MOISTURE CHANGES IN THE ORGANIC HORIZON OF THE FOREST SOIL UNDER DIFFERENT TREE SPECIES

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The course of soil moisture in the organic horizon of the forest soil depends mainly on the distribution of atmospheric precipitation and the air temperature during the year. The hydrological significance of the organic horizon of forest soil lies in the rainfall water retention and transfer of water to the lower (mineral) part of forest soil profile. Forest soil with a well developed organic horizon has a higher ability to retain soil moisture than the mineral component of forest soil. The effect of the forest type on the interception capacity is related to the leaf shape.

The primary aim of this paper was to analyse and statistically evaluate the changes of soil moisture in the organic horizons under the different tree species (oak, sycamore maple and beech). The evaluation of soil water storage (SWS) in examined organic horizons during the selected dry and wet period was another aim of paper. The soil moisture was measured with frequency domain reflectometry sensors every 10 days in the period from 29.6.2018 to 15.1.2020. The mean value of soil moisture measured in organic horizon under the oak was 13.44%, under sycamore maple 16.08% and under the beech 19.64%. The SWS in the examined organic horizons was determined for the selected dry (29.6.2018–30.8.2018) and wet period (14.3.2019–31.5.2019). The statistically significant difference was found between SWS in the organic horizon under the beech and other two examined organic horizons only during wet period.

KEY WORDS: moisture changes, organic horizon of forest soil, measurement of soil moisture, vegetation

Introduction

Soil moisture regime is influenced by a number of factors and has a specific dynamics and periodicity during the year (Ištoňa and Pavlenda, 2011). The course of soil moisture depends mainly on the distribution of atmospheric precipitation and the air temperature during the year (Rushton et al., 2006). The soils in the lowlands and hills regularly dry up in the summer and autumn, but there have been many extremely dry years, especially in the last few decades (Van den Hurk et al., 2008). In the dry season, the volumetric soil moisture values are generally low, so the range of the standard deviation is low for drought (Lee et al., 2014). In contrast, the higher variability expressed by the standard deviation of the average volume moisture is in the wet period (Famiglietti et al., 1998; Western and Grayson, 1998). Persistent change in climatic conditions is also reflected in changes of soil water storage, so it is necessary to monitor soil moisture (Robinson et al., 2012). The shortage and uneven distribution of precipitation, which has recently occurred in most of Slovakia, will affect the availability of forest soil water for plants, health and the production of forest trees from the lowlands to mountainous locations. Lowlands and hilly locations will be most endangered by the lack of moisture

(Škvarenina et al., 2006; Tužínsky, 2004).

Organic horizon (O-horizon) of forest soil profile is dominated by organic material, consisting of undecomposed or partially decomposed litter, such as leaves, needles, twigs, moss, and lichens, which has accumulated on the surface. O-horizons are not saturated with water for prolonged periods. The mineral fraction of such material is only a small percentage of the volume of the material and generally is much less than half of the weight. (Soil Survey Staff., 1996).

The largest and most important changes in the soil moisture of the forest organic horizons occur during the growing season due to vegetation (Leathers et al., 2000). The hydrological significance of the organic horizon of forest soil is in the distribution of precipitation, which is not captured on forest vegetation and falls on the soil surface. After infiltration of precipitated water into the organic horizon, it is either retained or percolate deeper to the mineral component of the forest soil profile lying below the organic horizon (Kavvadias et al., 2001). Forest soil with a well developed organic horizon has a higher ability to retain soil moisture (Zvala et al., 2018; Xing et al., 2018) than the mineral component of forest soil. A thick layer of forest organic horizon reduces evaporation from the surface and soil moisture at greater depths is less

responsive to short-term variability in environmental factors (Dickinson et al., 1991; Western et al., 2002; Wang et al., 2009). The moisture of the organic soil horizon has an impact on the decomposition of organic matter and the formation rate of the organic horizon (Cheng et al., 2018, Couteaux et al., 1995).

Litter layer as an upper part of forest soil organic horizon is an important buffer between the soil and atmospheric precipitation (Acharya et al., 2017; Dunkerley, 2015; Van Stan et al., 2017). Rainwater interception is one of the most important hydrological functions of the forest litter layer. The effect of the forest type on the interception capacity is related to the leaf shape (Li et al., 2013; Sato et al., 2004). Generally, leaf litter with a larger leaf area index attained a higher storage capacity than that with a smaller leaf area index. Li et al., 2021 found that also leaf distribution pattern notably impact leaf litter interception capacity, which is similar to leaf shape and slope impacts. Bulcock and Jewitt (2012) found that the leaf shape in the litter layer was an important factor influencing the interception rate of litter. Sato et al. (2004) noted that litter drainage not only flowed along the bottom of the litter layer but also produced lateral drainage during rainfall, which may be an important factor influencing the water conservation capacity of the litter layer and may also be affected by the leaf shape, forest floor slope, and leaf distribution.

Our hypothesis was that increased interception of litter, containing the leaves with specific leaf shape, may influence the infiltration process into the organic horizon and thus also influence the soil water storage in O-horizon. The primary aim of this paper was to analyze and statistically evaluate the changes of soil moisture in organic horizons under tree species (beech, sycamore maple and oak) with different shape of leaves. The evaluation of soil water storage (SWS) in examined organic horizons in selected dry and wet period was another aim of paper.

Material and methods

Study area

The research was conducted at Železná studnička locality (48° 11' 21" N`; 17° 04' 55" E) in Bratislava. The study area is part of the Bratislava Forest Park, located at the end of Mlynská dolina valley, belonging to the Malé Karpaty Mountains. The Vydrica stream flows through the central part of study area. The Vydrica valley has a hilly terrain with a height difference of about 250 meters.

Geologically, the area is formed by granitoid rocks, limestones, shales, phyllites and amphibolites (Atlas of the landscape of the Slovak Republic, 2002). The altitude of study area is 228 m above sea level. The soil cover is made up of Eutric Cambisols to Dystric Cambisols, associated with Leptosols and with Stagnic Cambisols, from medium heavy to lighter textured and stony weathering products of non-carbonate rocks (Atlas of the landscape of the Slovak Republic, 2002). The loess clays and sand walls occur locally as part of the slope system.

The average annual temperature of the area is 8–9°C and the average rainfall is in the range of 600–700 mm (Lapin et al., 2002).

The study area is dominated by species of the Carpathian foothills with the occurrence of lowland thermophilic species. According to the Catalog of Habitats of Slovakia (Stanová and Valachovič, 2002) following habitats occurs within the study area: beech and fir-beech flower forests, acidophilic beech forests, Carpathian oak-hornbeam forests, xeric and acidophilic oak forests, ash-alder floodplain forests and linden-maple forests. Forest covers about 98% of the study area, the remaining areas are permanent grasslands, water areas, reservoirs and built-up areas. (ENPRO, 2014).

Three measurement points (MP) of soil moisture (Fig. 1.)
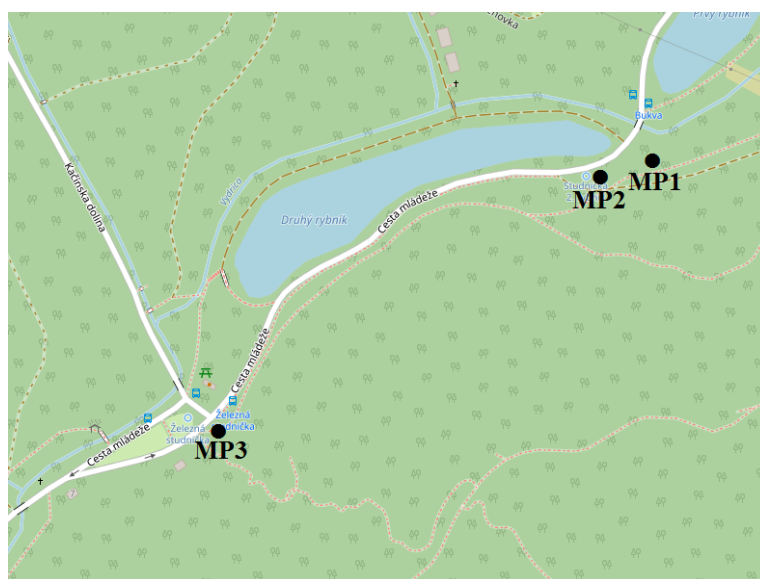

Fig. 1.   Location of measurement point MP1, MP2 and MP3 (black points and designation) at study area Železná studnička in Bratislava, Slovakia.

were chosen within the study area to capture the variability of the O-horizons. MP 1 represents the O-horizon under the oak; MP 2 includes the O-horizon under the sycamore maple and MP 3 very deep O-horizon under the beech. All measurement points were on slope with the average depth of the O-horizon of about 10 cm. The mineral horizon is located at a depth of 100 cm from the forest soil surface.

Meteorological data (monthly air temperature, 10 day precipitation totals) for the time period of θ_v monitoring, measured by SHMU at the nearest weather station Bratislava – Koliba are presented at Fig. 2.

Properties of leaves

The more or less decomposed organic material – litter, from which the O-horizon is mostly formed, contains leaves from different tree species with different shape and size.

Oak at MP 1 (*Quercus robur)* has grooved leaves with 4–7 roundish lobes, which reach a maximum of half of the leaf. The upper leaf surface is dark green; the underside of the leaf is blue-greenish. The leaves are 7x3 cm in size (Table 1) and deeply and irregularly lobed, with a short stalk (2–7mm) (Eaton et al., 2016; The Plant List, 2010).

The leaves of sycamore maple at MP 2 (*Acer pseudoplatanus* L.) have long, reddish colored stems, which are usually five-lobed, with the front three lobes are about the same size. The underside of the sycamore maple leaf is gray-green in color, while the top is dark green. The leaf position of this tree is opposite. The leaves turn intense in autumn, from gold-yellow to red. The size depends on the age, but may reach 18x26 cm (Table 1) (Pasta et al., 2016).

The elliptical-shaped leaves of the beech at MP 3 (*Fagus sylvatica* L.) are alternate and petiolate and entire or with a slightly crenate margin, 5–10 cm long and 3–7 cm broad (Table 1), with 6–7 veins on each side of the leaf. The buds are long and slender, 15–30 mm long and 2–3 mm thick (The Plant List, 2010).

Field measurement of soil moisture

Volumetric soil moisture content, θ_v, is the volume of water per unit volume of soil. This is a dimensionless parameter, expressed either as a percentage (% vol), or a ratio [$m^3\ m^{-3}$]. The soil water storage, *SWS*, represents the quantitative amount of water present in the soil with a specific thickness of the soil layer. It is expressed in mm (or cm) as the height of the water layer on an area of 1 m^2 for a soil layer of a given thickness.
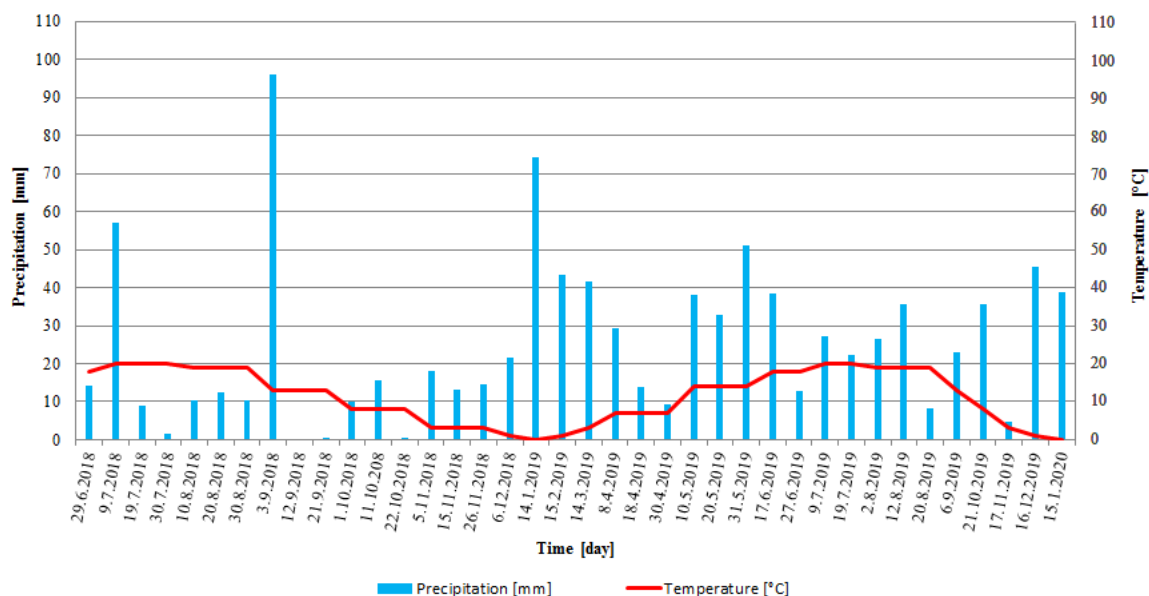

Fig. 2.   The daily precipitation totals and the average monthly air temperature for locality Železná studnička, Bratislava for a time period of θv monitoring (29.6.2018–15.1.2020) (SHMU, 2020).

Table 1.   Maximal leaf size of trees at MP1 (oak), MP2 (sycamore maple) and MP3 (beech)

Plant	Maximal size of leaf [cm]
oak (*Quercus robur*)	7x3
sycamore maple (*Acer pseudoplatanus* L.)	26x18
beech (*Fagus sylvatica* L.)	10x7

$θv$ was measured with the sensor ThetaProbe ML2x-UM-1.21. ThetaProbe use the FDR method, which belongs to the indirect methods of $θ_v$ measuring. This sensor measures directly the changes in the apparent relative permibility, which is converted into a DC voltage, virtually proportional to soil moisture content. The advantages of indirect methods are the non-destructiveness of the soil sample, the measurement results are immediately available, and the measurement can be performed repeatedly at the same place or stationary measurement with a computer controlled by a recorder of measured $θ_v$ data. The Soil Moisture Meter type HH2 applies power to the sensor and measures the output signal voltage returned. The meter converts the mV reading into soil moisture units using a linearisation table and soil-specific parameters. Linearisation tables are pre-installed for sensors, along with soil parameters for the following soils: organic, mineral, peat mix, coir, mineral wool and Perlite (Eijkelkamp, 2021).

Measurements of soil moisture content were conducted every 10 days in the period from 29.6.2018 to 15.1.2020 on an area of about 4 m² at every MP.

Statistical analysis

Differences between the parameters estimated at different measurement points were evaluated using single factor ANOVA with Tukey's Honest Significant Difference (HSD) post-hoc test. The Tukey-Kramer method (also known as Tukey's HSD method) uses the Studentized Range distribution to compute the adjustment to the critical value. The Tukey-Kramer method achieves the exact alpha level (and simultaneous confidence level $(1–α)$) if the group sample sizes are equal and is conservative if the sample sizes are unequal.

The statistical significance in the analysis was defined at $P<0.05$.

Results and discussion

Temporal changes in the moisture content of the deciduous forest organic horizon depend mainly on the distribution of atmospheric precipitation and on the air temperature during the year. Air temperature has here even greater effect than in mineral horizons, as organic material overheats faster and evaporation is more intense. The course of moisture at MP1, MP2 and MP3 was evaluated seasonally according to Fig. 3, 4 and 5. The highest values of moisture content were measured at all sites during spring season. At the start of summer, soil moisture decreases with the increasing air temperature. During the dry and hot summer season, soil moisture decreases to the lowest values. Soil moisture values are during summer reduced also by increased interception of trees and increased transpiration of vegetation. During the autumn, soil moisture values increased with the decrease of air temperature. The highest values of soil moisture during the monitoring period were measured during winter, as a consequence of the snow melting.

The mean values of soil moisture for the whole measurement period have, according Table 2, increasing trend in order MP1 (oak) < MP2 (maple) < MP3 (beech). Statistically significant difference is only between MP1 and MP3. The relationship between the different leaf size and soil moisture content was not confirmed in conditions of our study, as the mean value of soil moisture under the maple (tree with the largest leaves) is not significantly different from other two sites.

We found that the site MP1 (oak) differs most significantly from others. After more detailed analysis, we found that the lowest values of the SWS and soil
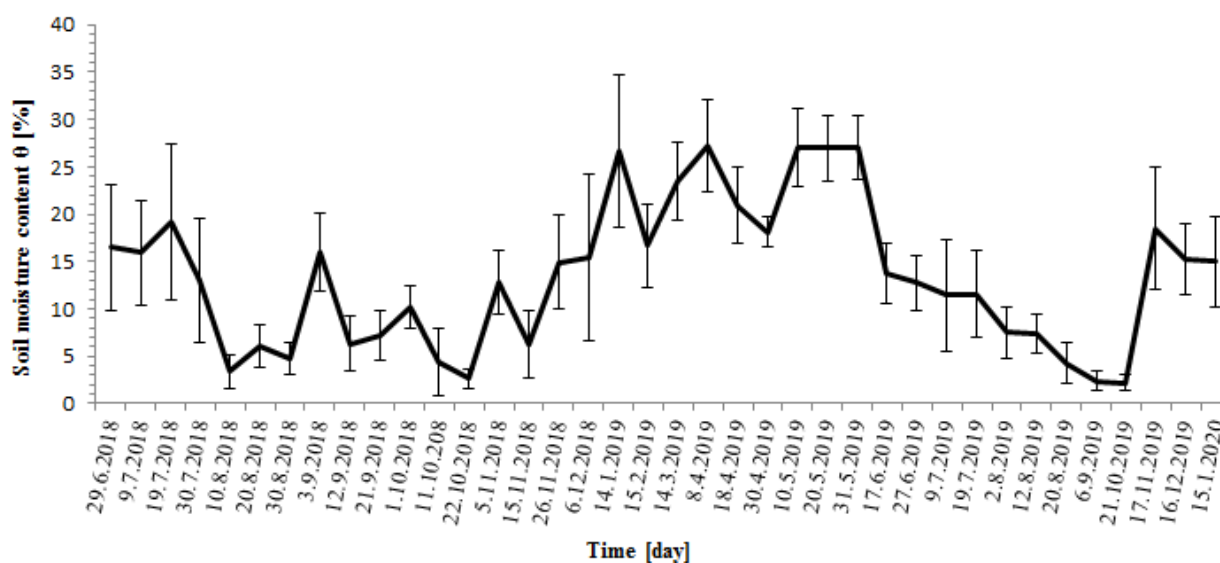

Fig. 3. *Volumetric soil moisture content of the organic horizon under the oak with a standard deviation of measurement.*
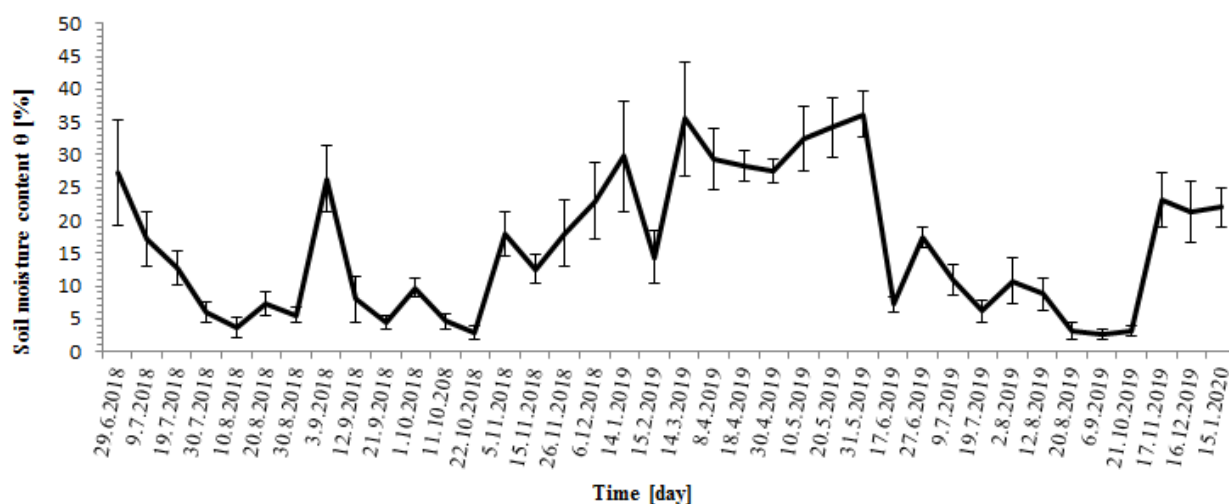
Fig. 4. Volumetric soil moisture content of the organic horizon under the sycamore maple with a standard deviation of measurement.
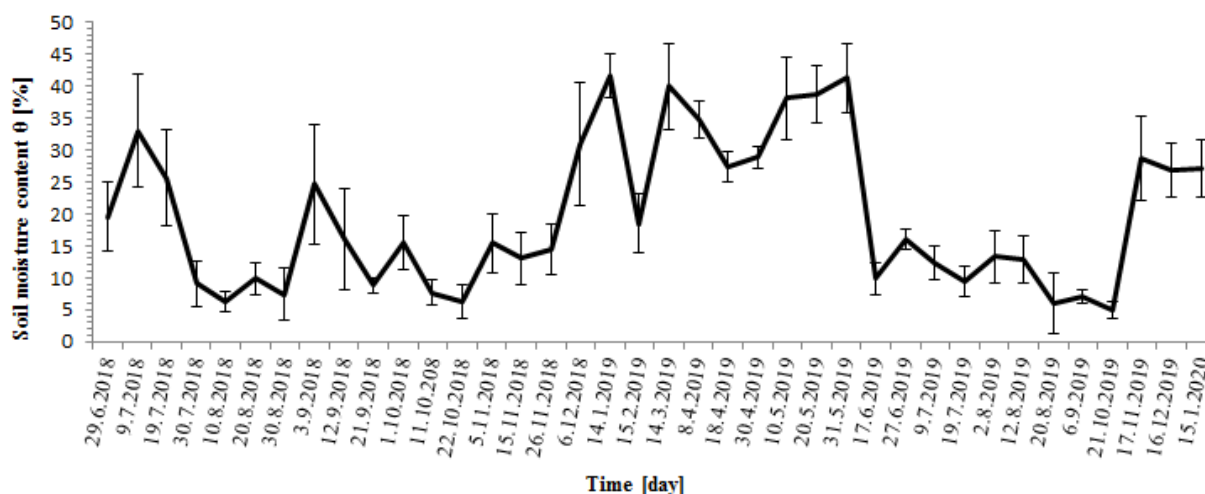

Fig. 5. Volumetric soil moisture content of the organic horizon under the beech with a standard deviation of measurement.

Table 2. Measured values of soil volumetric moisture, θ (±their standard deviation), θ_{min}–minimal value (lowest measured value of all measurements) of θ as the arithmetic mean of the 10 replicate measurements for maple, beech and oak, θ_{max}–maximal (highest measured value from all measurements) θ as the arithmetic mean of the 10 replicate measurements for maple, beech and oak, θ_{mean}–arithmetic mean of θ from every day of monitoring period, values of water storage in the organic horizon, W (±their standard deviation) during dry period 29.6.2018–30.8.2018 (W_{dry}) and during wet period 14.3.2019–31.5.2019 (W_{wet}); Arithmetic means with the same letter are not significantly different from each other (Tukey's HSD test, P>0.05)

Measuring point	θ_{min} [% vol.] (N=10)	θ_{max} [% vol.] (N=10)	θ_{mean} [% vol.] (N=38)	W_{dry} [mm] (N=7)	W_{wet} [mm] (N=7)
MP1 (oak)	2.21 ± 0.8[a]	27.05 ± 4.11[a]	13.44 ± 7.70[a]	1.12 ± 0.64[a]	2.44 ± 0.37[a]
MP2 (maple)	2.61 ± 0.84[a]	36.18 ± 3.57[b]	16.08 ± 10.69[a,b]	1.14 ± 0.84[a]	3.19 ± 0.35[b]
MP3 (beech)	4.98 ± 1.21[b]	41.6 ± 3.36[c]	19.64 ± 11.61[b]	1.58 ± 1.04[a]	3.55 ± 0.55[b]

moisture at MP1 may be related to the different mineral layer here, which is formed by fragments of weathering, accumulated at the foot of the slope. The layer of weathering fragments has better infiltration capacity, which may have effect on drainage of upper organic horizon. The properties of boundary layer between the mineral and organic horizon may have greater effect on SWS than the examined leaf size.

Conclusion

The soil moisture content during the period of measurement at sites MP1, MP2 and MP3 representing organic horizon formed from leaves of different trees (oak, sycamore maple and beech) has increasing trend during spring and autumn months and decreasing during summer. The group means of soil moisture content for whole measurement period increased in order: PM1<PM2<PM3. The statistically significant differences were found between MP1 and MP3. The relationship between the different leaf size and soil moisture content was not confirmed in conditions of our study. Group means of soil water storage (SWS) for whole period of measurement increased in the same order than the soil moisture content. Statistically significant difference between group means of SWS was determined only for the wet period between MP1 (oak) and other two measuring points. Statistically, the site MP3 (oak) differed mostly from other sites, which may be related with the different boundary layer between organic and mineral horizon.

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