SOIL WATER RETENTION PROPERTIES OF FOREST SOILS UNDER DIFFERENT LAND USE

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Abstract

Soil water retention properties of Eutric Leptic Cambisols Ochric, Dystric Cambisols Ochric and Dystric Cambisols Humic (IUSS Working Group WRB. 2015) under different land use (herbaceous, deciduous and coniferous vegetation) were evaluated using procedures similar to those described in ISO 11274:1998. The analyses were performed on undisturbed and disturbed soil samples taken from eleven surface (0-5 cm) and ten subsurface (10-25 cm) soil layers from 11 soil profiles within the territory of the experimental stations of the Forest Research Institute in the Gabra, Govedartzi and Igralishte Villages. The soil water retention curves were fitted with the van Genuhten model. The values for soil water retention at suctions lower than pF 2.5 (field capacity) varied significantly among the studied sites – from 6.9 to 60.6%. The influence of the total soil organic carbon content (SOC) on water retention was quantified using regression equations. SOC varied from 0.32 to 6.79% depending on soil differences, vegetation type, altitude and degree of soil erosion. The increase of clay in the surface layer of strongly eroded soils (Eutric Leptic Cambisols Ochric) on the grassland sites at the Gabra station also increased the water retention capacity. The obtained data for water retention characteristics of the studied shallow soils can be applied for estimation of soil water and energy balances.

Key words: soil water retention, soil organic carbon (SOC), Cambisols, herbaceous, deciduous and coniferous vegetation

INTRODUCTION

Soil hydraulic properties reflect the structure of the soil porous system comprising pores of different geometry, sizes and connectivity (Dexter, 1988; Letey, 1991; Horn et al., 1994; Rabot et al., 2018). Among the factors that influence soil structure formation and, hence, soil hydraulic properties are the periods / cycles of wetting and drying, the presence of organic matter, the chemical composition of soil particles, activities of soil biota and plant roots ability. The capacity of soil to retain water depends also on soil depth, which is closely related to the genesis and erosion of soil. In case of forest soils, the hydrological conditions of the site depend also on the topographical location, weather conditions and land use (Heiskanen, Mäkitalo, 2002).

Chandler et al. (2018) pointed out that most of the studies on the hydraulic properties of forest soils are related to the hydraulic consequences of changes of forestland
to arable or pasture land or to the effects of reforestation or afforestation. Many studies showed that forest soils are associated with higher rates of water infiltration and lower surface runoff generation than soils under other vegetation cover (Weiler, Naef, 2003; Jost et al., 2012). There are not many studies exploring the role of tree species on soil hydraulic properties, although the role of plant roots, soil organic matter accumulation and soil biota differ among different species (Heiskanen, Mäkitalo, 2002; Wahl et al., 2003; Bens et al., 2007; Jost et al., 2012). However, Chandler et al. (2018) found more significant effect of land use, e.g. grazed versus non-grazed land, than of the influence of tree species. The saturated hydraulic conductivity was found to be significantly higher under non-grazed Scots pine forests (1239 mm hr$^{-1}$) than under pastures (32 mm hr$^{-1}$).

The enhanced saturated hydraulic conductivity is associated with the presence and continuity of large pores. The comparison between Scots pine and Norway spruce forests show higher values of air- filled soil porosity and saturated hydraulic conductivity under Scots pines (Heiskanen, Mäkitalo, 2002).

The role of parent rock materials in forming different type of soils (Podzol, Stagnosol and Cambisol) with specific chemical and physical properties and also with different soil porous systems and soil hydraulic properties has been studied at the Slavkov Forest CZO (Critical Zone Observatory), Czech Republic, under Norway spruce forests (Rousseva et al., 2017).

The soil water retention characteristics of Cambisols has not been previously studied in mountain regions in Bulgaria under different land cover. Information on hydraulic properties of mountain-meadow soils from the Beklemeto Region, the Balkan Mountains was published by Dilkova (2014).

The long-term observations within the experimental stations Gabra, Govedartzi and Igralishte of the Forest Research Institute allow monitoring the hydrological consequences of different land use on forest soils in the Lozen Mountain, Rila Mountains and Maleshevska Mountain, South-Western Bulgaria. The obtained results are focused on soil erodability estimations (Marinov, 2018; Velizarova, Marinov, 2006; Velizarova, 2008; Velizarova et al., 2014) and migration of elements (Ninov, 1974).

The aim of this study is to determine the soil water retention characteristics of Cambisols soils under different land use in the experimental stations of the Forest Research Institute in the Lozen Mountain, Rila Mountains and Maleshevska Mountain.

**MATERIAL AND METHODS**

**Site description and sampling**

The analyses were performed on undisturbed and disturbed soil samples, taken from 11 surface (0-5 cm) and 10 subsurface (10-25 cm) soil layers from 11 soil profiles in the experimental stations of the Forest Research Institute in the Lozen Mountain – Gabra (herbaceous, deciduous and mixed forest); Rila Mountains – Govedartzi (herbaceous, Scots pine, Norway spruce); Maleshevska Mountain – Igralishte (herbaceous, deciduous – oak and Scots pine forest). Location, vegetation cover and classification of soil types
of the studied soil profiles are presented in Table 1. The parent materials in the Govedartzi station are weathered metamorphic rocks and igneous rocks (granites), as well as deluvial-proluvial deposits of gneiss and glacial deposits (Ninov, 1974). The parent materials in the other two experimental stations are of the same type – weathered metamorphic rocks and granites, as well as deluvial-proluvial deposits of gneiss.

The soil profiles were sampled starting from the surface layer (0-5 cm) following the soil genetic horizons. Most of the soil profiles were shallow or the presence of stones did not allow taking undisturbed soil cores from deeper depths. Vertically-oriented cores were sampled in four replicates in 100 cm$^3$ metal cylinders for determination of soil bulk density and soil water retention (ISO 11274:1998). Bulk density of fine earth was estimated taking into account the gravel (2-60 mm, FAO, 2006) content in each ring. The average “disturbed” sample from each sampling depth was formed by gently breaking and mixing the excavated fresh soil by hands into aggregates finer than about 15 mm.

**Soil laboratory analyses**

Particle-size distribution was determined by sieving and the pipette method (ISO 11277, 2009) after chemical dispersion of air- dry soil sample (<2 mm) with 25 cm$^3$ of sodium pyrophosphate ($Na_4P_2O_7$) 30 g.l$^{-1}$ (ISO 11277, 2009). Preliminary removal of the organic matter from the soil sample was done with 30% hydrogen peroxide. Fractions of sand (2-0.063 mm), silt (0.063-0.002 mm) and clay (<0.002 mm) were determined according to ISO 11277 (2009) for applying the textural classification of IUSS Working Group WRB, 2015; FAO, 2006).
Group WRB (2015). Particle-density analysis was carried out in water with 100 cm\(^3\) pycnometers.

Total soil organic carbon content (SOC, %) was determined by the modified Tjurin’s method [dichromate digestion at 125º C, 45 min., in the presence of \(\text{Ag}_2\text{SO}_4\) and \((\text{NH}_4)_2\text{SO}_4\cdot\text{FeSO}_4\cdot6\text{H}_2\text{O}\) titration, phenyl anthranilyc acid as indicator (Filcheva, Tsadilas, 2002; Kononova, 1966)]. The SOC content was classified according to Filcheva (Filcheva, 2014). The total soil nitrogen content (N, %) was determined using the Kjeldahl method and the C/N ratio was calculated, where C stands for soil organic carbon (SOC). Soil pH of samples was measured in water suspension 1: 2.5 and classified according to the FAO scale published by Penkov (1989) and later by Gyurov, Artinova, (2015). The cation exchange capacity (CEC\(_{8.2}\)) was determined using physico-chemical methods according to Ganev, Arsova, (1980).

Soil water retention of the samples at suctions less than 33 kPa was determined in 4 replicates (100 cm\(^3\) rings) with suction type apparatus (Shot filters G5 with diameters of the pores 1.0-1.6 µm). A negative matric pressure was applied by means of a hanging water column. In this study, we accept water retention at pF 2.5 (potential -33kPa) as Field Capacity as it is used in pedotransfer functions and hydrological modelling (Rawls et al., 2003; Saxton, Rawls, 2006; Tóth et al., 2014). The other widely accepted estimation for field capacity at field conditions is the water content at pF 2.0 (potential -10 kPa), especially for coarse-texture soils (e.g. Heiskanen, Mäkitalo, 2002; Dilkova, 2014). Soil water retention at suction 1500 kPa (pF 4.2 – Wilting Point, WP) was determined in three replicates using pressure membrane apparatus (ISO 11274:1998). Hygroscopic water content (pF 5.6) was determined using the vapour-pressure method with controlled 75% relative humidity of air in desiccators containing saturated solution of NaCl. Corrections for the skeleton were applied for points at pF 4.2 (Wilting Point) and pF 5.6 (Hygroscopic water content), as they were determined on fine earth samples.

Total porosity \((P_t)\) was calculated using the measured bulk density and particle density.

**Characteristics derived from soil water retention curve**

The effective pore radius \(r\), corresponding to the applied suction \((P)\), was calculated with the Jurin’s formula:

\[
P = \frac{2\gamma_{\text{H}_2\text{O}}}{r},
\]

where \(\gamma_{\text{H}_2\text{O}}\) was the surface tension of water (0.0729 J m\(^{-2}\)) and \(P\) was in Pa. The effective diameters \((\delta)\) of the pores corresponding to 1, 5, 10, 33 and 1500 kPa, were 300, 60, 30, 10 and 0.2 mm, respectively. Volume of air-filled pores at given suction \(P\) was calculated as the difference between soil total porosity \(P_t\), and the measured volume of water content \((\theta)\) retained at this suction.

The water retention experimental data at different suctions were approximated with the van Genuchten equation (van Genuchten, 1980):
\[ W = (W_{\text{sat}} - W_{\text{res}}) \times (1 + (\alpha h)^n)^{m-n} + W_{\text{res}}, \]  

(2)

where \( W \) was gravimetric water content (kg kg\(^{-1}\)), \( h \) was suction (hPa), \( W_{\text{sat}} \) was water content at saturation, \( W_{\text{res}} \) was residual water content (\( h \to \infty \)), \( \alpha \) (hPa\(^{-1}\)) and \( n, m \) were fitted parameters. Stable results for the parameters were obtained when a constraint was applied for \( m = 1 - 1/n \) (Mualem, 1976) and when the parameter \( W_{\text{res}} \) was fixed to zero in cases with estimated negative values.

The parameters \( W_{\text{sat}}, W_{\text{res}}, \alpha \) and \( n \) of the van Genuchten equation were fitted with the statistical regression analysis methods of the OriginPro 6.1 and used to calculate the slope \( S \) of the gravimetric water content against natural logarithm of the pore water suction at the inflection point \( W_i \) (Dexter 2004, 2006):

\[ S = -n * (W_{\text{sat}} - W_{\text{res}})^{m-1} \left[ \frac{1}{m} \right] \]  

(3)

\[ W_i = (W_{\text{sat}} - W_{\text{res}})^{m-1} + W_{\text{res}}, \]  

(4)

where water content at saturation (\( W_{\text{sat}}, \) kg kg\(^{-1}\)), residual water content (\( W_{\text{res}}, \) kg kg\(^{-1}\)), \( n \) and \( m \) were fitted parameters.

**RESULTS**

Basic soil characteristics of the studied Cambisols are presented in Table 2. The influence of the grass cover on soil texture of the studied Cambisols was well expressed in the experimental station in Gabra. The lower content of sand (2-0.063 mm) and increased content of silt (0.063-0.002 mm) determined the finer texture class (Loam – L) under herbaceous cover as compared to under trees. Such effect, but to a minor extent, was observed at the Igralishte station where the texture class of surface horizons was Sandy Loam (SL) under grass and it was Loamy Sand (LS) under trees. There was no difference in particle-size distribution among the studied sites at the Govedartzi station. This could be explained by the recent establishment of the herbaceous cover in the studied site there. The gravel content in surface layers under trees was higher than under grassland in Gabra. Although the gravel content was the lowest in surface layers of Cambisols, at the Igralishte station these soils were characterised with coarser texture. The clay content was below 7% and the sand content was above 70%. The clay content in the surface soil horizons was 20% in Gabra and Govedartzi, except under the mixed forests in Gabra – where it was 14%. The clay content decreased in depth for all studied soil profiles. Clay content above 15% is considered an important precondition for the formation of soil aggregates (Horn et al., 1994).

According to the FAO classification, commonly applied in Bulgaria (Penkov, 1989; Gyurov, Nedyalkova, 2015), the soil reaction was very strongly acid (pH 3.6 to 4.0) under the forest trees vegetation at the Gabra and Govedartzi stations and strongly acid (pH 4.1- 4.6) under the grass sites and at all sites in Igralishte (Table 2). The cation
exchange capacity (CEC) was the highest under herbaceous cover at the Gabra station – between 35 and 38 cmol.kg\(^{-1}\) and was lower under trees (20-24 cmol.kg\(^{-1}\)). The CEC in the surface soil layer of the studied sites in the Govedartzi station was between 28 and 29 cmol.kg\(^{-1}\). The lowest values were observed under grass at the Igralishte station (17-19 cmol.kg\(^{-1}\)). The values of CEC under oaks and under Scots pines were between 21 and 25 cmol.kg\(^{-1}\) in the upper soil layer, which was close to the observed at the Gabra station under trees, although the sites differed in soil texture.

The soil organic carbon content (SOC, %) varied significantly among the sites and in soil depths (Table 2). The SOC was very high (>3%) in all surface layers at the Govedartzi station, high (1.8–3%) under grass and deciduous forests at the Gabra and Igralishte stations. It was moderate (1.5%) under mixed forests at the Gabra station and under Scots pines (site 2 at Igralishte) and very low (0.3%) under Scots pines at site 1 (young plantation) at the Igralishte station. Sharp decrease in depth of the soil organic carbon content was observed at the Igralishte station (Table 2). The humus in all surface

<table>
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<tr>
<th>Land use</th>
<th>Sampling depth, cm</th>
<th>Gravel %</th>
<th>Sand %</th>
<th>Silt %</th>
<th>Clay %</th>
<th>Texture class</th>
<th>SOC%</th>
<th>C:N</th>
<th>pH in H(_2)O</th>
<th>CEC, cmol. kg(^{-1})</th>
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<td>47</td>
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Table 2. Basic soil characteristics

mineral layers was of the Mull type (C:N was between 9 and 18), with the exception of the surface layer under the second site of Scots pines in Igralishte where the type was Moder (C:N =21).

The high contents of soil organic matter in the humic horizons of Dystric Cambisols Humic at the Govedartzi station determined low values of soil bulk density, especially of bulk density of fine earth (BD$_f$=0.6-1.1 g.cm$^{-3}$; Table 3). The correlation coefficient between these parameters was high $R= - 0.88$ (Table 5). A similar effect of SOC was observed on the soil particle density ($R$=-0.89). Eutric Cambisols at the Gabra and Govedartzi stations were characterised with higher particle density (Ds=2.63-2.81 g.cm$^{-3}$). The total porosity of the surface layers at all sites varied from 49%vol. to 75%vol.

The water retention data at different potentials are presented in Table 3 and on Figure 1. The fitted curves via van Genuhten equation (Eq. 2) are also presented on

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<th>Db$_f$</th>
<th>Ds,</th>
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<td>% mass</td>
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Figure 1. The estimated parameters of the van Genuchten equation and the slope at the inflection point are presented in Table 4. The values of soil water retention at suctions less than pF 2.5 (Field Capacity) varied significantly among the studied sites – from 6.9 to 60.6%. The water retained between suctions pF 2.0 and pF 2.5 varied from 2 to 12.5% and on average it was 6%. The available for plants water (between pF 2.5 and pF 4.2) and the unavailable for plants water (at pF 4.2) also varied significantly: 4-39% and 3-20%, respectively (Figures 1, 2, Table 3).

As it can be seen from Table 5, the correlation coefficient ($R$) between soil organic carbon (SOC) and $W_{4.2}$ was 0.86 and it was even higher ($R=0.92$) between SOC and the water available to plants ($W_{2.5}-W_{4.2}$). The relationships of these important water retention characteristics with SOC were well described by simple linear regression models shown on Figure 3. The slope of the regression model was higher for the relationship of the available water content with SOC.

On the other hand, the correlation of large pores holding water at suctions less than 2.5 with SOC was not high ($R=0.58$). The differences among the studied sites could be explained by other factors which influence soil structure, such as plant roots, the activities of earthworms and other soil biota (Wailer, Naef., 2003). Although these pores are with drainage functions, they can play a significant role when hard rock impedes the vertical water movement. They had high correlation coefficients with the slope ($S$) at the inflection point and also with the bulk density (Table 5).

The proportions of the pores with drainage functions (effective pore diameter $\delta>10$ µm), pores holding plant available water ($0.2 \mu m<\delta<10 \mu m$) and pores holding water
unavailable to plants (δ<0.2 µm) to the total porosity were 5:3:2 (grass site at the Gabra station; coniferous vegetation at the Govedartzi station), 6:3:1 (deciduous trees in Gabra, herbaceous site in Govedartzi, herbaceous site 2 in Igralishte) and 7:2:1 -8:1:1 (mixed forests in Gabra, herbaceous site 1 in Igralishte, deciduous and coniferous trees in Igralishte).

Fig. 2. Distribution of the main water retention characteristics of the studied layers of Cambisols in the experimental stations under herbaceous (a), deciduous (b) and coniferous (c) plantations

Fig. 3. Linear regression between soil organic carbon content (SOC, %) and water (%mass) retained at pF 4.2 (W_{4.2} wilting point) and between pF4.2 and pF2.5 (available water content W_{2.5}-W_{4.2})
Table 4. Fitted parameters of the van Genuchten equation (1980) (Eq. 2), slope (S) and water content (Wi) at the inflection point (Eqs. 3, 4). SEE – standard error of estimate

<table>
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<th>Wsat</th>
<th>Wres</th>
<th>α</th>
<th>n</th>
<th>m</th>
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<tr>
<td></td>
<td>depth, cm</td>
<td>kg kg(^{-1})</td>
<td>kg kg(^{-1})</td>
<td>hPa(^{-1})</td>
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<td>kg kg(^{-1})</td>
<td>kg kg(^{-1})</td>
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<td>0.195</td>
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<td>0.210</td>
<td>-0.056</td>
<td>0.258</td>
<td>0.004</td>
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</table>

Table 5. Correlation matrix. |S| – absolute value of slope at the inflection point

|            | SOC  | clay | sand | Db  | Ds  | W\(_{<0.4}-W\(_{>2.5}\) | W\(_{<0.4}-W\(_{>2.5}\) | W\(_{<2.5}-W\(_{>4.2}\) | W\(_{<4.2}\) | |S|  |
|-------------|------|------|------|-----|-----|-----------------|-----------------|-----------------|-----------------|------|
| SOC         | 1.0  |      |      |     |     |                 |                 |                 |                 |      |
| clay        | 0.46 | 1.0  |      |     |     |                 |                 |                 |                 |      |
| sand        | -0.40| -0.95| 1.0  |     |     |                 |                 |                 |                 |      |
| Db          | -0.88| -0.24| 0.28 | 1.0 |     |                 |                 |                 |                 |      |
| Ds          | -0.89| 0.01 | 0.10 | 0.69| 1.0 |                 |                 |                 |                 |      |
| W\(_{<0.4}-W\(_{>2.5}\) | 0.58 | -0.23 | 0.15 | -0.81 | -0.46 | 1.0 | | | | | |
| W\(_{<2.5}-W\(_{>4.2}\) | 0.92 | 0.55 | -0.55 | -0.89 | -0.69 | 0.61 | 1.0 | | | | |
| W\(_{<4.2}\) | 0.86 | 0.72 | -0.69 | -0.71 | -0.63 | 0.46 | 0.90 | 1.0 | | | |
| |S| | 0.71 | -0.07 | -0.02 | -0.85 | -0.58 | 0.96 | 0.73 | 0.46 | 1.0 |
DISCUSSION

The obtained basic soil characteristics for the studied sites at the experimental stations of the Forest Research Institute coincided with results obtained by other authors concerning soil texture and SOC under grassland and oak vegetation at Igralishte (Velizarova, 2008), soil organic carbon, pH and CEC under Norway spruce at Govedartzi (Zhianski, 2018), soil texture class, SOC and pH under grass vegetation (Velizarova, Marinov, 2006).

The proportions of pores of surface layers of the studied Cambisols have confirmed that large pores dominate in this soil type. The obtained results for pore-size proportion from the observed territory in Gabra and Govedartzi are close to the proportion 6:2:2, found by Rousseva et al. (2017) for Cambisols from the Slavkov forest, Czech Republic and from Koiliaris watershed, Crete, Greece.

The water retention characteristics of these coarse textured soils strongly depended on the presence of organic carbon. This corresponds to the findings of Rawls et al. (2003) that organic carbon is a leading variable for predicting water content at pF 4.2 and pF 2.5 for coarse textured soils. The accumulation of SOC at the highest altitude at the Govedartzi site differed among the land use type. The data showed lower accumulation under Scots pines than under Norway spruce and, hence, lower water retention characteristics. These results confirmed the finding of Heiskanen and Mäkitalo (2002) that the pine sites in North Finland had thinner genetic soil horizons and lower SOC, less fine soil particles and a lower water retention capacity (WRC) than Norway spruce.

The climate conditions and age of forest or grass cover effect the thickness of humus layer and hence the WRC.

CONCLUSIONS

New data for basic soil properties and soil water retention characteristics under different vegetation covers in the experimental stations Gabra, Govedartzi and Igralishte were obtained. The water retention curves were described by fitted parameters of the van Genuhten equation. The influence of SOC on the water unavailable for plants and on the water available for plants of these coarse textured soils was well manifested by the regression equation. The obtained data for the hydraulic properties of the studied shallow soils can be applied as reference in other studies of soil water and energy balances.

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