THE DIFFERENT EFECTS OF DROUGHT ON SOIL MICROBIAL ACTIVITIES AND SOIL HYDROPHOBICITY IN PERMANENT GRASS COVER AND ARABLE LAND

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Abstract: The present work deals with the influence of drought on microbial activities and soil hydrophobicity in permanent grass cover and arable land. The values of basal respiration were chosen as indicator of microbial activity and the values of unsaturated hydraulic conductivity were used as indicator of soil hydrophobicity level. From March to October 2014 (during vegetation period) parameters were measured at two different experimental sites -the first one was permanent grass cover and the second one was arable land. Significant differences in effects of drought on individual experimental sites were found.

Keywords: Microbial activities, permanent grass cover, arable land, soda lime, hydraulic conductivity, soil hydrophobicity.

1 Introduction

In Central Europe, changes in weather conditions are predicted in future. Precipitation totals will be the same, but their layout will be changed in growing season. This situation will have a major impact on agricultural production and the stability of natural ecosystems.

Water deficit during drought spells is one of the most significant stress factors in crop production worldwide. It can lead to significant yield reduction or even crop failure. Beside the negative effects of water stress on the yield quantity, the quality can also be influenced. Even though the Czech Republic is not generally characterized as a drought prone region of Europe, drought (and flooding) still occurs and represents one of the most important climatic extremes in terms of economic damage. This is demonstrated by the examples of severe droughts recorded in 1935, 1976 and especially in 1947. Within recent years, this region of Central Europe experienced droughts in 2000, 2001 and 2003, with the first of these being particularly damaging (Hlavinka et al., 2009).

Quality and healthy soil is an essential prerequisite for ensuring production and non-production functions of agriculture. The primary consequence of quality and soil health is soil fertility. In recent years, Czech farmers have faced to decline of soil fertility and degradation of land resources. The direct causes of soil fertility depletion include: climate changes (long period of drought – precipitation totals are the same but their layout has been changed), cultivation of fragile and marginal lands, soil erosion and decrease in the organic matter application. Drought threat has significant consequences to soil carbon and nutrient cycling, thus significantly affects microbial activity in soil (Elbl et al., 2014).

There is increasing evidence that microbial activity has a direct influence on the stability and fertility of ecosystems. Soil microorganisms synthesize and secrete extracellular enzymes which constitute an important part of the soil matrix. Enzymes play an important role in soil nutrient cycles and, consequently, factors influencing soil microbial activity will affect the production of the enzymes which control nutrient availability and soil fertility (Hueso et al., 2012).

In particular, recent studies have emphasized the importance of microbial nutrient mobilization for the regulation of plant growth in nutrient-deficient systems. Consequently, such climatic changes may be particularly important in nutrient-limited habitats like heaths, and studies of soil and microbial processes at the ecosystem scale are needed to improve our understanding of temperate heathland ecosystem responses to changing climate (Jensen et al., 2003). Conversely, arable soils represent large system that is significantly influenced and controlled by human activities, and that affects the state of the environment. Therefore, the effect of human activity must be studied to find out how to minimize the impacts of climate change on our society and environment.

In present study the changes in soil microbial activities and soil hydrophobicity were quantified in response to 1) influence of drought and 2) type of soil ecosystem.

2 Materials and methods

The above objectives of work were tested by field experiment located at two experimental sites with different regime. The first one was heath – natural ecosystem and the second one was field – anthropogenically influenced ecosystem.

2.1 Experimental design

Basal respiration or cumulative production of CO_2 and level of soil hydrophobicity was measured at two different sites: a) Havraníky and b) Žabčice. Experimental site Havraníky (See Figure 1) is located in National Park Podyjí on the border between Czech Republic and Austria. Havraníky heath is an extremely dry area where annual climatic averages are 550 mm of precipitation and 9 °C mean of annual air temperature. The microbial activity and soil hydrophobicity was measured in the stand of *Carici humilis-Callunetum* and *Potentillo arenariae-Agrostietum vinealis*, which are situated on Bohemian Massif (biotite granite). Six areas were selected at these experimental sites: three located in the vegetation *Calamagrostis epigejos* and three in the vegetation of *Festuca ovina* (See Figure 3).

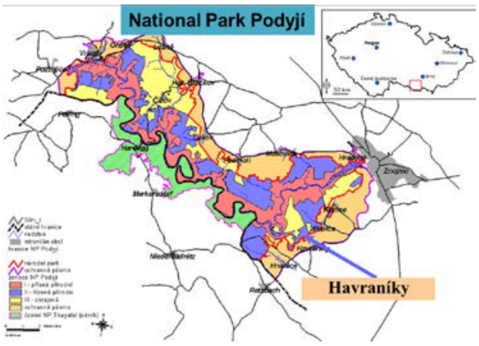

Fig. 1 The first area of our interest – Havraníky heath (authors: Záhora, Elbl)

Experimental site Žabčice (See Figure 2) is situated 30 kilometers south of the Brno where annual climatic averages are 480 mm of precipitation and 9.3 °C mean of annual air temperature. The microbial activity and soil hydrophobicity was measured on arable land (chernozem); estimated pedologic-ecological unit (BPEJ) 00401.

Fig. 2 The second area of our interest – Žabčice field (author: Elbl)

2.2 Determination of soil respiration

From March to October 2014, the basal respiration (BAS) was measured using soda limes granules at individual experimental sites at monthly intervals. Soda limes granules were applied into rhizosphere and non-rhizosphere soil, because: Soil respiration has two major components, which are heterotrophic respiration (based on decomposition and mineralization of soil organic matter, largely by microorganisms) and root respiration (Bujalský et al., 2014). Only values from rhizosphere soil are presented. BAS was measured by the method using soda lime granules according Keith & Wong (2006). This method was modified for measurement of CO_2 production from arable land and permanent grass cover.

Fig. 3 Application of measuring probes with soda lime granules at experimental site Havraniky (author: Elbl).

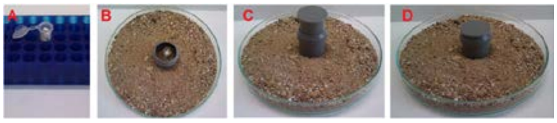

Fig. 4 Laboratory testing of measuring probes (author: Elbl).

The results of basal respiration (production of CO_2) were expressed in g of C m^{-2} day^{-1} and calculated by the modified formula, which was adjusted according Keith & Wong (2006):

$$\text{Soil } CO_2 \text{ efflux } (\text{g C m}^{-2}\text{ day}^{-1}) = \left\{ \frac{\text{sample weight gain (g) - mean blank weight gain (g)} \times 1.69}{\text{chamber area } (\text{m}^2)} \right\} \times \left[\frac{24\text{ h}}{\text{duration of exposure (h)}} \right] \times \left[\frac{12}{44} \right] \quad (1)$$

2.3 Determination of soil water repellency – hydrophobicity

Soil water repellency (SWR) is a widespread phenomenon, which affects infiltration as well as soil water retention and plant growth (Schaumann et al., 2007). SWR or soil hydrophobicity directly affects water motion in soil. High soil hydrophobicity slows water infiltration, i.e.: hydraulic conductivity is lower, and conversely (Buzcko et al., 2005 and Robichaud et al., 2008). Therefore, values of unsaturated hydraulic conductivity (K) were used as indicator of level of SWR.

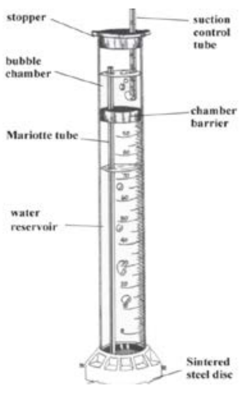

Fig. 5 The Mini-Disk Infiltrometer (Robichaud et al., 2008)

K was calculated based on the measured volume of water that infiltrated into the soil - cumulative infiltration, which was measured using Mini-Disk Infiltrometer (MDI) at monthly intervals.

Robichaud et al. (2008) describe the use of MDI for measuring soil hydrophobicity as follows: When the infiltrometer is placed on a wet-table soil surface, the suction from the soil side of the porous disk is able to break the water surface tension across the disk and water passes from the infiltrometer into the soil. As water passes through the porous disk into the soil, bubbles rise in the main chamber and in the bubble chamber. When the MDI is placed on strongly water repellent soil, there is not enough suction to break the water surface tension across the porous disk and no water infiltrates the soil. The suction on the infiltrometer side of the disk is controlled by the “suction control tube” (0.5 to 7 cm) at the top of the infiltrometer.

The calculation of K was performed by Šindelář et al. (2008), Lichner et al. (2007a, 2007b) based on these formulas:

$$I = C_1 t^{1/2} + C_2 t + C_3 t^{3/2} \quad (2)$$

where: I is cumulative infiltration, C_1 [$m \cdot s^{-1/2}$] and C_2 [$m \cdot s^{-1}$] are parameters of function and t [s] is time. These parameters are related to soil sorptivity and hydraulic conductivity of the soil. C_1 and C_2 are defined by according to Eq. (3) and (4).

$$C_1(h_0) = A_1 S(h_0) \quad (3)$$

and

$$C_2(h_0) = A_2 K(h_0) \quad (4)$$

where: $C_1(h_0)$ and $C_2(h_0)$ are the functions of the soil water content θ and suction (h_0) [cm]. A_1 and A_2 are dimensionless coefficients. Editing of Eq. (3) and (4) are necessary for the calculation of soil sorptivity S and unsaturated hydraulic conductivity of the soil K.

$$S(h_0) = C_1 / A_1 \quad (5)$$

and

$$K(h_0) = C_2 / A_2$$

where: C1 and C2 are calculated from Eq. (3) and (4). These parameters are obtained on the basis of values of cumulative infiltration for time, which is measured by MDI. A_1 and A_2 are dimensionless coefficients but variable with the total time of infiltration. These parameters were determined by Van Genuchten Eq. (6) and (7), which was described by Zhang (1997).

$$A_2 = \frac{11.65(n^{0.1}-1) \times exp[2.92(n-1{,}9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad (6)$$

For n ≥ 1.9

$$A_2 = \frac{11.65(n^{0.1}-1) \times exp[7.5(n-1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad (7)$$

For n ≤ 1.9

where: α and n are retention parameters of soil, r_0 is radius of MDI and h_0 is pressure energy of MDI. The values of A_2, which were calculated according Eq. (6) and (7), are presented in the Table 1. Only values of A_2 were calculated, because they are necessary for calculating the hydraulic conductivity.

Table 1 Van Genuchten Tables – the values of A_2

	radius	**2.3**	**h_0 [cm]**						
	alpha	n/h_0	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0	-6.0
			A_2						
Sand	0,15	2,7	2,8	2,4	1,7	1,2	0,9	0,6	0,5
Loamy sand	0,12	2,3	3,0	2,8	2,4	2,1	1,8	1,6	1,4
Sandy loam	0,08	1,9	3,9	3,9	3,9	3,9	4,0	4,0	4,0
Loam	0,04	1,6	5,5	5,7	6,3	6,9	7,5	8,3	9,0
Silt	0,02	1,4	7,9	8,2	8,7	9,3	9,9	10,5	11,2
Silt loam	0,02	1,4	7,1	7,4	7,9	8,5	9,2	9,9	10,6
Sandy clay loam	0,06	1,5	3,2	3,5	4,2	5,1	6,2	7,4	8,9
Clay loam	0,02	1,3	5,9	6,1	6,6	7,2	7,9	8,6	9,3
Silty clay loam	0,01	1,2	7,9	8,1	8,5	8,9	9,4	9,9	10,4
Sandy clay	0,03	1,2	3,3	3,6	4,1	4,7	5,4	6,1	7,0
Silty clay	0,01	1,1	6,1	6,2	6,4	6,6	6,8	7,0	7,2
Clay	0,01	1,1	4,0	4,1	4,3	4,5	4,7	5,0	5,2

Fig. 6 Detail of water infiltration into arable soil (author: Elbl)

2.4 Statistical analysis

Potential differences in values of BAS (cumulative CO_2 production) and unsaturated hydraulic conductivity were identified by one-way analysis of variance (ANOVA) in a combination with the Tukey´s test. All analyses were performed using Statistica 10 software. The results were processed graphically in the program Microsoft Excel 2010.

3 Results and discussion

Microbial activity

Soil respiration is responsible for most of the CO_2 released from terrestrial ecosystems into the atmosphere. Although respiration depends on temperature, the relationship between respiration and temperature may vary among soils (Bujalský et al., 2014).

Respiration is probably process the most closely associated with life. It is aerobic or anaerobic energy-yielding process. In the cell, reduced organic or inorganic compounds serve as primary electron donors and imported oxidized compounds serve as terminal electron acceptors (Bloem et al., 2006) and respiration represents one of the most important indicators of microbial activity in soil. For our research, soil basal respiration (BAS) was used for indication of microbial activity in soil. BAS is defined as the steady rate of respiration in soil originating from the mineralization of organic matter (Pell et al., 2006).

Basal respiration was determined as cumulative production of CO_2 during 24 h from rhizosphere soil and it was measured at experimental sites Havraníky and Žabčice. Six areas were selected at experimental sites Havraníky: three located in the vegetation *Calamagrostis epigejos* (CE) and three in the vegetation of *Festuca ovina* (FO). And three areas were selected at experimental site Žabčice (on arable soil; identified as Z).

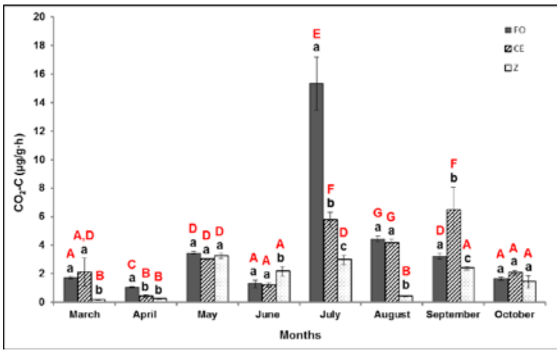

Fig. 7 Basal respiration (mean ±SD, n = 3); different small letters indicate a significant differences (P<0.05) between individual variants within the same group (month) and different uppercase letters indicate a significant differences between all individual variants (regardless months).

Soil respiration is often reported as a temporal mean that represents a plot, a stand, or a given ecosystem. From repeated measurements within a plot or stand, relationships between the respiration rates and soil climate can be resolved and annual rates of soil respiration can then be estimated through modeling (Martin & Bolstad, 2009). The above results indicate significant differences (ANOVA; P<0.05) in microbial activity (BAS) between individual experimental sites. The lowest values of BAS were found in March, April and October; this situation was caused by climate conditions (low temperature). The Figure 7 shows the highest significant differences in BAS between FO, CE and Z were found in months (July and August) of the highest temperatures and long periods of drought. Influence of temperature on microbial activity (See Figure 8) in soil was confirmed by Creamer et al. (2014).

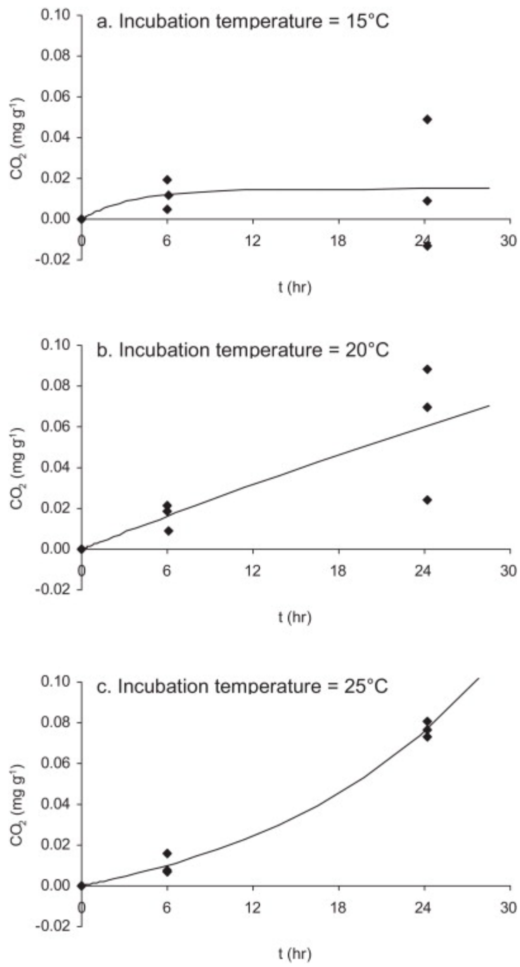

Fig. 8 An example (Hungary, grassland site, loam soil) of a typical response of CO_2 during the incubation period, for the three contrasting experimental incubation temperatures of a) 15 °C; b) 20 °C and c) 25 °C. Solid line shows best fit using the negative exponential model (Creamer et al., 2014).

Consider differences between individual variants and values of BAS in these months (July and August). The significant highest BAS was always found in variants FO and CE from about100 to 400 % in comparison with Z. These data indicated that the drought had different effect on grassland and arable land or different effect on natural ecosystem and ecosystem which is affected by human's activities.

In the short term, increased microbial activity can have a positive effect on soil properties, but in the long term it can cause depletion in soil fertility. High microbial activity accelerates the decomposition of soil organic matter and depletion of nutrients. Moreover, this state can result in a change of soil parameters (soil fertility – content of nutrients) and subsequently in the (bio)diversity of plants on the soil surface. The above changes can be a major problem for our agriculture and nature. Balser & Firestone (2005) stated that soil microbial communities mediate many biogeochemical processes that are central to ecosystem functioning, including carbon (C) mineralization to CO_2, nitrogen (N) cycling, and trace gas production and consumption. Moreover, a modification of the soil microbiota may in turn affect soil processes, providing a positive or negative feedback on plant productivity. Despite the crucial role of soil microorganisms in mediating belowground processes, the issue of how the diversity of soil microbiota influences processes such as decomposition or nutrient mineralization remains poorly studied Malchair et al. (2010).

Soil water repellency

SWR or soil hydrophobicity is a natural phenomenon that occurs in many ecosystems ranging from tropical to subarctic regions influenced by biotic and abiotic factors, and has been reported by many authors to reduce infiltration capacity, enhancing overland flow and even runoff production at the catchment scale (Schnabel et al., 2013). Many regions of the world are predicted to experience water scarcity due to more frequent and more severe droughts and increased water demands (Müller & Deurer, 2011).

K was used for quantification of SWR and it was calculated based on the values of water infiltration which were measured at the above experimental sites (FO; CE and Z) at monthly intervals. K represents important parameter for the determination of soil hydrophobicity degree as it represents ability of soil to accept water. Influence of SWR on water infiltration of water into soil was described by Buzcko et al. (2005) and Robichaud et al., (2008).

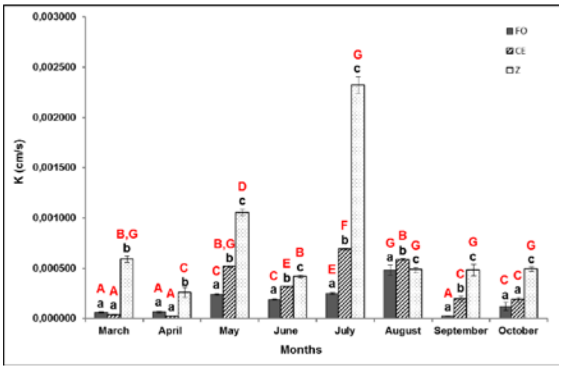

Fig. 9 Hydraulic conductivity (mean ±SD, n = 3); different small letters indicate a significant differences (P<0.05) between individual variants within the same group and different uppercase letters indicate a significant differences between all individual variants (regardless months).

The Figure 9 shows significant differences (ANOVA; P<0.05) in values of K, the highest values of K were always detected in variant Z (except August) during the vegetation period (from April to September). These data indicated the low level of SWR of arable soil surface in comparison with soil at other experimental sites.

Moreover, significant differences in K were found between FO and CE (from May to September). The highest values of K were always found at experimental sites CE. CE (*Calamagrostis epigejos*) is an invasive plant that sequentially occupies experimental sites Havraníky. The soil under CE has a higher level of SWR. This fact indicates a different life strategy of this plant allowing its rapid expansion to places where it previously did not occur. Müller & Deurer, (2011) state that water use efficiency by plants can be negatively affected by soil water repellency (SWR). There is a presumption that the CE in this way (by changing soil hydrophobicity) displaces the native species (*Festuca ovina* - FO).

Buzcko et al. (2005) state that SWR is a function of many factors including the soil water content, the previous wetting and drying of the soil, temperature, relative ambient air humidity, and the amount and quality of the SOM. Therefore, significant differences in SWR between arable soil and permanent grass land were found. Consider the highest values of K in variant Z which indicate the low level of SWR and consequently the soil's susceptibility to erosion phenomena. Cosentino et al. (2010) point to the fact that there is a direct linkage between the amount of hydrophobic compounds and stability of soil aggregates. Therefore the level of SWR must be monitored, because SWR can affect soil water retention, stability of soil aggregates and soil fertility (plant growth). Influence of SWR on soil properties was studied and confirmed for example by Buzcko et al. (2005), Schaumann et al. (2007) and Schnabel et al. (2013). The importance of the hydrophobicity for sorption of elements is shown in the Figure 10.

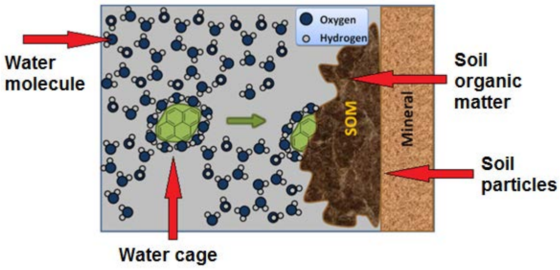

Fig. 10 Sorption driven by hydrophobicity (modified by Thompson & Goyne, 2012).

The optimal degree of soil hydrophobicity is essential for the resistance of the soil aggregates to erosion phenomena.

4 Conclusions

The main reason for examining the impact of drought on soil hydrophobicity is its effect on the stability of soil aggregates, the erodibility of the soil, the soil fertility and availability of nutrients. Changes in microbial activities and changes in the composition of microbial communities due to drought may be reflected in shifts of the soil hydro-limit values.

This can be very important for agriculture in the Czech Republic, because changes of weather conditions were detected there. Exactly, we expect long period of drought and short period of intensive rainfall. Changes of rainfall have negative influence on hydraulic conductivity. Its value decreases and, conversely, level of hydrophobicity increases. The higher hydrophobicity of arable soil could have a negative effect on the leaching of mineral nitrogen, water content in soil, and soil fertility.

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