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Evaluation of experimental field data from the modified earth resistance method used in trees and stands as integrated with selected classically estimated soil properties.

Diploma thesis

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April 2016 in Brno

Bc. Pavel Jagoš

Acknowledgements

I would love to start this acknowledgement by Robert Fulghum's quote:

"*I believe that imagination is stronger than knowledge.*
That myth is more potent than history.
That dreams are more powerful than facts.
That hopes always triumphs over experience.
That laughter is the only cure for grief.
And I believe that love is stronger than death."

Robert Fulghum

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my grandmother, my parents and my brother.

Title: Evaluation of experimental field data from the modified earth resistance method used in trees and stands as integrated with selected classically estimated soil properties.

Author: Bc. Pavel Jagoš

ABSTRACT:

This experiment tested the possibility of adding other information about the soil physical properties to existing modified earth impedance method, published by Čermák, Staněk, Aubrecht in 2006. For this experiment, this method for resistivity measurement of tree (trunk/soil), was employed.

The measurements were conducted on four different study plots with different soil textural classes located in the Czech Republic. The choice of localities was guided the most typical soil textural classes; Ivančice – loam soil, Jedovnice – sandy-loam soil, Soběšice – loamy-sand soil, Šanovec – sandy soil.

In laboratory was studied 27 soil physical and chemical properties and a connection between 11 of them and soil resistivity was verified. Especially soil properties related to actual state of soil water and soil texture.

Keywords: soil conductivity, soil resistivity, soil physical properties, soil texture, modified earth impedance method

Název: Evaulvace experimentálních terénních dat z metody modifikované půdní impedance použíté v lesních porostech ve spojení s vybranými klasicky odvozenými půdními vlastnostmi

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ABSTRAKT:

Tato práce prověřuje možnost obohatit výsledky z metody Modifikované půdní impedance pro měření aktivního kořenového povrchu publikované v roce 2006 Čermákem, Staněkem, Aubrechtem, o další informace popisující fyzikální půdní vlastnosti. Pro tento účel byla využita jejich metoda pro měření půdní resistivity (měrný odpor).

Pro toto měření byly vybrány čtyři různé lokality v České Republice, lišící se půdní strukturou. Byly vybrány lokality s nejtypičtějším půdním druhem; Ivančice – hlinitá půda, Jedovnice – písčito-hlinitá půda, Soběšice – hlinito-písčitá půda, Šanovec – písčitá půda.

Laboratorně bylo změřeno a porovnáno celkem 27 půdních vlastností a jejich vliv na měrný půdní odpor bylo potvrzeno u 11 půdních vlastností, a to vlastností popisující aktuální půdní vlhkost a texturu půdy.

Klíčová slova: půdní vodivost, měrný půdní odpor (resistivita), fyzikální vlastnosti půdy, textura půdy, modifikované půdní impedance

Content

1. Introduction 1
1.1. Hypothesis 1
2. Literature review 2
2.1. Resistivity review 2
2.1.1. Tree physiology and its resistivity 2
2.1.2. Direct current resistance method 4
2.1.3. Resistance profiling 4
2.1.4. Soil resistivity and soil structures 5
2.1.5. Water and resistivity 6
2.1.6. Electrodes and resistivity 6
2.1.7. Granger causality 6
2.2. Soil physical properties 7
2.2.1. Density [g/cm3] 7
2.2.2. Dry mass S^h [%] 7
2.2.3. Volumetric weight [g/cm^3] and Reduced volumetric weight [g/cm^3] 8
2.2.4. Porosity 8
2.2.5. Aeration and minimum air capacity 9
2.2.6. Soil moisture 9
2.2.7. Hygroscopicity [%] 10
2.2.8. Wilting point [%] 10
2.2.9. Lentocapillary point in 33% [%] 10
2.2.10. Decreased availability point [%] 10
2.2.11. Relative capillary moisture [%] 11
2.2.12. Volumetric moisture [%] 11
2.2.13. Water-bearing capacity 11
2.2.14. Maximum (Full) water-bearing capacity [%] 11
2.2.15. Maximum water-bearing capacity (2 hrs draining) and Water-bearing capacity (24 hrs draining) [%] 11
2.2.16. Actual water-bearing capacity [mm] 12
2.2.17. Gravity water (1/2 hrs draining) [%] 12
2.2.18. Gravimetric moisture in dry sample [%] and Gravimetric moisture in fresh sample [%] 12
2.2.19. Pore saturation [%] 12
2.2.20. Available water holding capacity to 20 cm [mm] and Available water holding capacity to decreased availability point [mm] 13
2.2.21. Accessible water supply to 20 cm [mm] 13
2.2.22. Soil texture 13
2.3. Chemical soil properties 13
2.3.1. Oxidizable carbon - C_{OX} 14
2.3.2. Soil reaction active and potential (pH) 14
3. Material 15
3.1. Bioregion 15
3.2. Individual biogeography units 15
3.2.1. Biogeography provinces 15
3.2.2. Biogeography sub-provinces 15
3.2.3. Biogeography region 15
3.3. Localities classification into biogeographical regions and its characteristics 16
3.3.1. Hercynian sub-province 17
3.4. Characteristic of localities in subject of matter 18
3.4.1. General situation in the Czech Republic 18

3.4.2. Ivančice in Jevišovice biogeographical region 21
3.4.3. Jedovnice in Macocha and Drahany biogeographical region 22
3.4.4. Soběšice in Brno biogeographical region (partly Ivančice and Jedovnice) 24
3.4.5. Šanovec pond near the Hradec Králové city in Třebechov biogeographical region 26
4. Methods 28
4.1. Field methods 28
4.1.1. Resistivity measurement 28
4.1.2. Soil sampling 28
4.2. Laboratory analysis 28
4.2.1. C_{ox} detection by spectrophotometer after chromosulforic acid (type A) oxidation 28
4.2.2. Soil reaction active and potential (pH) by VÁLEK (1954) and ISO/DIS 10390 (1992) 29
4.2.3. Soil texture 29
4.2.4. Density and reduced density - gravimetric determination 29
4.2.5. Soil density determination by pycnometer 30
4.3. Statistical analysis 33
4.3.1. Granger causality 33
4.3.2. Statistical description 33
4.3.3. ANOVA 33
5. Results 34
5.1. Resistivity results 34
5.2. Laboratory results 37
Ivančice 38
Jedovnice 40
Soběšice 42
Šanovec 44
5.3. Granger causality results 46
6. Discussion 48
6.1. Soil texture 48
6.2. Soil fraction 48
6.3. Parent rock 49
6.4. Soil water 50
6.5. Soil organic matter 50
6.6. Porosity 51
6.7. Resistivity of electrode, machine and soil application 51
6.8. Resume of discussion 51
7. Conclusion 52
8. Summary 54
9. References 55
10. Appendix 59

List of figures

Figure 1: Curve with potential (or resistivity) values (Čermák et al. 2006) 3
Figure 2: Scheme of measuring device and electrode connections in situ. (Aubrecht et al. 2006).....4
Figure 3: Resistivity as a function of the proportion of fine grained sediment total volume..............5
Figure 4: Resistivity of volume fraction water solutions on a solid part of the soil (Novotný 1973, modified). 5
Figure 5: Biogeographical regions in the Czech Republic is determined by Culek (1996) 17
Figure 6: Climatic regions in the Czech Republic (migesp.cz, 2016)...18
Figure 7: Soil types map of Czech Republic (Šára 2005, WRB 2006)...20
Figure 8:Geological map of the Czech Republic (Šára 2005)..21
Figure 9:Scheme of measured tree (Čermák et al. 2006) 31
Figure 10: Scheme of measured tree, current field in soil (Aubrecht et al. 2006)............................32
Figure 11:Resistivity levels depending on distance measured in Ivančice 34
Figure 12:Resistivity levels depending on distance measured in Jedovnice.....................................35
Figure 13:Resistivity levels depending on distance measured in Soběšice.......................................36
Figure 14: Resistivity levels depending on distance measured in Šanovec. 37

List of tables

Table 1: The legend for map of Climatic regions in the Czech Republic (migesp.cz, 2016): ……………………………………………………………………………19
Table 2: Statistical results from study plot Ivančice ……………………………………………39
*Table 3: Statistical results from study plot Jedovnice……………………………………………*41
Table 4: Statistical results from study plot Soběšice ……………………………………………43
*Table 5: Statistical results from study plot Šanovec ……………………………………………*45
Table 6:Grange causality table results ……………………………………………………………47

1. Introduction

In general, it is important to know soil physical properties. The reason is that they can be a limiting factor in the forest ecosystem. Čermák, Staněk, Aubrecht in 2006 put forward a method describing the measurement of root absorbing surface. This method provides several information about tree health and root surface area. However, the goal of this work is to test the possibility of adding other information about the soil physical properties.

The added information from this measurement would provide two major advantages, compared to traditional laboratory analysis. First would be the electric current flow through bigger soil area and as consequence analysed information about soil physics cover this big area. In comparison to point sampling for laboratory analysis. Second advantage is this analyses is less time consuming and cheaper than laboratory analysis.

On the other hand the laboratory analysis results are very precise and give high valuable information about the sampled point.

So the added soil physical information would by great advantage in terms of time and economic costs.

Analyses of the connection between soil physical properties and soil resistivity were done in this experiment.

1.1. Hypothesis

The main goal of this work is to test the possibility of adding other information on soil properties to Cermak´s (Cermak et al., 2006) method for measuring root absorbing surface. Although it is not possible for the range of this work to cover and interpret all the mechanisms of soil resistivity, 27 soil physical and chemical properties were studied and a connection between 11 of them and soil resistivity was verified.

2. Literature review

2.1. Resistivity review

2.1.1. Tree physiology and its resistivity

Field measurements of tree roots have always been a complex operation. Trees have both big conducting roots and small fine roots. There are several methods for measuring big roots but the measurements of fine roots are demanding in terms of time, terrain sampling as well as laboratory work such as microscopy. This electrical method (modified earth impedance, concept of Wenner electrode array) is focused on quantification of root absorbing surface. The basis of this method is founded on the scientifically verified postulate that, “electric current flows as water flow from soil to tree roots”. The root absorbing surface can be calculated at different tree tissue and soil resistivity levels (Aubrecht 2006).

Tree root measurements in field conditions are a complex operation, especially for adult trees with big and complex root system. Root absorbing surface (or root absorbing zone) prevents the means for plants to obtain soil water (water solution with minerals and nutrients). If tree root system is connected to an electric circuit the power of ion flows from the energy source to the root tips. This is because root parts with bark are not a part of the electric circuit. The different levels of tree tissue and soil resistivity can describe a root absorbing surface (Aubrecht 2006).

Electrical conductivity of the trees (or plants) and resistivity are inversely related. It is mainly dependent on water in cells with the electron conductivity playing a minor role. Tree tissues are made of cells and water-filled intercellular space. In the case of healthy living cells especially woody cells, it has been proven to have big electrical resistivity (104 –1010 Ωm ; parallel for technical insulators class 2), however the electric conductivity is created by the water-filled intercellular space (Aubrecht 2006).

Although, water-filled intercellular space in tree or plant cells is mainly responsible for electric conductivity, there are other several conductive elements such as are vessels, tracheids and phloem sieve tubes. These elements are primary water conductors in plant anatomy and this is why they are also very good electric conductors hence also allows ion movements in tree (plant) body. These primary water conductors which are water filled are called apoplasts and act in parallel with the symplast to increase the total water conductivity of the tree or plant (Aubrecht 2006).

Because of different electric resistivity in vessels, tracheids and other tree body parts, the electric current flow is distributed heterogeneously, drive by the differences in electric resistivity of tree tissue. The living woody tissue has lower electric resistivity then dead heartwood (Aubrecht 2006).

The electric resistivity and conductivity are not constants in plant (tree) body (Aubrecht 2006).

Illustration of the principle underlying the earth impedance method in a hypothetical plan: (Aubrecht 2006).

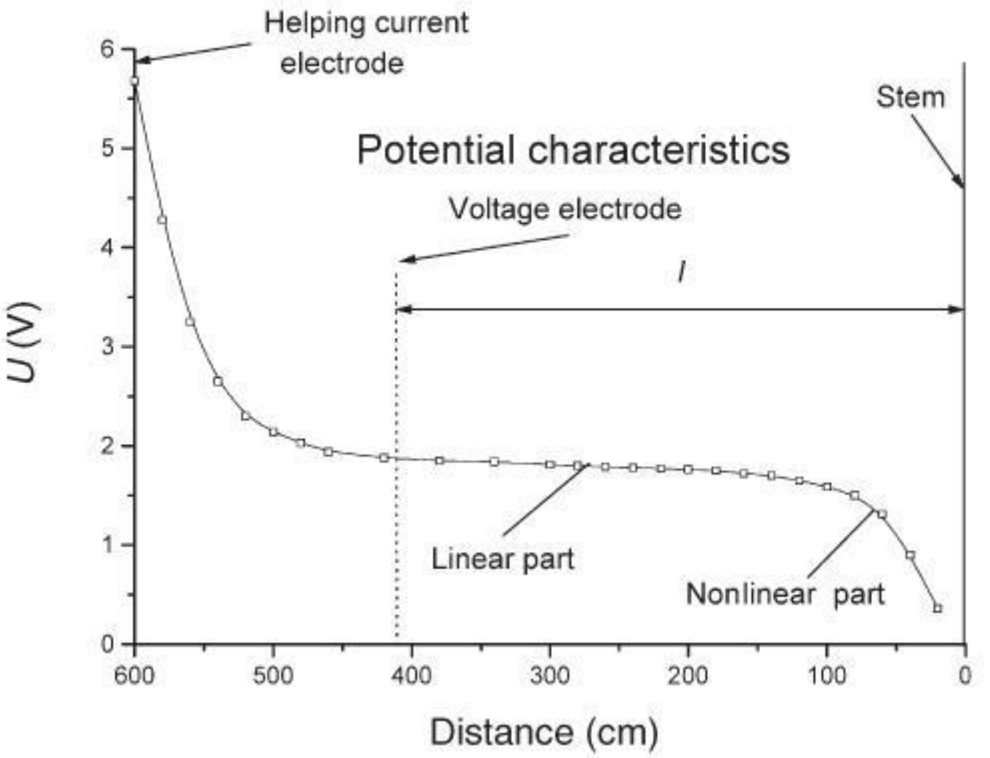

Figure 1: Curve with potential (or resistivity) values – y axe, distance on x axe [cm], I is current, U is potential [V] (or resistivity [Ω·m]) (Čermák et al. 2006).

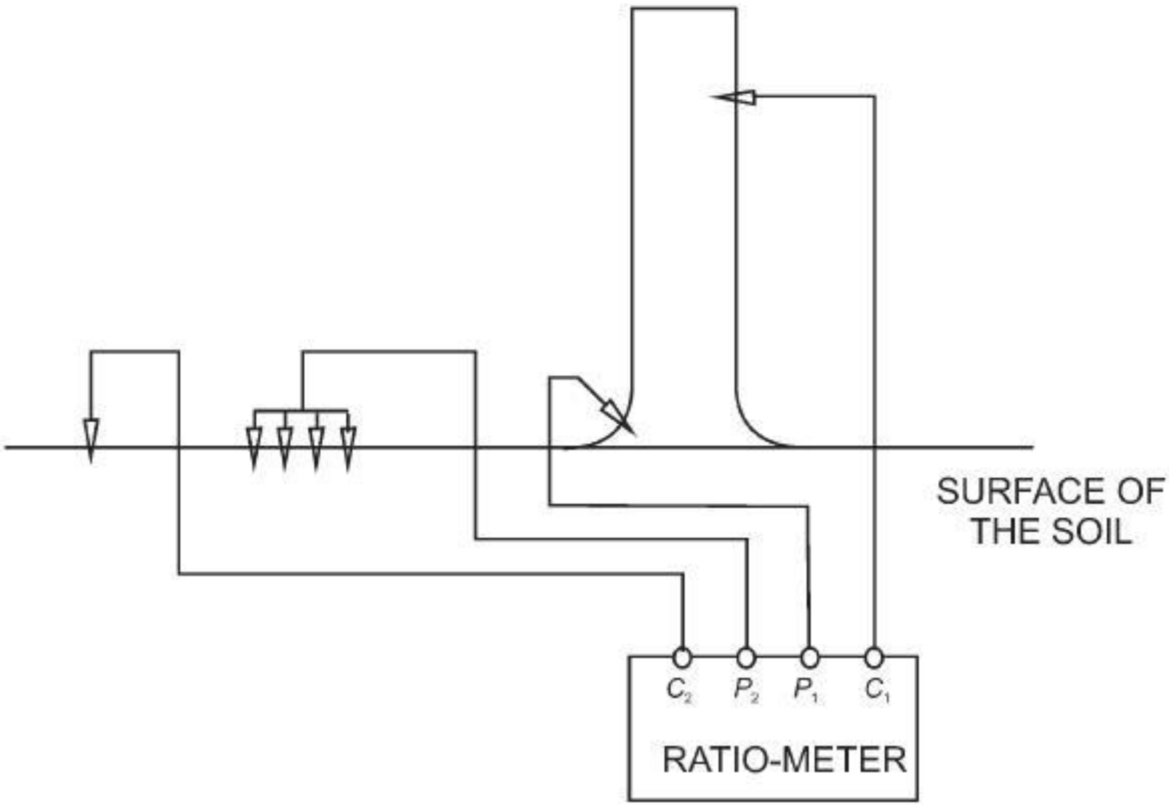

Figure 2: Scheme of measuring device and electrode connections in situ. Simplified example. C1 is current electrode in tree – stem, C2 is current electrode in soil (multiple electrode), P1, P2 are potential electrodes; modified Wenner electrode array (Aubrecht et al. 2006).

2.1.2. Direct current resistance method

The use of these methods is in measuring changes in electrical resistivity in analyzed environment. It is often used in geology to find the barriers between crystalline and sedimentary rocks. Also in hydrogeology, engineering geology, technical research in slopes deformation, ecology, analyzing of polluted environment and in plant physiology especially tree-ecophysiology method published by Čermák et al. (Pospíšil, Šutora 2003; Čermák et al. 2006; Aubrecht et al. 2006).

Resistance profiling and resistance probing are the most commonly used measuring techniques for mapping in horizontal and vertical directions respectively (Pospíšil, Šutora 2003).

2.1.3. Resistance profiling

This is used for horizontal direction mapping. In this method the electrodes are in one profile axe and along this axe the electrodes can be moved to measure the changes in electrical resistivity. Deep measurements vary and are dependent on the distance between electrodes e.g. Wenner electrode array (Pospíšil, Šutora 2003).

2.1.4. Soil resistivity and soil structures

Soil resistivity [Ω·m] is the resistance [Ω] of soil cube (1-meter-long) measured on opposite sides. The parent rock has always had big resistivity, e. g. new granite has hundred million Ω·m resistivity. The conducting environment is composed from soil, moisture and ions (inorganic and organic matter).

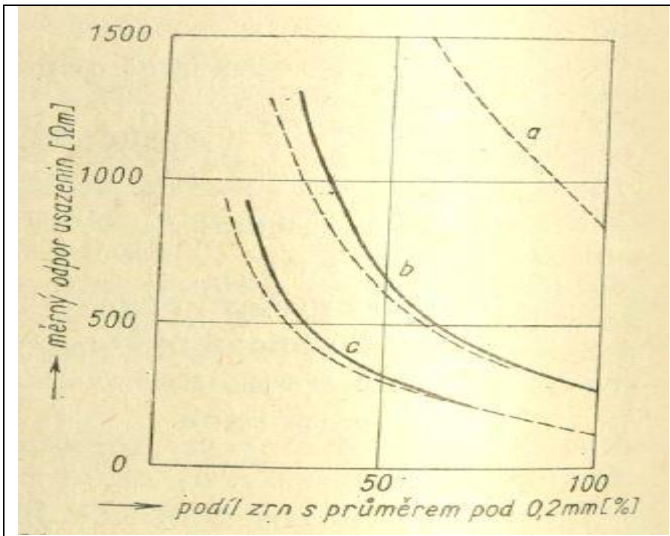

Figure 3: Resistivity as a function of the proportion of fine grained sediment total volume

----- theoretical finction

___ corrected finction

Měrný odpor usazenin – Soil resistivity of the sediment

Podíl zrn s průměrem pod 0,2 mm % - The proportion of grains with a diameter below 0.2 mm (Novotný 1973, modified).

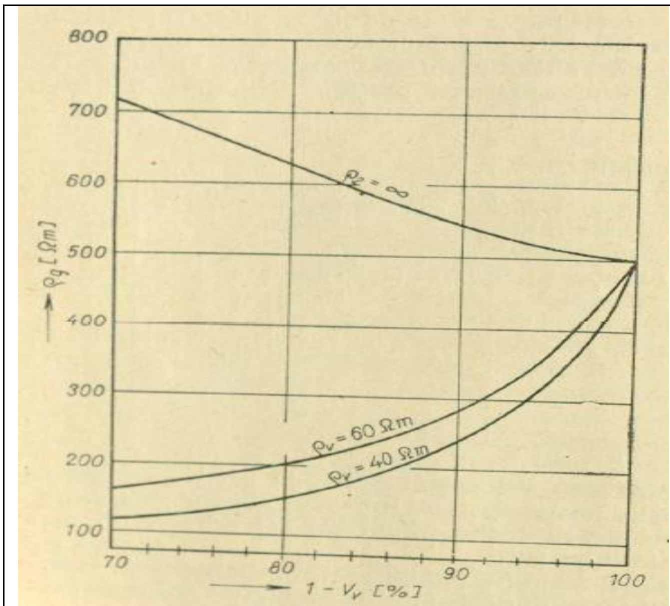

Figure 4: Resistivity of volume fraction water solutions on a solid part of the soil (Novotný 1973, modified).

Soil is composed mainly of silica and silicates and also from sulphates, phosphates and chlorides. A number of these depend on the parent rock. The silica and silicates act as insulators and soil conductivity is caused by moisture and salts (ions). Soils composed of silicates and poor in carbonates possesses low conductivity. On the other hand, carbonate rich soils from calcites or dolomites have high conductivity. This soils contain up to 20% carbonates, mainly calcium carbonate and magnesium carbonate. Due to the carbon dioxide in soils, there is the production of soluble carbonic acids which cause soil conductivity to increase (Novotný 1973). Soil physics deals with soil particle, size and quantity. Soil particles with water form an active surface which enhance conductivity conditions but negatively affects resistivity. Sandy soils cannot hold water for long. It dries up quickly and its resistivity is between 200 and 600 [Ω·m] in wet conditions and between 500 and 1500 [Ω·m] in dry conditions. Loamy and clay soils are able to hold water and their resistivity is between 20 and 200 [Ω·m]. However clayey soil in dry conditions can have higher resistivity than loamy soil (Novotný 1973).

2.1.5. Water and resistivity

There are three main types of water in soils. They are; hygroscopic water, capillary water and leaking water. The hygroscopic water is not able to aid in electric conductivity because it is held tightly to the soil particle (Novotný 1973, The free dictionary 2015).

2.1.6. Electrodes and resistivity

The soil resistivity has three main parts. These are the inner resistance of device, the resistance of the contact between the electrode and soil and the last part is the resistance of soil. Resistance of device is affected by the material it is composed of, quality of device, corrosion and etc. The resistance of the contact between the electrode and soil is affected by the electrode material, shape, size, corrosion as well as the contact environment (Novotný 1973).

2.1.7. Granger causality

Granger causality was published by C. W. J. Granger in 1969. The main advantage of Granger causality is that it theoretically proves the causality between two variables. This is done by mathematical statistics hence the analyses provide no information on the underlying structure of causality. The Granger causality between two variables proves the existence of a correlation between the values of one variable and the other having lagging values (Cipra 2013, Granger 1969, Granger 1969, Eichler 2011, Kočenda and Černý 2014).

Granger test results is in three dimensional states. Using x and y as the variables being understudied, the three main states are; if x Granger causes y, if y Granger causes x and finally the feedback casualty between x and y. If x Granger causes y and y Granger does not cause x; x is exogenous. Last state: if x does not Granger causes y and y does not Granger causes x; then x and y are Granger-independent (Cipra 2013, Granger 1969, Granger 2011, Kočenda and Černý 2014).

Appropriate lag length was chooses by minimizing Akaike information criteria (AIC).

2.2. Soil physical properties

2.2.1. Density [g/cm3]

Soil density is the weight of one cubic centimetre of soil without pores or water, units [g/cm3].

This is a basic soil feature mostly used in several calculations such as porosity. Soil density depends on the density of the various parts the makeup the soil such as minerals, humus. The heavy minerals like magnetite, hematite, and grenadier increase the density and amount of humus decrease the density (Baver 1972, Hanks 1980, Pelíšek 1957, Rejšek 1999).

The average density in local soils (Czech Rep.) is 2.6 g/cm3. The common range for mineral soils is 2.3 to 3.0 and in humidified soils and peat soils is less than 2.0 or even 1.5 g/cm3. Density of soils varies with varying distribution of humus. The top soil layers with high amount of humus are lighter than deep soil layers with low amount of humus (Pelíšek 1957, Rejšek 1999).

2.2.2. Dry mass S^h [%]

Fraction of dried soil and air humidity in percentage of weight [%]. Amount of dry mass S^h is equal weight of dried soil sample minus weight of water content, which is sourced by normal air humidity. Dried soil sample is dried to constant weight, after drying at 105°C (Hanks 1980, Pelíšek 1957, Rejšek 1999).

2.2.3. Volumetric weight [g/cm^3] and Reduced volumetric weight [g/cm^3]

Soil volumetric weight is the weight of one cubic centimetre of fresh soil including pores or water measured in [g/cm^3]. Reduced volumetric weight is the weight of one cubic centimetre of dried soil, after drying at 105°C, including pores, but without water measured in [g/cm^3] (Pelíšek 1957, Rejšek 1999).

The volumetric weight is a soil feature which describes the weight of soil in natural conditions. Volumetric weight is affected by volume of pores, amount of humus, edaphic life, the soil structure and artificial treatments (Pelíšek 1957).

2.2.4. Porosity

Porosity is an important feature, which is interconnected with amount of soil air and soil water. Porosity is defined by volume ratio of pores to volume of the soil sample measured in volume percentage [%] (Baver 1972, Hanks 1980, Pelíšek 1957, Rejšek 1999). The soil matter is composed from solid soil particles and pores, which are full filed by water or air or both. In heavily moist soils the pores are fully filled by water and in over dried soils the pores are full filled by air. The pores in soil differ in size (capillary pores are smaller than 0.2 mm and non-capillary pores are bigger than 0.2 mm) and in shape. Both properties are related to water mobility and aeration of soil. Non-capillary pores transmitting gravitational water and these pores have no tension. Pores 0.2 – 0.03 mm in diameter transmits capillary water that are very mobile. Pores 0.03 – 0.003 mm in diameter transmits capillary way that has moves with some difficulty and pores with diameter smaller than 0.0003 transmits capillary water that is very difficult to move (Pelíšek 1957).

Porosity is dependent on the amount of clay particles, soil structure, sorption, amount of humus, root penetration, edaphon, etc. Higher porosity leads to high flow of soil water and soil aeration. Also soil sorption affects porosity. The calcium and magnesium makes porosity higher because of their solid and stable structure in soils. On the other hand, sodium lowers porosity because of its destruction effect on soil structure. Root penetration and flora cover and edaphon increases the porosity (Pelíšek 1957).

The lowest percentage of pores is in sandy soils. The theoretical value is 25.95%. The highest percentage of pores is in the soil's upper layer with high amount of leaf fall (litter) and humus. The theoretical value is between 80 – 95%. The average percentage of pores is in forest soils ranging between 45 – 55% (Baver 1972, Pelíšek 1957).

With increasing depth, the amount of soil pores decreases (Baver 1972, Pelíšek 1957).

Forest soils have bigger amount of pores than non-forest soils, however the extremes in porosity (low or big value) negatively affects the soil structure. Broad-leaf forests have higher porosity than coniferous forests (Pelíšek 1957).

2.2.5. Aeration and minimum air capacity

The non-capillary pores of soils are fully filled with air. The (actual) aeration is defined by volume ratio of pores fully filled with air to volume of the soil sample. The minimum air capacity is volume of non-capillary pores (pores bigger than 0.2 mm). This describes a situation, where all capillary pores are fully filled with water or by the formula: minimum air capacity equals porosity minus maximum water-bearing capacity, units in volume percentage of [%] (Baver 1972, Hanks 1980, Pelíšek 1957, Rejšek 1999).

Aeration and minimum air capacity is affected by grain composition of soil and soil structure. Aeration decreases as clay particles of a soil increases and increase in soil particle size increases the volume of soil air. The highest aeration is in soil upper layer with high amount of leaf fall (litter) and humus (Pelíšek 1957).

Fertility and ecologic characteristics such as poor root development are strongly connected with minimum air capacity. Soils with low value of minimum air capacity are often muddy and this decreases biological activity, impedes humification process and reduces physiological depth. On the other hand, soils with high minimum air capacity are often very dry with poor water regime as in low water-bearing capacity (Baver 1972, Pelíšek 1957).

2.2.6. Soil moisture

Water in soils is critical in connecting the plant and the ground. The soil water functions can be categorized as soil-forming, biological and vegetation. Amount of soil water and its dynamics are variable. They change with respect to changing seasons, soil structure or soil depth. Water regime is strongly affected by grain composition of soil that is amount of clay particles, dust particles and sand particles influences soil’s water regime. Lightweight soils with low amount of clay particles are more permeable and with lower water-bearing capacity than heavy soils with high amount of clay particles. Heavy soils have low permeability of water and high water-bearing capacity hence the water is less availability for plants (Baver 1972, Pelíšek 1957).

Availability of water to plants presents two main categories of water. Water can be termed available or non-available. Available water is held by the capillary and non-capillary pores and it also encompasses gravitational water. Non-available is held by forces greater than the root's suction forces hence are not available to plants (Pelíšek 1957).

2.2.7. Hygroscopicity [%]

Hygroscopic water is soil water around soil particles, held by adhesive molecule forces between soil particles. The amount of hydroscopic water is measure in volume percentage [%]. It is a maximum volume of hygroscopy water at relative air moisture. The volume of hygroscopic water is affected by relative air moisture, temperature, soil structure and composition of colloids. Hygroscopicity increases with increasing relative air moisture and increasing colloid volume. Hygroscopicity decreases with increasing temperature. Hygroscopicity value is essential for calculations such as Active soil surface, lentocapillary point (Pelíšek 1957).

2.2.8. Wilting point [%]

Wilting point is defined as the minimal level of soil water required by plants to prevent wilting. This is thrice the hygroscopicity and also measured in volume percentage [%] (Pelíšek 1957, Vráblíková 1994).

2.2.9. Lentocapillary point in 33% [%]

The lentocapillary point is soil water surrounding soil particles in the form of thin liquid membrane. The thickness of membrane is irregular and is held by adhesive forces hence lentocapillary water is held tightly. The lentocapillary point represents the volume of this type of water and transits from tightly held to mobile lentocapillary, capillary water measured in volume percentage [%] (Pelíšek 1957).

2.2.10. Decreased availability point [%]

The decreased availability point is a volume of soil water at the liquid water starts to by hard moveable and its plants availability is week, units in volume percentage of [%] (Vráblíková 1994).

2.2.11. Relative capillary moisture [%]

The relative capillary moisture is defined by ratio between actual moisture volume and maximum capillary capacity (the volume of capillary pores full filled by water) measured in volume percentage [%] (Pelíšek 1957).

2.2.12. Volumetric moisture [%]

Volumetric moisture is the proportionate volume of water in fresh sample compared with volume of fresh sample. The volumetric moisture is equal to soil water weight multiplied by reduced volumetric weight of the soil sample measured in volume percentage of [%] (Rejšek 1999, Vráblíková 1994).

2.2.13. Water-bearing capacity

Water-bearing capacity is the amount of water, which the soil is able to hold in given circumstances and for certain time (Pelíšek 1957, Rejšek 1999).

2.2.14. Maximum (Full) water-bearing capacity [%]

Maximum (Full) water-bearing capacity is amount of water in soil, which full filed all pores, capillary and non- capillary. This state of water can be held in soil layers close to ground water, units in volume percentage of [%] (Pelíšek 1957).

2.2.15. Maximum water-bearing capacity (2 hrs draining) and Water-bearing capacity (24 hrs draining) [%]

Maximum water-bearing capacity (2-hour draining) or Water-bearing capacity (24-hour draining) is volume of soil water held by soil for some time. This water in soil is held by capillary pores and also contains water held closely to soil particles. Maximum water-bearing capacity or Water-bearing capacity (24-hour draining) is measured by unbroken soil sample, carry out in iron ring and this volume of water is take in by capillary forces and held in process of draining, result in no non-capillary water is include. This is volume of soil water after 2 or 24 hours of draining, units in volume percentage of [%] (Pelíšek 1957, Rejšek 1999).

2.2.16. Actual water-bearing capacity [mm]

Actual water-bearing capacity is equal to maximum (Full) water-bearing capacity minus volumetric moisture. Actual water-bearing capacity is the amount of water needed to fill up the maximum (Full) water-bearing capacity. It gives a description of the actual state and measured by the volume of water in millimetres [mm] (Pelíšek 1957, Rejšek 1999).

2.2.17. Gravity water (1/2 hrs draining) [%]

Gravity water is the water removed in the first two hours of draining in the laboratory. It is measured in volume percentage [%]. Gravity water is controlled by gravity and moves in a vertical direction mainly in non-capillary pore since capillary pores are controlled by other forces. The main source of this water is precipitation. The rate of infiltration is dependent on the amount of non-capillary and capillary pores. In non-capillary pores, water moves by its weight whereas the pressure of the water controls the movement of water in capillary pores. This pressure in the case of capillary water movement must be higher than forces in the capillary pores because infiltration of water into capillary pores is inhibited (Pelíšek 1957, Vráblíková 1994).

2.2.18. Gravimetric moisture in dry sample [%] and Gravimetric moisture in fresh sample [%]

The gravimetric moisture is defined by weight ratio of volumetric moisture to the weight of the soil sample, units in the volume percentage of [%]. In gravimetric moisture in dry sample the ratio is between volumetric moisture and weight of dry sample and in gravimetric moisture in fresh sample the ratio is between volumetric moisture and weight of fresh sample (Rejšek 1999).

2.2.19. Pore saturation [%]

Pore saturation is the percentage of pores full filed by water. It is counted like volumetric moisture divided by porosity, units in the volume percentage of [%] (Hanks 1980, Rejšek 1999).

2.2.20. Available water holding capacity to 20 cm [mm] and Available water holding capacity to decreased availability point [mm]

Available water holding capacity is the amount of water, which can with used by plants, in respect their physiological demands. Available water holding capacity to 20 cm [mm] is water-bearing capacity minus wilting point, units in volume of water in millimetres [mm] and available water holding capacity to decreased availability point [mm] is water-bearing capacity minus decreased availability point, this is a characteristic related to soil water properties, not actual state. Units in volume of water are in millimetres [mm] (Pelíšek 1957).

Volume of available water depends on the amount of colloids in the soil. The light weight soils held a higher amount of available water than heavy soils with high amount of clay particles. The heavy soils held the higher amount of physiological unavailable water (Pelíšek 1957).

2.2.21. Accessible water supply to 20 cm [mm]

Accessible water supply to 20 cm describes an actual state of available water holding capacity (Rejšek 1999, Vráblíková 1994).

2.2.22. Soil texture

The texture is one of the most important soil characteristic, which forms with connections to the other important properties the soil body. Soil texture can be divided by grain size. The granularity means grain dividing after dispersion of aggregates. The shape and a size of grains depend on mature mineral and physical and chemical, mainly water and wind weathering.

In generally we can find rougher particles, including quarts and other silica particles in contrary to fine size particles, which are made with isinglass and clay. It is important to know, that small size particles have a bigger volume than bigger size particles.

Fraction I: Clay colloid particles (< 0.002 mm) [%]

Fraction I: Clay particles (0.01 – 0.002 mm) [%]

Fraction II: Dust particles (0.05 – 0.01 mm) [%]

Fraction III and IV: Sand particles (2.0 – 0.05 mm) [%] (Zbíral et al. 2010).

2.3. Chemical soil properties

2.3.1. Oxidizable carbon - COX

The organic matter in the soil is an important component of soil, especially for plants, which is a source of nutrition. As the organic matter is formed by carbon, it is possible to describe the amount of organic matter by the amount of oxidizable carbon. Soil organic matter consists of live part: roots, microbes, edaphon and dead part: humus, organic residues. However, the dead part is a major part (more than 90% of) and from dead part the proportion of humus is 70 – 90%. The amount of humus is connected with soil physical properties, chemical properties and capability of holding water. For evaluation of organic component in soil used method Oxidizable carbon described by Walkeley and Black (1934) (Rejšek 1999, Šimek 2007).

2.3.2. Soil reaction active and potential (pH)

The soil reaction is an important soil feature related to physical, chemical and biological process in soil. Soil reaction is affected by biotic and abiotic factors, it is part of soil-forming process and affect microbial life in soil and the microbial life affect the soil reaction. Soil reaction affects plants physiological process and plants physiological process affects the soil reaction (Pelíšek 1957, Rejšek 1999, Šimek 2007).

3. Material

3.1. Bioregion

Nature diversity differs from the topic (local) to global level and is characterized by two main groups of biogeography: individual biogeography and typology biogeography. The goal of individual biogeography is to define connected, relatively homogeneous areas, differ in biotic populations. Individual biogeography accentuated specific and non-repeated feature of the area. The goal of typology biogeography is to define a type of biotic and non-biotic parts in areas; chains of non-continuous area segments, which are repeated in landscape and has a similar ecology and similar biotic properties. The typology biogeography accentuated repeated features of the area (Culek 2013).

Since this thesis is focused on soil properties, for this purpose is chosen the Biogeographical region in Individual biogeography, follows the summary of units in individual biogeography.

3.2. Individual biogeography units

3.2.1. Biogeography provinces

In the Czech Republic are two provinces; the Middle-European broad leaf forests province and Pannonian province (Culek 2013, Samec 2014).

3.2.2. Biogeography sub-provinces

Biogeography sub-provinces are individual (non-repeated) units of biogeography diversifying of the landscape. Its biota has the characteristic diversity with the typical combination of geological elements and its specific endemic species. Inside sub-provinces are same or similar geological-morphological relief and macro climatic conditions (Culek 2013, Samec 2014).

In the Czech Republic are occurring four sub-provinces; Hercynian, Polonic, West Carpathian and North Pannonian (Culek 2013, Samec 2014).

3.2.3. Biogeography region

Biogeography region is an individual unit of biogeography landscape differentiation in regional scale. In the area of the same biogeographical region is the same vertical vegetation zoning. The biogeographical region is characterised by geological-morphological relief, mesonic climatic conditions and soil conditions. Biogeographical region describes the potential vegetation, not the actual state of landscape vegetation and it is specifying changed by human activity in varied state of intensity. In generally biogeographical regions describe high variation of landscape types. The area of biogeographical regions is between 102 —103 square kilometres (Culek 2013).

In the Czech Republic is determined 91 biogeographical regions by Culek (1996); 71 in the Hercynian sub-province, 4 in Polonic sub-province, 11 in West Carpathian sub-province and 5 in North Pannonian sub-province (Culek 2013).

3.3. Localities classification into biogeographical regions and its characteristics

The localities were chosen because they represent the most quality areas with next four classes of soil, which are different from each other, because of their soil texture. The study plot near Ivančice was chosen because it is a former area for bentonite mining, this soil type is special from point of water bearing capacity. The study plot near Soběšice was chosen because soil is developed on eolian sediment – loam as the parent material. The study plot Jedovnice was chosen because there is a parent material containing clay with an influence of ground water, therefore the soil is gleyic. The study plot near Hradec Králové was chosen because there is a typical sandy soil . Soils in Hradec Králové region are developed on sandy sediments.

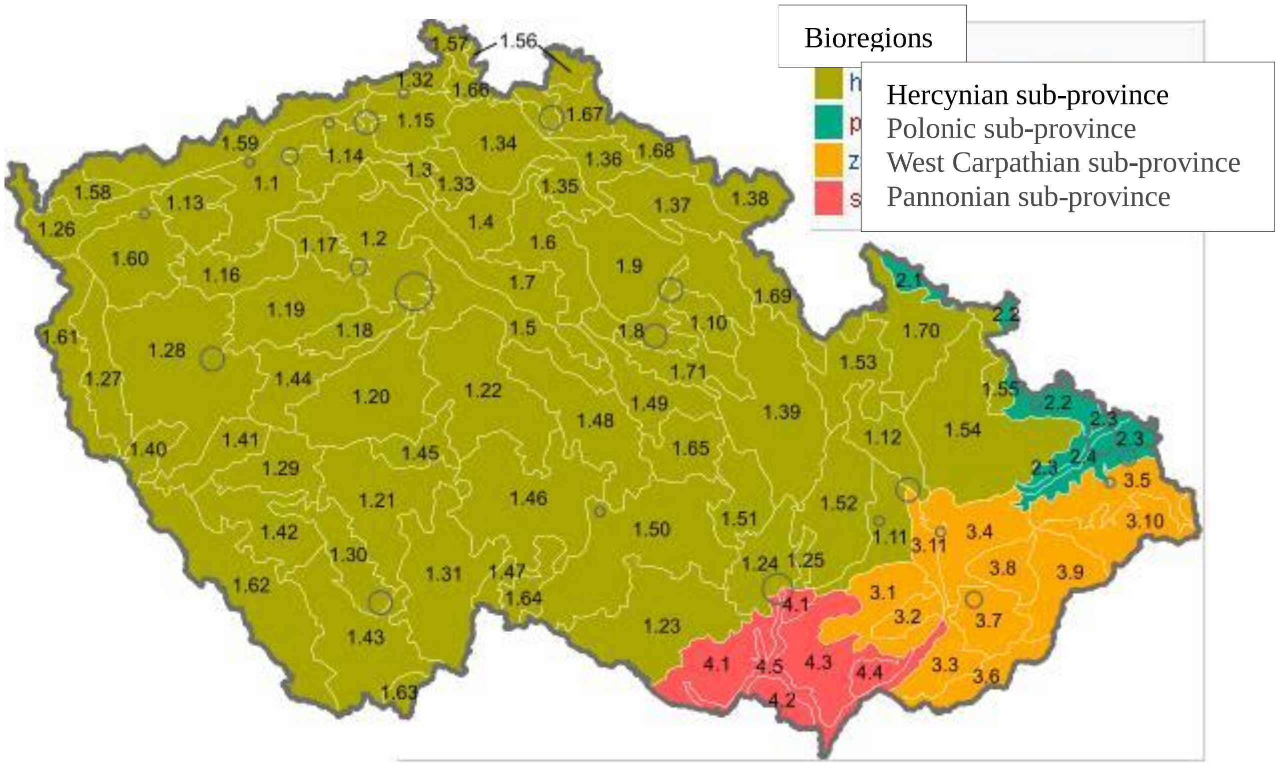

Figure 5: Biogeographical regions in the Czech Republic is determined by Culek (1996), modified.

Ivančice – 1.23 Jevišovice biogeographic region affected by 1.24 Brno biogeographic region

Jedovnice – on boulders of 1.25 Macocha biogeographical region and 1.52 Drahany biogeographic region

Soběšice – 1.24 Brno biogeographic region

Šanovec pound near Hradec Králové – 1.10 Třebechov biogeographical region

3.3.1. Hercynian sub-province

All localities are located in Hercynian sub-province and following description of the basic characteristics of this sub-province.

The biota of Hercynian sub-province (Hercynie) belongs to west and central middle-European unit. Flora is affected by geological sub-base of the Czech massive, mainly composed of acidic crystalline slate and deep volcanic rocks. On these rocks were developed acid and low nutrient soils. Alkaline and nutrient rich soils are occurred in small areas. The big part of the area is covered by sand stones, clay stones and argillite stones as components of the Czech Cretaceous pelvic. The landscape relief is mainly characterised by volcanic broken and arranged surface, groundswell to vary heights and eroded by stream valleys. The landscape relief is mainly shaped into the highlands and hills locally can be shaped into mountains (middle height mid mountains). At all area of Hercynian sub-province are located volcanic tabular basins and pelvic, fill in with Tertiary sediments. The climatic conditions are temperate, with the influence of oceanic climate and from the east is the patent influence of the continental climate. Lots of regional climatic specificity are occurring; temperature inversion in valleys, rainy shadow. In this sub-province is vertical vegetation zoning; from 1. *Quercus* vegetation zone to 8. sub-alpine vegetation zone (dwarf / bushes zone); in the highest mountains of Krkonoše biogeographical region (1.68, Figure 7). The most spread in the Czech Republic is the 4. *Fagus* vegetation zone (montane zone). The specific value of Hercynian sub-province is in wide spread cultural landscape (Culek 2013, Geology.cz 2016).

3.4. Characteristic of localities in subject of matter

3.4.1. General situation in the Czech Republic

Every locality in this chapter is regarded to one specific biogeographical region, or possibly it is regarded to two biogeographical regions, if there is a connection between the regions or if there is a contrasting comparison. Every sub chapter has four topics; general characteristic, relief and mountains, climatic conditions and the last one are soil conditions.

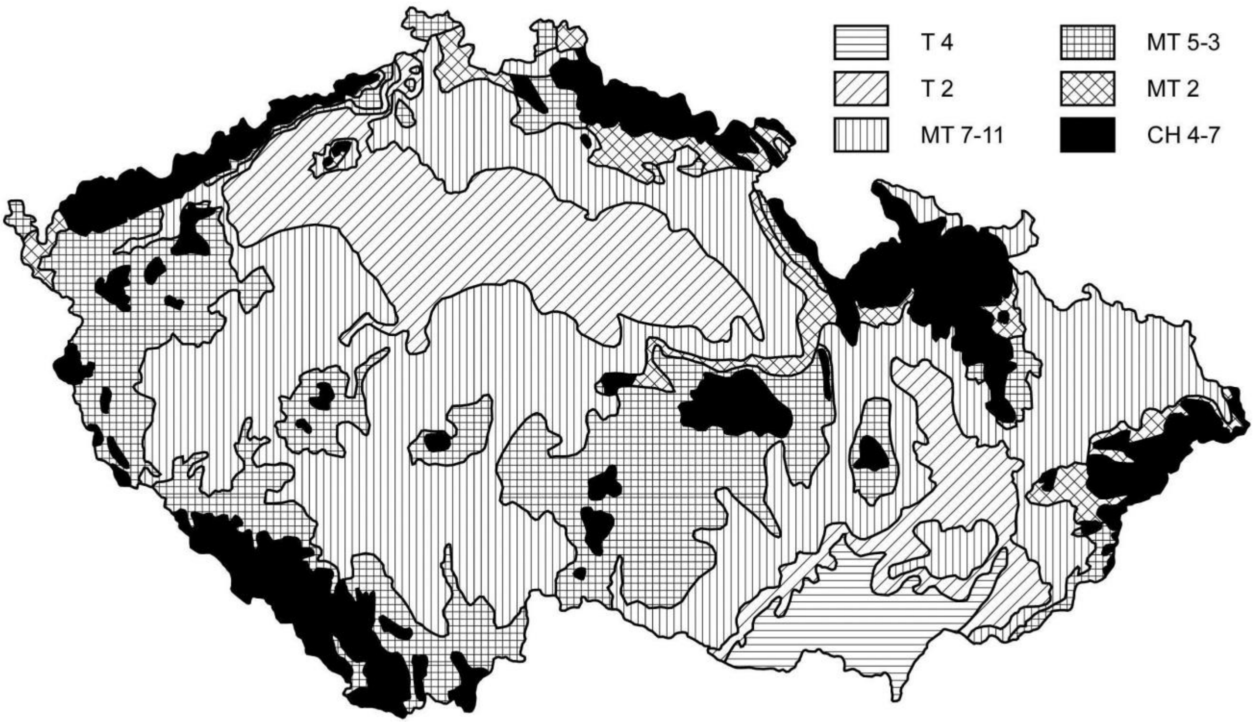

Figure 6: Climatic regions in the Czech Republic (migesp.cz, 2016).

Table 1: The legend for map of Climatic regions in the Czech Republic (migesp.cz, 2016):

	Teplá		Mírně teplá								Chladná		
	T2 oranžová	T4 červená	MT2 khaki	MT3 tmavě zelená	MT4 olivová	MT5 zelená	MT7 světle zelená	MT9 světle žlutá	MT10 žlutá	MT11 okrová	CH4 šedá	CH6 modrá	CH7 světle modrá
LetD	50-60	60-70	20-30	20-30	20-30	30-40	30-40	40-50	40-50	40-50	0-20	10-30	10-30
t I	-2 - -3	-2 - -3	-3 - -4	-3 - -4	-2 - -3	-4 - -5	-2 - -3	-3 - -4	-2 - -3	-2 - -3	-6 - -7	-4 - -5	-3 - -4
t VII	18-19	19-20	16-17	16-17	16-17	16-17	16-17	17-18	17-18	17-18	12-14	14-15	15-16
t IV	8-9	9-10	6-7	6-7	6-7	6-7	6-7	6-7	7-8	7-8	2-4	2-4	4-6
t X	7-9	9-10	6-7	6-7	6-7	6-7	7-8	7-8	7-8	7-8	4-5	5-6	6-7
sp	40-50	40-50	80-100	60-100	60-80	60-100	60-80	60-80	50-60	50-60	140-160	120-140	100-120

The legend for map of Climatic regions in the Czech Republic:

Teplá = Warm climatic region;

Mírně teplá = Moderately warm climatic region;

Chladná = Cold climatic region;

LetD = number of summer days per year;

t I = average January temperature [°C];

t VII = average July temperature [°C];

t IV = average April temperature [°C];

t X = average October temperature [°C];

sp = average month precipitation [mm / m^2].

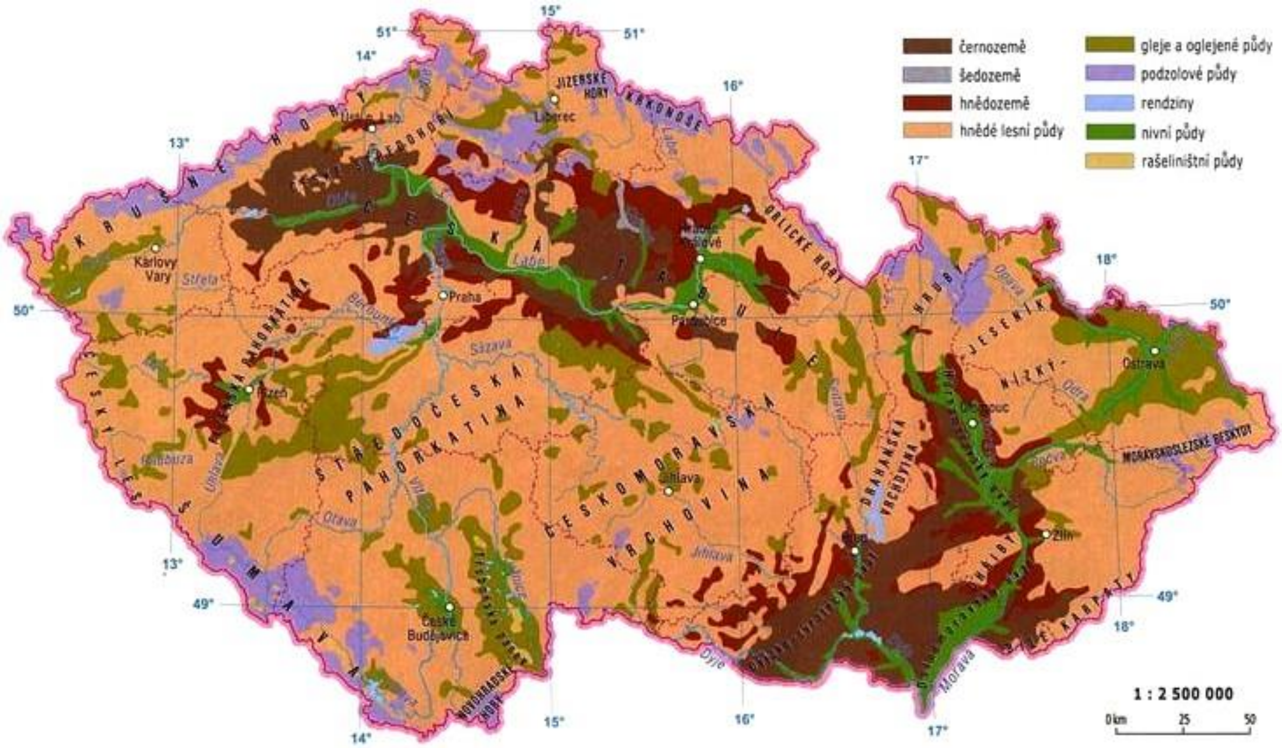

Figure 7: Soil types map of Czech Republic (Šára 2005, WRB 2006.)

černozemě = *chernozems;* *Gleje a oglejené půdy* = *gleysols*

šedozemě = *greic phaeozems;* *podzolové půdy* = *haplic podzols;*

hnědozemě = *haplic luvisols;* *rendziny* = *rendzic leptosols;*

hnědé lesní půdy = *forest haplic luvisols;* *nivní půdy* = *fluvisols;*

rašeliništní půdy = *histosols.*

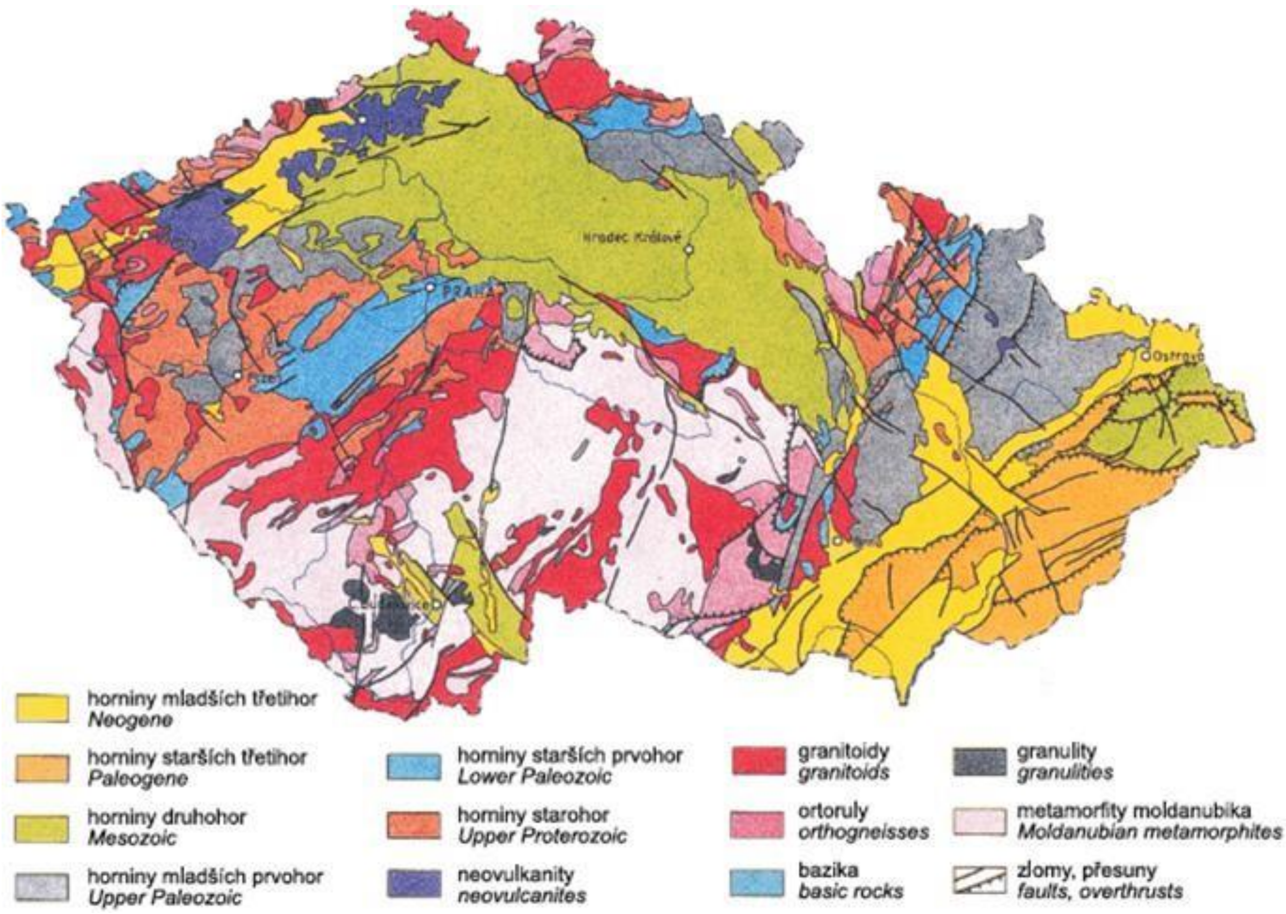

Figure 8:Geological map of the Czech Republic (Šára 2005).

3.4.2. Ivančice in Jevišovice biogeographical region

More or less is coincides with geo-morphological unit Jevišovice upland. It is created by small areas of crystalline slate, discontinued by rocks valleys. This area is transmitted between two biogeographical regions: Pannonian and Hercynian. The thermophilic fauna and flora intersect by valleys to the west and in opposite because of the inversion process piedmont fauna and flora transmitting to low lands east end of the area. The forests in valleys have the native species composition and are very valuable. On plates prevails agricultural land and human made forests with *Pinus* and *Picea* species. The history of human use is from Neolitic Age and its rapid increase in Bronze Age, which made this region special from rest of the Czech Republic. The typical use of the uplands was pasture. The rich composition of biota in deep valleys was changed by construction of water reservoirs (Culek 2013).

Topography

The geological characteristics of this large biogeographical region are very rich. In the east side of the region is formation of calcificated Permian conglomerates and in the Boskovická brázda are Miocene sediments in sand and clay form in small scattered areas. The landscape topography of dissected upland is created by contrasting deep river valleys (Oslava river) and coherent land tables. The lowest point is on river valley of the Jihlava river near Dolní Kounice city (190 m a.s.l.) and the highest point is Klučovská mountain (595 m a.s.l.) (Culek 2013).

Climatic conditions

Moderately warm and dry clime (MT11 – MT5) (Figure 8, Table 1) depends on sea level; the warmest area is in the south east area of the region (T2) (Figure 8). This region is affected by rainy shadow cost by Českomoravská vrchovina (uplands), this effect graduated to the east. The winters are dry and relatively cold with temperature inversions (referred to local name Moravian Siberia). The River valley is characterised by high temperature fluctuations in down level of the valley, but also extreme climatic conditions of exposing slopes; with very dry and high temperature south oriented slopes and wet cold north oriented slopes, especially at the bottom (Culek 2013).

Soil conditions

In south dry part of the region are alternated areas of saturated typical cambisols and haplic luvisols on loess and loess loam. On the east part of the region are spread in several scattered areas forest haplic luvisols and chernozems. The River valley is characterised by a mosaic of varied soils; lithic leptosols, leptosols, rendzic leptosols and on serpentine are developed rendzic leptosols with magnesium. Calcic leptosols are developed on limestones and perm conglomerates (Culek 2013, WRB 2006).

3.4.3. Jedovnice in Macocha and Drahany biogeographical region

The main part of Jedovnice cadastral territory is in area of Drahany biogeographical region (1.52) (Figure 7), the east boulder of Jedovnice in in Macocha biogeographical region (1.25) (Figure 7). Drahany biogeographical region is spread on monotonous culms sediments which created the Drahany upland. In this area is relatively high percentage of forest cover; however the dominating is agricultural land. The water streams are represented by autochthonous streams, however some human made pounds are presented, and the largest one is Olšovec pond near Jedovnice. In opposite the Macocha biogeographical region is created by limestones tables erupted by rock valleys with very wet conditions, caused by geomorphological characteristics of Moravian karst, with developed karst phenomenon and related unique vegetation and small fauna (Culek 2013).

Topography

The most of the Drahany biogeographical region is developed on monotonous culm (flysh) sea sediments; slates, graywackes and in the south part of the region are developed conglomerates. The central part is created by the concave table with character of dissected uplands (sectors up 75 – 150 m); often are steep slopes with dominant faults located on the boulders of the region. The most of the Macocha biogeographical region is created by pure Devonian limestones. Just party there is integrated granodiorite from the Brno massive or Devonian sandstone created by orogeny process. In the central part of karst are deep karst depressions fulfilled by decomposed rocks from the Jurassic period and Cretaceous period; clay stones, sandstones, roundstones (pebbles). Macocha region is developed into the dissected uplands (sectors up 150 – 200 m). The region is dissected by very steep and deep valleys, which in the north part of the region created by karst canyons or gorges with the minimum of water streams. Macocha Abyss is the characteristic unit of this region (Culek 2013).

Climatic conditions

Moderately warm clime is typical for Drahany biogeographical region with significant temperature gradient from boulders to central part; 6, 2°C to 8,4°C is an average year temperature and 649 – 550 mm average year precipitation. The medium wet conditions are typical for Drahany biogeographical region.

The Macocha biogeographical region is spread in two climatic regions; moderate warm climatic region MT11(Figure 8) on the south with warm and dry clime and moderate warm climatic region MT3 (Figure 8) on the North with cold and wet clime with comparing to MT11 (Figure 8). The extreme example of inverted temperature conditions is at the bottom of Macocha downfall (Culek 2013).

Soil conditions

In the top of Table 1. part in Drahany biogeographical region are developed dystrophic cambisols and in lower elevations are typical cambisols, often affected by gleying forming process, nowadays without influence of water.

On the east borders are developed typical haplic luvisols, on the limestone parent rock are rendzic leptosols (de calcified).On the surface termination of limestones in slopes of Macocha biogeographical region are developed de calcified rendzic leptosols. In specific areas, where are the surface layer not covered, are in fragmented areas, relict karst soils; *terra fusca* and *terra rossa* (Culek 2013, WRB 2006).

3.4.4. Soběšice in Brno biogeographical region (partly Ivančice and Jedovnice)

The biogeographical region is located on the east border of the Hercynian sub-province and it is developed on the edge of Hercynian upland. This region is under strong influence of the Carpathian and Pannonian sub-provinces. The biogeographical region is composed of granodiorite rock ridges and ramped valleys with loess. There are preserved areas of native *Quercus-carpinetum* and *Fagetum*, especially in Svitava valley and native meadows. Cultural land is represented by typical agricultural land and constructed human habitats. The largest water reservoir is the Brno dam. However, there is a small amount of pounds (Culek 2013).

Topography

The region is developed on Brno proterozoic massive; created mainly by amphibole granodiorite, locally by diorite and old whinstone. The massive is distorted by past volcanic activity and vary from Variscan massive located on the west. In the Babí lom () on Moravian karst boulder are developed extremely hard and acid Devonian conglomerates and soft claystones. Locally are occurring surface layers created by loess, the cover can be up to 10 metres deep. Often type of cover is sand loamy slopes. The region is tilted from north to south. The relief is created by ramp valleys and hills. The ramp valleys are characterised by flat, concave bottom (floor) created by loess. High level of biodiversity is caused by combination of factors; valley phenomenon in Svratka and Svitava basins, varying geological-morphological character of the local landscape. The lowest point is in the river bed of the Svratka and Svitava rivers (190 m.a.s.l.) and the highest point is Hořická mountain (596 m.a.s.l.) (Culek 2013).

Climatic conditions

The most of the region belongs to the moderate warm climatic region (MT11) (Figure 8, Table 1), the borders of the region belong to warm climatic region T2 (Figure 8) and the top areas of the region are moderate warm, belong to MT11 (Figure 8) climatic region. Climatic conditions are relatively warm and dry as a consequently low levelling and rain shadow caused by Českomoravská vrchovina .

Climatic conditions are strongly affected by dissecting landscape relief; there are common high temperature fluctuations and dry and warm clime of south oriented slopes (Culek 2013).

Soil conditions

There are haplic luvisols turning to chernozems on loess in lower elevations. On rock ridges are typical cambisols and albeluvisols in base of hills. In rock valleys and on tops of hills due to geological conditions are developed in different variations of soils; vary in types of lithic leptosols, leptosols, typical rendzic leptosols on limestone rock (Culek 2013, WRB 2006).

3.4.5. Šanovec pond near the Hradec Králové city in Třebechov biogeographical region

This small biogeographical region is spread on gravel-sand terrace with east alms. It is specificity by *Fagus* in lowlands and present of azonal associations on sandy soils, moorlands and peat lands. The human made *Pinus* forests are dominated, but there is the *Pinus* native species. There are preserved fragmented *Fagus* forests, native mixed forest with dominant *Quercus* and wide spread flood plain grasslands along a meandering the Orlice river. The acidophilic vegetation is typical for this region. Water bodies are represented by the Orlice river with dead arm of the river and often ponds (Culek 2013, Geology.cz 2016).

Topography

The relief is simple, but special. On parent rock from Turonian alms are conversed wide spread terraced tables, formed from acid fluvial gravels, sands and areas with a thin layer of blow sands. In monotony relief dominated terraced tables dissected by low frequently occurred shallows valleys.

The central axes of the area are represented by a flat basin of the Orlice river, bordered by 32 metres high descent relief on the south. According to the topography is flat upland relief segmented 30 to 75 meters. The lowest point is 230 m.a.s.l. The edge of the floodplain and the highest 354 m a.s.l. is Chlum (Culek 2013, Geology.cz 2016).

Climatic conditions

The region belongs to a moderately warm climatic region (MT2) (Figure 8, Table 1), nearing to warm climatic region (T2) (Figure 8, Table 1). The region has a sufficient supply of precipitation; average month precipitation is 80-100 mm / m^2, with increasing precipitation from east. However, the winters are common with low level of snow cover (Culek 2013).

Soil conditions

On the acid gravels sands soils are dominated acid cambisol with transition to cambisol podsols. Or transition of acid cambisol up to ferric podsols. In surface termination (surface outlier) of decalcification alms are developed pseudo-gleyey calcic leptosols. In river plain are developed mostly gleyic fluvisols, around the Divoká Orlice are a typical fluvisols. In waterlogged depressed lands on the sands are developed deposits of histosols (Culek 2013, Geology.cz 2016, WRB 2006).

4. Methods

4.1. Field methods

4.1.1. Resistivity measurement

Resistivity measurement was obtained by method published by Čermák in 2006: modified earth impedance method developed for measuring absorbing root surfaces. The two current electrodes was applied into the tree stem (C1) and into the soil (C2) and potential electrodes applied into the soil, net to the tree stem (P1) and into the soil in eighteen steps of increasing distance (P2), for example of application of multiple electrode C2 (Figure 9) and schematic example of measurement (Figure 10). The distance between tree stem and (P2) potential electrodes was [cm]: 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 350, 400, 450, 500, 600, 700 and 800. This operation was repeated four times for each side of the tree; North, South, East and West (Aubrecht 2006, Čermák 2006).

4.1.2. Soil sampling

On every locality were sampled 20 Kopecký iron rings and 4 soil probes in 3 depths. The sampling was done around the measured tree and every 5 Kopecký iron rings and 1 soil probe (3 deeps) for each side (North, South, East or West) were taken (sampled).

4.2. Laboratory analysis

4.2.1. C_{ox} detection by spectrophotometer after chromosulforic acid (type A) oxidation

For this analysis, we need to prepare fine soil II. The weight of each of soil samples depends on mineral or non mineral horizon. For probes detection we used weight of 0.5 g and for iron rings we used 0,2 g. To the each of soil samples we add 5 ml of potassium dichromate c($K_2Cr_2O_7$) and 7, 5 ml of sulphuric acid (H_2SO_4). After 30 min heating we need to decrease temperature to 25 °C, and then we add 50 ml of H_2O and shake it. Then we can add more H_2O up to 100 ml. After 60 min we can centrifuge part of this solution and after centrifugation need to be analyzed by spectrophotometer. The wavelength of 585 nm is the best for final detection.

For the final recalculation we have to use special formula:

Cox= (a/m) x (100+w)/100

Cox.......................................amount of oxidizable carbon

a..amount of organic carbon in soil sample [mg]

m...weight of soil sample [g]

w..water content depends on dry mass [%] (Zbíral 2011).

4.2.2. Soil reaction active and potential (pH) by VÁLEK (1954) and ISO/DIS 10390 (1992)

For this analysis, we need to prepare fine soil I. For active reaction we will weight 10 g each of soil sample and add 25 ml H_2O shake them for 5 min and then leave them for 2 hours. After this time we can use pH meter for detection of soil active reaction.

In the case of soil potential reaction we will use the same procedure, but instead of H_2O we will add 25 ml of potassium chloride (KCl) after 24 hours we can measure soil potential reaction (Rejšek 1999).

4.2.3. Soil texture

For the laboratory analysis, we need to weight of 10 g or 20 g dry fine soil I. it depends on heavy or light soil type. After that it is necessary to add dispersing agent (sodium polyphosphate $(NaPO_3)_6$ and sodium carbonate (Na_2CO_3)) after adding, we have to leave them for 24 hours into the room temperature. The next step is boiling for 1 hour. After boiling we sieve the soil solution through 0, 25 mm. soil samples are placed into the sedimentation cylinders (1000 ml) and filled up to 1000 ml. we need to take exactly 25 ml in 10 cm, 15 cm, ect. And place into the separate containers. The last step is weighting dry soil sample and soil sample in solution. All obtained data are very important for final calculation (Zbíral et al. 2010).

4.2.4. Density and reduced density - gravimetric determination

For this analysis, we need fresh soil samples in Kopecký iron rings (100 cm^3) and laboratory scales. After terrain collection we need to know actual weight – weighting iron ring with lids. Then it is necessary to leave all iron rings for 24 hours soak up water and then weight ones more. The next step is water draining for two hours and weighting. The last step is oven drying for 6 hours at 105 °C and then weighting.

ρ_d =(c-a)/V

ρ_d .... reduced volumetric weight [g/cm^3]

c .... weight of Kopecký iron rings and lids and soil sample dried to constant weight (g)

a .... weight of Kopecký iron rings and lids [g]

V .... volume of the Kopecký iron ring [cm^3] (Rejšek 1999, Zbíral et al 2010).

4.2.5. Soil density determination by pycnometer

From each of Kopecký iron rings we need to prepare fine soil I dried to constant soil moisture and Gay-Lussac pycnometer. We need to measure several parameters. Important is to weight of pycnometer with water, weight of dry soil sample (amount about ¼ of pycnometer). After that we have to heat pycnometers with soil samples and with H_2O for 30 min. after boiling add H_2O up to full and weigh.

Specific weight

$\rho_s = m_1/((m_1-m_2)m_3)$

ρ_s ....specific weight [g/cm^3]

m_1 ....weight of dried soil to constant state [g]

m_2 ....weight of pycnometer with H_2O [g]

m_3 ....weight of pycnometer with the soil after boiling and filled by H_2O [g] (Rejšek 1999).

These numerical calculations are basic for next calculations, after that we can obtain more physical parameters including: maximum (Full) water-bearing capacity [%], gravity water (2 h draining) [%], maximum water-bearing capacity (2 h draining) [%], water-bearing capacity (24 h draining) [%], Hygroscopicity [%], wilting point [%], lentocapillary point in 33%, decreased availability point [%], Volumetric moisture [%], Available water holding capacity to 20 cm [mm], Available water holding capacity to decreased availability point [mm], Accessible water supply to 20 cm [mm], Actual water-bearing capacity [mm], Dry mass [%], Volumetric weight [g/cm^3], Reduced volumetric weight [g/cm^3], Gravimetric moisture in dry sample [%], Gravimetric moisture in fresh sample [%], Porosity [%], Soil aeration [%], Minimum air capacity [%], Relative capillary moisture [%], Pore saturation [%] (Rejšek 1999, Zbíral et al 2010).

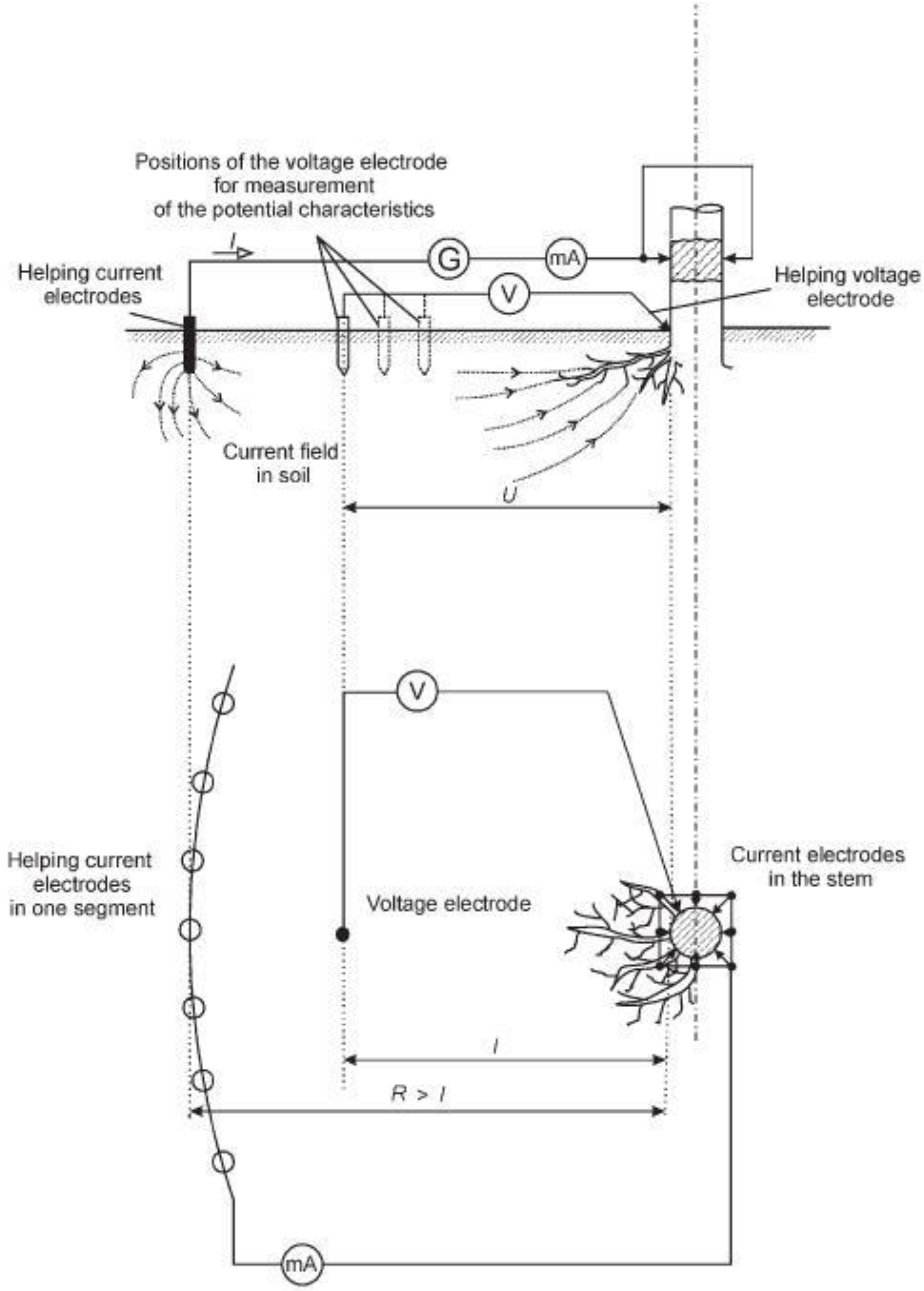

Figure 9:Scheme of measured tree, electrode connections and position, in situ. Simplified example. G is low frequency energy source, V is voltmeter, mA is miliamperemeter, I is current with direction, R is radius of the circle – position of multiple electrode (Čermák et al. 2006).

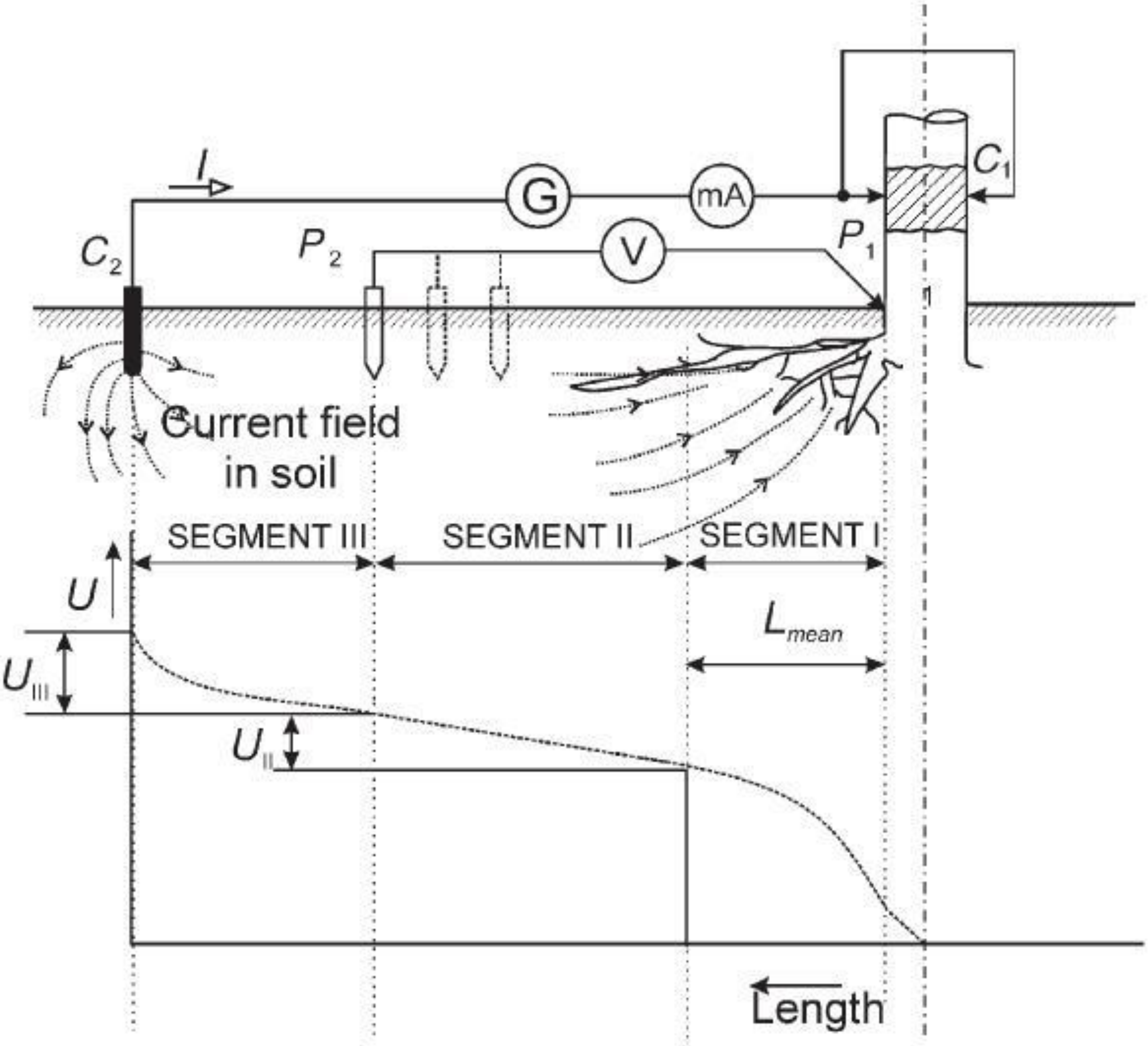

Figure 10: Scheme of measured tree, current field in soil, in situ. Simplified example. I is current with direction, G is low frequency energy source, V is voltmeter, mA is miliamperemeter C1 is current electrode in tree – stem, C2 is current electrode in soil (multiple electrode), P1, P2 are potential electrodes, UI and UII are potential differences on segments I and II, Lmean is mean distance (Aubrecht et al. 2006)

4.3. Statistical analysis

The data processing was done in R A Language and Environment for Statistical Computing.

4.3.1. Granger causality

The resistivity results were compared with laboratory results by Granger causality. Appropriate lag length was chosen by minimizing Akaike information criteria (AIC). The P-values from this analysis are summarised in tab. 10, chapter 4.5. It was used 95% family-wise confidence level ($\alpha = 0.05$); (Brandt 2015, Granger 1969, R core team 2013).

4.3.2. Statistical description

The laboratory results are summarised in tabs 6 – 9, chapter 4.5 and they are represented by mean and standard error of mean, mean confidence interval ($\alpha = 0.05$), variation and coefficient of variation and standard deviation (Grosjean 2014, R core team 2013).

4.3.3. ANOVA

The laboratory results with localities like factor are compared by Analysis of variance with 95% family-wise confidence level ($\alpha = 0.05$) and Tukey multiple comparisons of means (TukeyHSD) is presented. The figures and tab with *p-values* are in attachment (R core team 2013, Revelle 2013, Warnes 2013).

5. Results

5.1. Resistivity results

In the following tables and figures there are all resistivity measurements from the modified earth impedance method. In the tables are presented resistivity values [Ω · m] from four sides of tree related to distance from tree [cm]. In figures there is the graphical presentation of resistivity values [Ω · m] related to distance from tree [cm]. The curve with resistivity values has one linear part and two non linear parts, which can be seen in following figures. Resistivity numbers can be seen in appendix 28 – 31.

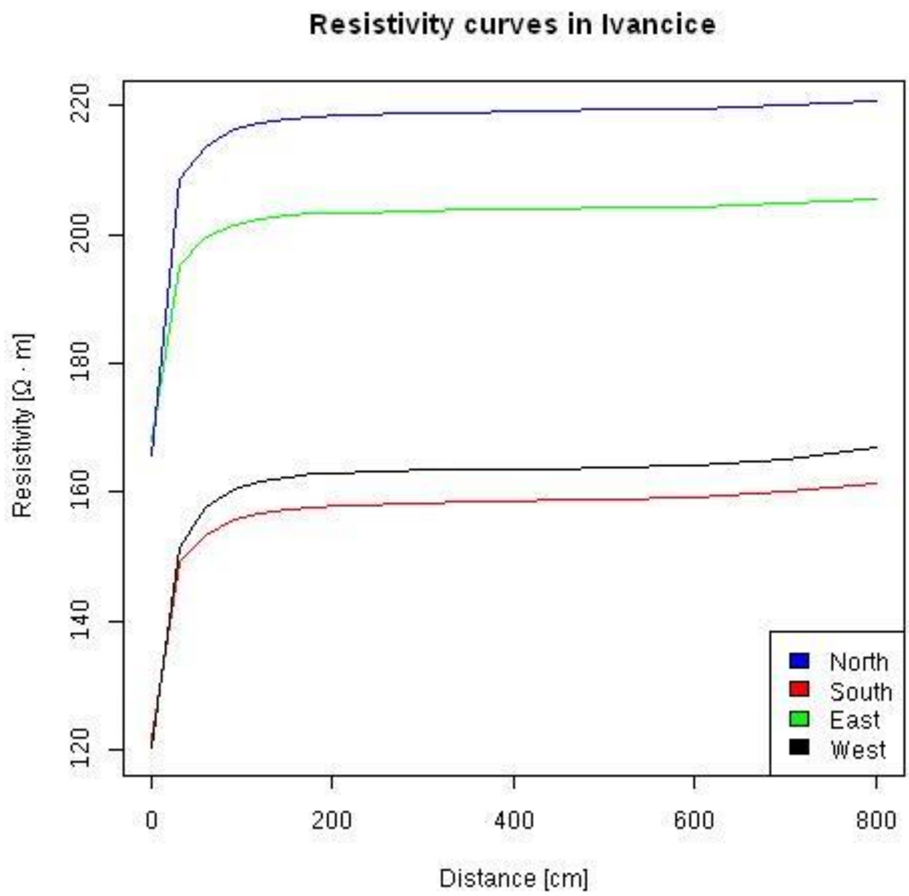

Figure 11:Resistivity levels depending on distance measured in North, South, East, West – Ivančice

.

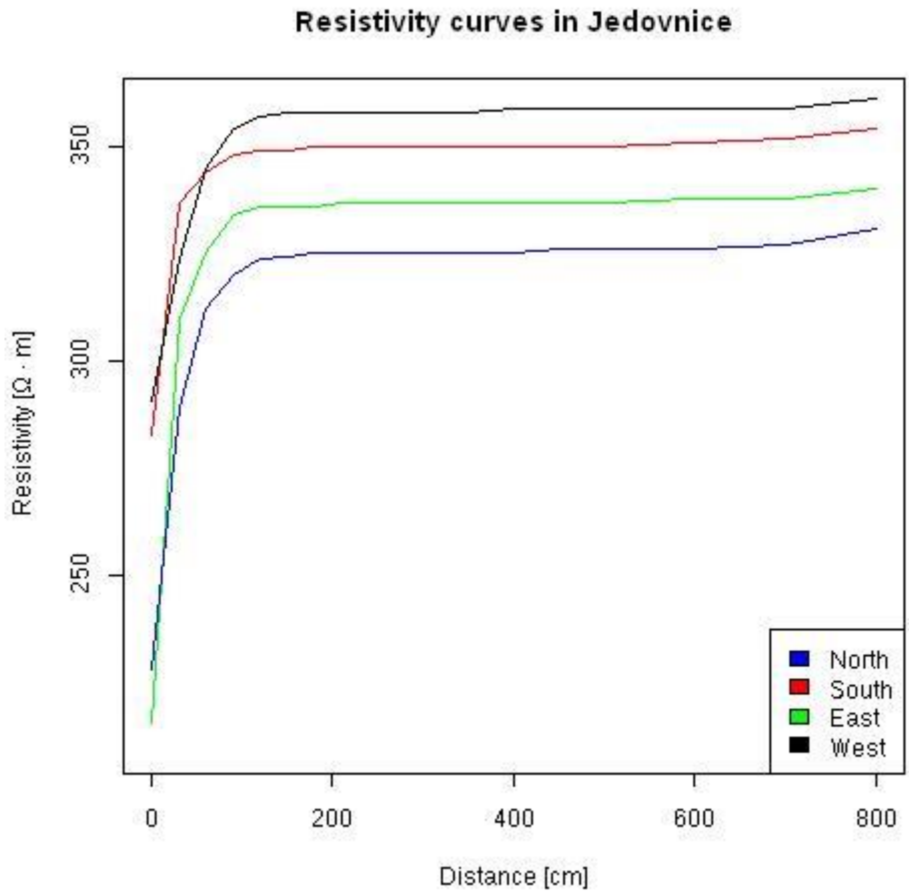

Figure 12:Resistivity levels depending on distance measured in North, South, East, West – Jedovnice.

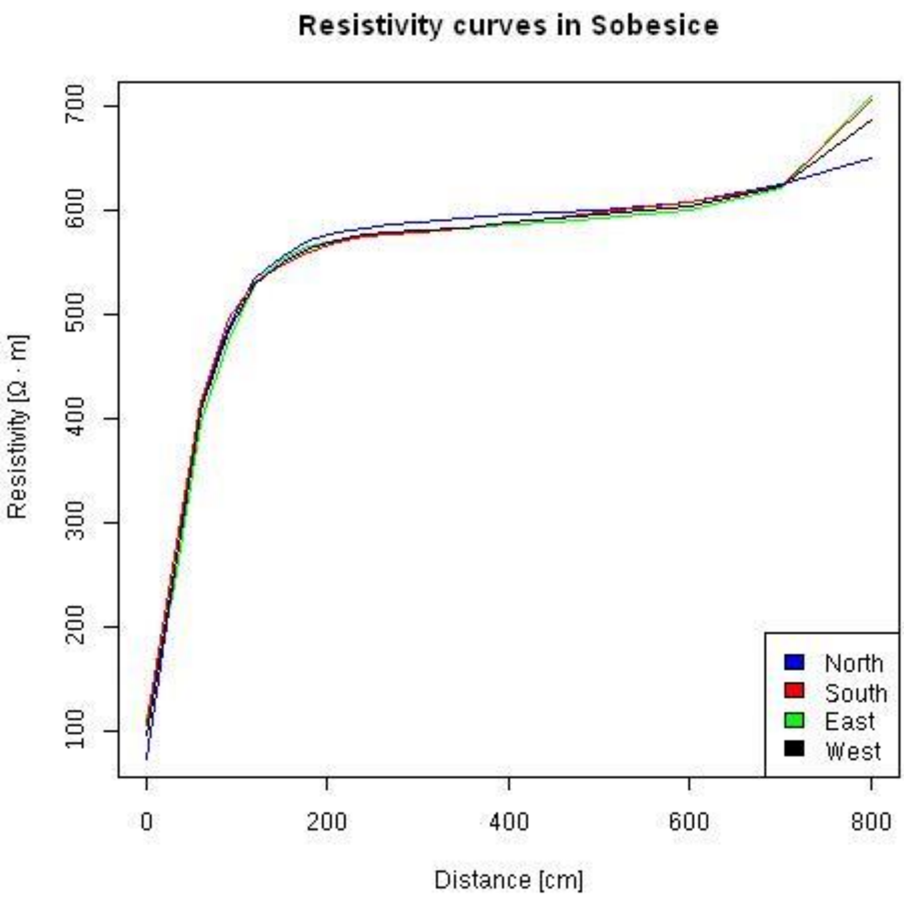

Figure 13:Resistivity levels depending on distance measured in North, South, East, West - Soběšice.

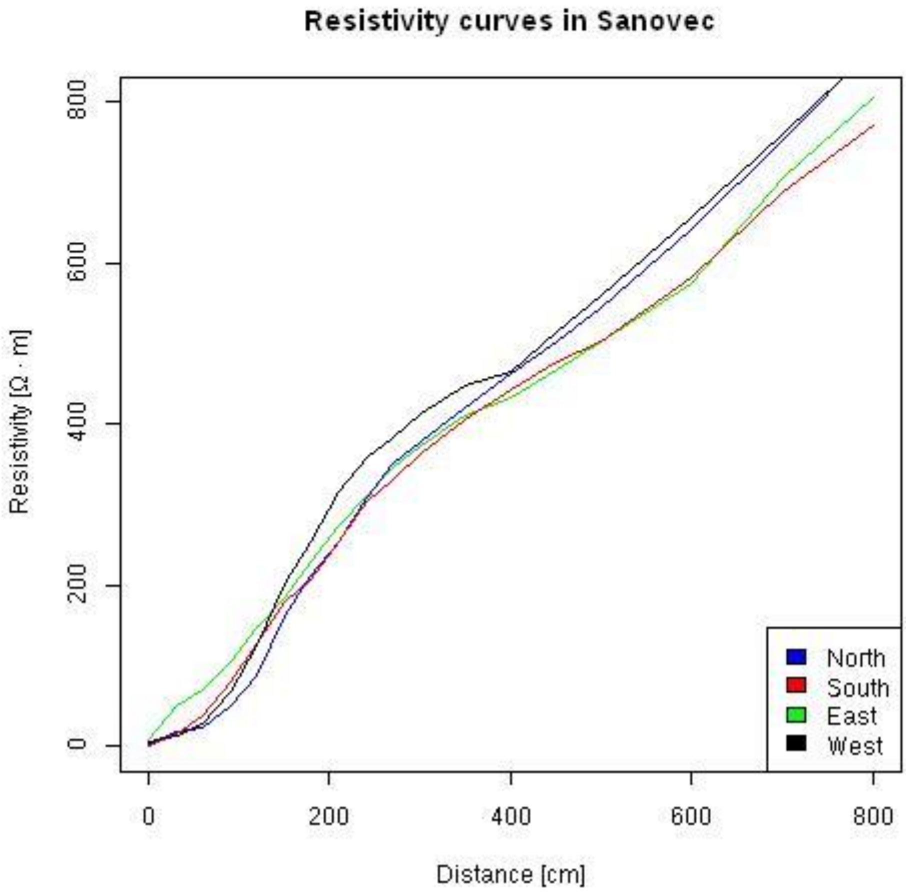

Figure 14: Resistivity levels depending on distance measured in North, South, East, West – Šanovec.

5.2. Laboratory results

In the next tables there are all results from laboratory analysis of soil samples. The several physical properties are pointed out and briefly described. All numbers are represented by mean and standard error of mean, mean confidence interval ($\alpha = 0.05$), variation and coefficient of variation and standard deviation in the table and by mean and its confidence interval in the text.

Ivančice

In the table below (Table 2) there are showed laboratory data from Ivančice locality. The density [g/cm^3] is 2.52 with confidence interval 0.03. Maximum water-bearing capacity [%] is 36.05 with confidence interval 2.27. Gravity water after 2 h of draining is 32.55 [%] with confidence interval 2.27. Maximum water-bearing capacity after 2 h of draining [%] is 31.43 with confidence interval 2.15. Water-bearing capacity after 24 h of draining [%] is 27.44 with confidence interval 2.34. Hygroscopicity [%] is 1.35 with confidence interval 0.21. Wilting point [%] is 4.04 with confidence interval 0.62. Lentocapillary point in 33% is 11.76 with confidence interval 0.91. Decreased availability point [%] is 15.74 with confidence interval 1.23. Volumetric moisture [%] is 25.04 with confidence interval 3.04. Available water capacity to 20 cm [mm] 46.82 with confidence interval 4.47. Available water capacity to water-bearing capacity [mm] 23.41 with confidence interval 2.37. Accessible water supply to 20 cm [mm] 42.02 with confidence interval 6.14. Actual water-bearing capacity [mm] is 4.8 with confidence interval 2.66, which is good up to strong water-bearing. Dry mass [%] is 99.27 with confidence interval 0.16. Volumetric weight [g/cm^3] is 2.00 with confidence interval 0.06. Reduced volumetric weight [g/cm^3] 1.75 with confidence interval 0.05. Gravimetric moisture in dry sample [%] is 14.41 with confidence interval 1.86. Gravimetric moisture in fresh sample [%] 12.50 with confidence interval 1.42. Porosity [%] is 30.67 with confidence interval 2.26, which is very low. Soil aeration [%] is 5.63 with confidence interval 3.67, which is not aerated. Minimum air capacity [%] is 6.80 with confidence interval 1.55. Relative capillary moisture [%] is 79.20 with confidence interval 6.87, which is slightly or fresh moist. Pore saturation [%] is 82.90 with confidence interval 10.01. The Organic Carbon in Soil [g/kg] is 8.58 with confidence interval 1.88. The soil active reaction is moderate alkaline and pH/H_2O is 7.26 with confidence interval 0.09. The soil potential reaction is neutral and pH/KCl is 6.37 with confidence interval 0.12. Amount of clay colloid particles [%] is 32.51 with confidence interval 8.04. Amount of clay particles [%] is 11.28 with confidence interval 3.94. Amount of dust particles [%] is 6.07 with confidence interval 0.96. Amount of sand particles [%] is 50.37 with confidence interval 9.60. And these values are related to loam soils (middle weight soils).

Table 2: Statistical results from study plot Ivančice

Ivančice	mean	SE.mean	CI.mean.0.95	var	std.dev	coef.var
Density [g/cm^3]	2.52	0.02	0.03	0.01	0.07	0.03
Maximum (Full) water-bearing capacity [%]	36.05	1.09	2.27	23.61	4.86	0.13
Gravity water (1/2 h draining) [%]	32.55	1.31	2.75	34.43	5.87	0.18
Maximum water-bearing capacity (2 h draining) [%]	31.43	1.03	2.15	21.05	4.59	0.15
Water-bearing capacity (24 h draining) [%]	27.44	1.12	2.34	24.89	4.99	0.18
Hydroscopicity [%]	1.35	0.10	0.21	0.20	0.44	0.33
Wilting point [%]	4.04	0.30	0.62	1.78	1.33	0.33
Lentocapillary point in 33%	11.76	0.43	0.91	3.75	1.94	0.16
Decreased availability point [%]	15.74	0.59	1.23	6.94	2.63	0.17
Volumetric moisture [%]	25.04	1.45	3.04	42.09	6.49	0.26
Available water holding capacity to 20 cm [mm]	46.82	2.26	4.74	102.39	10.12	0.22
Available water holding capacity to decreased availability point [mm]	23.41	1.13	2.37	25.60	5.06	0.22
Accessible water supply to 20 cm [mm]	42.02	2.93	6.14	171.93	13.11	0.31
Actual water-bearing capacity [mm]	4.80	1.27	2.66	32.28	5.68	1.18
Dry mass S^h [%]	99.27	0.08	0.16	0.12	0.34	0.00
Volumetric weight [g/cm^3]	2.00	0.03	0.06	0.02	0.13	0.06
Reduced volumetric weight [g/cm^3]	1.75	0.03	0.05	0.01	0.12	0.07
Gravimetric moisture in dry sample [%]	14.41	0.89	1.86	15.78	3.97	0.28
Gravimetric moisture in fresh sample [%]	12.50	0.68	1.42	9.24	3.04	0.24
Porosity [%]	30.67	1.08	2.26	23.30	4.83	0.16
Soil aeration [%]	5.63	1.75	3.67	61.42	7.84	1.39
Minimum air capacity [%]	6.80	0.74	1.55	9.75	3.12	0.46
Relative capillary moisture [%]	79.20	3.28	6.87	15.66	14.69	0.19
Pore saturation [%]	82.90	4.78	10.01	47.69	21.39	0.26
Organic Carbon in Soil [g/kg]	8.58	0.90	1.88	16.19	4.02	0.47
Soil active reaction [pH/H_2O]	7.26	0.09	0.19	0.17	0.41	0.06
Soil potential reaction [pH/KCl]	6.37	0.12	0.26	0.31	0.56	0.09
Clay coloid particles (< 0.002 mm) [%]	32.51	3.84	8.04	295.16	17.18	0.53
Clay particles (0.01 – 0.002 mm) [%]	11.28	1.88	3.94	70.99	8.43	0.75
Dust particles (0.05 – 0.01 mm) [%]	6.07	0.46	0.96	4.19	2.05	0.34
Sand particles (2.0 – 0.05 mm) [%]	50.37	4.59	9.60	421.16	20.52	0.41
Evaulvation of water-bearing capacity	good up to strong water-bearing capacity					
Evaulvation of moisture	slightly or fresh moist					
Evaulvation of porosity	very low					
Evaulvation of aireation	not aerated					
Evaulvation of soil active reaction	moderate alkaline					
Evaulvation of soil potential reaction	neutral					
Evaulvation of soil texture	Loam soil (middle weight soil)					

Jedovnice

In the table below (Table 3) there are laboratory data from Jedovnice locality. The density [g/cm^3] is 2.43 with confidence interval 0.03. Maximum water-bearing capacity [%] is 53.0. with confidence interval 1.95. Gravity water after 2 h of draining is 48.31 [%] with confidence interval 2.02. Maximum water-bearing capacity after 2 h of draining [%] is 44.78 with confidence interval 2.09. Water-bearing capacity after 24 h of draining [%] is 36.41 with confidence interval 1.83. Hygroscopicity [%] is 3.02 with confidence interval 0.29. Wilting point [%] is 9.07 with confidence interval 0.86. Lentocapillary point in 33% is 18.09 with confidence interval 1.04. Decreased availability point [%] is 22.74 with confidence interval 1.21. Volumetric moisture [%] is 21.77 with confidence interval 1.44. Available water capacity to 20 cm [mm] 54.68 with confidence interval 3.05. Available water capacity to water-bearing capacity [mm] 27.34 with confidence interval 1.53. Accessible water supply to 20 cm [mm] 25.41 with confidence interval 2.20. Actual water-bearing capacity [mm] is 29.28 with confidence interval 1.98, which is strongly water-bearing. Dry mass [%] is 97.34 with confidence interval 0.19. Volumetric weight [g/cm^3] is 1.35 with confidence interval 0.08. Reduced volumetric weight [g/cm^3] 1.14 with confidence interval 0.08. Gravimetric moisture in dry sample [%] is 19.39 with confidence interval 1.57. Gravimetric moisture in fresh sample [%] 16.19 with confidence interval 1.07. Porosity [%] is 5.33 with confidence interval 2.93, which is middle or high. Soil aeration [%] is 31.56 with confidence interval 3.49, which is not aerated or the middle aerated. Minimum air capacity [%] is 8.55 with confidence interval 3.89. Relative capillary moisture [%] is 48.60 with confidence interval 2.07, which is fresh moist. Pore saturation [%] is 41.49 with confidence interval 4.00. The Organic Carbon in Soil [g/kg] is 11.61 with confidence interval 2.70. The soil active reaction is moderately acid and pH/H^{2}O is 5.58 with confidence interval 0.52. The soil potential reaction is middle acid and pH/KCl is 4.12 with confidence interval 0.40.

Amount of clay colloid particles [%] is 24.80 with confidence interval 4.17. Amount of clay particles [%] is 33.07 with confidence interval 1.93. Amount of dust particles [%] is 19.74 with confidence interval 2.15. Amount of sand particles [%] is 24.11 with confidence interval 4.00. And these values are related to sandy – loam soil (middle weight soil).

Table 3: Statistical results from study plot Jedovnice

Jedovnice	mean	SE.mean	CI.mean.0.95	var	std.dev	coef.var
Density [g/cm^3]	2.43	0.01	0.03	0.00	0.06	0.02
Maximum (Full) water-bearing capacity [%]	53.03	0.92	1.95	15.32	3.91	0.07
Gravity water (1/2 h draining) [%]	48.31	0.96	2.02	16.48	4.06	0.08
Maximum water-bearing capacity (2 h draining) [%]	44.78	0.99	2.09	17.73	4.21	0.09
Water-bearing capacity (24 h draining) [%]	36.41	0.87	1.83	13.53	3.68	0.10
Hydroscopicity [%]	3.02	0.14	0.29	0.33	0.58	0.19
Wilting point [%]	9.07	0.41	0.86	3.00	1.73	0.19
Lentocapillary point in 33%	18.09	0.49	1.04	4.40	2.10	0.12
Decreased availability point [%]	22.74	0.57	1.21	5.91	2.43	0.11
Volumetric moisture [%]	21.77	0.68	1.44	8.33	2.89	0.13
Available water holding capacity to 20 cm [mm]	54.68	1.45	3.05	37.63	6.13	0.11
Available water holding capacity to decreased availability point [mm]	27.34	0.72	1.53	9.41	3.07	0.11
Accessible water supply to 20 cm [mm]	25.41	1.04	2.20	19.64	4.43	0.17
Actual water-bearing capacity [mm]	29.28	0.94	1.98	15.89	3.99	0.14
Dry mass S^h [%]	97.34	0.09	0.19	0.15	0.38	0.00
Volumetric weight [g/cm^3]	1.35	0.04	0.08	0.03	0.16	0.12
Reduced volumetric weight [g/cm^3]	1.14	0.04	0.08	0.02	0.15	0.13
Gravimetric moisture in dry sample [%]	19.39	0.74	1.57	9.96	3.16	0.16
Gravimetric moisture in fresh sample [%]	16.19	0.51	1.07	4.64	2.15	0.13
Porosity [%]	53.33	1.39	2.93	34.83	5.90	0.11
Soil aeration [%]	31.56	1.66	3.49	49.34	7.02	0.22
Minimum air capacity [%]	8.55	1.84	3.89	61.17	7.82	0.91
Relative capillary moisture [%]	48.60	0.98	2.07	17.34	4.16	0.09
Pore saturation [%]	41.49	1.90	4.00	64.69	8.04	0.19
Organic Carbon in Soil [g/kg]	11.61	1.23	2.70	18.03	4.25	0.37
Soil active reaction [pH/H_2O]	5.84	0.25	0.52	2.07	1.44	0.25
Soil potential reaction [pH/KCl]	4.12	0.20	0.40	1.22	1.10	0.27
Clay coloid particles (< 0.002 mm) [%]	24.80	2.04	4.17	129.07	11.36	0.46
Clay particles (0.01 – 0.002 mm) [%]	33.07	0.94	1.93	27.67	5.26	0.16
Dust particles (0.05 – 0.01 mm) [%]	19.74	1.05	2.15	34.50	5.87	0.30
Sand particles (2.0 – 0.05 mm) [%]	24.11	1.96	4.00	118.92	10.91	0.45
Evaulvation of water-bearing capacity	strong water-bearing capacity					
Evaulvation of moisture	fresh moist					
Evaulvation of porosity	middle or hihg					
Evaulvation of aireation	not aerated or the middle aerated					
Evaulvation of soil active reaction	moderate acid					
Evaulvation of soil potential reaction	middle acid					
Evaulvation of soil texture	Sandy – loam soil (middle weight soil)					

Soběšice

In the table below (Table 4) are showed laboratory data from Soběšice locality. The density [g/cm^3] is 2.54 with confidence interval 0.02. Maximum water-bearing capacity [%] is 45.79, with confidence interval 1.28. Gravity water after 2 h of draining is 41.19 [%] with confidence interval 0.94. Maximum water-bearing capacity after 2 h of draining [%] is 40.29 with confidence interval 0.93. Water-bearing capacity after 24 h of draining [%] is 36.95 with confidence interval 0.92. Hygroscopicity [%] is 2.09 with confidence interval 0.11. Wilting point [%] is 6.27 with confidence interval 0.32. Lentocapillary point in 33% is 16.39 with confidence interval 0.44. Decreased availability point [%] is 21.61 with confidence interval 0.55. Volumetric moisture [%] is 80.24 with confidence interval 9.78. Available water capacity to 20 cm [mm] 61.38 with confidence interval 1.66. Available water capacity to water-bearing capacity [mm] 30.69 with confidence interval 0.83. Accessible water supply to 20 cm [mm] 73.97 with confidence interval 9.82. Actual water-bearing capacity [mm] is 38.60 with confidence interval 3.97, which is strongly water-bearing. Dry mass [%] is 98.28 with confidence interval 0.11. Volumetric weight [g/cm^3] is 2.02 with confidence interval 0.11. Reduced volumetric weight [g/cm3] 1.22 with confidence interval 0.05. Gravimetric moisture in dry sample [%] is 66.35 with confidence interval 8.65. Gravimetric moisture in fresh sample [%] 41.03 with confidence interval 3.55. Porosity [%] is 52.02 with confidence interval 1.79, which is middle. Soil aeration [%] is 28.84 with confidence interval 3.25, which is the middle aerated. Minimum air capacity [%] is 11.73 with confidence interval 2.01. Relative capillary moisture [%] is 200.02 with confidence interval 25.29, which is moist and wet and muddy. Pore saturation [%] is 154.95 with confidence interval 19.63. The Organic Carbon in Soil [g/kg] is 16.37 with confidence interval 1.53. The soil active reaction is moderately acid and pH/H_2O is 6.48 with confidence interval 0.15. The soil potential reaction is middle acid and pH/KCl is 5.05 with confidence interval 0.29.

Amount of clay colloid particles [%] is 19.35 with confidence interval 4.20. Amount of clay particles [%] is 31.97 with confidence interval 3.22. Amount of dust particles [%] is 26.82 with confidence interval 3.49. Amount of sand particles [%] is 20.94 with confidence interval 5.77. And these values are related to loamy – sand soil (light soil).

Table 4: Statistical results from study plot Soběšice

Soběšice	mean	SE.mean	CI.mean.0.95	var	std.dev	coef.var
Density [g/cm^3]	2.54	0.01	0.02	0.00	0.05	0.02
Maximum (Full) water-bearing capacity [%]	45.79	0.61	1.28	7.51	2.74	0.06
Gravity water (1/2 h draining) [%]	41.19	0.45	0.94	4.02	2.01	0.05
Maximum water-bearing capacity (2 h draining) [%]	40.29	0.45	0.93	3.97	1.99	0.05
Water-bearing capacity (24 h draining) [%]	36.95	0.44	0.92	3.84	1.96	0.05
Hydroscopicity [%]	2.09	0.05	0.11	0.05	0.23	0.11
Wilting point [%]	6.27	0.15	0.32	0.48	0.69	0.11
Lentocapillary point in 33%	16.39	0.21	0.44	0.89	0.94	0.06
Decreased availability point [%]	21.61	0.26	0.55	1.37	1.17	0.05
Volumetric moisture [%]	80.24	4.67	9.78	36.64	20.90	0.26
Available water holding capacity to 20 cm [mm]	61.38	0.79	1.66	12.64	3.55	0.06
Available water holding capacity to decreased availability point [mm]	30.69	0.40	0.83	3.16	1.78	0.06
Accessible water supply to 20 cm [mm]	73.97	4.69	9.82	440.46	20.99	0.28
Actual water-bearing capacity [mm]	38.60	1.88	3.97	63.82	7.99	0.21
Dry mass S^h [%]	98.28	0.05	0.11	0.05	0.23	0.00
Volumetric weight [g/cm^3]	2.02	0.05	0.11	0.05	0.23	0.11
Reduced volumetric weight [g/cm^3]	1.22	0.02	0.05	0.01	0.11	0.09
Gravimetric moisture in dry sample [%]	66.35	4.13	8.65	341.89	18.49	0.28
Gravimetric moisture in fresh sample [%]	41.03	1.70	3.55	57.67	7.59	0.19
Porosity [%]	52.02	0.85	1.79	14.61	3.82	0.07
Soil aeration [%]	28.84	1.54	3.25	42.63	6.53	0.23
Minimum air capacity [%]	11.73	0.96	2.01	18.43	4.29	0.37
Relative capillary moisture [%]	200.02	12.08	25.29	2920.78	54.04	0.27
Pore saturation [%]	154.95	9.38	19.63	1759.74	41.95	0.27
Organic Carbon in Soil [g/kg]	16.37	1.53	3.01	21.54	6.27	0.56
Soil active reaction [pH/H_2O]	6.48	0.08	0.15	0.18	0.43	0.07
Soil potential reaction [pH/KCl]	5.05	0.14	0.29	0.64	0.80	0.16
Clay coloid particles (< 0.002 mm) [%]	19.35	2.05	4.20	126.55	11.25	0.58
Clay particles (0.01 – 0.002 mm) [%]	31.97	1.57	3.22	74.35	8.62	0.27
Dust particles (0.05 – 0.01 mm) [%]	26.82	1.71	3.49	87.38	9.35	0.35
Sand particles (2.0 – 0.05 mm) [%]	20.94	2.82	5.77	238.49	15.44	0.74
Evaulvation of water-bearing capacity	strong water-bearing capacity					
Evaulvation of moisture	moist and wet and muddy					
Evaulvation of porosity	middle					
Evaulvation of aireation	middle aerated					
Evaulvation of soil active reaction	moderate acid					
Evaulvation of soil potential reaction	middle acid					
Evaulvation of soil texture	Loamy – sand soil (light soil)					

Šanovec

In the table below (Table 5) are showed laboratory data from Šanovec locality. The density [g/cm^3] is 2.54 with confidence interval 0.04. Maximum water-bearing capacity [%] is 37.98, with confidence interval 2.11. Gravity water after 2 h of draining is 33.03 [%] with confidence interval 2.20. Maximum water-bearing capacity after 2 h of draining [%] is 27.95 with confidence interval 2.44. Water-bearing capacity after 24 h of draining [%] is 15.66 with confidence interval 1.61. Hygroscopicity [%] is 0.43 with confidence interval 0.16. Wilting point [%] is 1.30 with confidence interval 0.47. Lentocapillary point in 33% is 6.04 with confidence interval 0.78. Decreased availability point [%] is 8.48 with confidence interval 0.98. Volumetric moisture [%] is 17.10 with confidence interval 1.24. Available water capacity to 20 cm [mm] 28.73 with confidence interval 2.68. Available water capacity to water-bearing capacity [mm] 14.36 with confidence interval 1.34. Accessible water supply to 20 cm [mm] 31.60 with confidence interval 2.42. Actual water-bearing capacity [mm] is 10.98 with confidence interval 1.36, which is good up to strong water-bearing. Dry mass [%] is 99.64 with confidence interval 0.15. Volumetric weight [g/cm^3] is 1.53 with confidence interval 0.06. Reduced volumetric weight [g/cm3] 1.36 with confidence interval 0.06. Gravimetric moisture in dry sample [%] is 12.90 with confidence interval 1.34. Gravimetric moisture in fresh sample [%] 12.13 with confidence interval 1.12. Porosity [%] is 46.52 with confidence interval 2.39, which is low up to middle. Soil aeration [%] is 29.43 with confidence interval 2.48, which is the middle up to strongly aerated. Minimum air capacity [%] is 18.58 with confidence interval 2.59. Relative capillary moisture [%] is 62.49 with confidence interval 3.88, which is slightly moist. Pore saturation [%] is 37.19 with confidence interval 3.04. The Organic Carbon in Soil [g/kg] is 14.35 with confidence interval 1.86. The soil active reaction is strong acid and pH/H^{2}O is 3.95 with confidence interval 0.07. The soil potential reaction is strong acid and pH/KCl is 3.48 with confidence interval 0.20. Amount of clay colloid particles [%] is 5.41 with confidence interval 2.37.

Amount of clay particles [%] is 0.11 with confidence interval 2.55. Amount of dust particles [%] is 0.87 with confidence interval 0.22. Amount of sand particles [%] is 95.02 with confidence interval 0.97. And these values are related to Sandy soil (light soil).

Table 5: Statistical results from study plot Šanovec

Šanovec	mean	SE.mean	CI.mean.0.95	var	std.dev	coef.var
Density [g/cm^3]	2.54	0.02	0.04	0.01	0.10	0.04
Maximum (Full) water-bearing capacity [%]	37.98	1.03	2.11	29.63	5.44	0.14
Gravity water (1/2 h draining) [%]	33.03	1.07	2.20	32.15	5.67	0.17
Maximum water-bearing capacity (2 h draining) [%]	27.95	1.19	2.44	39.49	6.28	0.22
Water-bearing capacity (24 h draining) [%]	15.66	0.79	1.61	17.31	4.16	0.27
Hydroscopicity [%]	0.43	0.08	0.16	0.17	0.41	0.94
Wilting point [%]	1.30	0.23	0.47	1.49	1.22	0.94
Lentocapillary point in 33%	6.04	0.38	0.78	4.07	2.02	0.33
Decreased availability point [%]	8.48	0.48	0.98	6.42	2.53	0.30
Volumetric moisture [%]	17.10	0.60	1.24	10.20	3.19	0.19
Available water holding capacity to 20 cm [mm]	28.73	1.31	2.68	47.77	6.91	0.24
Available water holding capacity to decreased availability point [mm]	14.36	0.65	1.34	11.94	3.46	0.24
Accessible water supply to 20 cm [mm]	31.60	1.18	2.42	38.93	6.24	0.20
Actual water-bearing capacity [mm]	10.98	0.67	1.36	16.19	4.02	0.37
Dry mass S^h [%]	99.64	0.07	0.15	0.15	0.39	0.00
Volumetric weight [g/cm^3]	1.53	0.03	0.06	0.03	0.16	0.11
Reduced volumetric weight [g/cm^3]	1.36	0.03	0.06	0.03	0.16	0.12
Gravimetric moisture in dry sample [%]	12.90	0.65	1.34	11.86	3.44	0.27
Gravimetric moisture in fresh sample [%]	12.13	0.55	1.12	8.41	2.90	0.24
Porosity [%]	46.52	1.16	2.39	37.92	6.16	0.13
Soil aeration [%]	29.43	1.21	2.48	40.74	6.38	0.22
Minimum air capacity [%]	18.58	1.26	2.59	44.77	6.69	0.36
Relative capillary moisture [%]	62.49	1.89	3.88	100.16	10.01	0.16
Pore saturation [%]	37.19	1.48	3.04	61.55	7.85	0.21
Organic Carbon in Soil [g/kg]	14.35	1.86	3.77	27.75	11.30	0.79
Soil active reaction [pH/H_2O]	3.95	0.03	0.07	0.06	0.24	0.06
Soil potential reaction [pH/KCl]	3.48	0.10	0.20	0.51	0.71	0.20
Clay coloid particles (< 0.002 mm) [%]	5.41	1.18	2.37	72.17	8.50	1.57
Clay particles (0.01 – 0.002 mm) [%]	0.11	1.27	2.55	83.70	9.15	85.48
Dust particles (0.05 – 0.01 mm) [%]	0.87	0.11	0.22	0.64	0.80	0.92
Sand particles (2.0 – 0.05 mm) [%]	95.02	0.49	0.97	12.25	3.50	0.04
Evaulvation of water-bearing capacity	good up to strong water-bearing capacity					
Evaulvation of moisture	slightly moist					
Evaulvation of porosity	low up to middle					
Evaulvation of aireation	middle up to strongly aerated					
Evaulvation of soil active reaction	strong acid					
Evaulvation of soil potential reaction	strong acid					
Evaulvation of soil texture	Sandy soil (light soil)					

5.3. Granger causality results

In the next table are showed all soil properties compared with resistivity measurement via Granger causality analysis.

In the first column are the names of soil properties, in the second and third column are p-values of Granger causality analysis. The second column, named “Y cause X(r)”, say if the soil feature (Y) cause (or does not cause) the values of the soil resistivity (X(r)), if the p-value is smaller (or higher) then alpha. The third column, named “X(r) cause Y”, say if soil resistivity (X(r)) cause (or does not cause) the values of the soil feature (Y), if the p-value is smaller (or higher) than alpha. In the fourth column are values of lag length factor, required by the Granger causality analysis.

For next soil properties p-value is higher than alpha (in both columns) and the both variables, soil feature and soil resistivity are Granger-independent; i.e. soil resistivity does not Granger causes soil feature and soil feature does not Granger causes soil resistivity: Density, Maximum (Full) water-bearing capacity, Gravity water, Maximum water-bearing capacity, Water-bearing capacity, Hygroscopicity, Wilting point, Lentocapillary point, Decreased availability point, Available water holding capacity to 20 cm, Available water holding capacity to decreased availability point, Dry mass, Volumetric weight, Soil aeration, Pore saturation, Soil active reaction, Soil potential reaction, Clay colloid particles, Clay particles, Sand particles.

For next soil properties p-value is smaller than alpha (in both columns) and the both variables, soil feature and soil resistivity has feedback (Granger) causality; i.e. soil resistivity Granger causes soil feature and soil feature Granger causes soil resistivity: Volumetric moisture, Accessible water supply to 20 cm, Reduced volumetric weight, Gravimetric moisture in dry sample, Gravimetric moisture in fresh sample, Porosity.

For next soil properties p-value is smaller than alpha in first column and higher than alpha in second column; i.e. soil feature Granger causes soil resistivity and soil resistivity does not Granger causes soil feature : Actual water-bearing capacity, Relative capillary moisture, Organic Carbon in Soil, Dust particles.

For next soil properties p-value is higher than alpha in first column and smaller than alpha in second column; i.e. soil feature does not Granger causes soil resistivity and soil resistivity

Granger causes soil feature : Minimum air capacity.

Table 6: Granger causality table results

P-value	Y cause X(r)	X(r) cause Y	LAG
Density [g/cm^3]	0.205018	0.1412246	4
Maximum (Full) water-bearing capacity [%]	0.3824191	0.6005692	5
Gravity water (1/2 h draining) [%]	0.6641477	0.563979	1
Maximum water-bearing capacity (2 h draining)[%]	0.6860692	0.3340517	5
Water-bearing capacity (24 h draining) [%]	0.64362745	0.05933534	1
Hydroscopicity [%]	0.271124	0.1495785	5
Wilting point [%]	0.271124	0.1495785	5
Lentocapillary point in 33%	0.2759643	0.1166746	5
Decreased availability point [%]	0.3196047	0.1302738	5
Volumetric moisture [%]	**0.0420992**	**0.0379629**	1
Available water holding capacity to 20 cm [mm]	0.6142114	0.0883704	1
Available water holding capacity to decreased availability point [mm]	0.6142114	0.0883704	1
Accessible water supply to 20 cm [mm]	**0.0391137**	**0.0689738**	1
Actual water-bearing capacity [mm]	**0.0278198**	0.2173664	1
Dry mass S^h [%]	0.3106285	0.1748064	2
Volumetric weight [g/cm^3]	0.4866998	0.1628890	5
Reduced volumetric weight [g/cm^3]	**0.0077422**	**0.0063212**	2
Gravimetric moisture in dry sample [%]	**0.0205065**	**0.0154544**	1
Gravimetric moisture in fresh sample [%]	**0.0185354**	**0.0018300**	1
Porosity [%]	**0.0105056**	**0.0027512**	2
Soil aeration [%]	0.2190826	0.6020896	1
Minimum air capacity [%]	0.0682287	**0.0495789**	1
Relative capillary moisture [%]	**0.0451186**	0.1857378	1
Pore saturation [%]	0.2309639	0.1516437	1
Organic Carbon in Soil [g/kg]	**0.0154731**	0.2402379	1
Soil active reaction [pH/H_2O]	0.4716846	0.9573317	2
Soil potential reaction [pH/KCl]	0.8336060	0.8994394	2
Clay coloid particles (< 0.002 mm) [%]	0.8192308	0.0586054	2
Clay particles (0.01 – 0.002 mm) [%]	0.1257025	0.4000136	2
Dust particles (0.05 – 0.01 mm) [%]	**0.0410825**	0.2785532	2
Sand particles (2.0 – 0.05 mm) [%]	0.1817838	0.1073262	2

6. Discussion

There exist general knowledge about electric conductivity and this is a comparison and discussion with results of modified soil impedance method, results of laboratory and results of granger causality (Aubrecht 2006, Čermák 2006, Mareš 1979, Novotný 1973).

6.1. *Soil texture*

Electrical conductivity mainly depends on amount of water in soil. Although, soil texture is a driving mechanism of water regime in the soil; moving of water and holding of water in terms of time or water amount. So, sand, loamy or clay soils are differing in water regime (Mareš 1979, Novotný 1973, Tabbagh et al. 2000).

Resistivity levels in sand soil are up to 600 [Ω·m] in wet soil, respectively up to 1500 [Ω·m] in dried soil. Resistivity levels in loam or clay soil are lower compared to sand soil; up to 200 [Ω·m] (Novotný 1973).

In this experiment the resistivity levels depend on distance and for every locality had several levels. However comparison of the trend in resistivity levels measured on different soil textures is discussed here. The localities had following soil texture: Ivančice loam soil, Jedovnice sandy-loam soil, Soběšice loamy-sand soil, Šanovec sand soil.

Resistivity levels in sand soil on Šanovec locality reached the highest values, up to 868 [Ω·m] and resistivity levels in loam soil on Ivančice locality reached the smallest values, up to 220.8 [Ω·m].

Resistivity levels in loamy-sand soil on Soběšice locality reached the middle values, up to 710 [Ω·m] and resistivity levels in sandy-loam soil on Jedovnice locality reached the middle values, up to 361 [Ω·m]. Respectively resistivity levels on localities with high portion of sand particles reached high resistivity values and resistivity levels on localities with high portion of clay particles reached low resistivity values.

Results of this experiment agreed with previous experiments published by several authors in the literature (Mareš 1979, Novotný 1973, Tabbagh et al. 2000).

6.2. *Soil fraction*

Novotný (1979) discovered that, soil resistivity levels decreasing with amount of soil particles (smaller than 0.2 mm in diameter) increasing. It is increasing soil water capacity.

In this experiment were measured four soil fractions; clay colloid particles (< 0.002

mm), clay particles (0.01 – 0.002 mm), dust particles (0.05 – 0.01 mm), sand particles (2.0 – 0.05 mm).

It was confirmed that the Ivančice locality have the most clay colloid particles also have the smallest resistivity. It was confirmed that the Šanovec locality have the lowest colloid particles also have the highest resistivity. It was confirmed that the Soběšice locality have the middle amount of colloid particles also have the middle values of resistivity. It was confirmed that the Jedovnice locality have the middle amount of colloid particles also have the middle values of resistivity. Respectively the Jedovnice locality have higher amount of clay colloid particles than Soběšice locality and also Jedovnice locality have smaller resistivity than Soběšice locality. However, the fraction with soil particles smaller than 0.2 mm was not measured. This experiment was not able to verify an influence of 0.2 soil particles on the soil resistivity.

Novotný statement and Granger causality results were compared in this experiment. Between dust particles (soil particles with diameter between 0.05 – 0.01 mm) and soil resistivity exist Granger causality. Respectively dust particles Granger cause soil resistivity and soil resistivity does not Granger cause amount of dust particles. Next soil fractions: clay colloid particles, clay particles, sand particles and soil resistivity are granger independent.

6.3. Parent rock

Parent rock affects soil chemical composition, which was developed on it. This soil chemical composition affects a range of soil resistivity levels. Typically low conductivity is in soils composed of silicates and poor in carbonates. Typically high in conductivity is in carbonate rich soils arised from calcite or dolomite (Carr 1982, Culek et. al. 2013, Mareš 1979, Novotný 1973).

This assumption was verified by soil resistivity results from individual localities. If the calcium prevails in the parent rock, the resistivity is lower. Soil resistivity for Ivančice plot is the lowest. It is cause by calcium rich soil, developed on perm conglomerates and limestones. For soil in Jedovnice locality is soil resistivity the middle, respectively higher than resistivity in Ivančice locality and lower than resistivity in Soběšice locality and Šanovec locality. It is cause by calcium rich soil, developed on culms sea sediments; slates, graywackes and conglomerates. For soil in Soběšice locality is soil resistivity higher than resistivity in Ivančice locality and Jedovnicelocality. It is cause by calcium poor soil and simultaneously silicate rich soil, developed on amphibole granodiorite. For soil in Šanovec locality is soil resistivity the highest. It is cause by calcium poor soil and simultaneously silicate rich soil, developed on Turonian alm.

6.4. Soil water

It is general knowledge, that water is quality electric conductor. And that is why this experiment compared influence of several types of soil water on soil resistivity. The influence of hygroscopic water, capillary water and leaking water is compared (Aubrecht 2006, Carr 1982, Mareš 1979, Novotný 1973, Thefreedictionary 2015).

For evaluation this assumption was used Granger causality results.

In case of Hygroscopicity water was not detected Granger causality, respectively Hygroscopicity water and soil resistivity are Granger-independent variables. This result agreed with literature assumption.

In case of Relative capillary moisture was detected Granger causality and literature assumption was agreed. Respectively Relative capillary moisture Granger causes soil resistivity. On the other hand soil resistivity does not predict amount of Relative capillary moisture, because the Granger causality results does not supported, respectively and soil resistivity does not Granger causes Relative capillary moisture.

Leaking water is represented by Gravity water in our experiment and in case of Gravity water was not detected Granger causality, respectively Gravity water and soil resistivity are Granger-independent variables. This result does not agre with literature assumption. However is important to known the Gravity water is a soil feature, which describe potential state of soil water. It is describe amount of water, which can be taken very quickly by macro (non-capillary) pores. And that is why Gravity water does not respond to actual soil moisture.

6.5. Soil organic matter

Organic matter increases capability of soil to hold water, increases also capability of soil to conduct an electric current, respectively decreases soil resistivity (Mareš 1979, Novotný 1973). In this experiment was amount of soil organic matter measured by amount of soil organic carbon.

For evaluation this assumption was used Granger causality results. And between amount of soil organic matter and soil resistivity Granger causality was detected, which agreed the literature assumption. Respectively, amount of soil organic carbon Granger causes soil resistivity. On the other hand soil resistivity does not predict amount of soil organic carbon, because the Granger causality results does not supported, respectively and soil resistivity does not Granger causes soil organic carbon.

6.6. Porosity

Pores in soil are filled by air or water. As a consequence it can be increased or decreased soil resistivity (Mareš 1979, Novotný 1973, Tabbagh et al. 2000).

For evaluation these assumptions were used Granger causality results. Feedback causality was detected and literature assumption was agreed.

6.7. Resistivity of electrode, machine and soil application

As was described by several authors, the results of resistivity measurements are influenced by resistivity of used electrodes, machine (computer) and the resistivity influenced by application of electrode into soil. This resistivity values was not measured, because in the experiment was used same machine and same electrodes for all measurements. And the level of this resistivity is constant. The resistivity influenced by application of electrode into soil is constant too, cause by multiplying of electrodes. The most often used tools there is this resistivity minor compared to soil resistivity (Aubrecht 2006, Mareš 1979, Novotný 1973).

6.8. Resume of discussion

In resume of all Granger causality results the relationship between soil resistivity and eleven soil properties were detected and between sixteen were not.

In general the feedback causality (or one side causality) was detected between soil resistivity and soil properties related to or describing an actual state of soil water. On the other hand the Granger causality was not detected between soil resistivity and soil properties related to or describing a potential state of soil water.

7. Conclusion

This experiment tested the possibility of adding other information about the soil physical properties to existing modified earth impedance method, published by Čermák, Staněk, Aubrecht in 2006. In this thesis, the method for resistivity measurement of tree (trunk/soil), was employed.

The measurements were conducted on four different study plots with different soil textural classes located in the Czech Republic. The choice of localities was guided the most typical soil textural classes; Ivančice – loam soil, Jedovnice – sandy-loam soil, Soběšice – loamy-sand soil, Šanovec – sandy soil.

27 soil physical and chemical properties were studied in the laboratory.

Comparison of the trend in resistivity levels measured on different soil textures is presented here. The localities had following soil texture: Ivančice loam soil, Jedovnice sandy-loam soil, Soběšice loamy-sand soil, Šanovec sand soil. The localities had following soil resistivity levels in increasing order: Ivančice, Jedovnice, Soběšice, Šanovec. Obtained results were verified.

This trend is also respect to amount of soil clay colloid particles, respective decreasing amount of soil clay colloid particles, soil resistivity increase.

Soil composed of silicates and poor in carbonates has lower conductivity. And carbonate rich soils developed from calcite or dolomite are very high in conductivity. This assumption was verified by soil resistivity results from individual localities. For calcium rich soil in Ivančice and Jedovnice is soil resistivity lower than calcium poor soil and simultaneously silicate rich soil in Soběšice and Šanovec.

Experiment compared influence of several types of soil water on soil resistivity. The influence of hygroscopic water, capillary water and leaking water is compared by Granger causality.

In case of hygroscopicity water was not detected Granger causality. This result agreed with literature assumption.

In case of relative capillary moisture was detected Granger causality and literature assumption was agreed.

Leaking water is represented by gravity water in our experiment and in case of Gravity water was not detected Granger causality. This result does not agreed with literature assumption. However is important to known the Gravity water is a soil property, which describe potential state of soil water. And that is why Gravity water does not respond to actual soil moisture.

Organic matter increases capability of soil to hold water, increases also capability of soil to conduct electric current, respectively decreases soil resistivity. Between amount of soil organic matter and soil resistivity Granger causality was detected, which agreed the literature assumption.

Pores in soil are filled by air or water. As a consequence it can be increased or decreased soil resistivity. Feedback causality was detected and literature assumption was agreed.

Granger causality was not detected between soil resistivity and soil properties related to or describing a potential state of soil water.

8. Summary

Tato práce prověřuje možnost obohatit výsledky z metody Modifikované půdní impedance pro měření aktivního kořenového povrchu publikované v roce 2006 Čermákem, Staňkem, Aubrechtem, o další informace popisující fyzikální půdní vlastnosti. Pro tento účel byla využita jejich metoda pro měření půdní resistivity (měrný odpor).

Pro toto měření byly vybrány čtyři různé lokality v České Republice, lišící se půdní strukturou; Ivančice – hlinitá půda, Jedovnice – písčito-hlinitá půda, Soběšice – hlinito-písčitá půda, Šanovec – písčitá půda.

Laboratorně bylo změřeno a porovnáno celkem 27 půdních vlastností a jejich vliv na měrný půdní odpor bylo potvrzeno u 11 půdních vlastností.

Literární přehled i výsledky experimentu potvrzují vliv půdní struktury na velikost měrného půdního odporu. Dále potvrzují vliv obsahu karbonátů a silikátů, které se do půdy dostávají z mateřské horniny, na měrný odpor půdy. Také potvrzují vliv vlhkosti půdy, respektive vliv půdních vlastností popisujících aktuální půdní vlhkost, na měrný odpor půdy.

9. References

Software

BRANDT, P. (2015): *MSBVAR: Markov-Switching, Bayesian, Vector Autoregression Models*. R package version 0.9-2. http://CRAN.R-project.org/package=MSBVAR.

GROSJEAN, P., IBANEZ, F. (2014): *Pastecs: Package for Analysis of Space-Time Ecological Series*. R package version 1.3-18. http://CRAN.R-project.org/package=pastecs.

R CORE TEAM (2013): *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

REVELLE, W. (2013): *Psych: Procedures for Personality and Psychological Research*, Northwestern University, Evanston, Illinois, USA, http://CRAN.R-project.org/package=psych Version = 1.4.2.

WARNES, R. G., BOLKER, B., BONEBAKKER, L., GENTLEMAN, R., HUBER, W., LIAW, A., LUMLEY, T., MAECHLER, M., MAGNUSSON, A., MOELLER, S., SCHWARTZ, M., VENABLES, B. (2013): *Gplots: Various R programming tools for plotting data*. R package version 2.12.1.
http://CRAN.R-project.org/package=gplots

Literature

AUBRECHT, L., STANĚK, Z., and KOLLER, J. (2006): *Electrical measurement of the absorption surfaces of tree roots by the earth impedance method: 1. Theory*. Tree Physiol. 26: 1105–1112.

BAVER, L. D., GARDNER, W. R. and GARDNER, W. H. *Soil physics*. 4. Ed. New York: Wiley, 1972. ISBN 0-471-05974-9.

CARR, C. (1982): *Handbook on soil resistivity surveying*. 676 pp. ISBN 0-942118-13-8 Record Number 19831977471.

CIPRA, T. (2013): *Finanční ekonometrie*. 2., upr. vyd. Praha: Ekopress. ISBN 978-80-86929-93-4.

CULEK, M. (ed.) (1996): *Biogeografické členění České republiky*. Enigma, Praha. 244 s. ISBN 8085368803

CULEK, M.; GRULICH, V., LAŠTUVKA, Z., DIVÍŠEK, J. (2013): *Biogeografické regiony České republiky*. Astron, Praha. 447 s. ISBN 978-80-210-6693-9.

ČERMÁK, J., R. URICH, Z. STANĚK, J. KOLLER and L. AUBRECHT (2006): *Electrical measurement of tree root absorbing surfaces by the earth impedance method: 2. Verification based on allometric relation-ships and root severing experiments. Tree Physiol*. 26: 1113–1121.

EICHLER, M. (2011): *Causal inference in time series analysis*. Department of Quantitative Economics, Maastricht University. Maastricht, the Netherlands.

GRANGER, C. W. J. (1969): *Investigating Causal Relations by Econometric Models and Cross-spectral Methods*. Econometrica, Vol. 37, No. 3. (Aug., 1969), pp. 424-438.

HANKS, R. and ASHCROFT G. L. (1980): *Applied soil physics: soil water and temperature applications*. Berlin: Springer. Advanced series in agricultural sciences. ISBN 3-540-09457-1.

ISO/DIS 11465 (1993) in REJŠEK, K. (1999): *Lesnická pedologie: cvičení*. Vyd. 1. Brno: Mendelova zemědělská a lesnická univerzita. ISBN 80-7157-352-3.

KOČENDA, E. and ČERNÝ, A. (2014): *Elements of time series econometrics: an applied approach*. 2nd ed. Prague: Karolinum. ISBN 978-80-246-2315-3.

KOPECKÝ, J. (1928) in REJŠEK, K. (1999): *Lesnická pedologie: cvičení*. Vyd. 1. Brno:

Mendelova zemědělská a lesnická univerzita, 1999. ISBN 80-7157-352-3.

MAREŠ, S. (1979): *Úvod do užité geofyziky*. 1. Vyd. Praha: SNTL - Nakladatelství technické literatury.

NOVÁK, V. (1932) in REJŠEK, K. (1999): *Lesnická pedologie: cvičení*. Vyd. 1. Brno: Mendelova zemědělská a lesnická univerzita. ISBN 80-7157-352-3.

NOVOTNÝ, V. (1973): *Uzemění a jeho měření*. SNTL – Státní nakladatelství technické literatury (Praha).

PELÍŠEK, J. (1957): *Lesnické půdoznalství*. Vyd. 1. Praha: Státní zemědělské nakladatelství. Lesnická knihovna, sv. 25.

POSPÍŠIL, L., ŠÚTORA, A. (2003): *Praktická geofyzika: učební texty pro geodety : úvod do užité geofyziky*. Brno: Akademické nakladatelství CERM. ISBN 80-214-2429-X.

REJŠEK, K. (1999): *Lesnická pedologie: cvičení*. Vyd. 1. Brno: Mendelova zemědělská a lesnická univerzita. ISBN 80-7157-352-3.

SAMEC P., KUČERA A. and REJŠEK K.: Soil heterogeneity reflected in biogeography of beech forests in the borderland between the Bohemian Massif and the Outer Western Carpathians. Ekológia (Bratislava), Vol. 33, No. 4, p. p. 321-343, 2014.

ŠÁRA, P. and TESAŘÍKOVÁ, P. (eds.). *Školní atlas: Česká republika a Evropa*. Vizovice: Schocart, 2005. Školní program. ISBN 80-7224-247-4.

ŠIMEK, M. (2007): *Základy nauky o půdě*. 2., upr. a rozš. vyd. České Budějovice: Jihočeská univerzita v Českých Budějovicích, Biologická fakulta, dotisk. ISBN 80-7040-747-6.

TABBAGH, A., DABAS, M., HESSE, A., PANISSOD, C. (1998): *Soil resistivity: a non-invasive tool to map soil structure horizonation*. GEOFCAN, UMR 7619, «Sisyphe» Université Pierreet Marie Curie, et CNRS, Centre de Recherches Géophysiques, Garchy 58150, France.

VRÁBLÍKOVÁ, J. and SLAVÍK, L. (1994): *Základy pedologie a ochrany půdního fondu*. 1. vyd. Ústí nad Labem: Univerzita J.E. Purkyně,.

WALKLEY, A., BLACK, I. A. (1934) in REJŠEK, K. (1999): *Lesnická pedologie: cvičení*. Vyd. 1. Brno: Mendelova zemědělská a lesnická univerzita, 1999. ISBN 80-7157-352-3.

IUSS Working Group WRB. (2006): *World reference base for soil resources 2006*. World Soil Resources Reports No. 103. FAO, Rome. ISBN 92-5-105511-4.

ZBÍRAL, J., HONSA, I., MALÝ, S. (2010): *Analýza půd I – jednotné pracovní postupy*. ÚKZÚZ Brno.

ZBÍRAL, J., MALÝ, S., VÁŇA, M.(2011): *Analýza půd III – jednotné pracovní postupy.* ÚKZÚZ Brno.

Online

MIGESP. (2016): Klimatické regiony ČR. [online] cited 13. 2. 2016. Available on: http://www.migesp.cz/klimaticke-regiony-cr.

PETRÁNEK, J. (1993): *Malá encyklopedie geologie*. [online] cited 22. 3. 2016. Available on: http://www.geology.cz/aplikace/encyklopedie/term.pl.

THEFREEDICTIONARY. (2010): *Random House Kernerman Webster's College Dictionary*. [online] cited 3. 6. 2015. Available on: http://www.thefreedictionary.com/Electrical+resistivity.

10. Appendix