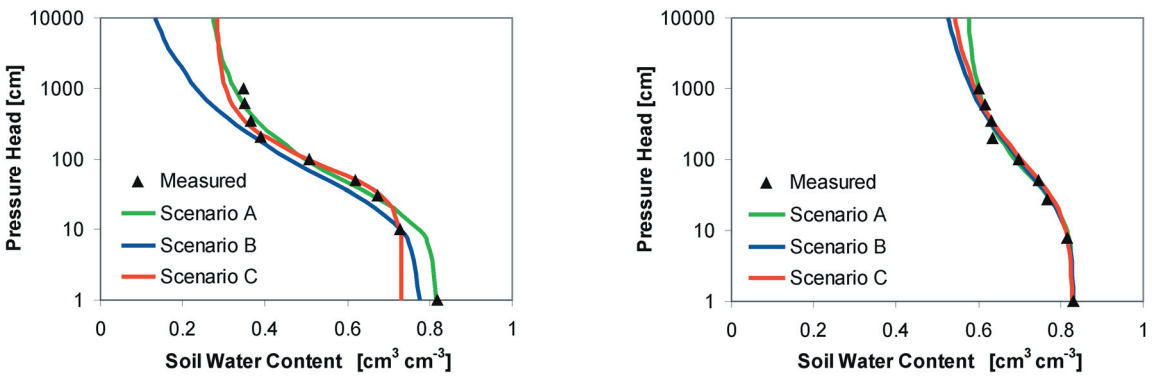

Fig. 4 Soil water retention curves obtained on the soil sample characterizing the H subhorizons of the soil profile under the spruce forest (a) and grass vegetation (b).

Table 1 Parameters of the van Genuchten functions for the soil sample characterizing the H subhorizon of the soil profile under the spruce forest.

Scenario	θ_s [cm^3 cm^{-3}]	θ_r [cm^3 cm^{-3}]	α [cm^{-1}]	n [-]	K_s [cm h^{-1}]	R^2
A	0.8177*	0.2573	0.0412	1.568	7.978	0.9953
B	0.7784	0.0607	0.0430	1.378	2.853	0.9976
C	0.7325	0.2819	0.0169	2.065	0.495	0.9997

* not optimized

Table 2 Parameters of the van Genuchten functions for the soil sample characterizing the H subhorizon of the soil profile under the grass vegetation.

Scenario	θ_s [cm^3 cm^{-3}]	θ_r [cm^3 cm^{-3}]	α [cm^{-1}]	n [-]	K_s [cm h^{-1}]	R^2
A	0.8299*	0.5678	0.0333	1.591	1.213	0.9983
B	0.8334	0.4772	0.0387	1.330	1.164	0.9991
C	0.8272	0.5166	0.0282	1.428	0.515	0.9992

* not optimized

The soil porous systems detected on the micromorphological images do not represent the pore size distributions under the naturally moist conditions due to the large volume changes of the dry organic matter and the presence of tree and grass roots. No gravitational pores and pores smaller than 40 micrometers are presented on the images. However, the rations of the various pore clusters indicate the observed difference between the retention abilities of the studied H subhorizons. Some results will be also presented by Kodešová et al. (2007).

Conclusions

The different organic materials and their decomposition by the various organisms in the H subhorizons under the spruce forest and under the grass vegetation resulted in the different micromorphological features of the studied soil samples. The H subhorizon under the spruce forest showed the less compact structure, highly connected porous system and consequently the lower retention ability. The H subhorizon under the grass vegetation showed the more compact structure, lower pore connectivity and the higher retention ability. The soil hydraulic properties were in both cases affected by the tree and grass roots. The root impact on the soil hydraulic properties of the agricultural soils was studied for instance by Gerke and Kuchenbuch (2007) and Kodešová et al. (2006). The soil hydraulic properties obtained from the inversion of scenario C characterized the mobile water domains. The fractions of the large capillary and gravitational pores potentially available for the preferential water flow under the conditions close to saturation were indicated. The effect of the preferential flow in the soil profile defined as the Dystric Cambisol with the peat soil cover in the Jizera Mountains on the rainfall-runoff was previously described by Šanda et al. (2006). The higher retention ability of the varying organic matter horizon observed in this study may cause lower water and dissolved substances flux through the soil profile and lower degree of soil degradation. On the other hand water regime is greatly affected by the evapotranspiration of different vegetation and a rainfall interception.

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