VLIV EKOLOGICKÝCH FAKTORŮ STANOVIŠTĚ NA FYZIOLOGICKÉ PARAMETRY STROMU A MOŽNOSTI JEJICH MĚŘENÍ POMOCÍ KOMBINACE TERÉNNÍCH METOD

THE INFLUENCE OF ECOLOGICAL FACTORS OF SITES ON PHYSIOLOGICAL PARAMETERS OF TREE AND POSSIBILITIES OF THEIR MEASUREMENTS USING COMBINATION OF OPEN FIELD APPLICABLE METHODS

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ABSTRACT

So far the description of the site conditions of tree habitats has been conducted by standard field methods and measurements of the soil, understory (e.g. understory and soil type recognition *in situ*) and biometrics of main tree species. Recent technological progress in field methods allows deeper and easier insight into selected abiotic factors of the environment and their relation with physiological parameters of trees in stand e.g. soil structure and moisture linked together with water uptake by the root system. In our research approach, we have expanded forestry measurements by a complex of open field applicable methods from other scientific fields, particularly geophysics, biophysics, and hydrology. The usage of these methods allowed us to gather more complex information on abiotic components of tree surrounding environment (water, soil, and air) along with monitoring of the plant physiological activity (e.g. sap flow, photosynthesis rate). As a result, we received complex diagnostic information on selected relations which occur on a research plot and their effects on a tree. Moreover, we were searching for the response of the tree physiology, to the natural or forced environmental changes (e.g. precipitations, stress, and artificial irrigation). In this paper, we present selected results from the experiment which combined geophysical, climatological and physiological measurements on the research plot, with an Ash tree growing on a heavy soil. It allowed us to monitor a water penetration of a small volume rainfall into deeper soil layers and water uptake by the tree (roots). That was also confirmed by water potential and electrical resistivity tomography repeated measurements indicating soil layers unchanged after applied irrigation.

Keywords: Tree ecophysiology, Tree diagnosis, Instrumental and Simple Methods, Complex Studies, Tree Water and Energy, Plant stress

INTRODUCTION

An investigation of a selected tree or site closest habitat is a standard field work necessary for a habitat description in e.g. botany, silviculture, forest typology and management (DYKSTERHUIS, 1949; BURTON et al., 1982; PYATT, 1997; WILSON et al., 2011). However, this action informs only about "visible" parameters and conditions, without getting a deeper insight into functional relations between a tree and its abiotic environment (ČERMÁK & KUČERA, 1990A; FERNÁNDEZ, 2001; ČERMÁK et al., 1984, 2014). Causes of some current forestry problems and its stands (e.g. drying, bark beetle, windfalls) can be studied and explained by a precise and detailed investigation of soil conditions around a root system along with physical parameters of air. For reaching a tree optimal growth there is a need of fulfilling all the basic tree physiological requirements depending on environmental conditions which, in many cases, are the limiting bottlenecks (e.g. a soil water availability, soil sorption capacity, solar radiation etc.) (VERTESSY, 1998; NADEZHDINA, 1999). Complex *in situ* measurements of such selected parameters was suggested that may give more informative data on both the tree and the stand level (GIRONA, 1993; NADEZHDINA, 1997; WULLSCHLEGER, 1998; NICOLOTTI et al., 2003; NADEZHDINA et al., 2012; ČERMÁK et al., 2014). Diagnosis for the need of this project is a prospecting, detection, and representation of changes in the tree organism that are or might become the reason of the stress, physiological activity decrease or illnesses e.g. a root rot decreases the root absorptive area, which means declining amount of water transported to the crown. The diagnosis may be conducted by modern non-invasive or little-invasive field applicable technologies (NICOLOTTI et al., 2003; MAREŠ et al., 2004; ZENONE, 2008; NADEZHDINA et al., 2012; HAGREY, 2007; ČERMÁK, 2014). This topic becomes important when current trends of climate change shows that stressful factors (e.g. water deficit), are getting severe in long time periods and most of the trees and forests are not well prepared (adapted) for this changing situation caused by e.g. planting economically most profitable species in monocultures which are often not suitable from the geobiocoenology point of view (WILSON, 2001).

The goal of our work was to test selected methods for a complex detection of environmental and physiological parameters of habitats and trees as well as the applicability of these technologies in a practical forestry.

MATERIALS AND METHODS

The research has been carried out in the research area Michovka of the Silva Taroucy Research Institute for Landscape and Ornamental Gardening (VUKOZ) in village Průhonice (SE from Prague; 49.9919031 N, 14.5765778 E). It is equipped for research of trees and flowers on agricultural land in field conditions and their utilization in bioenergy, horticulture and gene pool protection. There are several experimental plantations with a wide assortment of allochthonous and autochthonous tree species. This paper concerns experiment with the selected tree of European ash *Fraxinus excelsior var. Atlas*, which is a semi-solitary tree growing on the edge of an experimental tree nursery planted in 2004. On the northern side of the research plot, there is an old tree nursery with Linden, Maple, Ash, Mountain Ash and other species (Fig. 1). During 14 years selected trees in the nursery were removed or cut down for experiments or sale and therefore a tree crown canopy has never closed completely around our experimental Ash tree (see figures). On the southern side, there has been an open grassland which is now prepared for new plantations – a tree gene pool collection of poplar and ash. The experimental plot is situated in a flat location at an altitude of 330 m a.s.l. The soil type is a cambi soil with a clay-loam texture and a loess. Groundwater level is about 5–6 m deep. The long-term mean daily temperature is 8.8 °C and the annual sum of precipitation is 580 mm (WEGER & BUBENIK, 2012; WEGER et al., 2013).

On the experimental plot (roughly 14 x 14 m) with the selected Ash tree we carried out measurements using the following techniques: Electrical resistivity tomography (ERT,ARES system, GF Instruments, Czech Republic), Dipole electromagnetic profiling (DEMP, CMD Explorer, GF Instruments, Czech Republic), Ground penetrating radar (GPR, RAMAC X3M, MALÅ, Sweden), Sap flow sensor (Sap Flow Module EMS 51.1, EMS Brno, Czech Republic), Stem decay investigation by non-destructive acoustic testing (ArborSonic 3D, Fakopp Enterprise Bt., Hungary), Gas exchange - meter measured *ad hoc* each our (LiCor-6400XT, Li-COR, USA). In parallel, we measured a soil moisture (point sensors Lolly, TOMST Measurement System, TOMST s.r.o., Czech Republic) and a soil water potential (WP4C Dew Point PotentiaMeter, METER Group, Inc., Pullman WA, USA). Physical parameters of the air were measured every 10 minutes by a meteorological monitoring station (Fiedler-Mágr, Czech Republic) located 100 m from the plot.

Figure 1. The selected Ash tree plot grid measurement, on left – north side an old tree nursery, and on right – prepared plot for the newAsh tree plantation

The first measuring period lasted for four days and was performed between the 7th and 10th of June 2017. At the beginning, the plot was measured with an electrical resistivity tomography and a dipole electromagnetic profiling. Then the sap flow device, soil moisture sensors, and LiCor-6400XT were installed. The soil samples were taken by a probe from depths 5–15 cm and 40–50 cm during the experiment and their water potential was measured. This kind of investigation was repeated during the vegetation season of 2017 to monitor both the physical parameters of air, soil and soil water content together with a tree physiological activity. The expected measurable phenomena would be the tree response to environmental changes like an increase or decrease of physiological activity (e.g. the sap flow or photosynthesis rate). In the case of a positive stimulation, we expected the increase of sap flow, transpiration or photosynthesis daily curves. Otherwise, the decrease of e.g. a photosynthesis rate during the day, informs about the limiting influence of the soil water (water shortage) and protection of the tree assimilation apparatus from overheating by a closure of stoma. Consequently, this indicates the water stress (SCHULZE et al., 1985; PATHRE et al., 1998; BARTÁK et al., 1999; ALARCÓN et al., 2000; WULLSCHLEGER et al., 2001; LONG & BERNACCHI, 2003; PŠIDOVÁ et al., 2005). The semi-solitary Ash tree was chosen as a model species without a current tree – tree interaction for several measurements during the vegetation season. This paper presents the results from one measuring period.

Figure 2. An investigation conducted by a complex of open field applicable methods on an Ash tree example. Visible: Sap flow meter (tree stem), portable photosynthesis system, electrical resistivity tomography electrodes (metal electrodes around the tree with orange wires) and soil moisture meter (in the tree shadow), during the site measurements.

RESULTS AND DISCUSSION

The first type of conducted analysis was a single medium parameter (soil, air and tree physiological activity) interpretation. Secondly, of all environmental factors along with the tree physiological activity monitoring was combined together (Fig. 3). The recordings of sap flow and photosynthesis indicate that the water stress was present during the June 8^{th} and 9^{th} (SCHULZE et al., 1985; PATHRE et al., 1998; BARTÁK et al., 1999; NADEZHDINA, 1999; ALARCÓN et al., 2000; WULLSCHLEGER et al., 2001).

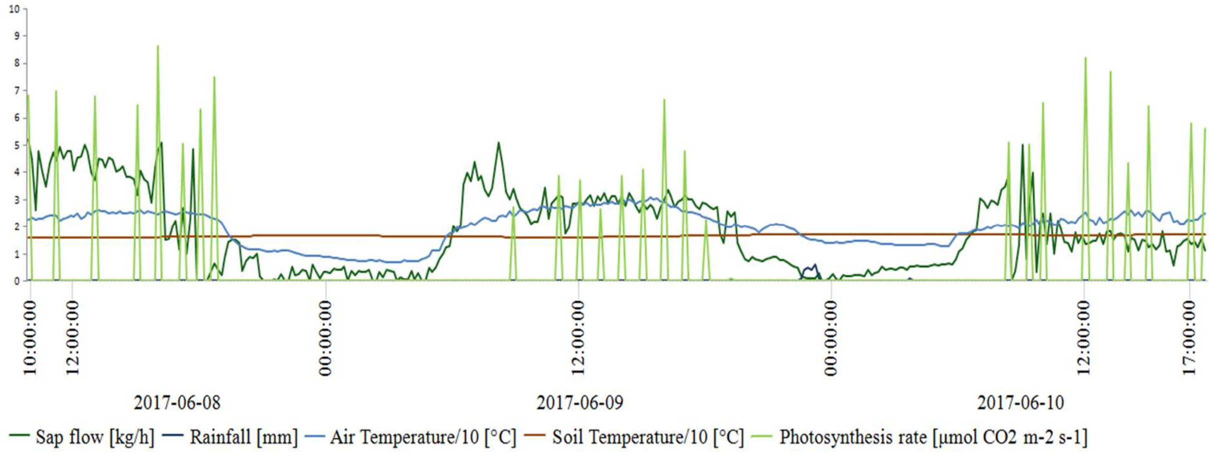

Figure 3. Comparison of the sap flow (kg/h per tree) (dark green) and photosynthesis rate (µmol CO^2 m^{-2} s^{-1}) (bright green) with 10 times decreased values of: air temperature (°C) (bright blue), soil temperature (°C) (brown), and 10 times increased value of rainfall (mm) (dark blue) during diurnal changes in 8–10 June

The measured distribution of resistivities (Fig. 4) in the more or less homogeneous environment, as can be found on the investigated site, is influenced more by changes in the soil moisture content then by changes in lithology. Especially for very low water contents (less than 1%), the resistivity decreases very quickly with increasing moisture (SASS AND VILES 2010). Hence the large variations of resistivities in the uppermost layer (depth up to 0.5 m, interpreted as a layer of soil) are addressed to changes of water content in soil most likely caused by changes in superficial vegetation. The drying effect of the vegetation is the largest in the vicinity of the object of the study (MAREŠ et al., 2004; HAGREY, 2007; ZENONE et al., 2008; FERRÈ, et al., 2008). The ash tree was rooted at x = 7 and y = 7 m. The "drying depth" indicated within the area x = (5–8) and y = (6–11) probably originates from the influence of two root systems (Fig. 4 left panel): first from investigated ash tree and second from other cut ash tree stamp which is still alive, even though it is without the crown, trying to grow once again. The Layer 4 (Fig. 4 right panel) seems to already map resistivities of the clayey weathered proterozoic bedrock which is in a good agreement with excavated soil samples from the depth of 5–6 meters (WEGER & BUBENIK, 2012; WEGER et al., 2013).

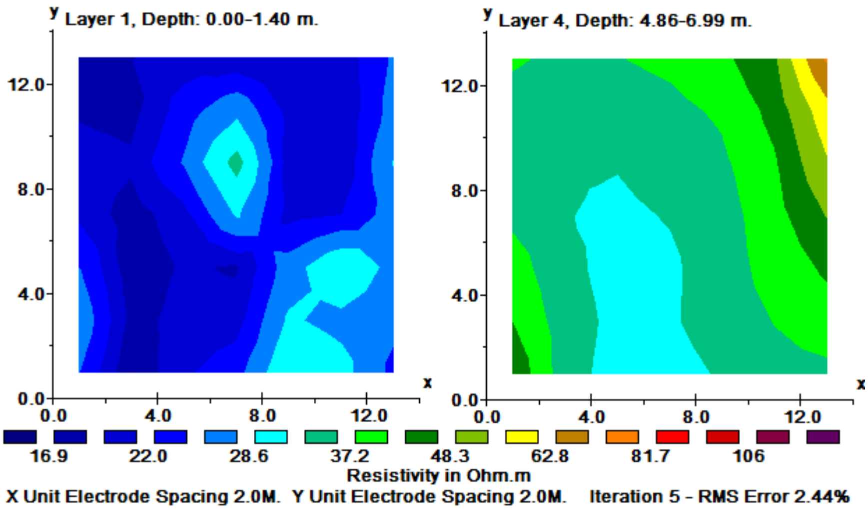

Figure 4. The ash tree plot measured by the 3d pole-pole electrical resistivity tomography method. The ash tree was rooted at x = 7, y = 7 m (left panel, area with increased resistivities). The right panel indicates the presence of weathered bedrock at depths 5 m and more.

An application of the DEMP method (Fig. 5) allowed distinguishing the range of soil affected by the root water uptake visible as a higher resistivity more than 50 Ωm – green, yellow and red color areas –lack of water caused probably by the tree uptake. The ash tree was rooted at x = 7, y = 7 m and arrays of other trees at x = (0–2) and y = (7–12). In the case of the rest of the research area, the blue color is visible (lower resistivities), where no trees were rooted. The dark blue areas coincide with the holes in the ground after the tree excavation from the plantation. We observed that the presence of holes in the field benefits the water storage in the habitat. After the tree removal from the north side of the nursery, the holes were left (Fig. 1). These are places of locally lower altitude where the cool night air flows to endure the hotter day. That field phenomena refrigerates the soil and prevents water evaporation (HUTH & POULTON, 2007).

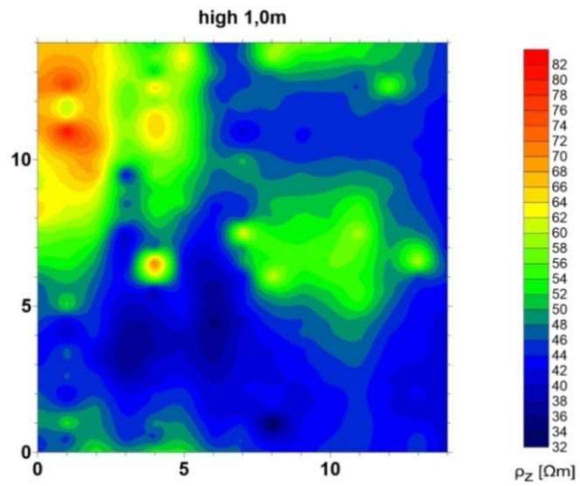

Figure 5. Isolines of apparent resistivities measured by the DEMP method, showing areas with higher (more than 50 Ωm – green to red–lack of available water) and lower resistivities (blue – damp soil). The ash tree was rooted at x = 7, y = 7 m.

This analysis confirms the hypothesis that the investigated Ash tree grows in a compacted (heavy) soil, which does not allow the air moisture, rain and artificial water to penetrate into the deeper soil layers (Fig. 4, 5). Moreover, the measurements of the soil water potential confirm that in short time periods after the rainfall the water is available only for a shallow root section. Furthermore, the detection of the root system by the ERT was successful (Fig. 4, 5) (MAREŠ et al., 2004; ZENONE et al., 2008; HAGREY, 2007).

Additionally, no root or decay changes in the Ash tree stem were found after the investigation by ArborSonic 3D. It suggests that the stem tissue is healthy and may conduct the water and nutrients uptake by the root system without any limiting influence on the sap flow, transpiration, and photosynthesis (WANG, 2004).

Moreover, after the low-intensity rainfall during the night, the photosynthesis curve took the Gaussian shape (Fig. 3), which suggests that water was available at shallow soil layers and the photosynthesis limitations depended only on the solar radiation (VERTESSY, 1998; PATHRE et al., 1998; BARTÁK et al., 1999; PŠIDOVÁ et al., 2005).

On the other hand, we observed the constant decrease of the Ash tree physiological activity during the vegetation season, particularly in the late summer. Probably, an early termination of the vegetation season has occurred (PATHRE et al., 1998; BARTÁK et al., 1999; PŠIDOVÁ et al., 2005).

The factor characterized by the smallest amplitude changes during the day was the soil temperature that is why this parameter was found as the less affective on the tree physiology because there is no water phase change during the vegetation season (Fig. 5).

CONCLUSION

The article presents a possibility of practical usage of a new complex of open field applicable methods for a complex research of tree-environment relations. All applied methods were found as contributing to this goal in the methodological sequence. They provide information on a tree closest environment and its limitations for an optimal growth caused by artificial or environmental changes. However, application of single-point soil moisture sensors seems to be less useful in comparison with the geophysical methods (ERT and DEMP). The most important drawback of the point soil moisture sensors is the fact of a local water accumulation and a soil structure disturbance around the sensor, while in the case of multi-point electrodes applied by geophysical methods the disturbance is limited. In a further development of our research, this can significantly contribute to complex studies of the tree physiological parameters and their changes caused by negative and positive environmental effects, or, alternatively, by an artificial stimulation of such changes. The further analysis of experimental complex measurements of the Ash tree including artificial irrigation, soil type effects and results of ground penetrating radar measurements will be presented in a following paper.

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