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Soil water dynamics in drained and undrained meadows

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Abstract: Tile drainage belongs to one of the most important meliorative measures in the Czech Republic. It has been hypothesised that it may improve some soil properties which are influenced by the groundwater and their water regime. In the case of meadows, the used management method may also influence the soil properties. In this study, different physical soil properties (particle and bulk density, total soil porosity, maximum capillary water capacity, minimum air capacity, water retention capacity and saturated water content, volumetric water content and matric potential) at depths of 15, 35 or 40 and 60 cm in differently managed meadows (drained versus undrained) located near the village of Železná in the Czech Republic (mildly cold, humid climatic region) were investigated. The drained meadow is used mainly for grazing (extensively) and the undrained meadow is mown twice a year. In addition, the actual evapotranspiration was estimated for the 2018 vegetation season. The selected physical soil properties were significantly ($P < 0.05$) different between the experimental meadows, especially at depths of 0–28 versus 0–35 cm (particle and bulk density, total soil porosity, maximum capillary water capacity, water retention capacity and saturated water content) and 28–49 versus 35–45 cm (particle density, water retention capacity and saturated water content). In the case of all the studied soil depths, the volumetric water content and matric potential were significantly ($P < 0.05$) different between the experimental meadows in the years 2016–2019. The actual evapotranspiration was also significantly different ($P < 0.05$) between the meadows. The obtained differences in the measured soil properties and estimated actual evapotranspiration were probably influenced by the used tile drainage and also by the type of management of the meadow. It is necessary to obtain more research findings with respect to different types of management in the case of drained meadows and also undrained meadows to understand the role of both treatments (tile drainage, management).

Keywords: evapotranspiration; land use; physical soil properties; soil water regime; tile drainage

The soil water balance is given by the input (rain, irrigation) and output (drainage, evaporation, transpiration and runoff) of the water and its dynamics are highly complex (Chavarria & dos Santos 2012). Daly and Porporato (2005) hypothesise that precipitation represents the main input of the water to the soils and the effective precipitation (e.g., > 5 mm during drier periods) influences the soil water. Evaporation and transpiration occur simultaneously; it is difficult to separate these two processes (Allen et al. 1998). Tile drainage belongs to one of the most important meliorative measures in the Czech Republic (Tlapáková 2017). In the Czech Republic, approximately 1 087 000 ha of agricultural land are drained annually. From this number, 98% is related to systematic tile drainage (Tlapáková et al. 2017).

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For example, the systematic tile drainage system was realised to improve both the water regime and soil properties (e.g., aeration, temperature, texture and structure, sorption ability, soil organic matter mineralisation, nitrification and denitrification, etc.), development of the soils and it enabled both the conversion of grasslands into arable land and the better use of fertilisers (e.g., Fučík et al. 2015; Karásek et al. 2015; Vopravil at al. 2018). A period of inappropriate or absent maintenance and repairs of the drainage systems started after 1989 and, according to Tlapáková (2017), still continues nowadays.

The water content in the soil has an impact on its oxygen status, some of the most important phases of the carbon and nitrogen cycle and the availability of nutrients (Hanks & Ashcroft 1980). Soil moisture conditions are commonly expressed as the soil moisture deficit, which is the amount of water (expressed in mm of precipitation) required to replenish the soil water content (SWC) to the field capacity (FC) (Keane 2001; Schulte et al. 2005). James et al. (2003) reported that the soil water regime differed between vegetation types (grassland and shrub communities, forests) and found, for example, little interception of precipitation, which did not differ between these vegetation types. The authors indicated that grasses are especially able to reduce the soil moisture content during periods without rain. The factors which influence the water regime of extensively used grasslands are summarised by Duffková (2008).

As reported in the work by Schulte et al. (2005), a soil water regime may have an impact on the agronomic management and the environment (length of grazing season, land-spreading of artificial fertilisers and slurry, nutrient and pathogen transport and nitrogen loss). The SWC can be continuously monitored by installing time-domain reflectometry or impedance and capacitance sensors in fields. The sensors measure the SWC very precisely and are robust and suitable for different soils (Zermeño-González et al. 2012).

To describe the soil water status, both the water content and matric potential (ψ_m) have to be measured. Relationships between the soil water content (gravimetric or volumetric) and ψ_m can be described by soil water retention curves (Novák & Hlaváčiková 2019). ψ_m is a component of the soil water potential (ψ_w). It is, according to Braudeau et al. (2014), the pedostructural water potential; the pedostructure is an assembly of primary peds. In theory, ψ_m is zero in a saturated soil and can be determined directly (tensiometers or the measurement of the relative humidity) or indirectly using the filter paper method or porous matrix sensors (Oliveira & Marinho 2008; Whalley et al. 2013). For example, the filter paper method is based on the assumption that two porous materials in liquid contact will exchange water until their matric potential is the same (Hanks & Ashcroft 1980). When the above-mentioned materials are in vapour contact, this method can be used to estimate their water potential.

The saturated water content is the water content at 0 kPa, the FC is the water content at –10 or –33 kPa and the permanent wilting point (WP) is measured at –1 500 kPa (Minasny & McBratney 2018). Increasing the soil organic matter (SOM) increases the saturated water content, FC and WP; the SOM mostly increases the FC more than the WP, which has a positive effect on the available water capacity (Huntington 2006). The effect of the SOM is different between the topsoil and subsoil and depends on the amount of SOM and the clay content; a negative effect of the SOM on the water retention was mainly reported in fine-textured soils (Minasny & Mcbratney 2018).

The above-mentioned tile drainage has been hypothesised to improve some properties of soils influenced by the groundwater and their water regime. In the case of meadows, the used management method may also influence the soil properties. In particular, the aim of the research was to find out the soil water retention (and infiltration) within the context of the soil classification, climate extremes and anthropogenic influences; different soil types (Chernozems, Stagnosols, Cambisols) in different climatic regions of the Czech Republic (very warm and dry, mildly cold and humid, etc.) were investigated. In this study, the aim was to monitor the soil water regime (including the soil water matric potential) of differently managed meadows (drained versus undrained) from 2016–2019 and to investigate some other physical soil properties of the different horizons of the meadows. Also, the aim was to estimate the actual evapotranspiration in the meadows using meteorological data to calculate the reference crop evapotranspiration (ET_0) and also the coefficient of water stress (K_s).

MATERIAL AND METHODS

Study site. The drained experimental meadow (49.5780883N, 12.5862297E) and the undrained experimental meadow (49.5680911N, 12.5911489E) are located near the village of Železná in the Czech Republic close to the border with the Federal Republic

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of Germany (Figure 1). The locality (approximately 360 ha) lies in the cadastral area of Železná u Smolova, approximately 30 km north-west of Domažlice; it lies in the basin of the Danube. Geomorphologically, the area belongs to Česká vysočina and the sub-province of Šumava, the geomorphological complex of Český les. In the case of the soil survey, it was performed in the years 1970–1974, 2004, 2009, 2010 and 2013. Different soil types occur in the locality; Stagnic Cambisols form approximately 40% of the soil cover and Haplic Stagnosols form 25% (see Vopravil et al. 2008). The development of the hydrographic network has been elaborated upon. In the 1980 s, the area around Železná was systematically tile drained (to improve the physical soil properties, water regime and agricultural production) using flexible plastic pipes and the drained plots were used as arable land. Before this area was drained, the groundwater level in some parts of this area was, for example, at depths of 60–110 cm and also above the soil surface (10–15 cm). Špaček (1974) described the groundwater level and soils before the drainage was constructed. Information on the fluctuation of the groundwater level during the study period as well as its depth are not available. Since the 1990 s the plots have been used as meadows. The drained meadow is used mainly for grazing (extensively) and the undrained meadow is mown twice a year. The undrained meadow is surrounded by forests. The drainage lines were placed at a depth of 1 m (Vopravil et al. 2008) and the system is still functional. According to Vopravil et al. (2008), the spacing of drains is between 7.5 and 11 m. In this locality, Vopravil et al. (2018) collected drainage

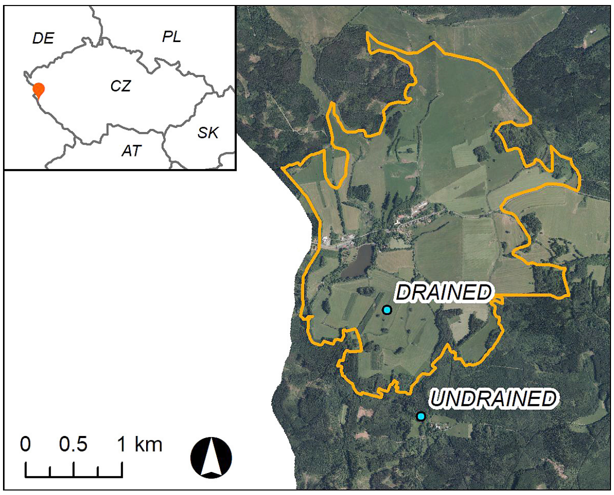

Figure 1. The experimental meadows near the village of Železná in the Czech Republic

water samples (plus stream and underground water samples) and measured different chemical indicators in these samples. Vopravil et al. (2008) reported that the drainage water collected in the locality was not polluted and its flow rate was relatively low. The water in the outflow point was not examined during the observation period. The area lies at an altitude of 500–593 m a.s.l. The locality belongs to a mildly cold and humid climatic region. This region is characterised by a mean annual air temperature of 5–6 °C and by a mean annual precipitation of 700–800 mm. The sum of temperatures above 10 °C is 2 000–2 200 °C. The soil survey was performed using boring bars in the year 2013; consequently, soil pits were excavated in the case of sites typical for the individual localities to detail the soil profiles (characteristics). The locations of the pits were recorded; the description plus the photo documentation of the pits have been elaborated upon. Soil samples were taken from the topsoil. In the case of the excavated soil pits, disturbed and undisturbed (using a Kopecky cylinder with a volume of 100 cm^3) soil samples were taken from whole profiles and analysed (soil pH measured in the water and in 1 mol/L KCl at 1 : 2.5 soil (g)/solution (mL) ratio, total soil organic carbon, hot water soluble carbon, water stable aggregates and mean weight diameter, permanent wilting point, particle and bulk density, total porosity, maximum capillary water capacity, water retention capacity, etc.). The soil survey showed the drained area relief was mostly plain (1–3°); in some cases, a gentle slope (3–7°) was found. The locality belongs to Moldanubicum of Český les; the geological map of the locality is shown in Figure 2.

Measurements and calculations. A soil profile was excavated from each of the meadows. The soil type and sub-type of the drained meadow (DM) and the undrained meadow (UM) is Haplic Stagnosol (IUSS Working Group WRB 2006). The disturbed and undisturbed (using a Kopecky cylinder core) soil samples (3 samples per each of the studied soil depths on the DM as well as the UM) for the determination of the selected physical properties (particle and bulk density, total porosity, maximum capillary water capacity, minimum air capacity, water retention capacity and saturated water content) were taken on July 11, 2018. These properties are described in the works by Flint and Flint (2002a, b) and Duffková and Kvítek (2009). The maximum capillary water capacity was obtained after 2 h suction (on filter paper) of the fully saturated soil samples. The minimum air capacity is the air content of the soil when it is wetted to its maximum

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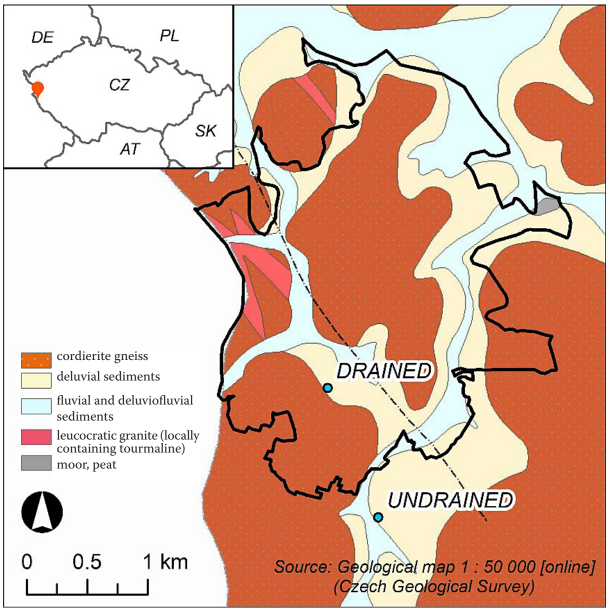

Figure 2. Geological map of the locality Železná

capillary water capacity and was calculated from the total porosity and maximum capillary water capacity (Vopravil et al. 2017). The water retention capacity (e.g., Šimečková et al. 2016) was determined after 24 h suction (on filter paper) of the fully saturated soil samples. The saturated water content is obtained after the soil samples are fully soaked with capillary water. The above-mentioned soil properties were measured at the depths of 0–28, 28–49 and >49 cm in the drained meadow and at the depths 0–35, 35–45 and >45 cm in the undrained meadow. The particle-size distribution (according to ISO 11277:2009) in the studied soils is listed in Table 1.

The volumetric water content (θ_v), matric potential (ψ_m) and temperature were continuously measured at a depth of 15 cm in both meadows, at a depth of 35 cm in the DM and at a depth of 40 cm in the UM. At a depth of 60 cm, only the measurement of θ_v was performed. This measurement was performed using calibrated sensors from May 17, 2016 to July 25, 2019.

A GS1 (Meter Group, USA) sensor was used for the measurement of θ_v (frequency domain, dimensions 9.6 × 3.5 × 1.5 cm, measurement range 0–0.570 m^3/m^3, accuracy ± 3%, measurement speed 10 ms, sensor operating temperature from –40 to +50 °C, voltage 3–15 Vdc, power consumption 1 mA). An MPS-6 (Meter Group) sensor was used for the measurement of ψ_m and the temperature (dimensions 9.3 × 2.4 × 6.5 cm, range from –9 to –100 000 kPa, accuracy ± (10% of reading + 2 kPa); range from –40 °C to +60 °C, accuracy ± 1 °C; measurement time 150 ms, power requirement 3–15 Vdc, output SDI-12). An EM50 datalogger (Meter Group, USA) was used.

An automatic meteorological station, a TeranosALA (AMET Velké Bílovice, Czech Republic), was installed. This station was placed close to the soil profile which was excavated in the drained meadow. The soil profile in the drained meadow was also close to sampling point K3/D where Vopravil at al. (2018) collected the drainage water samples in the previous years. The station was fitted with Honeywell HIH 4000 sensors (Honeywell, USA) to measure the relative air humidity and Dallas semiconductor DS18B20 sensors (Maxim Integrated, USA) to measure the air temperature. The data were measured in an hourly time-step. The meteorological data were used to calculate the reference crop evapotranspiration (ET_0). The actual evapotranspiration (ET) was calculated for the 2018 vegetation season (from April to October) by conversion from ET_0 using the coefficient of water stress (Allen et al. 1998). This coefficient (K_s) is dependent on the available soil water and its calculation is described by Duffková (2003). K_s is dimensionless and is calculated according to Equation (1):

$$K_s = TAW - D_r/TAW - RAW = TAW - D_r/(1 - P)\ TAW \quad (1)$$

where:

TAW – total available soil water in the root zone (mm);

D_r – root zone depletion (mm);

Table 1. Particle-size distribution (in %) in the soils of the meadows

Meadow	Depth (cm)	< 0.001	< 0.01	0.01–0.05	0.05–0.25	0.25–2.0
	0–28	7.60	22.50	21.00	25.00	31.50
Drained	28–49	7.40	21.30	30.30	23.00	25.30
	> 49	14.50	23.30	14.90	37.50	24.30
	0–35	7.60	24.40	18.60	31.80	25.10
Undrained	35–45	16.90	34.10	28.00	22.70	15.10
	> 45	13.20	24.50	22.50	33.00	20.00

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P – fraction of TAW that a crop can extract from the root zone without suffering water stress (dimensionless);
RAW – the readily available soil water in the root zone (mm), RAW = P TAW.

TAW is calculated according to Equation (2):

$$TAW = 1000\ (FC/100 - WP/100)\ Z_r \qquad (2)$$

where:
FC – field capacity (vol. %);
WP – permanent wilting point (vol. %);
Z_r – the rooting depth (m).

D_r is calculated according to Equation (3):

$$D_r = TAW - (SWS - WP\ Z_r\ 10) \qquad (3)$$

where:
SWS – soil water storage in the root zone (mm).

The equation for the calculation of P is described by Allen et al. (1998), Duffková (2003), etc.

ET_0 (mm/day) was calculated according to the FAO Penman-Monteith equation (Allen et al. 1998). The values of solar radiation used for this calculation were estimated according to Hargreaves et al. (1985). As reported by Warren et al. (2005), θ_v is dependent on the soil texture. The FC and WP values (vol. %), which are necessary to calculate the above-mentioned coefficient of water stress, were obtained according to Equations (4) and (5):

$$FC = 6.66 + 1.03\ (\text{particles with diameter} < 0.01\ \text{mm in \%}) - 0.008\ (\text{particles with diameter} < 0.01\ \text{mm in \%})^2 \qquad (4)$$

$$WP = 2.97 + 0.33\ (\text{particles with diameter} < 0.01\ \text{mm in \%}) - 0.0012\ (\text{particles with diameter} < 0.01\ \text{mm in \%})^2 \qquad (5)$$

The mentioned continuous pedotransfer functions are described by Novotný et al. (1990). Also, the extraction of water from a depth (rooting zone) according to Fiala (1997) was considered.

Statistical analyses. The differences in the selected soil physical properties were tested using a one-way analysis of variance (ANOVA). The ET, ψ_m and θ_v in the DM versus the UM were tested using the Mann–Whitney U test. All the statistical analyses were performed with STATISTICA Cz, Ver. 10 software (StatSoft, Inc. 2011).

RESULTS AND DISCUSSION

The different parameters of the Haplic Stagnosol obtained using physical-chemical and chemical methods (e.g., soil pH measured in water, cation exchange capacity measured with the use of 0.1 mol/L $BaCl_2$, pH 8.1, base cation content and base saturation) for both meadows are similar; the soil pH on the meadows is acid, adverse sorption properties were found in the case of both meadows as well. The meadows differ in the particle-size distribution (Table 1). The soil from the DM is a sandy loam at depths of 0–28, 28–49 and > 49 cm, whereas the soil from the UM is loamy at a depth of 35–45 cm. The total organic matter content is high/very high and it was found to decrease with the soil depth; it was low (28–49 and 35–45 cm) or very low (> 49 and > 45 cm) in the case of the drained and undrained meadow.

The particle density was significantly ($P < 0.05$) higher at a depth of 0–28 cm in the drained meadow in comparison with a depth of 0–35 cm in the undrained meadow (A_h horizon). On the other hand, and as listed in Table 2, this property was significantly ($P < 0.05$) higher at a depth of 35–45 cm in the undrained meadow in comparison with a depth of 28–49 cm in the drained meadow. The same applies to the values of the particle density at depths of > 45 versus > 49 cm (see Table 2). The values of the bulk density at different depths ranged from 1.24 to 1.62 g/cm^3 in the drained meadow and from 0.91 to 1.59 g/cm^3 in the undrained meadow. The total porosity range was 38.20–51.86% in the drained meadow and 41.23–64.12% in the undrained meadow. The average values of the bulk density and total porosity are listed in Table 2. In the case of maximum capillary water capacity, the range was 26.94–48.13% in the drained meadow and 40.25–55.75% at depths of 0–35 cm and 35–45 cm in the undrained meadow. The minimum air capacity range was 1.74–13.84% in the drained meadow and 1.43–12.27% at depths of 0–35 and 35–45 cm in the undrained meadow. In the drained meadow, the values of the saturated water content and water retention capacity ranged from 37.21% to 56.18% and from 17.59% to 39.40%, respectively. At depths of 0–35 and 35–45 cm in the undrained meadow, these properties ranged from 43.02% to 68.95% and from 37.37% to 43.79%, respectively. The values of the bulk density, total porosity, maximum capillary water capacity, saturated water content and water retention capacity were significantly ($P < 0.05$) different at a depth of 15 cm when

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Table 2. Soil physical properties of the meadows (mean ± standard error)

Meadow	Depth (cm)	PD	BD	P	MCWC	MAC	SWC	WRC
Drained	0–28	2.58 ± 0.02^{a}	1.25 ± 0.01^{a}	51.33 ± 0.29^{a}	46.34 ± 1.40^{a}	4.98 ± 1.68^{a}	55.08 ± 0.70^{a}	38.07 ± 1.08^{a}
	28–49	$2.58 \pm 0.003^{*}$	$1.42 \pm 0.015^{*}$	$45.16 \pm 0.59^{*}$	$41.76 \pm 1.26^{*}$	$3.39 \pm 1.13^{*}$	$48.71 \pm 1.38^{*}$	$33.95 \pm 0.64^{*}$
	> 49	$2.64 \pm 0.01^{+}$	$1.58 \pm 0.02^{+}$	$40.11 \pm 0.95^{+}$	28.24 ± 0.76	11.86 ± 1.62	38.47 ± 0.82	18.45 ± 0.44
Undrained	0–35	2.53 ± 0.003^{b}	0.95 ± 0.03^{b}	62.18 ± 1.38^{b}	53.93 ± 1.13^{b}	8.25 ± 2.47^{a}	66.39 ± 1.43^{b}	42.43 ± 1.06^{b}
	35–45	$2.63 \pm 0.00^{**}$	$1.45 \pm 0.01^{*}$	$45.07 \pm 0.32^{*}$	$41.68 \pm 0.87^{*}$	$3.39 \pm 0.99^{*}$	$44.15 \pm 0.66^{**}$	$38.12 \pm 0.59^{**}$
	> 45	$2.69 \pm 0.01^{++}$	$1.56 \pm 0.01^{+}$	$42.05 \pm 0.82^{+}$	ND	ND	ND	ND

PD – particle density (g/cm^3); BD – bulk density (g/cm^3); P – total soil porosity (% vol.); MCWC – maximum capillary water capacity (% vol.); MAC – minimum air capacity (% vol.); SWC – saturated water content (% vol.); WRC – water retention capacity (% vol.); ND – not determined; different letters or symbols mark significant (P < 0.05) differences between the same horizons

the meadows were compared (Table 2). The saturated water content was significantly (P < 0.05) higher at a depth of 28–49 cm in the drained meadow when compared with a depth of 35–45 cm in the undrained meadow. On the other hand, the values of the water retention capacity were significantly (P < 0.05) higher in the undrained meadow. The mentioned significant differences probably reflect the different soil organic matter content and particle-size distribution in the meadows (e.g., Biswas et al. 2014; Liu et al. 2019). These differences may be due to the mentioned tile drainage; the management methods may also influence these soil properties. For example, Duffková and Kvítek (2009) reported that some chemical and physical soil properties (soil organic carbon, particle and bulk density, porosity, maximum capillary water capacity, etc.) of the studied drained and undrained permanent grasslands were significantly influenced by the used management methods.

The values of the air temperature measured at a height of 2 m are listed in Figure 3. The ranges from –18.6 °C to 31.0 °C (2016), from –21.3 °C to 35.0 °C (2017), from –15.5 °C to 35.2 °C (2018) and from 14.8 °C to 35.0 °C (2019) were found. The values of the precipitation measured at 15 min intervals are listed in Figure 4. The minimum value was 0 mm in all years and the maximum precipitation was 23.76 mm in the year 2016, 11.07 mm in the year 2017, 18.36 mm in the year 2018 and 5.13 mm in the year 2019.

In the drained meadow, the highest and lowest values of the volumetric water content (0.46 and 0.14 m^3/m^3) were measured at a depth of 15 cm (Table 3) and this is also the case for the values of the matric potential in both meadows (Figures 5–7). The values of the matric potential are listed in Table 4. In the undrained meadow, the highest value of the volumetric water content was measured at a depth of 60 cm in the year 2016 (0.53 m^3/m^3). The lowest value was found at a depth of 15 cm in 2018 (0.16 m^3/m^3). The coefficient of variation values are listed in Table 3. The average temperatures at a depth of 15 cm in the meadows were 11.7 °C and 11.9 °C (2016), 8.9 °C and 8.6 °C (2017), 9.1 °C and 8.9 °C (2018), 8.3 °C and 8.0 °C (2019). The average temperatures at the depths of 28–49 and 35–45 cm in the drained meadow and the undrained meadow were 11.5 °C and 11.7 °C (2016), 8.9 °C and 8.6 °C (2017), 9.1 °C and 8.9 °C (2018), 8.0 °C and 8.0 °C (2019), respectively. In the drained meadow, the values of the volumetric water content and matric

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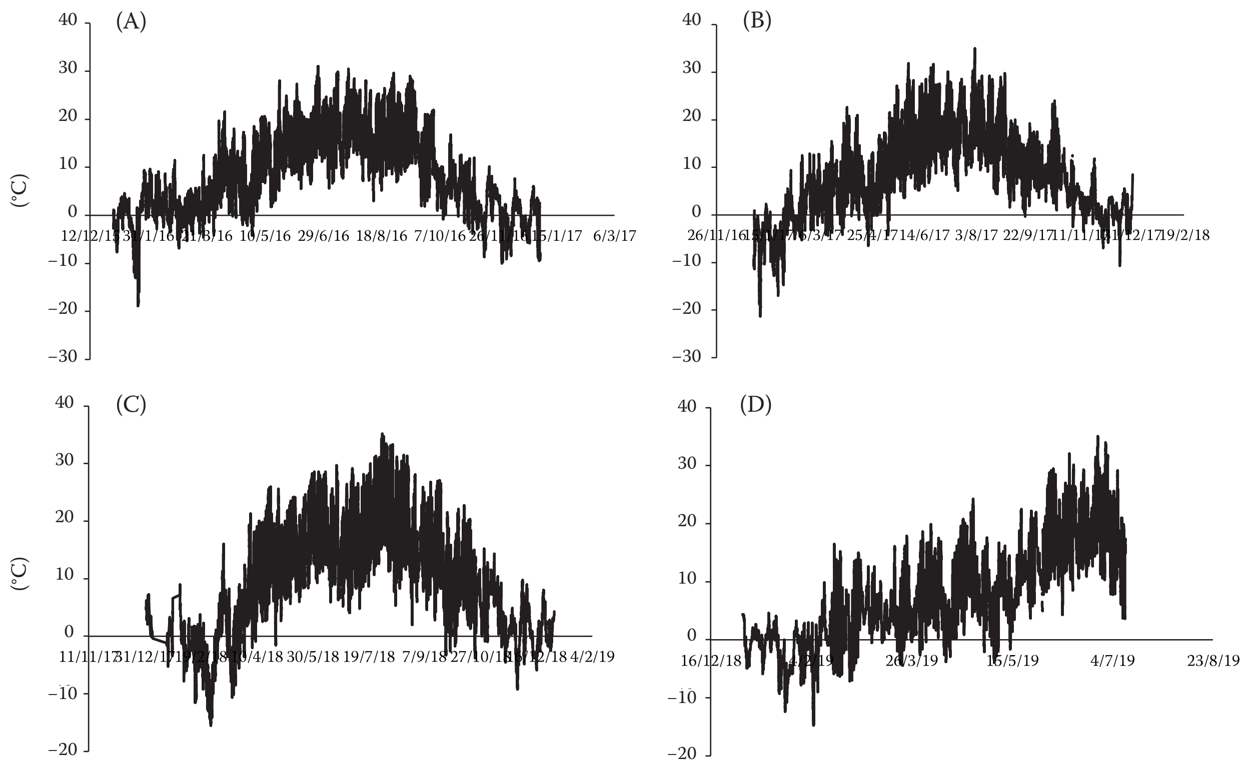

Figure 3. Air temperature in the year 2016 (A), 2017 (B), 2018 (C) and 2019 (D)

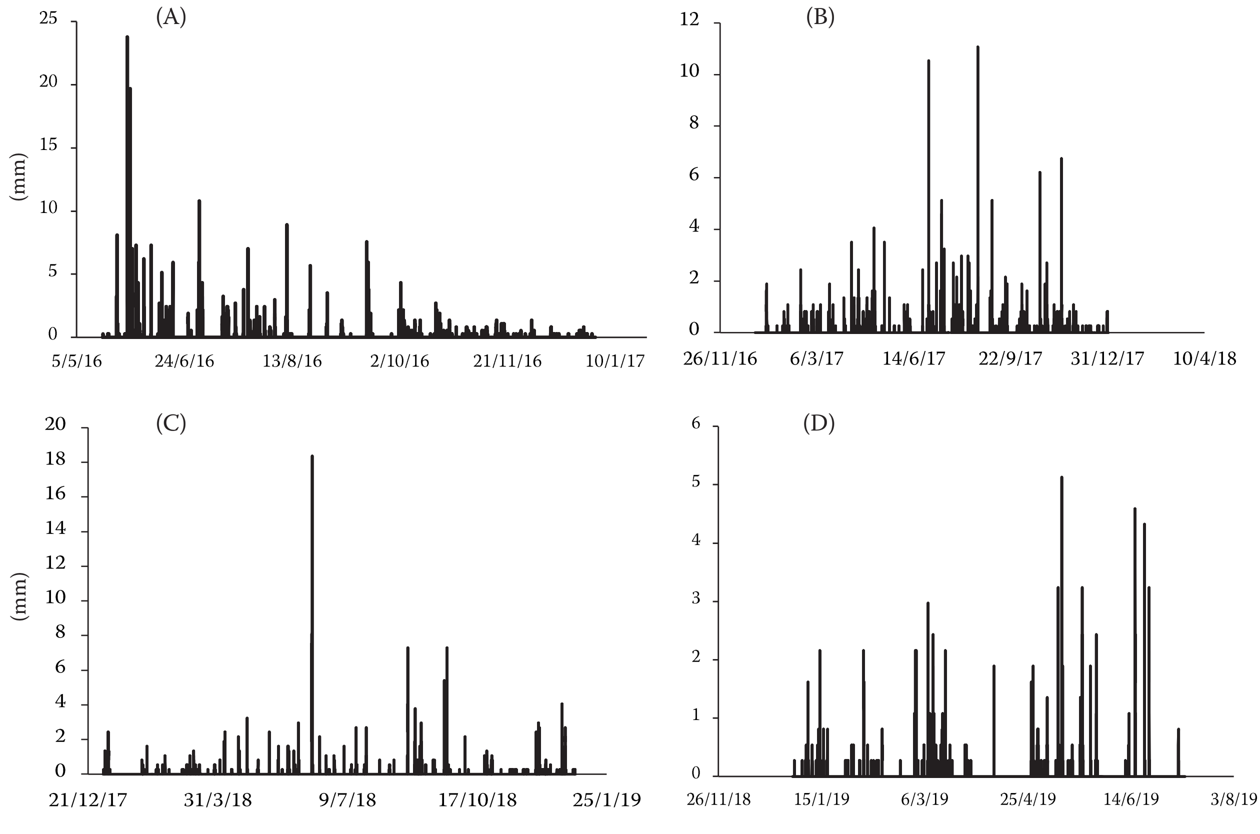

Figure 4. Precipitation in the year 2016 (A), 2017 (B), 2018 (C) and 2019 (D)

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Table 3. Volumetric water content in the different depths of the studied soils (minimum–maximum), the coefficient of variation values (in %) are marked in parentheses

Meadow	Depth (cm)	Volumetric water content (m^3/m^3)			
		2016	2017	2018	2019
Drained	15	0.28–0.46 (8.1)	0.18–0.46 (25.6)	0.14–0.46 (35.0)	0.17–0.45 (22.1)
	35	0.30–0.39 (15.7)	0.24–0.38 (13.4)	0.17–0.37 (19.1)	0.28–0.36 (6.2)
	60	0.29–0.39 (8.9)	0.24–0.39 (15.0)	0.24–0.39 (16.1)	0.27–0.38 (11.9)
Undrained	15	0.40–0.48 (3.3)	0.21–0.49 (11.3)	0.16–0.48 (31.6)	0.21–0.46 (17.9)
	40	0.41–0.47 (3.6)	0.37–0.47 (5.1)	0.29–0.47 (13.4)	0.31–0.44 (9.5)
	60	0.37–0.53 (3.0)	0.37–0.43 (2.2)	0.34–0.42 (4.4)	0.38–0.41 (1.4)

The values of volumetric water content at a depth of 15 cm are significantly ($P < 0.05$) different between the meadows in each of the years; the same applies to the values from a depth of 35 versus 40 as well as 60 cm

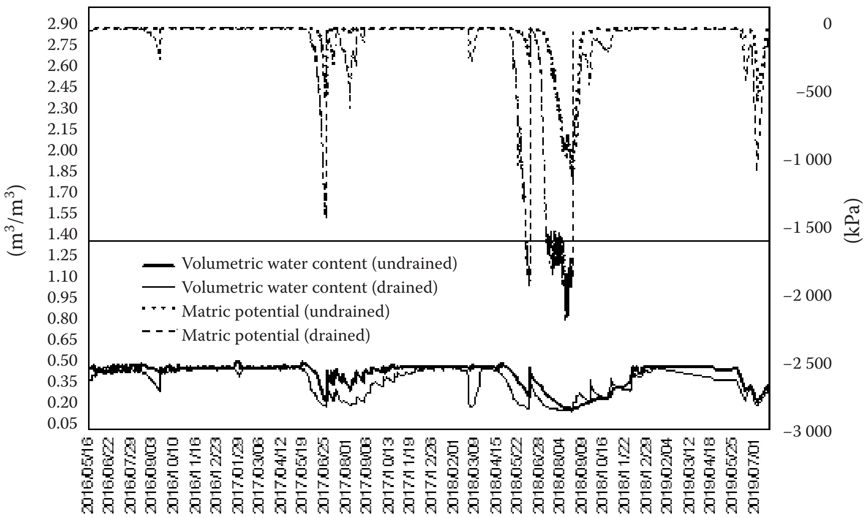

Figure 5. The volumetric water content (θ_v) and matric potential (ψ_m) at a depth of 15 cm from 2016 to 2019

potential measured at a depth of 15 cm in the year 2016 decreased from ca. mid-August and the lowest values were measured in September (0.28 m^3/m^3, –243.18 kPa). In the year 2017, the values 0.18 m^3 per m^3 and –1408.2 kPa were measured in June and the values 0.14 m^3/m^3 and –2203.6 kPa were obtained

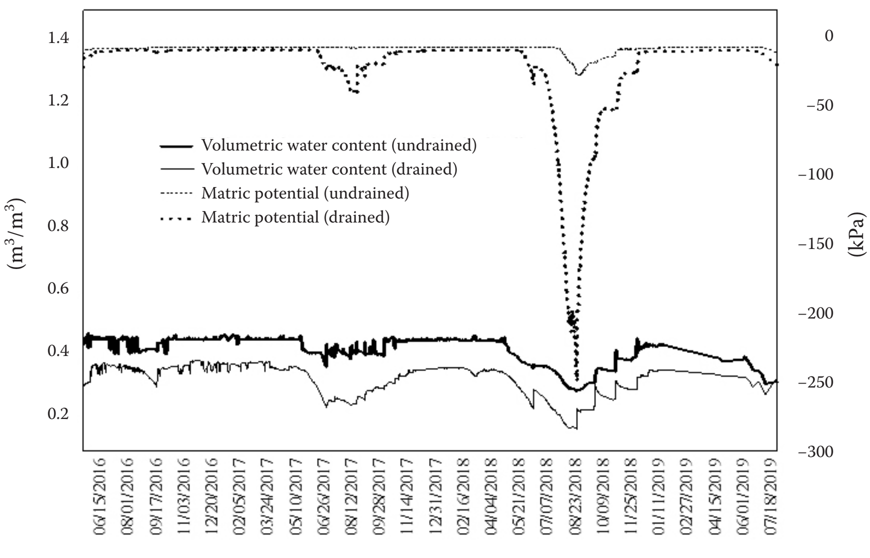

Figure 6. The volumetric water content (θ_v) and matric potential (ψ_m) at a depth of 35 cm in the drained meadow and at a depth of 40 cm in the undrained meadow from 2016 to 2019

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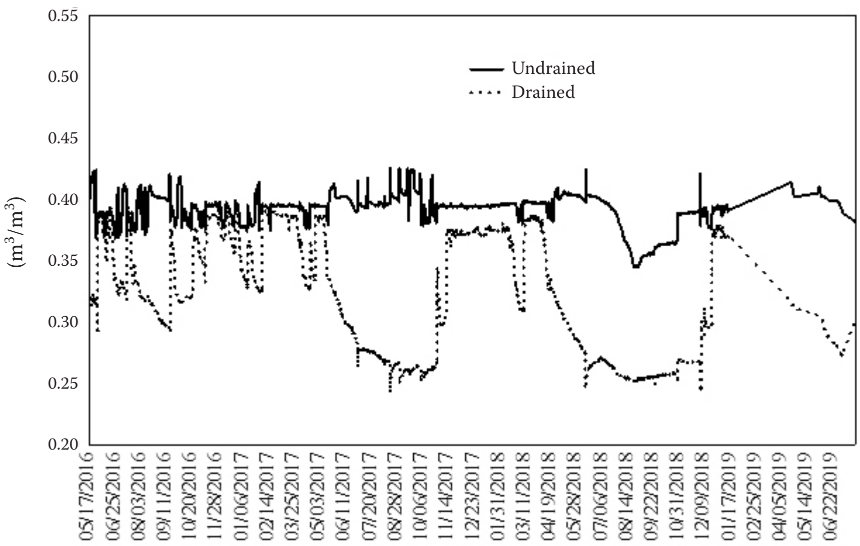

Figure 7. The volumetric water content (θ_v) at a depth of 60 cm from 2016 to 2019

Table 4. Soil water matric potential in the different depths of the studied soils (minimum–maximum)

Meadow	Depth (cm)	Matric potential (kPa)			
		2016	2017	2018	2019
Drained	15	–243.18 to –6.20	–1 408.2 to –5.90	–2 203.6 to –6.00	–1 081.7 to –6.20
	35	–14.58 to –8.30	–40.60 to –8.30	–250.0 to –8.70	–20.50 to –8.90
	60	ND	ND	ND	ND
Undrained	15	–32.07 to –5.90	–532.00 to –5.80	–1 114.10 to –5.80	–554.30 to –5.90
	40	–21.12 to –6.90	–7.10 to –6.80	–27.6 to –6.80	–10.60 to –7.00
	60	ND	ND	ND	ND

The values of soil water matric potential at a depth of 15 cm are significantly ($P < 0.05$) different between the meadows in each of the years; the same applies to the values from a depth of 35 versus 40 cm; ND – not determined

in August 2018, respectively. The lowest values of the volumetric water content and matric potential measured at a depth of 15 cm in the year 2019 were obtained in July (Figure 5). In the undrained meadow, the lowest values measured at a depth of 15 cm were obtained in May (2016), June (2017), August (2018) or July (2019).

The highest differences in the volumetric water content in the meadows (except those values measured at a depth of 60 cm) were found in the year 2018 (Table 3). For this reason, the values of the ET were calculated for the 2018 season. The field capacity and permanent wilting point values obtained from the pedotransfer functions and used to calculate the coefficient of water stress are listed in Table 5. Significant differences ($P < 0.05$) in the ET between the meadows were calculated. The estimated values of the ET in the meadows increased from the beginning of the season (1.50 mm/day) to ca. mid-May (14.5.2018, 4.99 mm/day in the drained meadow and 5.05 mm/day in the undrained meadow). In the drained meadow, the lowest ET value in the first half of this season was estimated in May (24.5.2018, 1.03 mm/day). The highest ET value was estimated in June (21.6.2018, 5.64 mm/day) and the lowest ET value was estimated in October (28.10.2018; 0.23 mm per day). In the undrained meadow, the highest ET value was estimated in July (4.7.2018, 5.79 mm per day). Consequently, the values tended to decrease and the lowest ET value was estimated at the beginning of September (1.9.2018, 0.44 mm/day). The daily differences in the ET between the meadows ranged

Table 5. The field capacity (FC) and permanent wilting point (WP) values calculated according to Novotný et al. (1990)

Meadow	FC	WP
	(vol. %)	
Drained	25.79	9.79
Undrained	27.03	10.31

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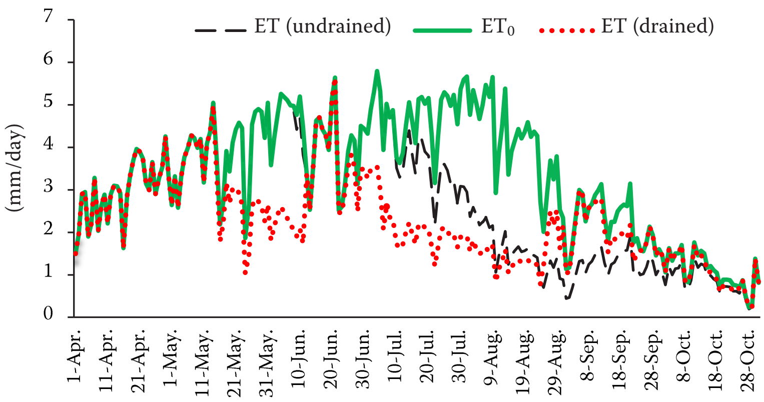

Figure 8. Daily actual and reference evapotranspiration in the year 2018

ET – actual evapotranspiration, ET_0 – reference evapotranspiration

from 0 to 2.8 mm and the CV was 45.6% (DM) and 54.9% (UM) (see Figure 8). The total estimated ET was 484.4 mm and 567.7 mm in the DM and the UM, respectively. The estimated values of the ET may be influenced by the used tile drainage (see Duffková et al. 2011). The studied meadows are differently managed and their use may also influence the values of the ET and volumetric soil water content (Duffková 2002, 2003, 2008; Duffková & Kvítek 2009). It is, for example, due to the different effects on the surface litter and transpiring biomass and it depends on the values of precipitation, etc. (Duffková 2008). Different management methods and also the previous drainage may cause changes in the botanical composition of grasslands and different grassland plants differ in their transpiration intensity; for example, leguminous plants have higher water requirements than grasses (Dufková & Lexa 2007). Duffková et al. (2011) also reported the groundwater level and soil texture influenced the ET values in their study. In the period from April to October 2018, the ET was higher than the precipitation (317.5 mm) for both meadows. Duffková (2008) studied extensively used grasslands and found that the values of the ET were higher than the precipitation only when the precipitation values obtained during the studied vegetation seasons were not highly above-normal. From April to October 2018, the maximum temperature in the rooting zone was 19.7 °C and 17.0 °C (DM and UM, respectively). The minimum temperature in the same layer was 2.9 °C and 4.1 °C (DM and UM, respectively).

As reported by Allen et al. (1998), the reference crop evapotranspiration (ET_0) expresses the evaporation power of the atmosphere at a specific location and time. It does not consider crop characteristics and soil factors. The daily values of the ET_0 calculated in this work are in the range of those values published by Pozníková et al. (2014). ET is assumed to equal ET_0 when the soil moisture is not limiting the plant growth (Aslyng 1965). The daily values of the ET in the studied meadows estimated for the period from April to October 2018 are in the range of the values of grass in a warm region of the Czech Republic measured from 2013–2016 using lysimeters (e.g., Doležal et al. 2018). Khand et al. (2017) reported that tile drainage caused ET differences of up to 1.75 mm/day between drained and undrained fields (soybean, corn).

CONCLUSION

The selected physical soil properties were significantly ($P < 0.05$) different between the experimental meadows, especially at depths of 0–28 versus 0–35 cm (particle and bulk density, total soil porosity, maximum capillary water capacity, water retention capacity and saturated water content) and 28–49 versus 35–45 cm (particle density, water retention capacity and saturated water content). Some of these properties were more favourable in the undrained meadow. Also, the volumetric water content and matric potential at all the studied depths (15, 35 or 40 and 60 cm) were significantly ($P < 0.05$) different between the experimental meadows in the years 2016–2019. The values of the actual evapotranspiration estimated using the reference crop evapotranspiration and coefficient of water stress were also significantly different ($P < 0.05$) between the experimental meadows. The obtained differences in the measured soil properties and estimated actual evapotranspiration were probably influenced by the used tile drainage and also by the type of management. Further experiments (different types of management in the case of the drained meadow and also the undrained meadow) are necessary to understand the role of the tile drainage and management.

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