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THE EIS METHOD CAN IDENTIFY CHANGES IN WATER CONTENT IN SOIL PORES: DETECTION OF DRY AND WET SOIL BY EIS METHOD IN THE CHERRY ORCHARD IN ŽABČICE, CZECH REPUBLIC

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Abstract: Climate change is a complex and to some extent defining problem of our time, including the issue of their monitoring. From shifting weather patterns that threaten food production, to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global in scope and unprecedented in scale. The each other interconnected processes of mass and energy transfer are well visible in an integrated dynamic system called the hydrosphere. The hydrosphere is the combined mass of water found on, under, and above the surface of the Earth. Meteorological conditions undoubtedly have, in addition to different agro-ecological conditions, a significant influence on the monitored yields and crop quality. The paper presents the results of the soil monitoring at cherry orchard Žabčice, Czech Republic in place with different species of grassland with different lengths of their roots. Monitoring was realized manually with frequency one per month with using Z-meter devices developed through international EUREKA programme. The monitoring system allows measurement at one selected frequency of the measuring signal, or measurement in a frequency band. Both approaches were used to monitor changes in soil water content. Changes in the water content in the soil were monitored during artificial irrigation of grass (frequency spectrum) with a mobile probe and due to changes in the weather - drought and after torrential rain on the site (chosen frequency of the measuring signal) with stable probes. For practical reasons to limit the influence of uncertainties, the measurement was conceived as relative, and therefore calibration was not carried out for e.g. relative humidity of the soil. The monitoring results show the possibility of using the measuring system for the given purpose in full, including the possibility of its automation.
Key words: vegetation cover, electrical impedance spectrometry (EIS), Z-meter device.

1. INTRODUCTION

The Czech Republic (CR) lies on the watershed divide of three seas – The North, Baltic and Black Seas. The watershed of these seas divides the territory of the CR into three international catchment areas (Labe, Odra, and Danube). It is obvious that practically all significant watercourses in the CR drain water beyond its boundary on the territories of the neighbouring states, resulting in the fact that water sources in the CR are practically dependent on the amount and distribution of atmospheric precipitation. In the context of discussing changing climatic conditions, atmospheric precipitation of very different intensities increases the likelihood of the occurrence of extreme floods and dry episodes. The theme of protection from the consequences of floods and drought is part of joint debates of all states and international commissions. The approach to the solution of the issues above, however, can be different because it is based on the current conditions of the given international catchment area. Many fields and areas give attention to the theme of threats posed by natural

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disasters created by flood situations, including snowmelt floods, and drought not only from the view of science. It is not possible to prevent floods or drought by the present scientific knowledge and technical options. In case of floods, it is possible to reduce their impact on the lives and property of inhabitants by constructing efficient flood control works. However, it is necessary to have in mind that even the best flood control measure will only be as reliable, efficient and safe as its weakest element will be reliable, efficient and safe.

When addressing the issue of drought in the CR, it is necessary to realise that the absolute majority of water sources depends on the retention and accumulation of water in the territory of the CR. At present, the impacts of drought and lack of water in the conditions of the CR are significantly mitigated by the existing water management infrastructure. However, it can be expected for the future that the existing water sources will not be sufficient. Not only the aspect of the potentially diminishing available amount of surface water and subsurface water in the CR will be problematic, but also the aspect of the unsuitable quality of water. Also from this aspect, it is necessary retain and accumulate water in the landscape.

The reality is that every inhabitant of the CR is a significant user of its water sources, and it is necessary to bear the responsibility for them. Unfortunately, people usually realise neither the significance nor the value of the discussed irreplaceable nature wealth for everyday life, nor the scope of activities and financial costs that are associated with this "matter of course".

In this paper, the team of the authors provides a view of international cooperation and its achievements when dealing with a project of applied research in the EUREKA programme, which was focused on the development and construction of monitoring technology enabling changes in water content to be monitored in a porous medium. The selected results are documented in a link to some measures applied to soil in the conditions of the CR, emphasising the use of the method of electrical impedance spectrometry. The authors are aware of the fact that it is only a fragment of the solution of the complex of the outlined issue. However, it is obvious that without the safe operation of water management works, whose monitoring is an irreplaceable part, water resources cannot be secured or managed, that is, water can be used appropriately for the agro technical or other purposes.

1.1 Specification of the porous soil environment and monitoring of water in the CR

Earth is a natural part of the national wealth of every state. It is where we can find earth organisms and wild plants; also where grow culture plants. The soil itself is the regulator of the material cycle; it can function not only as a repository of potentially risky substances, but also as their source.

The porous soil environment, in this part, means earth and soil, including water content. It is the regulator of the material cycle. It can function not only as a repository of potentially risky substances but also as their source. It forms not only a complicated open, dynamic system but also a relatively independent system by its capability of self-regulating internal processes [1-4]. While earth can be defined as an independent natural feature formed by surficial solid products of weathering of the Earth's crust and by organic residues under the action of soil-forming factors, the term soil is used in the engineering-geological classification of rocks and is based on their structural cohesion. The soil is designated as unconsolidated rocks that are subdivided into cohesive (clay), non-cohesive (sand, gravel), organic (peat) and artificial rocks (material of dump sites, fills, etc.).

In terms of monitoring, it is a very complicated three-component environment (Fig. 1), the composition of which differs by the place of sampling and by the depth from which the sample was collected (e.g. hummus, loamy, sandy, clayey earth, etc.). The physical, chemical and biological properties of the given medium are measured and monitored.

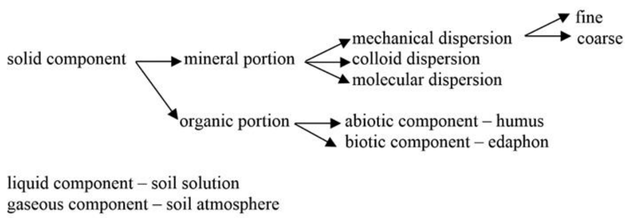

Figure 1 Schematic composition of the porous soil environment

The issue of earth and soil monitoring is closely tied to water monitoring [5, 6]. It's good to remember that agricultural earth in the Czech Republic has been monitored for more than 50 years, systematically since 1992 by the Central Control and Testing Institute of Agriculture falling under the Ministry of Agriculture. Monitored are its basic agrochemical properties. Collection of samples is regularly carried out, as well as their chemical analyses and data processing and interpretation. Two fundamental organisations work in the section of water stage monitoring in the CR, the Czech Hydro meteorological Institute (CHMI) [7] and the T.G. Masaryk Water Research Institute (WRI) [8]. The CHMI mainly collects data and creates hydrological information, and the WRI chiefly collects data from the catchment basins and creates water-resource balances for water management purposes. Both the organisations together have built a hydro ecological information system (HEIS), the main objective of which is to take inventory of water resources, information about their regime, balancing of data from monitoring the

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hydrosphere, publishing of information for the needs of decision-making of the state administration bodies, etc.

Water monitoring is divided into the observation of surface and subsurface waters (particularly groundwater). It comprises data on the physical and chemical properties of water and their spatial and temporal occurrence.

1.2 Temperature and electrical conductance of earth and soils

There are many factors which influence in the temperature of soil and its moisture content. Some of them are clime, hydrological and ecological factors and also by the type of vegetation and its properties (species, age, root system, etc.). The temperature of soil influences overwintering of cultural crops, their germination, rooting and nutrition. It is important as far as sowing, planting, mineral content, uptake and movement of nutrients are concerned, but it also influences the electrical conductance of soil; it is one of uncertainties in measurement of soil moisture content.

The sun and solar radiation is the most important source for the soil, it heats the surface and then this heat is transferred to the deeper layers of the soil. The type, structure and moisture content of soil influence its thermal and electrical conductance [9].

Another parameter is the electrical conductance of soils. The benefit of its mapping [10] is based on the existence of the relationships between electrical conductance and other parameters of soil, such as capillary water capacity, depth of topsoil, ion exchange capacity, the content of organic matter, the content of nutrients, the properties of the substrate, etc., which highly influence the productive capability of soils. When using the maps of the electrical conductance of soils in the system of precise agriculture, this concerns a comparison of maps with other information layers by means of GIS programs, such as yield maps, maps of supply of soil with nutrients, soil investigations, historical knowledge of plots of land, etc. These comparisons can help reduce the costs of inputs, such as seeds for sowing, fertilizers or chemical preparations, increase yields and reduce environmental burdens.

2. LOCATION AND MEASURING PROBES

The soil moisture and temperature is influenced by climatic, hydrological and pedological factors and also kind of vegetation and its features (species, age, root system etc.). In frame of the study the influence of different meteorological conditions soil moisture and temperature under different types of grass cover was electrical impedance spectrometry method used.

Experiments were done at the cherry orchard in locality Žabčice through electrical impedance [11-13], about the Z-meter device is possible obtained information in the same literature or in [14-16], so that it isn't described in this paper. Monitoring was realized manually with frequency one per month with using Z-meter devices from the 2014 yet.

2.1 Location of Žabčice and the place of study

Žabčice is a village and municipality in Brno-Country District in the South Moravian Region of the Czech Republic. The municipality covers an area of 8.23 m^2 and it lies approximately 20 km south of Brno and 197 km southeast of Prague.

Figure 2 Location of Žabčice inside Czech Republic

Experimental area Žabčice [17], practical training and research centre for students of Mendel's University is in this locality (Fig. 3), lays in altitude 184 m a. s. l. approximately in alluvial plane of Svratka river (maize production region and orcharding). Dominant soil type in this area is middle heavy to heavy gleyic fluvisols FLq and fluvisol FLg.

Figure 3 Layout plan of the area of interest in the School Agricultural Enterprise of MENDELU at Žabčice

From parameters that have a major impact on the value of the electrical impedance of soil in field conditions, the attention was focused on vegetation cover, soil moisture, soil temperature [18], soil type and slope and exposure of the terrain [19]. In experimental area was realized following types of measurement using Z-meter devices – frequency analysis through which were studied homogeneity or non-homogeneity of the area from the view of electrical signal transport, effective grain size estimate, influence of irrigation and long term measurement. The results of frequency analysis measured by Z-meter were compared with values measured by device developed at Technical University Varna (TU Varna), Bulgaria [20].

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2.2 Characteristics of the studied area

The measurements take place in an orchard full of corridors between lines of trees, located inside the experimental area of Mendel´s University. Monitoring area is located in the third corridor of the orchard we have mentioned before. The area consists of a piece of a rectangular area 7 m long and 2 m wide, therefore it is covering 14 m^2 of field. Measuring points are named from A to H in long and form 0 to 2 in wide. The axial distance between the tree trunks is 5.6 m and the distance between the outermost measuring points and the tree trunk is 1.8 m. The type of vegetation or soil in place is very important because it implies different kinds of roots and these could take more or less moisture from the soil.

Two species of grass cover are monitored at the site. In the text below, tall fescue is denoted as the cultural grass - measured profile 1-2 or rod 1 and 2, the successive vegetation from annual weeds is denoted as the natural grass - measured profile 3-4 or rod 3 and 4. Profile 2-3 was 3 years ago disturbed, so it is different soil porosity (Fig. 4).

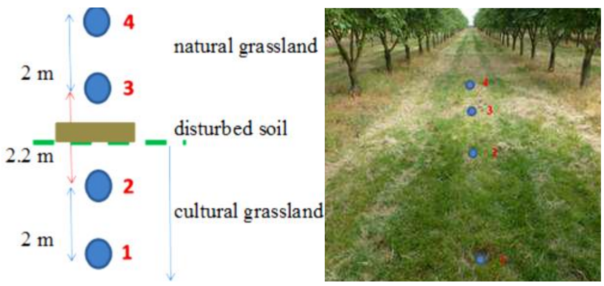

Figure 4a Measurement scheme with a stable rod probe

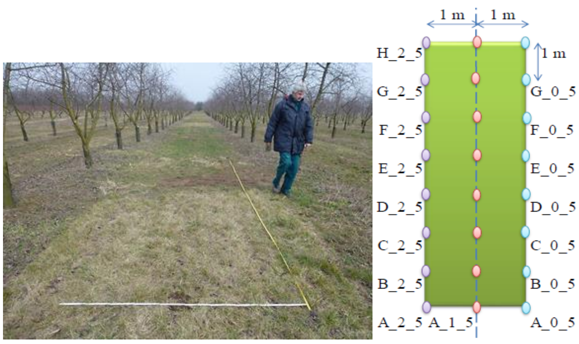

Figure 4b Measurement scheme with a mobile fork probe

Using stable probes the measurement was done to two-terminal connection when measured profile of soil represents straight cable which length is about 2 m. Attention was also given to the three-terminal connection of the measuring electrodes, where the connection of the electrodes on the individual rods was provided by the adapter connected to the Z-meter measuring device. An approximately spherical surrounding environment of the probe is sensed, where the diameter of the sphere is defined by the spacing between two neighbouring electrodes. In the given case, the probes designated as VL1 and VL2 are placed in the soil covered by the cultural grassland and the probes designated as VL3 and VL4 are covered in the soil by the natural grassland. In both cases of connections, the measured components of electrical impedance are evaluated as resistance (real part) and reactance (imaginary part).

2.3 Types of measurements and measuring probes

In the experimental area containing two types of grass cover, three pilot types of measurement were carried out as follows:

- Frequency analysis of soil, through which information was obtained about the homogeneity of soil in the studied area from the point of view of their electrical properties; measurements took place under the common weather on the day of measurement in the spring months and in the conditions of simulated rain precipitation;
- Measurement of electrical impedance of a soil layer using a mobile fork probe to a depth of 0.20 m;
- Monitoring of a chosen profile of soil using a stable tube probe to a depth of 0.85 m.

Based on the frequency analysis performed in a range of 1,000 Hz to 100,000 Hz, where a fork probe monitored an area of 14 m^2 with both species of grass cover at heights of -0.025 m, -0.075 m, -0.125 m and -0.175 m, the frequency f = 2,000 Hz was selected for monitoring. Based on the results obtained from the experiments, we can assess the similar structure of soil of a loamy-sandy character with the size of the effective grain d_{ef} = 4.4 mm in the whole area of interest. Moreover, it is possible to believe that the soil becomes “loosened” due to the root system of the cultural grassland, equally as in the place of the dug pit, whereas in the area of the natural grassland it is more compact.

The monitoring of the site was done using a mobile fork probe and a stable tube probe. In both cases, it is an application of the contact method of measurement using the construction of passive probes. Soil monitoring by the stable tube probe was conceived as long-term monitoring of changes that take place in the soil because of the weather effects on different grasslands.

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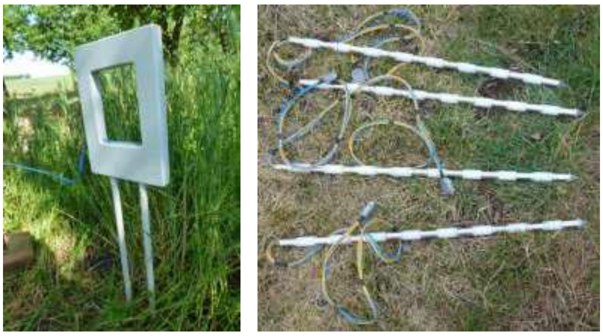

Figure 5 Mobile fork probe, stable rod probe with 9 measurement levels

On the base of these measurement requirements were designed the probes. Probes are mounted in a longitudinal axis of the area of interest of grassland between alleys of sour cherry trees.

To carry out the frequency analysis of the field was used mobile fork probe – a pitchfork with two prongs, measuring electrode, of the length 0.025 m a distance between them 0.1 m (Fig. 5 left). When applying this mobile probe, the measurement was made from the soil surface 0.025 m to a depth of 0.175 m with a step of 0.05 m. It means were measured four different layers in 24 sites of tracked area.

For long time measurement was used stable rod probe where measuring electrode have length 0.05 m (Fig. 5 right), total length of one probe was 0.85 m, the division of the electrodes on the probe is regular and enabled measurement in 9 horizontal layers, the first electrode was placed 0.05 m below the soil surface. The electrodes were made of a stainless steel tube of an outer diameter of 0.025 m and with its wall being 0.001 m thick. They can be connected to a Z-meter device using two terminals, or three terminals by means of an adapter. The interconnecting conductors run through the centre of the tube; their free length is 2.0 m and they are terminated with a 25-pin connector of the Canon type for connection to the Z-meter. The connectors, including the conductors, are laid beneath the grass cover for the reason of their security and protection against vandalism.

Polyamide of the same outer diameter as the electrodes was used as a spacer and insulation material between the electrodes. The smoothness of the outer surface of the probe is significant in its installation into the soil. A regular division of both elements was selected in probe construction because of not knowing the soil structure on the measured profile in more detail and in relation to the experiment.

The stable probes were parallel implemented in the axis of the monitoring field in the mutual distance 2.0 m of the electrodes located on the individual probes at the same level opposite each other.

2.4 Data processing

The processing of the measured data was carried out using the MS Excel program, Surfer 8 and special software developed in MATLAB at TU Varna.

According to the established Cartesian system of coordinates, the patterns of the electrical resistance R and reactance X (or other electrical parameters like conductance, admittance, electrical resistivity and so on) determined as the arithmetic average of the values from the number of repetitions $n = 5$ were plotted for the individual points at all depths. During the simulation of changes in the water content in the soil, sprinkler irrigation was carried out, when 10 l of water was applied to an area of 1 m^2.

2.5 Measuring system

The module of the processor used provides a range of the output voltage (0.02 ÷ 2) Vpp. The virtual mass of the input stage of the processor is offsetted compared to the mass of the power source. The input stage of the device increases the signal level of the virtual mass. At output voltage of the module 2 Vpp, the input stage provides ranges of the measured impedance: 100 Ω; 1 kΩ; 10 kΩ; 100 kΩ; 1 MΩ. At other output voltages, such as the module provides, can be realized other ranges of the studied impedance, subject to the condition that the voltage in the output of the input stage of processor should not exceed 2Vpp.

For the measurement was used output voltage of the module 1 Vpp. Using mobile probe was (Fig. 6) measured frequency range was from 1 kHz to 100 kHz, using stable probes the measurement was done on the frequency 2.0 kHz.

Using module TU Varna was measured only the surface of the soil because the probe is small and short. It was used pair probe. Overall, the system was designed for use in laboratory conditions. For measurements in the field, it was rather fragile, which was reflected in the collapse of the connection cables from the probe to the processor in the initial measurement. The mentioned fact was corrected directly in the field, but also because of this, the measurement could not be started at the same time as the measurement with the Z-meter.

Figure 6 Measurement by the EIS system with a mobile fork probe and the Z-meter IV device, including the use of a control device SATURO

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Output frequency is 0.2 Hz – 19.2 kHz in 5 subranges. The software that was used is based on the software of TU Varna, but with graphical user interface. It's used PC with MatLab connected to PC module via USB cable (Fig. 7).

Figure 7 Module of TU Varna during the measurement in situ

3. RESULTS AND DISCUSSION

The following section presents some of the results achieved in the implementation of frequency analysis and standard measurement on one frequency of soil materials in the field conditions including comparison with result obtained from TU Varna system in relation to the weather recorded on the selected measurement days.

3.1 Frequency analysis

Frequency analysis was measured with a mobile probe before artificial irrigation of the specified area by spraying, immediately after irrigation application and then 24 hours after irrigation. For comparison of the results with results from TU Varna module is important the blue line which represents the surface layer (Fig. 8).

The measurement was realized at 2016, May 23 from 7:00 h to 10:00 h. Evaluated were the same points as Z-meter device. But the conditions of the soil were during the measuring time a little different (Fig. 8). The surface layer with the grass was in all tracked area during measurement with TU Varna module more droughts the influence of higher air temperature.

Date of measurement: 23.05.2016

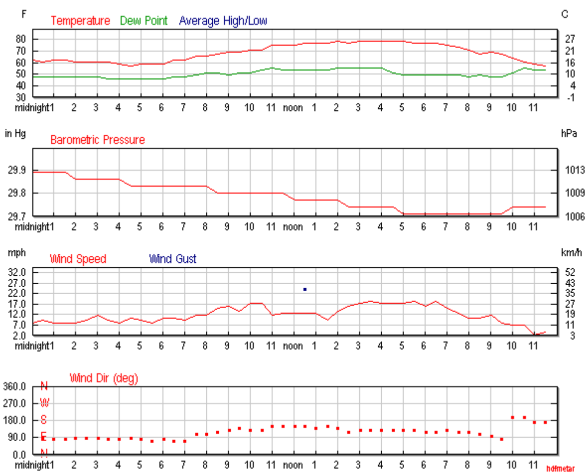

Figure 8 Meteorological situations during measurement [21]

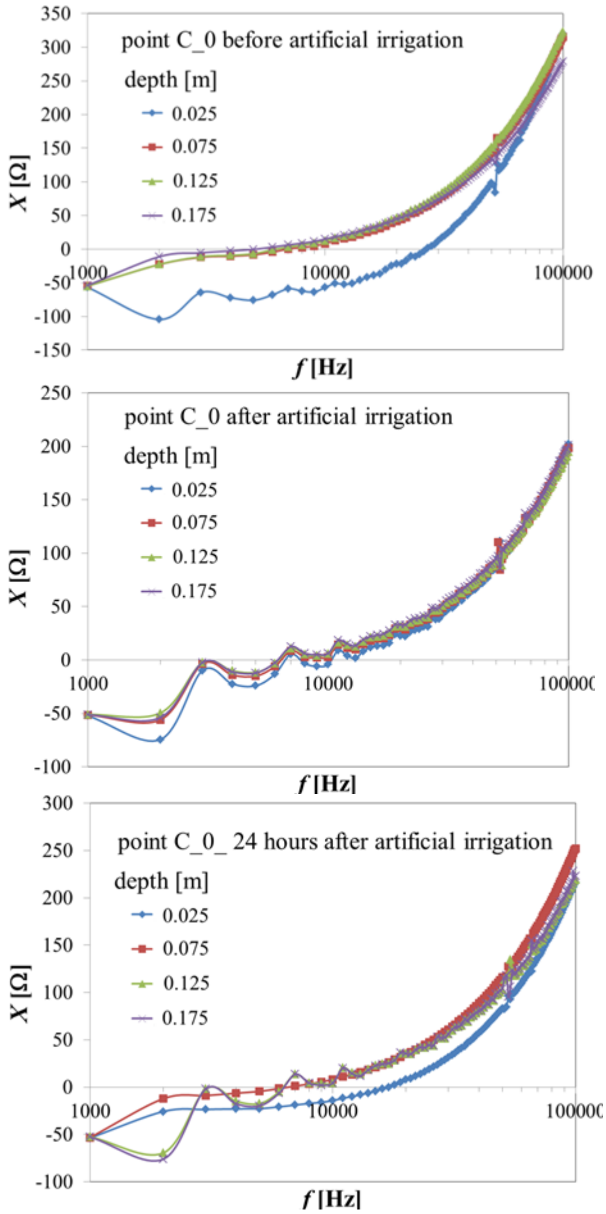

Figure 9a Frequency analysis measured by EIS system (cultural grassland)

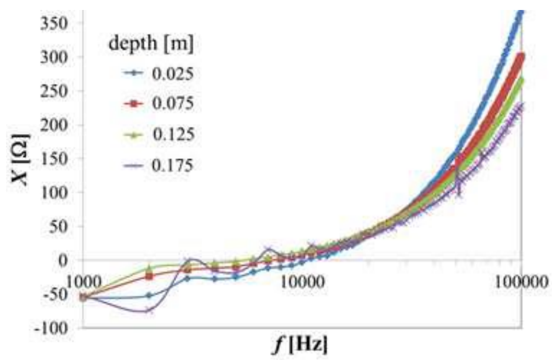

Figure 9b Frequency analysis measured by EIS system (natural grassland)

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The results comparison from both similar measuring system was done only for surface layer of the soil, depth 0.025 m, and for its the “dry” consistence, it means before artificial irrigation.

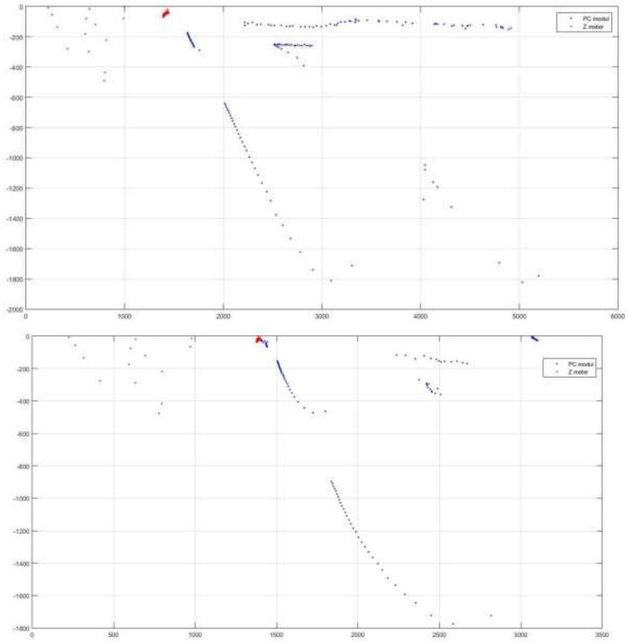

Figure 10 The frequency analysis measured by module of TU Varna

Frequency analysis measured for two different points, but for the same as in Fig. 9a, of the tracked area is shown in Fig. 4b. It is possible to see differences between the soil conditions during the measurement in 7:00 h (Fig. 9a) and 10:00 h (red points in Fig. 10). That's why was done calibration for the start point of measurement. After calibration were for each point obtained similar frequency characteristics (blue points in Fig 10). The suitable measuring frequency for the type of soil in the first point (Fig. 9a before artificial irrigation) identify from measurement using the device Z-meter is 2.5 kHz ((the minimum extremum on the curves), using the module TU Varna is 3 kHz and 5 kHz (Fig. 10 above). The characteristic was measured in part with cultural grassland. For the second point G_0 (Fig. 9b and Fig. 10 down) – part of natural grassland, the suitable measuring frequency is 2.5 kHz determined according to both devices. However, due to the characteristics of the entire area monitored by both systems with the Z-meter device, a measurement frequency of 2.0 kHz was chosen, regardless of the detailed analysis of measurements at individual points and levels.

3.2 *Horizontal resistance map*

Another result taking into account the influence of the grass root system in relation to irrigation is evident both from the realized frequency analysis (Fig. 9a) and from the measurement of soil electrical resistance (quantity primarily taking into account the water content in the soil pores). Electrical resistance maps of the area of interest before the application of artificial irrigation are shown for different depths (Fig. 11).

By comparing the results of the frequency analysis at a depth of 0.025 m before the application of artificial irrigation, the measurement carried out at points C (cultivated grass surface) and G (natural overgrown grass surface) can be used to obtain another identification feature of the soil.

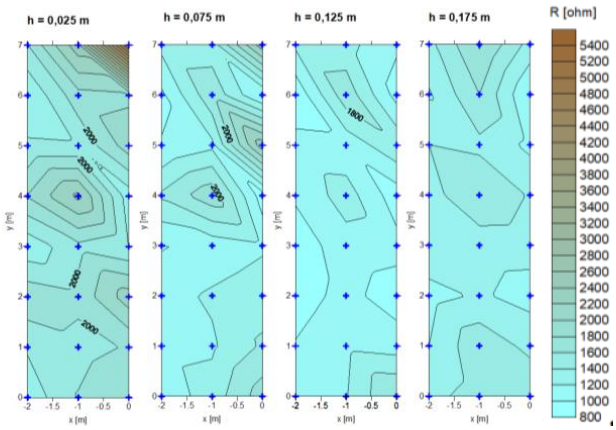

Figure 11 Maps of electrical resistance measured by EIS system in different depth (blue colour means higher water content in the soil, brown colour means drier soil)

3.3 *Soil grain size estimation*

This is the identification of the soil grain size. While the Bode plot at point G shows a relatively smooth curve, at point C there are irregularities pointing to the possible inhomogeneity of the soil in terms of its granulometry [22, 23]. After taking a soil sample from said location C, it was found that the soil matrix contains an admixture of sand grains (Fig. 12). Based on experience and the results of laboratory experiments and tests which were focus on the determination the effective grain size of the soil samples and its estimate using the multiple frequency electrical impedance analyser Z-meter, it can be assumed that the size of the effective grain of the soil ranges between 0.9 mm (matrix) and 3.9 mm (grain of the sand) on the whole monitored profile.

Figure 12 Soil sample from point C

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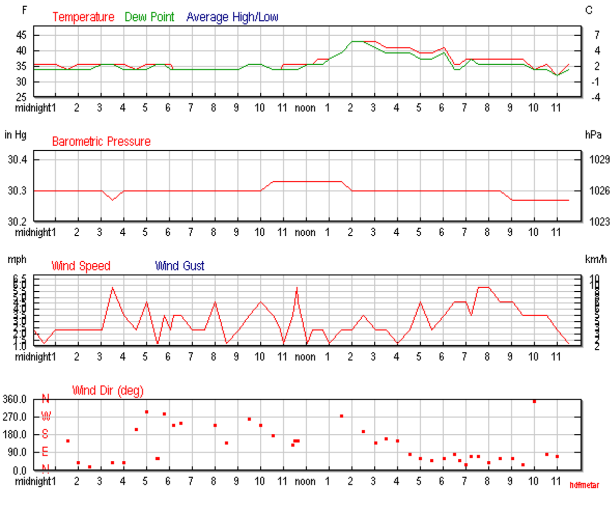
3.4 *Electrical characteristics of soil*

Other measurement results obtained by stable probes draw attention to the fact from which depth the grasses are able to obtain water. The cultural grassland is the fescue grass with length of roots to 2 m while natural grassland has roots with length to 0.3 m. The meteorological situation (Fig. 13) is documented for the next two selected days of soil electrical impedance measurement.

Date of measurement: 26.01.2016



Date of measurement: 23.08.2016

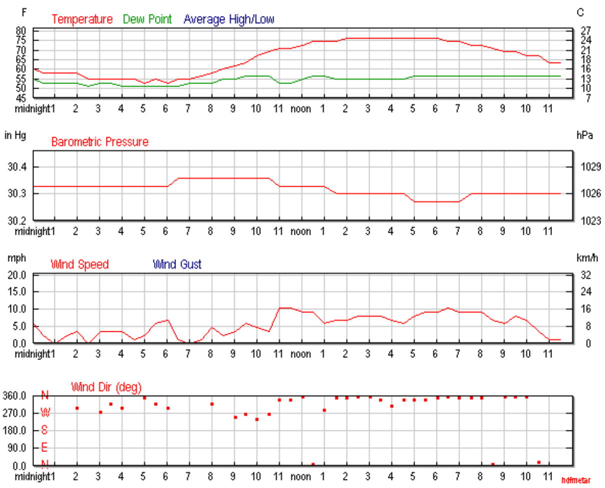


Figure 13 Meteorological situations during measurement [21]

In two-terminal connection of pair probes, a probe designated as VL1_2 is placed in the cultural grassland; probe VL2_3 in the disturbed soil; and probe VL3_4 monitors the profile covered by natural grassland. In this connection, the soil can be characterized as a straight electric conductor with its length being governed by the spacing between the measuring electrodes on the individual rods. It is necessary for the reason of the relevant evaluation of ongoing changes so that the rods of probes be installed into the soil in parallel. Whether the soil will be a good or a poor electric conductor is determined by its other characteristics, decisive of which is water content in the conditions of the Czech Republic. The results obtained from monitoring carried out are given in (Fig. 14) evaluating the measured components of electrical impedance.

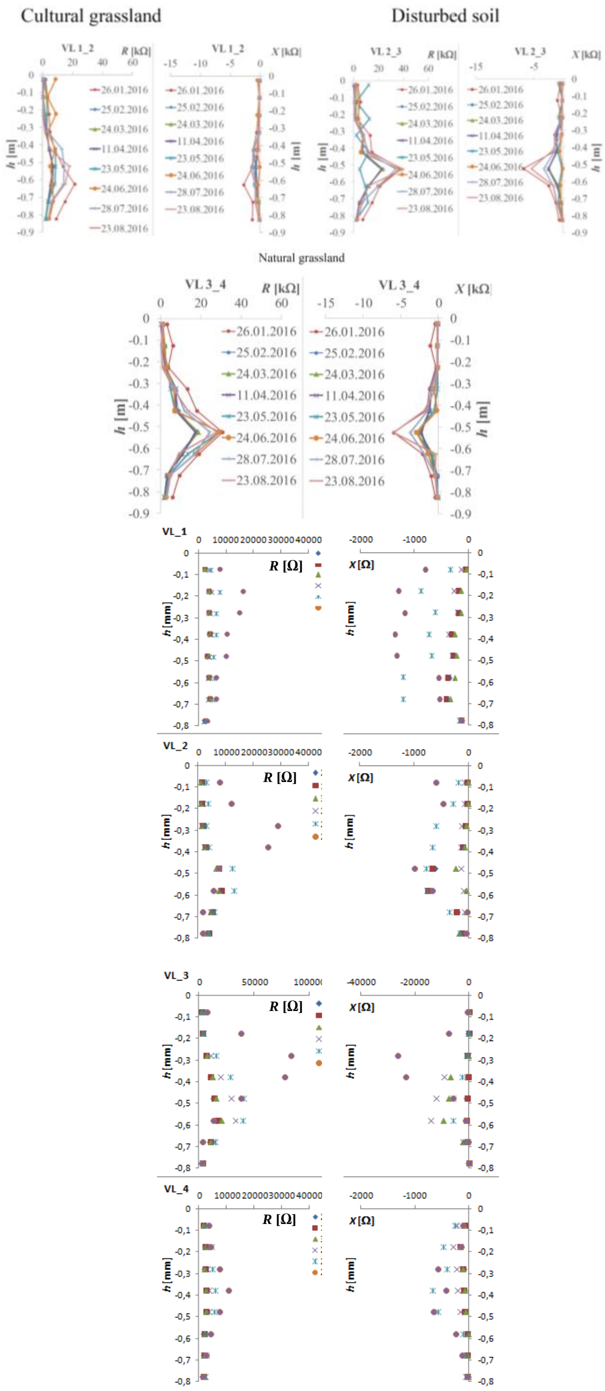


Figure 14 Stable probes – patterns of electrical impedance components (two-terminal connection top image, three-terminal connection bottom image, measurement days were identical)

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Using two-terminal probe connection small extremes are measured in cultural grassland by VL1_2 probe. The result is predictable, as the long roots of the fescue grass receive water evenly from a wide area.

Using three-terminal probe connection more extreme results are given in the probe VL_3, which is located between disturbed soil and natural grassland, it is logical because these are the less compact and drier soils. In contrast, the probes 1 and 4 are the most homogeneous due to be farther from the disturbed soil.

Another support for the conclusion given is done by the patterns of electrical conductance (Fig. 15) and the maps of electrical conductance (Fig. 16) measured during or after extreme meteorological situations at the locality. Examples of measurements and processing for one winter month (January 26, 2016), during a long-lasting drought during a summer month (July 30, 2016) and one day after a summer local torrential rainfall (August 23, 2016) are given. Electrical conductance maps were also processed from identical data.

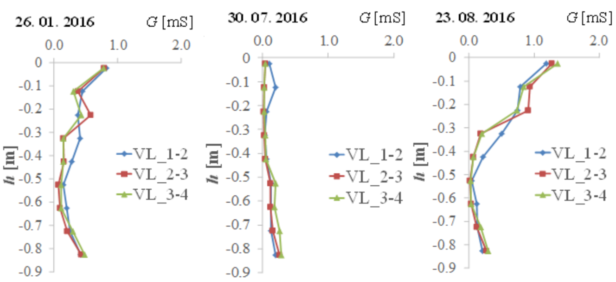
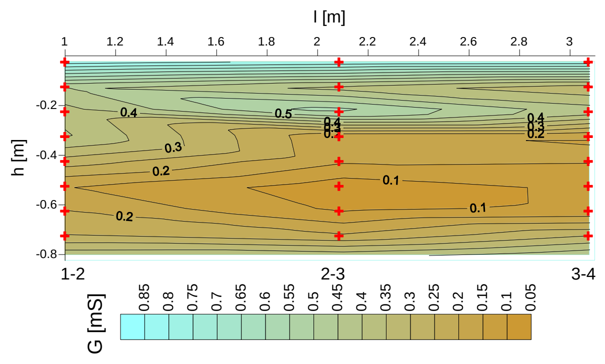


Figure 15 Stable probes – patterns of electrical conductance for different meteorological situations (two-terminal connection)

From all three dependencies, even in view of extreme meteorological situations, it is obvious that good water management is achieved by the long root system of the cultural grass cover (fescue). Although the measured electrical impedance values on the soil surface and at a depth of 0.85 m are very close, the vertical transport of water by the fescue grass measured by the VL_1-2 probe shows a higher water content in the soil (higher values of electrical conductance), in the case of torrential rainfall, their more uniform decrease.



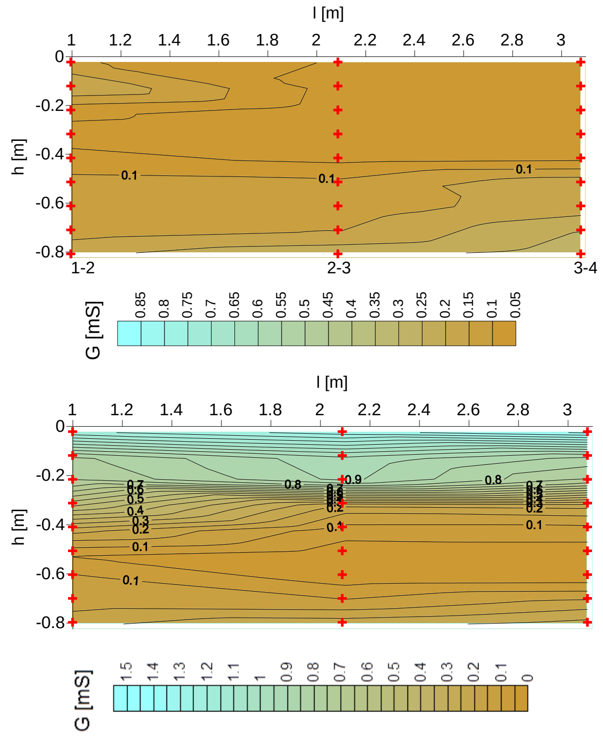


Figure 16 Stable probes – maps of electrical conductance for different meteorological situations (two-terminal connection)

The colour scale of electrical conductivity is the same for the first two maps, but it is significantly different for the third map recording the situation after torrential rain at the location. With a more detailed analysis of the maps of the individual situations, it can be assumed that, due to the geological situation of the locality under consideration, the level of the groundwater level at a depth of approximately 1.0 m to 1.5 m

4. CONCLUSIONS

Discussing the work performed has been appreciated that EIS method is really clear and allows analyzing the data once it is on the computer easily through graphics. Data also could be used to create different kinds of useful tools such as the monitored soil profiles, to show them to people who are not able to analyze the graphics.

Regarding the results, all of them follow logic being consistent one to each other and with the following ones. This means that this method does not make big mistakes and is reliable to work with.

Currently, the measuring system can also be fully automated with the possibility of transferring data to a server and thus can be available to any user. It is possible to choose the frequency of measurements over a 24-hour period, the number of measurement repetitions, and it is now possible to measure the soil temperature in the individual horizons of the measured profile in addition to the electrical impedance components.

In relation with results it is demonstrated that winter and spring seasons are the dampest ones, while summer is the driest one. Although this point, it cannot be demonstrated for the month of August because of a heavy rain the day of the data collection. Although old data from 2016 may appear to be processed (due to the use of the most comprehensive data set), the situation is highly current even for 2023.

Was shown that the vegetation in the terrain is directly related with the moisture of the soil, as well as the kind of roots. If the roots of vegetation are stronger and larger, soil will be damper and the properties of the soil will be nearly unchangeable during the time and against the possible pits which could be dug or other movements on the soil.

Also, based on a detailed frequency analysis of a soil profile in a staked-out are and the monitoring of soil on stable profiles to a depth of 0.85 m, it can be stated that the soil appears as homogeneous in terms of electrical properties. Based on experience and results of laboratory experiments, it can be assumed that the size of the effective grain of the soil ranges between 0.9 mm and 3.9 mm on the whole monitored profile. For a more detailed description of the soil properties (for example: determination of a suitable measuring frequency) it would be necessary to deal with other parameters of the soil, including mineralogical composition.

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