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Occurrence of dry periods in oak stands and their effects on soil water supply

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Abstract

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The presented paper deals with the impact of long lasting dry periods on the water regime in oak forest stands growing in lowlands. Cycles of low or insufficient available water supply reflect changes to soil moisture conditions that may cause physiological weakening of the trees. The research was carried out on the research plots in Čifáre, during years 1984–2007. Soil samples were taken from the depth of 0–20 and 0–100 cm. Soil water dynamics was observed especially in the extremely dry years 2000 and 2003. The results have confirmed the soil desiccation beginning in autumn. Dry periods in the growing season are characterized by an semiarid and arid soil moisture interval in the upper 20 cm soil layer. Here, also the hardly accessible or even inaccessible for plants water was observed. Across the whole physiological soil profile, the semiarid interval with soil moisture content ranging between the point of diminished availability (PDA) and the wilting point (WP) was dominant.

Key words

climatic changes, drought, hydrologic thresholds, oak forest stands, soil water

Introduction

Climatic measurements performed in Slovakia over the last 100 years show an increasing trend in the mean annual air temperature – by 1.1 ^{o}C. At the same time, there has been recorded a decrease in annual precipitation totals – by 5.6% on average, with the values lower in southern areas (Lapin et al., 2001, Lapin in Balajka et al., 2005). Minďáš and Škvarenina (2003) suggest that the precipitation deficiency can negatively influence soil moisture conditions, health condition and production of forest woody plants not only in ecosystems situated in the lower lower vertical forest vegetation zones (vfvz) with dominant oaks (1st–3nd vfvz) but also in forest associations with prevailing beech (4th–6th vfvz) or in even higher vertical forest vegetation zones (vfvz). The influence of the climatic factors on diamet-er increment in oak trees is described in more detail in the paper Pajtík and ištoňa (2003). Ištoňa and Čaboun (2006, 2007) observed the forest soil water regime in the 1st–5th vfvz, and found out that the drought risk did not concern only oak forest stands in lowlands and uplands but also beech forest stands in the 2nd–4th vfvz. This threat was especially critical in case of intensive evapo-transpiration and extended dry periods (Soroková 2001).

In relation to the climatic scenarios for Slovakia, air temperature and evapo-transpiration are expected to increase continually. For both lowlands and uplands, this can mean significantly decreased soil water supply during the growing seasons, followed by severe droughts causing physiological damage to the woody plants.

Our main objective was to analyse selected extreme long lasting dry periods in the years 1984–2007 and their effects on the soil moisture dynamics on two model research plots in Čifáre.

Material and methods

The paper presents analyses of hydro-climatic cycles in forest soils at a research site situated in the Kozmálovské hills. The experimental data were assembled from two research plots belonging to the area of the Forest Administration Čifáre, OLZ (Branch Forest Enterprise) Levice.

The discussed research plots belong to the warm climatic area with 60–70 summer days. The mean annual temperature is 9 °C, over the growing season 16 °C, the mean annual precipitation total is 560 mm, the total precipitation amount in the growing season 290 mm (Table 1). The values in Table 1 have been provided by the Slovak Hydrometeorological Institute in Bratislava, the Mochovce observatory.

The research plots are situated in the 1st vfvz, in the Carpineto-Quercetum forest type group (Zlatník, 1959, 1976). The forest cover on the first plot consists exclusively from sessile oak [*Quercus petraea* (Mattusch.) Liebl.], approx. 100 years of age. The second research plot is covered by common oak (*Quercus cerris* L.) aged 85 years. The canopy density on both plots is 90%, the stocking density is 0.7. The cover of bush and herb layer with grass makes 90%.

Hydro-physical soil characteristics as well as the values of hydrologic thresholds on the two plots are identical in typology and materials – see Table 2 (Tužinský, 2004).

The soil type is a loamy luvisol, with clay-loam in deeper layers, slight marks of gleying, medium texture differentiation, very acidic to acidic, strongly leached around the oak root systems, with low humus supply. The parent rock material is silt loam, the aeration and hydration at the depth of 40 cm is worsened. The soil is physiologically deep, richer root systems are at the depth of 45–50 cm, sporadically even deeper.

The actual soil water supply was observed at intervals of 14 or 10 days. Its values were determined with using the gravimetrical method. Soil samples were taken with a soil bore, in 3–5 repliques from each 10 cm layer up to the depth of 100 cm. The results were presented in weight % or in volume %.

The amount of water available for plants was calculated as immediate soil water supply subtracted by "dead" water. The limit between the physiologically available and the "dead" water was determined as the limit for WP. The supply of available water (Table 3) was calculated according to Kutílek (1966), and the

Table 1. Main climatic variables

Air temperature in °C, Nový Tekov 1931–1960													
XI.	XII.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	Year	GS
4.7	0.1	–2.5	–1.5	4.2	10.2	15.0	18.1	20.3	19.5	15.6	9.7	9.5	16.4
Precipitation in mm, Čifáre 1931–1960													
57	46	38	39	35	35	53	62	56	52	33	48	554	291

GS, growing season

Table 2. Hydro-physical soil characteristics

Characteristic	Soil depth in cm					∑ mm
	0–10	20–30	40–50	70–80	90–100	0–100
Bulk density [g cm^{-3}]	2.41	2.49	2.54	2.57	2.58	–
Weight volume [g cm^{-3}]	1.31	1.40	1.45	1.49	1.52	–
Porosity [vol. %]	50.3	47.8	43.5	41.8	41.6	–
MCC [vol. %][1]	36.7	36.0	33.8	32.8	30.5	334.2
PDA [vol. %][2]	25.3	25.7	25.3	23.5	24.0	246.1
WP [vol. %][3]	15.5	15.4	15.3	15.2	15.1	150.5

[1]maximal capillary capacity, [2]point of diminished water availability, [3]wilting point

Table 3. Available water supply (according to Kutílek, 1966)

Available water supply			
Soil layer 0–20 cm		Soil layer 0–100 cm	
Good	>40 mm	Very good	>160 mm
Sufficient	20–40	Good	130–160
Insufficient	<20	Sufficient	90–130
		Low	60–90
		Very low	<60

ecological classification of the soil water regime was made according to the same author (Kutílek, 1971).

Results and discussion

The term "drought" represents in general water insufficiency in soils, plants and atmosphere. Water insufficiency in soils can result in water supply dropped below the wilting point (WP). The recent measurements show that the drought periods in growing seasons are prolonged and more intensive with the progressing climatic change.

Most changes in soil hydro-physical characteristics are observed over the whole year, especially in lowlands and uplands with oak associations belonging in the 1st and the 2nd vfvz, in which the soil drying related to the temperature and precipitation regime is characterized by its dynamics. The Fig. 1 and Fig. 2 show that there were small intervals with sufficient water supply even in the growing seasons of the driest years. Except of these intervals, water supply in the growing season was insufficient. Winter is the season of soil moisture accumulation, hence the moisture levels at the beginning of the growing season are in general good. The upper 20 cm layer of the soil profile is supplied with water especially during the snow melting and the soil de-freezing. In this period, when the day temperatures do not exceed 20 °C, the capillary mobile water is present across the whole physiological soil profile (0–100 cm), as good and very good available water supply (>130 mm). In such a way, the sufficient water amount in the soil for the following growing season is guaranteed also in case of insufficient precipitation totals.

In extremely dry years, the soil drying off starts already in autumn. This is well demonstrated in Fig. 1 and Fig. 2 showing the dynamics of the soil water supply in the extremely dry year 2000.

It is necessary to add that extremely dry years are accompanied by a significant positive deviation in the average temperature not only in autumn but also in some winter months, furthermore by occurrence of very poor in precipitation or even dry seasons lasting for several weeks or months, often accompanied by windy weather that accelerates the early drought start.

During the growing season, the soil water supply is mainly influenced by the vegetation (except for precipitation totals). Output components of the water balance represent interception losses being 26% of the precipitation totals. Precipitation less than 1 mm evaporates. The amount of precipitation intercepted by herb and grass layer varies from 9 to 38%. Water infiltration to the soil reaches higher values only during winter accumulation period (20–30% of precipitation totals), while during the growing season it does not exceed 10%. In the second half of the growing season, we can consider infiltration as a negligible component. The infiltration is also connected with the root system influence directly increasing the soil porosity. Very significant are active roots growing in deeper soil layers which play an important role especially during dry summer season when the upper soil layers are strongly desiccated (Tužinský, 2004).

The most considerable changes in the soil water content can be observed in the upper soil layers. Here the soil moisture varies from the category of moist soil to the WP. In dry seasons, the soil moisture condition is characterized by insufficient supply of available water, WP is not an exception.

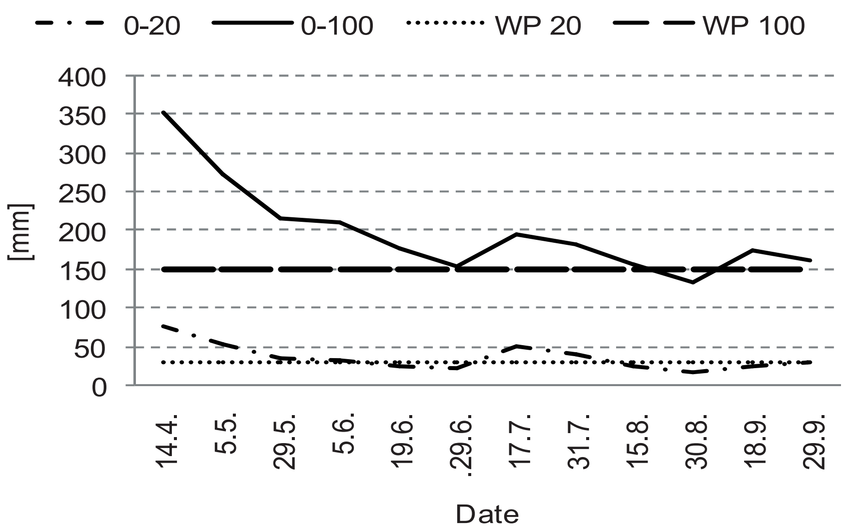

Fig. 1. Dynamics of soil water content in layers 0–20 and 0–100 cm during the vegetation period 2000. The figure includes the limit values for each layer (wilting point).

Water requirements on the water balance output are usually higher than the precipitation totals during the growing season. In dry seasons with no precipitation and high air temperature, the water requirements for evapotranspiration are higher than 5 mm day^{-1} (Tužinský, 1999, 2004), representing a very high day values. Such water requirements result in a fast loss of available soil water. The decrease in water amount is visible even in deeper layers of the soil with active roots presence (0–40 cm). In the upper soil layer up to 20 cm, which is mostly threatened by drought, often a zero available water supply can be observed (Table 4). In the deeper soil layers (>60 cm), the water amount varies between the points PDA and WP. After longer lasting dry periods, a very low supply of available water was observed across the whole soil physiological profile (<60 mm).

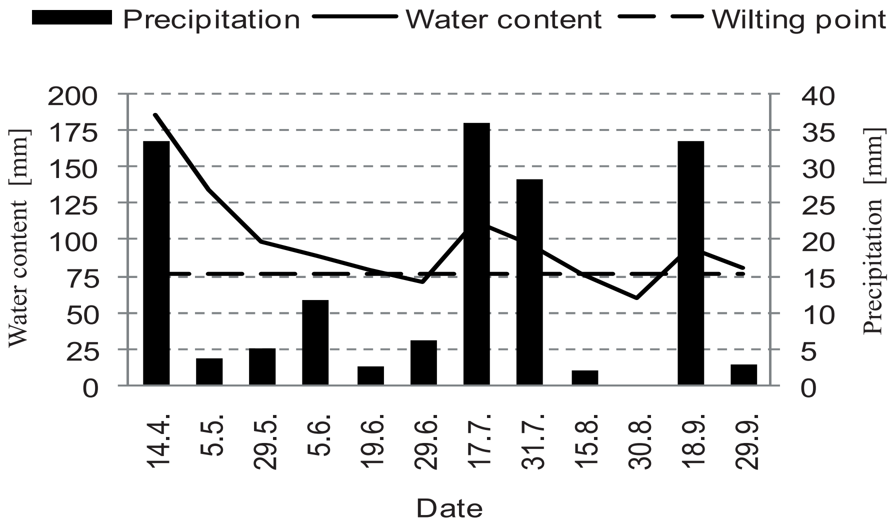

Fig. 2. Dynamics of precipitation amount and soil water content in the layer 0–50 during the vegetation period 2000. The figure includes the limit values for this layer (wilting point).

Table 4. Water supply in the dry periods of the growing seasons (Čifáre)

Season		Water supply [mm]		Available water [mm]		Intervals of the soil water Available water	
		0–20 cm	0–100 cm	0–20 cm	0–100 cm	0–20 cm	0–100 cm
1988	1. 7.	40.1	242.4	10.9	91.9	SA/IS	SA/S
	31. 7.	21.1	169.2	0	18.7	A/0	SA/VL
1988	5. 8.	40.2	200.7	11	50.2	SA/IS	SA/VL
	20. 8.	19.1	148.7	0	0	A/0	SA/VL
1989	1. 9.	43.5	181.4	13.8	30.9	SA/IS	SA/VL
	30. 9.	26.9	164.8	0	14.3	SA/0	SA/VL
1990	11. 7.	68.1	223.9	38.9	73.4	SU/S	SA/L
	31. 8.	21.9	159.9	0	9.4	A/0	SA/VL
1991	2. 8.	31.6	216.1	2.4	65.6	SA/IS	SA/L
	16. 9.	18.1	156.1	0	5.6	A/0	SA/VL
1992	14. 7.	22.6	231.9	0	71.4	A/0	SA/L
	31. 8.	18.1	169.1	0	18.6	A/0	SA/VL
1993	28. 7.	24.4	206.4	0	55.9	SA/0	SA/VL
	22. 8.	19.7	161.7	0	11.2	A/0	SA/VL
1994	14. 7.	28.7	232.9	0	82.4	SA/0	SA/L
	11. 8.	21.7	156.9	0	6.4	A/0	SA/VL

Table 4. Continued

Season		Water supply [mm]		Available water [mm]		Intervals of the soil water Available water	
		0–20 cm	0–100 cm	0–20 cm	0–100 cm	0–20 cm	0–100 cm
1995	3. 7.	53.7	291.8	24.5	141.3	SA/S	SA/G
	21. 8.	23.6	179.4	0	28.9	SA/0	SA/VL
1997	22. 7.	46.1	217.9	16.9	67.4	SA/IS	SA/L
	30. 9.	29.1	168.2	0	17.7	SA/0	SA/VL
1999	23. 7.	78.5	345.9	49.3	195.4	SU/G	U/VG
	15. 8.	48.9	214.8	19.7	64.3	SA/IS	SA/L
1999	17. 8.	48.9	214.8	19.7	64.3	SA/IS	SA/L
	30. 9.	18.9	122.4	0	0	A/0	SA/0
2000	1. 8.	37.7	163.3	8.5	12.8	SA/IS	SA/VL
	15. 9.	20.1	127.2	0	0	A/0	SA/0
2001	1. 6.	39.3	217.5	10.1	67.0	SA/IS	SA/L
	30. 6.	23.1	141.3	0	0	SA/0	SA/0
2002	17. 6.	34.9	241.2	0	90.7	SA/0	SA/S
	12. 7.	23.1	159.1	0	8.6	A/0	SA/VL
2003	1. 8.	36.2	207.3	7	56.8	SA/IS	SA/VL
	28. 8.	18.7	163.2	0	12.7	A/0	SA/VL
2004	27. 8.	28.1	142.7	0	0	SA/0	SA/0
	21. 9.	15.3	132.3	0	0	A/0	SA/0
2006	3. 7.	37.6	224.3	8.4	73.8	SA/IS	SA/L
	28.7.	21.4	148.7	0	0	A	SA

Intervals of the soil water:	Available water: 0–20 cm	0–100 cm
A, arid interval (<WP)	G, good	VG, very good
SA, semiarid interval (PLA–WP)	S, sufficient	G, good
SU, semiuvidic interval (MCC–PLA)	IS, insufficient	S, sufficient
U, uvidic interval (>MCC)		L, low
		VL, very low

Table 4 shows dry periods with no precipitation or with precipitation totals lower than 5 mm (except for the 1st ten-day period of July 1990 and the 2nd ten-day period of July 1999). Our observations in Čifáre allow us to declare that such precipitation totals are not significant for supplying the soil with water in dry periods. This table also shows that in the upper 20 cm soil layer, a total use of the available water can be observed. Such soil moisture condition results in plant wilting, ground vegetation dieback, bushes wasting as well as tree growth processes slowed down or even terminated (Pajtík and Ištoňa, 2003).

The ability of forest soils to provide sufficient water amounts depends on their infiltration, percolation, retention, and retarding properties. Forest soil water regime is also a result of atmospheric water presence and on transforming effects of forest ecosystem on mutual processes. In our case, the hydro-physical soil properties in the oak stand are very favorable in the upper and middle layers of the soil profile. The available water supply decrease in this physiological soil profile can be explained as worsening of the climatic conditions.

The infiltration represents the main source of the soil water on our research plot. According to the soil physiological profile structure and texture, the soil water redistribution is very variable. Other soil profiles, with less skeleton and low water holding capacity, especially in the oak zone of the 1st and 2nd vfvz (mostly on steep slopes of andesite agglomerates), are even drier in their whole (Ištoňa and Čaboun, 2006, 2007).

Luvisols and cambisols are characteristic with their horizons alternating according to different physical properties. From the hydro-physical point of view, the illuvial horizon is more compact and thus less permeable for the water. On the other hand, in such horizon drying off takes longer. Thus, in seasons with sufficient precipitation totals, the water supply from the upper layers is limited, and in dry periods, the water transport from the deeper soil layers is slowed by interruption of the upper horizons.

According to the moisture condition, its duration and the soil moisture stratification (Kutílek, 1971) semiarid and arid soil moisture intervals with capillary water less mobile or even immobile were observed in the upper 20 cm soil layer during dry periods. The category of capillary mobile water and for plants available water was reached only for a short period of time after rich precipitation.

The semiarid interval with the soil moisture content between PDA and WP dominates across the whole physiological profile and during dry periods of the growing season. In this case, the water mobility is reduced; the osmotic pressure of soil solution increases, and thus water becomes less available for plants. In the critically dry period with insufficient water supply the water amount approaches the lower limit of the WP. Significant increase in the soil moisture in the whole physiological profile was observed only after a longer lasting precipitation activity.

Forest represents biological systems influencing the water circulation more than other plant associations – because a forest's influence on water balance components (interception, transpiration, seepage, runoff, etc.) is complex. Also the soil texture and structure affect not only soil water mobility but also the water retardation ability.

Very diverse is the relation between forest woody plants and water regime. Each tree has its own biorhythm depending on the site conditions, supply of accessible nutrients and available water supply. Spruce with its shallow root system draws water from upper soil layers, beech mostly from middle layers and oak always from the whole physiological profile. As for beech ecosystems, their more favourable moist conditions can be explained by increased water uptake from the stemflow.

The herb vegetation draws water mostly from the upper soil layers, from deeper ones, only after longer lasting dry periods.

Ištoňa and Čaboun (2006, 2007) observing the forest soil water regime (1st–5th vfvz) found out that increasing soil water content with decreasing water availability reflects the high water consumption for evapotranspiration, especially from June (lower vfvz) to July (higher vfvz). The lowest values are reached towards the end of June or July and they persist up to August and September, sometimes even longer (e.g. autumn of 2005 and 2006). The lowest values of the soil moisture content were observed at the end of August and at the beginning of September, especially in the forest type groups CQ and FQ in which the soil moisture dropped below 10 weight percent corresponding to a decrease below the WP critical value. Similarly, in these months, the soil moisture reached its minimum in the forest type groups Fp (the 3rd vfvz) and FT (the 4th vfvz). Here, the soil moisture content decreased below 20 % representing a decreased water availability. The data obtained in the locality Mláčik – forest type group FAc (the 5th vfvz) – show that even in these sites, the soil moisture decreases in summer, although the 25–40% soil water content is still considered as good.

Tužinský (2007) carried out long lasting monitorings of soil water content, moisture presence duration and moisture stratification (ecological classification of the soil moisture). Based on the obtained results, he declares significant changes in soil moisture dynamics and in the available water supply over the past 35 years. These changes can be documented by a more frequent presence of soil moisture cycles with a low or even insufficient available water supply, furthermore by the presence of dry periods that significantly contribute to the worsened health condition of forests even in higher forest vegetation zones.

Conclusions

A typical hydrological year consists of two seasons. The winter represents mostly the accumulation season – which means that the soil water supply is mostly good. This secures a good start of the growing season for the vegetation. During the growing season, especially in the lower forest vegetation zones, the water output dominates over the water uptake resulting in gradual water supply decrease and the drought. In case of longer lasting dry periods this can result in the water stress of the vegetation.

Tužinský (2007), exploring his results of a long lasting monitoring of the soil water, states that over the last 35 years, there were observed significant changes in the soil moisture dynamics and available water supply during the growing season. This was demonstrated mostly by the frequent occurrence of soil moisture cycles with a low or insufficient supply of available water and the presence of dry periods, in which was observed a significant decrease in the available water supply during a relatively short time.

The soil is significantly dried out and the available water supply decreases especially in the upper soil layers (0–20 cm). Within the whole physiological soil profile (0–100 cm), the available water amount decreases to the category low or even very low. In the case of a longer lasting drought, the vegetation is threatened by physiological weakening, premature defoliation, assimilation decrease or even termination, decrease of transpiration and growth, damage to forest stands, their vitality loss, and decrease of trees natural resistance against abiotic and biotic harmful agents.

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Výskyt suchých periód v dubinách a ich vplyv na zásoby pôdnej vody

Súhrn

V práci sú uvedené hydropedologické cykly, ktoré boli zaznamenané v suchých periódach, vo vegetačných obdobiach rokov 1988 až 2006, v dubovom ekosystéme, typologicky patriacom do slt Carpineto-Quercetum. Z údajov monitoringu dynamiky vlhkosti pôdy a obsahu vody vo fyziologickom profile pôdy, ako indikátora prírodného prostredia vyplýva, že v pôdach najnižších lesných vegetačných stupňov dochádza k postupnému zvyšovaniu výskytu suchých periód, v dôsledku čoho sa mení aj objem vody v zóne aerácie a jej pripravenosť pre rastliny vo vegetačnom období. V analyzovaných suchých periódach, na ich začiatku, v obidvoch sledovaných vrstvách pôdy (0–20 cm, 0–100 cm) dominuje semiaridný interval s množstvom vody medzi hydrolimitmi bodom zníženej dostupnosti (BZD) a bodom vädnutia (BV). Na ich konci, v prevažnej miere v povrchovej vrstve pôdy, sa znižuje obsah vody do oblasti aridného intervalu, so stavom vody, s nedostatočnou až nulovou zásobou využiteľnej vody pre rastliny. Prítomnosť hydropedologických cyklov s veľmi nízkou zásobou využiteľnej vody v celom fyziologickom profile pôdy, s kapilárne ťažko pohyblivou až nepohyblivou vodou, možno odôvodniť meniacimi sa ekologickými podmienkami, osobitne zvyšovaním teploty vzduchu a deficitom zrážkových úhrnov. Reakciou rastlín na daný vlhkostný stav je zvýšená mortalita prízemnej vegetácie, zníženie asimilácie, transpirácie a prírastku, predčasný opad asimilačných orgánov a zníženie odolnosti stromov proti pôsobeniu škodlivých činiteľov.

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