Global Water Partnership
Central and Eastern Europe

Integrated Drought Management
Programme in Central and Eastern Europe

Activity 5.1:

DROUGHT MANAGEMENT BY AGRICULTURAL PRACTICES AND MEASURES INCREASING SOIL WATER HOLDING CAPACITY

Joint Final report, 2015

Number and name of the activity	5.1. Drought management by agricultural practices and measures increasing soil water holding capacity
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Duration of the activity	March 2013 – February 2015
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Date	February, 2015

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1. INTRODUCTION

Soil is one of the most important water storage in nature. It means that water content in the soil is very significant parameter of water regime of the country which significantly depends on soil area and quality of soil. Lower acreage of soil and lower soil quality lead to less water content in the country and vice versa. Because both, acreage and quality of soil, still more and more depends on human activities (agriculture, forest management, soil sealing) those influences are still important factors of water regimes of land. Mainly agriculture drives the soil water regime from positive or negative points of view. It is because of permanent influences of agriculture on soil by many farming operations. Because not only soil degradation but also soil improvement could be attained in result of soil use by agriculture, it is worth to look for such farming systems which can bring positive effects on water regime of the country.

During the last few decades agricultural practices used several practices which decrease water infiltration intensities into the soil profile and lower water accumulation by soil profile compaction. It is result of heavy machine use, lack of organic matter application into the soil and not sufficient share of deep root plants in the crop rotations. As result of this situation, less water in the soil is available for agriculture and for many essential environmental needs as well. Drought is more and more a dangerous phenomenon in agricultural land and in the scale of the entire countries. Moreover in case of heavy rain falling in areas of compacted soils, increasing frequency and intensity of flooding accidents are observed due to increased surface runoff. Since both drought and flood potentials increase due to soil compaction, it is necessary to mitigate these effects by soil quality improvements which must be developed, verified and implemented in the agricultural practices.

All the above is confirmed by the existing data published in several key documents. For example, in Slovakia about 600 thousands ha of agricultural soils (at least 30 % of the total area) are compacted what decreased the total water infiltration into the soil at the level 100 million m^3 (BIELEK 2014), what is about 10 % of the total volume of all artificial water reservoirs built up in Slovakia (54 reservoirs) (SEA 2015). It means that loss of water due to lower soil water holding capacity of compacted soils in Slovakia, equals the volume of about 5 existing Slovakian artificial national water reservoirs. Total average potential of water infiltration into the all Slovakian soil is about 11 billion of m^3 per year (ŠÚTOR 2003). Decrease of crop yields due to soil compaction and water deficiency are estimated in Slovakia at 10-40 % depending on degree of compaction (HOUŠKOVA 1999). Relatively high share of light soils in Poland (60.8 % in comparison to 31.8 % in EU), as well as low precipitation are decreasing yields due to low water retention in soils. According of FABER (2002) with respect to WOFOST as crop growth model results, potential yields in Poland are limited by water shortage by 46.9 % for winter wheat, 42.9 % for spring barley, 60 % for winter rape and 58.9 % for potatoes. Significant decrease of other soil functions as results of lower water content in the soil should also be noticed. For example, lower soil water holding capacity can contribute to more frequent floods appearance in Czech Republic, Slovakia, Poland and Slovenia what was observed in the last (presented in national reports). As far as of water availability is concerned, there is a special situation in Slovenia. There is high precipitation (country average: 1567 mm per annum) but soil drought is also a problem in this country, mainly in Sava, Savinja, Drava and Mura river basins. It is due to shallow soils, higher content of skeleton, sand contents, and low soil organic matter content. Therefore, there is a critical need to improve those soil parameters mainly by composting tillage. Simply, water is not only "blue gold" for nature and society (BARLOW AND CLARK 2002) but also dangerous medium against both. "Fighting for water saving and against water threats" is one of the fundamental principles of water management theory and practice in many countries and soil has a critical position in this philosophy.

2. THEORY TO PROBLEMS

2.1 SHORT HISTORY OF THE PROBLEMS

Regulation of soil water regimes is well known in agriculture. Both, drainage and irrigation technologies have been significantly developed and implemented in agriculture in the beginning of the past century as regulators of soil production potentials in favour of agricultural production. In the middle of past century a new so-called "industrial agriculture" was developed, using a new farming systems and heavy machines in soil cultivation. Both have brought new progressive and effective practices in agriculture but simultaneously led to soil degradation as well. Mainly soil compaction as physical degradation of soil was observed. Besides of negative influence of soil compaction on cultivated plants also soil water regimes have deteriorated (mainly of heavy soils). Compacted soils are suffering from lower water infiltration into the soil, lower soil and country moisture and higher surface water removal from the soil what increased flooding intensity especially in the areas of compacted soils. It is more dangerous under climate change conditions where heavy rains are often observed.

For mitigation of those problems both agriculture and water management practices have to be concerned. Mainly after adoption of the "EU Water Framework Directive" those problems started to be more sensitive because of water management programs needs. Also EU Recommendation for Soil Protection (R/92/8) is a significant document where soil as water reservoir is considered and because of that function is asked to be protected.

Technical and technological solutions of these problems use several different approaches and have been developed for the purpose of agriculture. The technology of subsoiling developed in the beginning of the second half of last century for improvement of root growth conditions is now studied from the soil and country water regime improvements point of view. Besides, reduced tillage methods (digging to 10 cm depth), tied-ridge tillage, minimal soil cultivation (paraplough, chisel, rotary grape), no-tillage, appropriate plant cover and organic matter application into the soil, all is a good way to achieve higher water infiltration into the soil profile (Reynolds et al. 2007; Moraru and Rusu 2010; Alliaume et al. 2013; Hartman et al. 2012).

2.2 PRESENT STATE OF THE KNOWLEDGE

Agricultural drought is dominantly starting when the amount of water in the soil is at the level of wilting point. Wilting point (WP) is defined as a minimal content of soil moisture which the plant requires not to wilt. Simply when moisture has decreased to this or any lower point, the plants cannot longer recover their turgidity after being placed in saturated atmosphere for 12 hours. The physical definition of the wilting point is defined as the water content at -1500 J/kg of suction pressure or negative hydraulic head (Wösten et al. 1999, Givi et al. 2004, Patil et al. 2012). Approximately the value of a wilting point is possible to assess according to the representation of the I. category of soil texture in volume percents (Valla et al. 2006).

This concept was introduced in the early 1910s. Lyman Briggs and Homer LeRoy Shantz (1912) proposed the wilting coefficient, which is defined as the percentage of water content in the soil when the plants growing in that soil are first reduced to a wilted condition and they cannot recover in approximately saturated atmosphere without the addition of water to the soil (Taiz and Zeiger 1991). Simply, the soil wilting point is achieved when water absorption by the roots is lower than water , transpiration of the plant.

The soil types with higher total available water are generally more conductive to high biomass productivity because they can supply adequate moisture to plants during time when rainfall does not occur. Sandy soils are more prone to drought and will quickly (within a few days) be depleted of their available water when evapotranspiration rates are high.

The European Soil Bureau in Ispra (European Union, DG-Environment) created the data base for soil of Europe (EU-25) as a background for water availability in soils (JONES-ZDRULI-MONTANARELLA,2000) As was concluded in this study soils of Slovakia and Slovenia belongs to the more dry territories of Europe where is necessary to solve this problem. In Czech Republic and Poland situation is a little better.

The water content in the soil depends primarily on water infiltration into the soil profile, water evaporation from the soil, water transpiration from plants and on vertical water movement to the deeper layers of soil and groundwater respectively. The amount of infiltrated and stored water in the soil is most important parameter from all mentioned processes. This amount of water is affecting not only by conditions for plant cover of soil, but represents the portion of rainfall water which can be saved by soil and territory for many kinds of functions in nature. For example, the total amount of the annual rainfall on the territory of Slovakia is about 53 billions of cubic meters and from that about 11 billions of cubic meters are infiltrated into the soil. In the scale of the whole world, approximately about 0.05 % of fresh water is in the soil.

In Trends in Sustainable Development (UN 2008) it is mentioned that from 10 world top natural disasters during the years 1974-2007 at least 5 had been due to drought. Droughts often result in heavy crop damage and livestock losses, disrupt energy production and hurt ecosystems. They cover wide areas of land and often affect several neighbouring regions or countries simultaneously. Drought can lead to famines, loss of life, mass migration and conflicts. Hence, drought can wipe out development gains and accumulated wealth in developing countries, especially for the poorest. In a number of countries, drought wiped out significantly more than 5 % of the previous year`s GDP (GUHA-SAPIR 2004).

2.2.1 Soil water holding capacity as a land factor limiting water storage

Soil water holding capacity is the portion of water that can be absorbed by plant roots. Moreover, it is amount of water what is saved for the all essential functions of land. Besides, this is the capacity of nature against of floods disasters in the nature and in favour of the socio-economic use of water. Simply, more water saved by soils means better conditions for nature and people.

By definition it is the amount of water stored, or released between field capacity and the wilting point water content. The average amounts of total contents of water in soil depends on its textural characteristics mainly as follows: coarse sand 5 %(volume) , fine sand 15 %, loamy sand 17 %, sandy loam 20 %, sandy clay loam 16 %, loam 32 %, silt loam 35 %, silty clay loam 20 %, clay loam 18 %, silty clay 22%, and peat 50%.

Of course, this is also depending on place to place and on many other factors. Firstly it depends on the soil use (agriculture, forestry, etc.), on farming systems (soil tillage, cultivated plants, fertilizing, machines use, etc.) and on use of soil conservation farming systems (approaches) in agriculture and forestry. No correct farming can lead to soil compaction significantly decreasing the soil water holding capacity and the total amounts of water which is able to infiltrate into the soil profile.

The soil compaction historically is not here for a long time and/or is not a traditional threat to soils. It is the result of new farming systems in principles and approaches. It has started after heavy machines use and as a result of economy pressure on the farming systems. Generally, soil compaction as deformation of soil structure is caused mainly by agricultural and forestry machines whenever machines are too heavy and too heavily loaded, and/or where the stability of the soil is low due to high soil water contents. Because mechanical loads have a three-dimensional effect extending deep into the soil, soil often suffer from irreversible damage over the long term (GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE: WORLD IN TRANSITION: THE THREAT TO SOILS, 1994).

2.2.2 Arguments for increasing soil water holding capacity

Several studies have been presented during the past 30 years in this scientific problem. Most of those studies have been focused on decrease of farming production due to soil compaction. There was identified that high axle loads can cause compaction zones developed below deep of 30 cm and may be extended to 50 cm or deeper (VOORHEES ET AL. 1986, LOWERY AND SCHULER 1991, GAMEDA ET AL. 1985). Axle loads ranger from 8 to 20 Mg is not excessive when a modern four-wheel drive tractor may weight 12-16 Mg. Large combine harvesters can have a loaded weight 24 Mg with 75 % of the weight on the front axle, and large grain carts can carry loads of 20-36 Mg on a single axle. The increase bulk density and soil strength below normal tillage depths are only slowly ameliorated by natural forces such as freezing and thawing or wetting and drying (VOORHEES ET AL. 1986).

Increased awareness of the problems associated with soil compaction and subsoil compaction has generated an interest in the possible benefits that could be obtained from a deep tillage such as subsoiling. At the beginning it was not a popular technology because it requires higher energy input and it was not effective for a long period. In spite of that a new mainly research activities have been carried out.

New knowledge about it brought new ideas. Information was accepted that subsoiling is a technique commonly used to alleviate the adverse effects of soil compaction and improve soil physical conditions, in both cropping and pastoral agriculture. In ideal conditions, subsoiling should break the soil at depth and produce vertical cracks through the soil profile. The depth of subsoiling was 25 cm to loosen topsoil or much deeper (50 cm) to loosen dense B soil horizons. Subsoiling has been reported to increase the total volume of pores and increase the proportion of macropores (HARRISON ET AL, 1994). Macroporosity volume could be increased up to 30 % of total soil volume what is a good message for higher yields and for higher water holding in soil. It is also affecting the yields because of reducing of crop water stress during dry conditions. Yield increases for up to three years have been observed where soil has been effectively subsoiled, but where soil disturbance was minimal, the effect of subsoiling were less persistent. Results from New Zealand show, that subsoiling increased macroporosity by up to 39 %, and increased saturated hydraulic conductivity and air permeability by up to two orders of magnitude. Improvements of soil physical conditions have been proved for two years after subsoiling (DREWRY ET AL, 2000).

Another result shows that the soil water storage under subsoiling from the soil surface to a depth of 100 cm was more than that was under no-tillage. Compared with no-tillage, subsoiling could reduce the water consumption of oats in the 0-50 cm depth and increase the water consumption in the 50-100 cm depth. Also, subsoiling increased the yield by 18-29 % and the water use efficiency by 16.8 % in two years in average. The effect of subsoiling on water conservation and yield increase were affected by precipitation, and a well-proportioned rainfall was better to increase yield and water use efficiency (QIN HONG-LING ET AL, 2008).

MOHANTY ET AL. (2007) informed that subsoiling will not overturn the soil but disturbs and breaks the plough layer, which results in improving the permeability of soil water, creating additional water reservoir. nderneath the soil surface, increasing the efficiency of rainwater use, and improving the ability of water conservation in arid areas. Subsequently, subsoiling can minimize the effect of drought and lead to an increase in crop yield. Moreover it has been shown in practical results that subsoiling technique caused an increase in winter wheat yield by 18.8 % and water use efficiency was also increased by 16 %.

From several results received it is possible to say, that it was not necessary to conduct subsoiling every year - mostly is the recommendation is to use it every 2-4 years. In agriculture under intensive technologies (used in developed countries), subsoiling is important procedure to eliminate areas (at least temporary) of degraded soils by compaction and loss of structure. This is too important also in relation to soil water holding capacity increase not only for agriculture but also in favour of better water regimes in the country. Mainly in rain-feed water regimes and under influence of climate change it could be strategy towards more sustainable agriculture and quality of environment.

Soil compaction in Slovakia represents about 600 thousands ha really compacted soils. The area of potential compaction can be assumed for about next 600 thousands ha. Only about 1.1 million ha of agricultural land (from total 2.4 million ha) are not endangered by compaction (BIELEK 2008). It is deduced on the basis of textural parameters of soils in Slovakia. FULAJTAR (2006) presents conclusions that the soil compaction starts to be dangerous when bulk density of soil is over of 1.5 $g.cm^{-3}$, but in case of heavy soils it can be from 1.3 to 1.4 $g.cm^{-3}$. Field determination of soil compaction can be done with the help of a penetrometric study usually into the depth to 1 m of soil profile. In comparison to protection against compaction by better farming practices, more realistic is improvement of compacted soils by subsoiling mainly (best is into the depth 40-60 cm). Higher effect of subsoiling could be achieved when first plant cultivated on subsoiled soil will be plants with deep roots as e.g. clover, or alfalfa plants.

The total annual rainfall brings to Slovakian territory about 53 billion m^3 of water, from that about 11 billion is keeping in the soil. By qualified assumption we can expect that when mentioned 600 thousands ha of compacted soils would be subsoiled, it could be additional 100 million of m^3 more what will be infiltrated (saved) in the soil cover of Slovakia. It can be fruitful for agriculture and against of flooding as well. Moreover it can be favourable for all water regimes in the country.

The subsoiling is a green technology effective for both agriculture and water management. This is a technology for great areas of land and brings a success for large segments of population and for the nature. It is because the share of agricultural land in total areas of the countries is in OECD countries about 40 %, about 50 % in EU-15 and almost 60 % in the Central European countries.

Some positive results from subsoiling technology are known but mostly for favour of soil quality and agriculture production.

Many other studies dealt with the effect of soil cultivation on its water content, water holding capacity and other characteristics connected with infiltration. GUZHA (2004) states the highest soil water content of soil profile of Dystric Regosols (FAO) during the seasons under the cover of sorghum by topsoil ridging, then it is followed by reduced tillage method – digging to 10 cm depth with a hand hoe to form a strip in which planting of the seed was done and a three-furrow disc plough, pulled by a 50 HP tractor ploughing at a depth of 15 cm. In spring the highest soil water content was found at uncultivated soils, then it was followed by flat cultivation with a hand hoe which involved digging across the slope to a depth of 10 cm, the use of a hand hoe in row and three-furrow disc plough. According to JOSA AND HERETER (2005) soil water content of upper 20 cm of soils is according to the observing in Mediterranean climate for Calcic Cambisol (CEC) in this order: no tillage > limited cultivation > conventional soil cultivation. MIRITI ET AL. (2012) compared the content of water accessible for plants at three ways of cultivation of Chromic Luvisols (FAO). The highest contents of soils were presented at tied-ridge tillage and lower values for ox-ploughing and subsoiling-ripping, which weren't mutually statistically different. MORARU AND RUSU (2012) found out higher soil water content at Argic-Stagnic Faeoziom (Romanian System of Soil Taxonomy) under the cover of wheat, corn and soya at direct sewing or minimal soil cultivation (paraplough, chisel, rotatory grape) than at conventional cultivation. Statistically significant change was proved only for soils with direct sowing of wheat. MORARU AND RUSU (2010) describe higher soil water retention using minimal soil cultivation (paraplough, chisel plough, rotary harrow) than conventional method, for Haplic Luvisols by 1–6 %, for Mollic Fluvisols and Cambic Chernozems by 11–15 %. On the contrary in Germany, GRUBER ET AL. (2011) did not record any statistically significant changes in soil water content for different soil cultivation methods (from conventional to other types of minimal or no cultivation), which was similar to the study of VAN DEN PUTTE ET AL. (2012) in case of conventional ploughing and protected cultivation up to the depth of 0.15 and 0.3 m in Belgium.

ALLIAUME ET AL. (2013) show on the example of Mollic Vertisols (Hypereutric), Luvic/Vertic Phaeozems (Pachic) and Luvic Phaeozems (Abruptic/Oxyaquic) (WRB, 2006) that volumetric soil water content within 10–100 kPa was on an average by 2.3 mm 10 cm−1 higher on the places undisturbed by agriculture than on cultivated land for all three observed soil types. ABID AND LAL (2009) also came to the conclusion that volumetric soil water content of topsoil cultivated conventionally is at potentials −3 a −6 kPa lower than of uncultivated soil. Also in the comparison study of Zibilske and Bradford (2007) volumetric soil water content cultivated conventionally at the pressure of −10, −33 and −100 kPa in semiarid areas, also have lower values than ridge tillage; the highest soil water content thus showed an un-cultivated land. For Oxic Tropudalf (USDA) at the pressure of 4.5 kPa OSUNBITAN ET AL. (2005) describe higher values of volumetric soil water content for no-tillage soil and soil with manual tillage (hoe) than for soils with plough-plough tillage and with plough-harrow tillage. For pressures 50 and 150 kPa statistically conclusive higher soil water content was for soils with no tillage.

BESCANSA ET AL. (2006) state that water holding capacity of soil was higher for no-tillage than for reduced or conventional cultivation, where the change was related only to retention in potential −33 till -50 kPa. Similar conclusion was also for the study of SHUKLA ET AL. (2003) who compared mouldboard ploughing, chisel ploughing and no-tillage. Statistically conclusive changes were displayed only in the upper 10 cm of soil; water content at full saturation was the highest for soil with no-tillage. Retention is higher at different potentials using chisel plough than at plough, the values of volume density of no-tillage soils are usually within their range. FARKAS ET AL. (2009) found an increase in water holding capacity while using intercrops in comparison with no intercrops in the soil layer of 5-10cm and 15-20cm for the cultivation of soil by ploughing, harrow tillage together with aeration and sewing into non-ploughed soil. Using of harrows itself didn't lead into increase in water holding capacity. REYNOLDS ET AL. (2007) describe differences in water holding capacity in the upper 10cm topsoil, where the values of ideal water holding capacity are for soils which was never cultivated while the other ways of cultivation, including permanent grassland, mostly reached only limited or not good value of water holding capacity. The values of water holding capacity are not significantly changed at changes in the ways of cultivation, mostly because of compensating changes at field capacity and wilting point (REYNOLDS ET AL. 2007). Similarly ABID AND LAL (2009) states that soil with no-tillage in comparison with conventional cultivation did not statistically influenced the values of water holding capacity in the uppermost 10cm of soil.

HARTMANN ET AL. (2012) describe differences in hydraulic characteristics of soil at conventional and conservational cultivated areas. In Ap horizon saturated hydraulic conductivity is bigger at conventionally cultivated soil than at soil cultivated by protective way, while in Eg horizon it is the other way around. *Bell at all (2003)* state, that the decrease in hydraulic conductivity by the impact of conventional cultivation is set in the cultivated layer (ca upper 30cm); this characteristic is not influenced in higher depths. SHUKLA ET AL. (2003) proved the impact of agrotechnology only in topsoil, where saturated hydraulic conductivity was higher on soils with no-tillage than on soils cultivated by chisel plough and mouldboard ploughing. REYNOLDS ET AL. (2007) recorded in the surface layer of soil similar saturated hydraulic conductivity values for: soil which was never cultivated, permanent grassland, soil with no-tillage and also by one degree lower saturated hydraulic conductivity for cultivated soils. SHUKLA ET AL. (2003) proved the impact of agrotechnology only at the uppermost soil layer, where saturated hydraulic conductivity was higher for soils with no-tillage than for soils cultivated by chisel plough and mouldboard plough. MORARU AND RUSU (2010) found higher values of saturated hydraulic conductivity for minimally cultivated soils (paraplough, chisel plough) in comparison with soil cultivated conventionally. OSUNBITAN ET AL. (2005) found the highest saturated hydraulic conductivity for soils with no-tillage and the lowest value for soils twice ploughed by plough-plough tillage; however conductivity of soils with manual tillage (hoe) did not differ from the ploughed soils too much. While comparing conventional tillage with minimal cultivation by harrow tillage and subsoiling, PAGLIAI ET AL. (2004) found that topsoil with conventional ploughing have due to more developed surface crust significantly lower saturated hydraulic conductivity than soil cultivated alternatively. In a depth of 10-20cm it has significantly lower values of saturated conductivity than minimally cultivated soil. At conventionally cultivate soil a compact layer is expressed at the depth of ploughing by decrease in saturated hydraulic conductivity (PAGLIAI ET AL. 2004). JIANG ET AL. (2007) did not find any significant differences in saturated hydraulic conductivity at cultivation of soil by different protective technologies.

REYNOLDS ET AL. (2007) point at the decrease in saturated hydraulic conductivity due to changes of cultivation from permanent grassland or uncultivated soil into arable land, which happens right in the first year of change and during the following three years there are no more significant changes. On the contrary, change of cultivation from ploughing to no-tillage lead to an increase in saturated hydraulic conductivity during the first year. These changes are probably caused by sensitivity of characteristics on soil structure and organic matter amount. The rate of infiltration is significantly influenced by tillage. ABID AND LAL (2009) and SHUKLA ET AL. (2003) state, that arable land has lower infiltration rate than no-tillage soils. On the contrary, GUZHA (2004) found, that water infiltrates faster on cultivated soil. MCCONKEY ET AL. (1997) mention an increasing amount and depth of water infiltrated for subsoiled land, if rainfalls during November-April was on an average. At lower rainfalls the increase was not expressed. On the contrary, MOROKE ET AL. (2009) did not record statistically significant changes in infiltration rate at various soil types of different soil texture in dependence on the way of cultivation (conventional ploughing, double ploughing, deep ripping).

2.2.3 Real state of practices and perspectives

Saving water is not sufficiently introduced into the agricultural practices of moderate climate zones. Even in areas where water deficiency for agriculture is occurring, most preferable actions are not for water saving in the soil but rather soil and plant irrigation. In opposite, wetland areas are drained what is against of water saving in the soil or those areas are not using by agriculture. Also in official agricultural policies (EU, national) some efficient measures for higher water saving in the soil profile are missing and/or are not supported as subsidiary items. This is because of low level introduction of EU Water Framework Directive principles into agricultural practices and mainly because of not enough accepted role of soil and agriculture in effective national water management policies of the countries. Result is that the needs of water saving in the nature are not asked as multi sectorial approach with soil and agriculture ignorance. Our activities focusing on that can bring some motivations for change of this situation.

Within the framework of soil science research and step by step in agricultural practice, as well are more and more popular activities, are focusing on the so-called conservation agriculture. There are several new farming systems (no-till, mulch-till, ridge till, low input, precision farming, eco-farming and others) saving the soil and soil properties. Inside of conservation agriculture is now very perspective so-called water saving farming systems belonging to the conservation agriculture and saving the water in agriculture as a whole including that of soil. This is a good space for many activities of the research and development both related to water management (plans and implementations) in the country. Activities of this project are a concrete contribution to those problems. Here are some main characteristic of the mainly used farming systems which are relevant to soil and country water regimes characteristics.

Conventional Tillage: Mouldboard Ploughing. The mouldboard plough was designed to control weeds, loosen compact soils, incorporate residues and fertilizers into the soil, and improve seed germination (BLANCO-CANQUI AND LAL 2008). The introduction of mouldboard plough changed the shape of the fields and increased the size of the cultivated area and food supply particularly. However, intensive ploughing causes soil erosion (e.g., the Dust Bowl), depletes soil nutrients, and reduces biological activities. One of the major factors by which mouldboard ploughing influences soil productivity is by altering the amount of crop residue left on the soil surface. Mouldboard plough chops and buries the residues in the soil. Because ploughing leaves little or no residue cover, it increases soils' susceptibility to wind and water erosion. Surface cover, essential to erosion control, is a direct function of tillage intensity. It affects the physical and chemical processes and attributes of the soil. Bare ploughed soils are extremely susceptible to crusting and surface sealing. Raindrops striking on bare soil disrupt aggregates and slaking leads to formation of thin films that clog up the pores and reduce water infiltration capacity.

Excessive tillage increases erodibility of the soil, destroys natural soil architecture, reduces microbial processes, and degrades soil cultivation. It reduces aggregate stability and the number of soil organisms such as earthworms, which are important to loosening the soil, recycling nutrients, and creating macropores for increased water-air and gaseous exchange in the soil. The loose soil structure following tillage is highly unstable. Ploughed soils are sensitive to internal capillary forces, wetting and drying, and crusting and surface sealing. Crusts can also reduce seedling emergence, plant growth, and crop yields, particularly in fine-textured soils.

Conservation Tillage System is an alternative to conventional tillage. Any tillage system that leaves at least 30% of residue cover on the soil surface is called conservation tillage (FAO 2015). This definition is, however, too narrow to define the appropriate tillage systems that effectively conserve soil and water. While the 30% of residue cover may be appropriate for some soils, it is insufficient in others to reduce soil erosion to permissible levels. When combined with prudent management of crop residues, crop rotations, and cover crops, conservation tillage is a useful technology for protecting soil and increasing/sustaining crop production.

The optimum conservation system should have enough vegetative cover or crop residues to increase soil surface roughness and improve the infiltration capacity. A conservation tillage system must be specifically designed for each soil based on site-specific criteria (e.g., farm profitability, severity of soil erosion, soil type, topography, climate).

No-till farming

No-till or zero tillage refers to a system where a crop is planted directly into the soil with no primary or secondary tillage (FAO 2015). It is an extreme form of conservation tillage, in which soil remains undisturbed at all times except during planting. It is a practice that leaves all surface residues (stalks, cobs, leaves, etc.) on the soil following harvest. Weeds are normally controlled with herbicides unless proper cropping systems such as crop rotations and cover crops are used as supporting conservation practices. No-till farming represents a paradigm of soil management for conserving soil and water.

No-till farming in Europe started in the 1950s. Abundant residues on the soil surface and restrictions on straw burning induced proliferation of weeds, slowing a rapid expansion of no-till. The lower production costs in machinery, fuel, and labour under no-till are attractive to farmers over conventional tillage because whatever reductions in crop yields under no-till are easily compensated by the reduction in production costs and improvement in soil and environmental quality. Direct planting without ploughing saves time and energy. About 16% of the cultivated soils in Europe are highly prone to degradation (HOLLAND 2004).

A narrow and shallow furrow is created using coulters or in-row chisels to place the seeds. Theoretically, the term no-till may not be a suitable name if soil is significantly disturbed at planting through the opening of transient furrows for seed placement. The amount of disturbance needed at planting is a function of soil compaction, amount of residue cover, and other site-specific characteristics.

The no-till farming is among the top of the portfolio of strategies to control soil erosion and reduce tillage costs. It is also an option to maintain crop productivity and environmental quality. It conserves soil and water while improving tillage and increasing soil organic matter. The performance of no-till systems for improving soil functions depends, however, on the soil-specific, topographic, and climate characteristics. The major beneficial impacts of no-till are particularly noted within the upper soil horizons where most crop residues are concentrated. Most of the beneficial aspects of no-till technology are attributed to the crop residues mulch. Thus, no-till systems which leave little or no crop residues after harvest may affect soil properties as adversely as conventional tillage does. Residue left on the surface of no-till soils absorbs and buffers the erosive energy of raindrops and generally improves soil properties. This buffering process reduces aggregate detachment and surface sealing and crusting, thus decreasing risks of surface runoff and soil erosion.

Water infiltration rates and saturated hydraulic conductivity tend to be higher under no-till than in ploughed soils because of abundant macropores. Macropores remain intact in no-till soils. Earthworms can increase water infiltration by 10–100 times depending on the soil (EDWARDS ET AL. 1990). Presence of continuous macropores increases the hydraulic conductivity and can offset any reductions in hydraulic conductivity due to compaction. Long-term no-till practices impact aggregate strength, density, and water retention capacity different from conventional tillage. Excessive tillage, rapid post-tillage consolidation, and low organic matter concentration in ploughed soils alter aggregate formation and properties. Increases in soil organic matter can both increase or decrease the strength of aggregates depending on the soil texture, nature of organic matter, and soil water content. No-till management enhances formation of C-enriched macro- and micro-aggregates. Ploughed soils often have denser, more compact, and stronger aggregates compared to no-till following post-tillage consolidation. The strength of aggregates tends to increase with increase in no-till induced changes in organic matter concentrations in clay soils and decrease in silt loam and sandy soils (IMHOFF ET AL. 2002; BLANCO-CANQUI ET AL. 2005).

No-till and subsoiling

Subsoiling, also known as deep tillage, is a practice that loosens soil to below the up horizon without inverting and mixing the plough layer. It fractures and slightly lifts the soil while minimizing vertical mixing. This practice is used to break up compacted subsurface layers that form between 25 and 40 cm below the soil surface from natural consolidation or machinery traffic. This compacted layer, also called ploughpan, restricts seedling emergence, root growth, and down- and upward water and air movement. In some cases, the soil may be saturated with water above the ploughpan and unsaturated below due to the virtual impermeability of the ploughpan. Plant roots often concentrate above the ploughpans with reduced access to subsurface available water and often wilt when supply of surface water is limited.

Subsoiling can alleviate the above problems. It has been used as a companion practice to no-till. Subsoiling mouldboard ploughed soil is sometimes desirable before converting the system into no-till. The water content of the compacted layer must be dryer than field capacity prior to subsoiling. Soils that are too wet during subsoiling can create additional compaction problems. Subsoiling does not always increase crop yields, depending on soil type. Silty clay loam soils appear to respond to subsoiling better than heavy clayey soils. Choice of subsoiling equipment is critical. While subsoiling is designed to allow the practice of no-till in soils susceptible to compaction, some subsoiling machines tend to mix and disturb the whole plough layer. Machines equipped with narrow shanks reduce disturbance of the plough layer and maintain residue cover on the soil surface must be used. Because subsoiling of deep layers can be expensive, controlled traffic decreases the need of subsoiling and prolongs the benefits of no-till farming. Depending on the traffic and soil susceptibility to compaction, subsoiling is done every 3–4 yr.

Reduced tillage refers to any conservation system that minimizes the total number of tillage primary and secondary operations for seed planting from that normally used on field under conventional tillage (FAO 2015). It is also called minimum tillage because it reduces the use of tillage to minimum enough to meet the requirements of crop growth. Reduced tillage is a conservation management strategy that leaves at least 30% residue cover to minimize surface runoff and soil erosion, improve soil functions, and sustain crop production. Reduced tillage is becoming an important conservation practice like no-till. These systems reduce surface runoff and soil erosion and improve or maintain crop yields compared to conventional systems. Surface runoff and soil erosion from minimum or reduced tillage are generally between those from conventional tillage and no-till. Some of the systems within reduced tillage include mulch till, ridge-till, and strip-till.

Mulch tillage is a practice where at least 30% of the soil surface remains covered with crop residues after tillage. Tillage under this system is performed in a way that leaves or maintains crop residues on the soil surface. Mulch tillage is an extension of reduced tillage and is also called mulch farming or stubble mulch tillage. The soil under mulch tillage is often tilled with chisel and disk plough instead of mouldboard ploughs, and thus it minimizes soil inversion.

One of the advantages of mulch tillage over no-till is that it can control weeds better by tillage. Minimizing the secondary tillage is important in mulch tillage to conserve and maintain residue cover. While soil erosion in mulch tillage is commonly lower compared to that in conventional tillage, it can be higher than that in no-till systems because mulch tillage leaves less residue cover on the soil surface than no-till. The use of mulch tillage requires the modification of tillage implements and operations. The choice of implement for mulch tillage is specific to each soil and management.

Strip tillage. This system is also called partial-width tillage and consists of performing tillage in isolated bands while leaving undisturbed strips throughout the field. By doing so, strip tillage combines the benefits of no-till and tillage. Only the strips that will be used as seedbeds are tilled. The strips between the tilled rows are left under no-till with under residue cover. Strip tillage loosens the tilled strip and temporarily improves drainage and reduces soil compaction. The strip tillage can be an alternative to no-till farming in poorly drained and clayey soils. Where no-till has not maintained or improved corn production, strip tillage is a recommended option.

Ridge tillage is a system in which 15- to 20-cm high permanent ridges are formed by tillage during the second cultivation or after harvest in preparation for the following year’s crop. The ridges are maintained and annually re-formed for growing crops. Crops are planted on the ridge tops, a practice known as ridge planting. This system is designed to reduce costs of tillage, improve crop yields, and reduce losses of surface runoff and soil. Ridge tillage can reduce soil erosion by as much as 50% as compared to conventional tillage (GAYNOR AND FINDLAY 1995). A specialized equipment assembly of a ridge-till cultivator, coulter, and disk hiller is used to cut through the residues and form ridges. The disk hiller throws the soil towards the row and forms peak ridges. Shallow scalping (2–5 cm deep) of the ridge tops and residue removal by a row-cleaner are necessary for placing seeds. The residue removal temporarily leaves the ridge crests bare but the residue is moved back during ridge reforming. Also, residue produced at harvest is left on the soil surface to protect the ridge tops. In soils with low ridges, direct planting (no-till) may be preferred over scalping.

Organic farming is an agricultural system where no synthetic fertilizers or pesticides are used to produce food and fibre in contrast to chemically-based conventional farming systems. It is also called biological or biodynamical agriculture because it improves soil biology, enhances soil’s natural fertility, and promotes plant biodiversity. It is a system that comprises a host of environmentally friendly agricultural practices to sustain crop production. Organic fertilization to add nutrients and mechanical and biological practices to control pests are two key exclusive components of organic farming (REGANOLD ET AL. 1987). Crop rotations, cover crops, manuring, residue mulch, and compost are among the alternative sources of nutrients used in organic farming. Organic farming encompasses all crops (e.g., grains, cotton, vegetables, flowers), and animal products (e.g., meat, dairy, eggs) and processed foods.

3. DESCRIPTIONS OF EXPERIMENTAL METHODS AND PROCEDURES

Within the framework of IDMP CEE research and observations have been carried out by field experiments. Field observations have been carried out during 2013-2014.

3.1 FARMING SYSTEMS USED

Several farming systems in different soil conditions have been verified and studied.

Czech Republic. In 2013 the Research Institute for Soil and Water Conservation has started field experiments concerning mainly the comparison of cultivation effects at experimental plots. The experimental sites were in:

1. Prachov – (Haplic Stagnosols) subsoiling and conventional tillage; 1-year
2. Ouběnice – (Haplic Cambisols) organic farming, subsoiling, conventional tillage; 1-year
3. Třebsín – (Haplic Cambisols) conventional tillage + green manure, conventional tillage + manure, conventional tillage and fallow; 2-year.

At Oběnice site (395 a.s.l.), ecological farming system with triticale as a crop were compared with the variant of subsoiling (maize) and with a control variant under conventional tillage (maize). At Třebsín site, the fallow land was compared with use of organic fertilizers, green fertilizers (mustard) and a control variant under conventional tillage. Soil sampling and they analysis for study site Třebsín was ongoing for the second year. In both cases it was the soil type Haplic Cambisols. This soil type was selected because in the Czech Republic Cambisols are the most widespread soil type. The Prachov field plot (286 a.s.l.) was as third experimental plot. At this experimental plot, the influence of subsoiling on infiltration and retention properties of soil was compared with conventional tillage. The terrain is flatted with slope less than 2°.

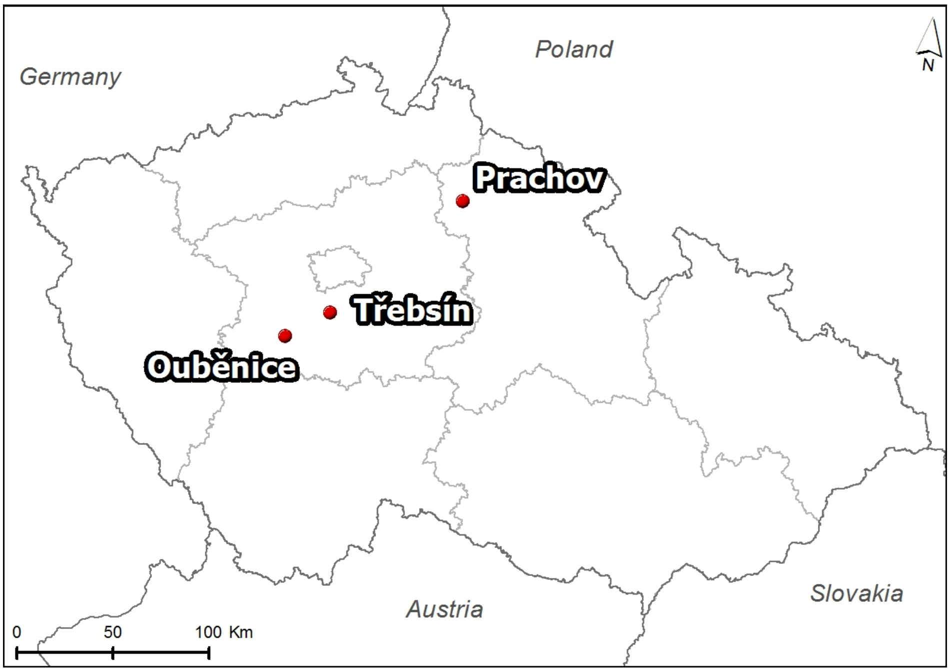


Fig.1 Location of experimental plots in Czech Republic

Poland. Two farms located in the southern part of Wielkopolska in the district Gostyń in the municipality of Borek Wielkopolski were chosen to obtain the quantitative characteristics of investigated soils and to compare the effects of impact of two tillage systems on the water retention capacity of the soils. The investigations have been carried out in two years: 2013 and 2014.

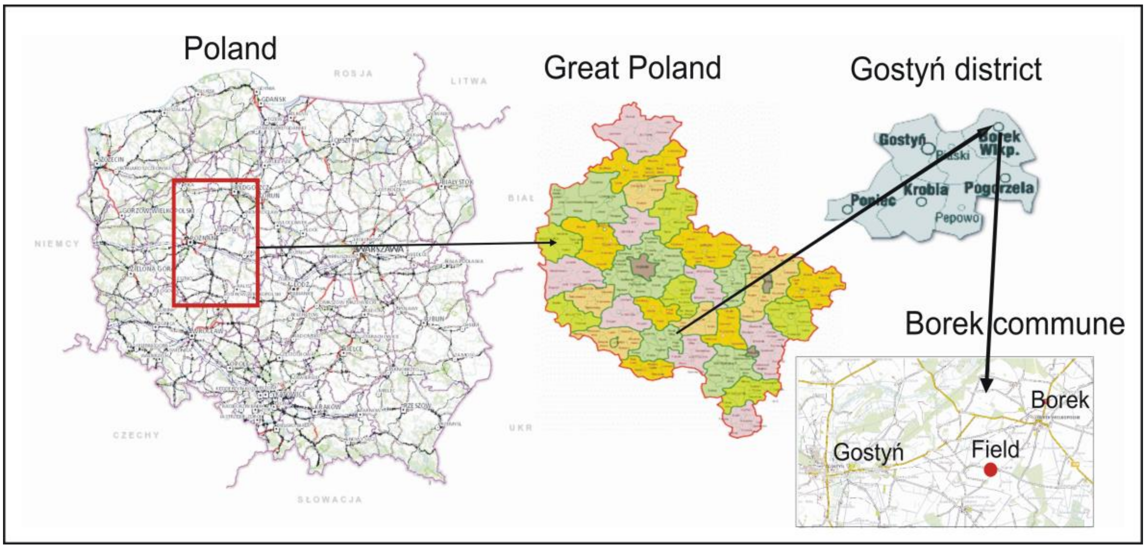


Fig.2 Location of experimental fields in Poland

Two experimental fields, located one by one, were taken under consideration. One field was cultivated traditionally, while the other one was cultivated by no-tillage system. On each field two soil profiles were analyzed in detail. On no-tillage fields the crop rotation was as follows: rape, winter wheat, sugar beet. On tilled field typical agronomy operations were used, with use the plough, ploughing to 30 cm depth, while on the no-tillage field only a few centimetres of upper layer were loosened.

Slovakia. Field experiments have been located in the area of Agricultural cooperative in Kolíňany, nearby Nitra city used as the Experimental Research Station of the Slovak University of Agriculture in Nitra. Soil subtype is Haplic Luvisols (HMa). Organic carbon content (C_{ox}) is lower or middle (range 0.96 to 1.31 %) and soil pH in KCl is strongly acid (range 4.59-5.39). Field experiments have been started in the spring 2013. It was in April 27, when two plots of field experiment have been set up on area 200 m^2 each: (1) subsoiled soil and (2) no subsoiled soil. Subsoiling has been provided into the depth of 0.6 m by special agricultural machine (Artiglio Moschra). Maize has been cultivated. In season 2013-2014 it was winter barley. In autumn 2013 new additional experimental fields have been set up closely to the first experiments with following plots: (3) no subsoiled soil, (4) singly subsoiled soil and (5) crossly subsoiled soil. From autumn 2013 winter wheat was cultivated here by no till farming system. On July 2nd, 2014 the yields of both cultivated plants have been harvested. Inventory of the field experiments:

2013: 1. no subsoiled field (maize) 2. singly subsoiled field (maize)

2014: 1. no subsoiled field from 2013 (winter barley)

2. singly subsoiled field from 2013 (winter barley)

3. new no subsoiled field (winter wheat)

4. new singly subsoiled field (winter wheat)

5. new crossly subsoiled field (winter wheat)

Fig.3 Locations of experimental plots in Slovakia

Slovenia. One field experiment is a long-term tillage experiment, lasting continuously from 1999 (called "Rašica") and the other one was established in 2011 (called "Mamino"). The third experiment ('Kumrovo') is 5 km away, located in the area of river Pesnica fine alluvial deposits, the soil type is Gleysol. Soil at 'Kumrovo' is much 'heavier', containing over 50% of clay, and < 2 % sand, classified as silt-clay.

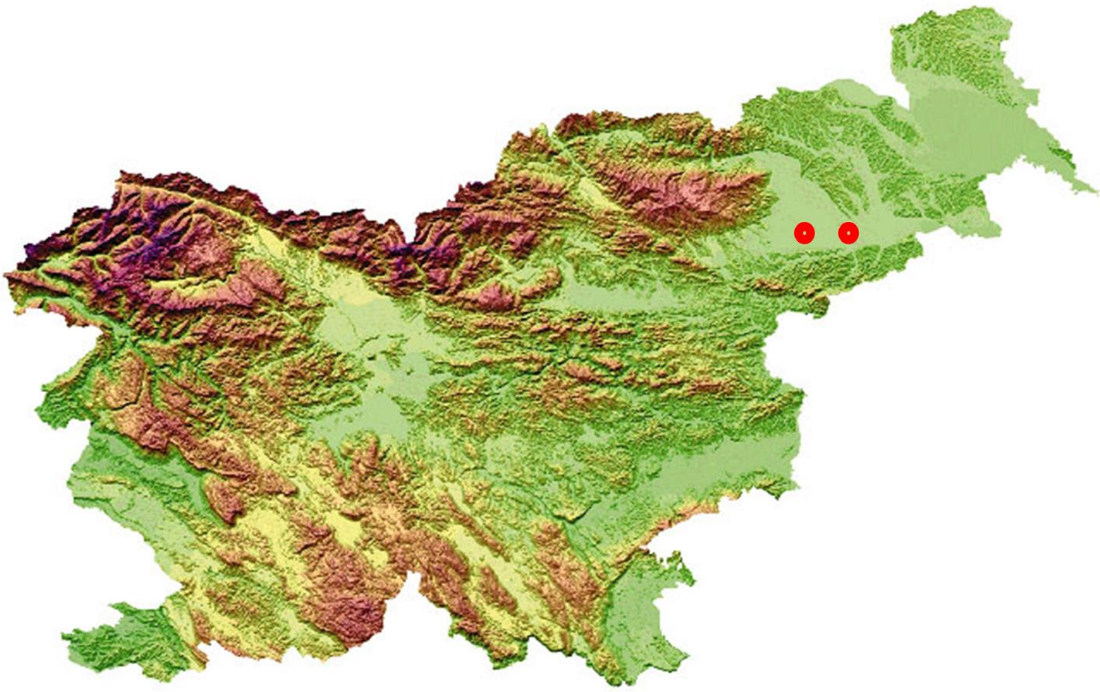


Fig.4 Location of experimental plots in Slovenia

The field experiment, called “Rašica”, which is continuously conducted since 1999, is divided into two plots/treatments (each 15 m wide and 80 m long), with four randomly chosen replicates in each. There was observing the effects of conservation tillage (ca. 10 cm deep cultivation either with chisels or discs, always at least 30% of soil permanently covered with crop debris) in comparison to conventional mouldboard ploughing plus among others additional harrowing, disking, levelling for seed bed preparation. Additional to this long-lasting experiment, two field trials were established in the autumn 2011 in the same geographical area (all three experiments are in a radius of ca. 5 km; the area has almost the same climate), one in a heavy soil, and the other in a light textured sandy-loam soil, both in the same area. From 2011 was started test of ‘the Composting tillage’ (CT) in comparison to traditional mouldboard ploughing and seedbed preps (P) at all three experiments. Tested were also the effects of sub-soiling (S) at ‘Mamino’ and ‘Kumrovo’.

Summary of experimental places and plots: 8 different soil-ecological conditions in 4 countries, 5 verified farming systems (conventional farming, subsoiling, no-till farming, 10 cm deep cultivation and composting tillage) all by using of 18 field plots. The main technical and technological equipments of used field tillage systems (not conventional operations) are presented on following pictures.

Machine for subsoiling

A key machine for the Composting tillage

3.2 PERFORMED OBSERVATIONS

Several different observations of field experiments have been done.

3.2.1 Penetrometric study

This is a study for determination of soil compaction in a soil profile. The penetrologger Eijlkelkamp P1-52 has been used for that in Slovakia (see Fig. 5). Ten observations have been done in every field in time of determination. It was done in time 3-5 weeks after spring subsoiling and during the spring in case of subsoiling in autumn. Received were computerized penetrometric records and afterward the concrete generalized data presenting the soil resistance against water penetration into the soil profile have been deduced. It is important information for water penetration potential of soil profile (subsoiled in comparison to not subsoiled).

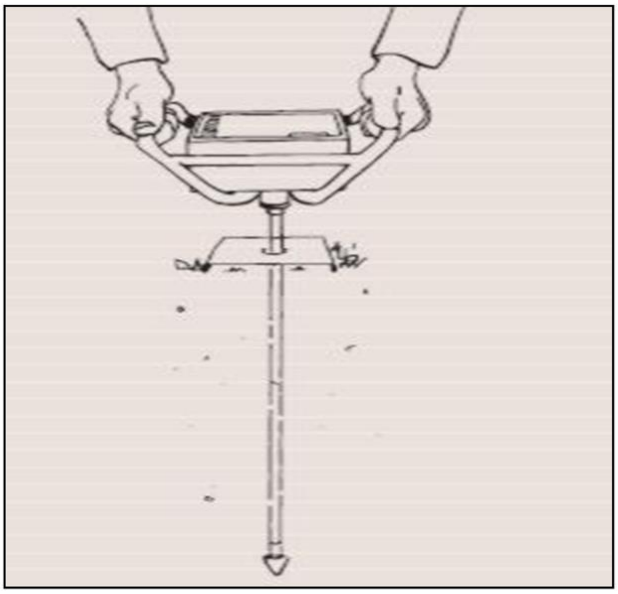


Fig.5 Screen and scheme of penetrometer

Soil penetration resistance in Slovenia was measured by Step Systems soil compaction tester (similar to the previous).

3.2.2 Water infiltration into the soil profile observed by simplified method of experiment

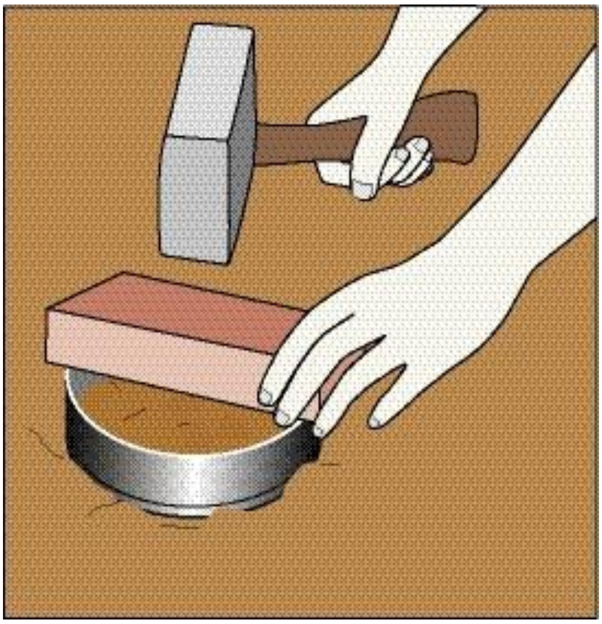
This experiment was done in Slovakia only in the year of 2013 (SK) on both experimental plots (subsoiled and not subsoiled) by especially prepared conditions for water infiltration (fenced infiltration area was 0.8 x 0.4 m, applied 80 l of water per each infiltration area). It was carried out in July 9, 2013 after the three weeks long dry season, and soil profile moisture have been determined in next day.

Fig. 6 Water infiltration principle and presentation of infiltrated soil profile

3.2.3 Water infiltration experiments (saturated hydraulic conductivity)

The ability for the soil to transmit the water (permeability) is determined through steady state calculations and this called Saturated Hydraulic Conductivity (K_{sat}), which is universally used as an empirical constant to quantify specific soil-water flow and infiltration capacity problems. K_{sat} "is one of the most important factors playing a role in many agronomic, engineering and environmental activities". An infiltration test help to determine if the soil or soil properties are suitable for certain types of storm water management measures. The infiltration test brings the data how quickly water can soak in and flow through the soil.

How to do it? Clear the sampling area of soil surface residue. If the site is covered with vegetation, trim it as close to the soil surface as possible. Place the can in the section of soil. Lay a wooden board over the top of the can. Strike the board with the hammer until the can is driven into the ground to the three-inch mark.



Pour clean water into the can, up to the four-inch mark. As soon as the water has been poured, begin the stopwatch.

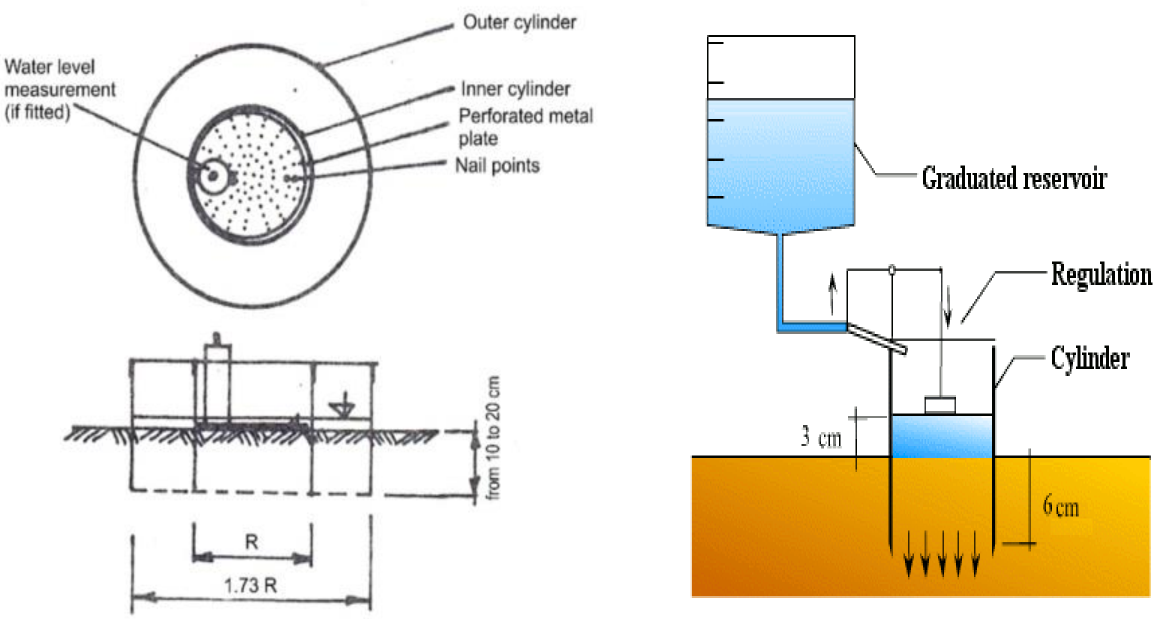


Fig. 7 Step by step how the saturated hydraulic conductivity is determined

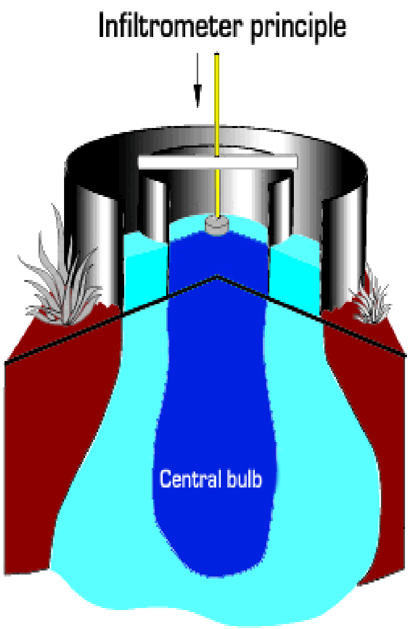


Fig. 8 Vertical water flow during of infiltration

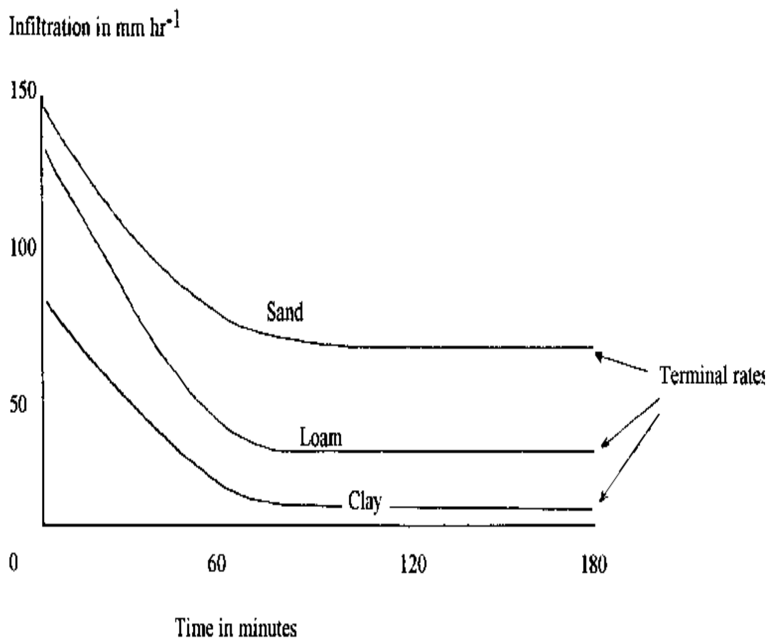


Fig. 9 Course of water infiltration during of water infiltration experiment

Fig. 10 Infiltrometers installed on the experimental field.

3.2.4 Water retention by tensiometric method

Water retention of the soil was determined using flooding and tensiometers methods (in Poland). In field were installed a frame having size 1.5 x 1.0 m which were filled by water. The amount of water was sufficient to saturate the 0.5 meter layer of soil. The frame was covered by plastic sheet to prevent evaporation. After two days the tensiometers were installed in the soil at 30 and 60 cm and the soil samples were taken.

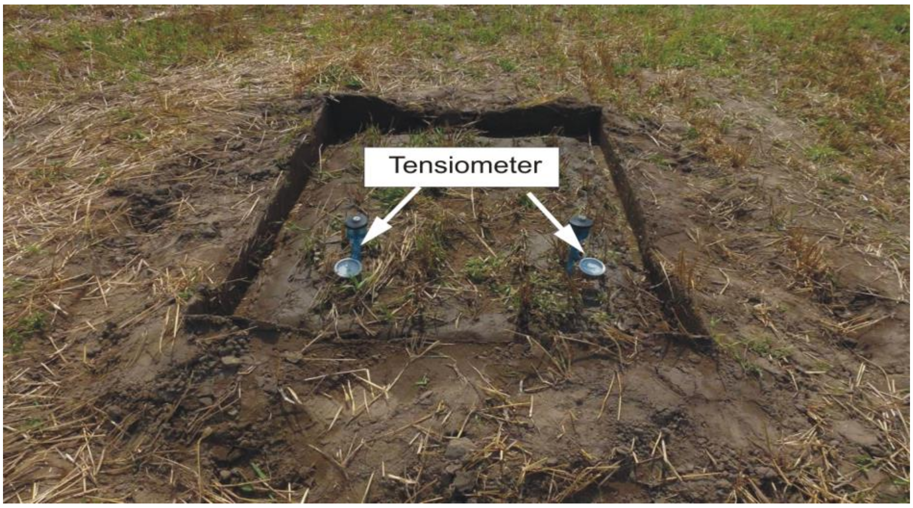


Fig. 11 Water retention by tensiometric study

3.2.5 Yields of plants determination

Yields of plants were determined by traditional methods relevant to kind of plant (main product and residual product).

4. RESULTS

Results of experiments have been achieved separately in participating countries. Detailed presentations are published in national reports. Here the generalized data mostly are presented .

4.1 PENETROMETRIC STUDY

From received results (Slovakia) can be summarized very visible differences of penetrometric results in soil profile between subsoiled and no subsoiled soils. When soil is subsoiled there is a lower resistance of soil profile against whatever penetration into the depth in comparison to no subsoiled soil. It is too much visible in layer from 15 to 30 cm and it was stabilized as better conditions for penetration also in lower depths of the soil profile. Those differences lead to better conditions for roots growth into the subsoiled soil and simultaneously it is the argument for a better water infiltration into this soil profile. In opposite, in no-subsoiled soil there are lower possibilities for root penetration into the deeper layers of soil profile and we can expect a lower water infiltration into the soil as well. All is visible in Fig. 12.

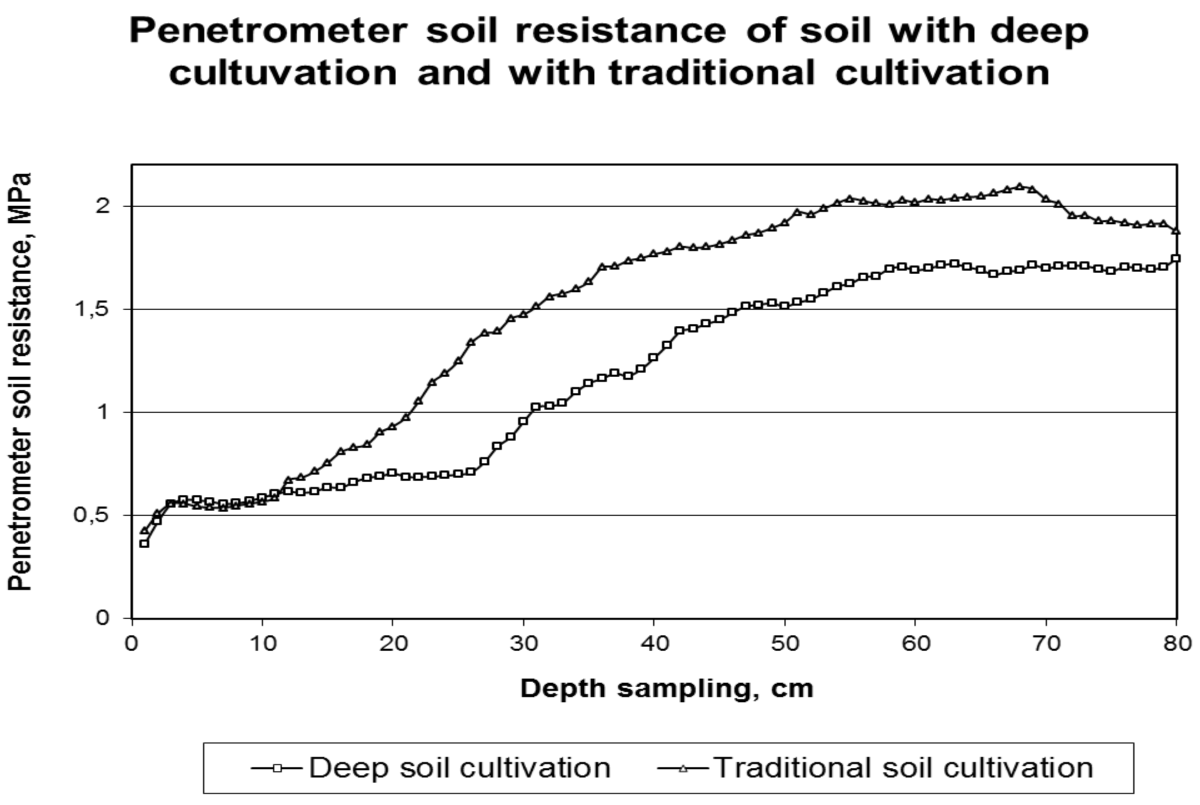


Fig. 12 Penetrometric results received from subsoiled and no subsoiled fields in the year 2013.

During of year 2014 the comprehensive penetrometric study was carried out on all plots of experimental fields (no subsoiled and subsoiled in spring 2013, subsoiled and cross-subsoiled in autumn 2013). In Fig. 13 we can see lower penetrometric resistance in deeper horizons of subsoiled soil in comparison to no subsoiled soil (one year after subsoiling). It is more visible in deeper layers than 20-25 cm of soil profile where

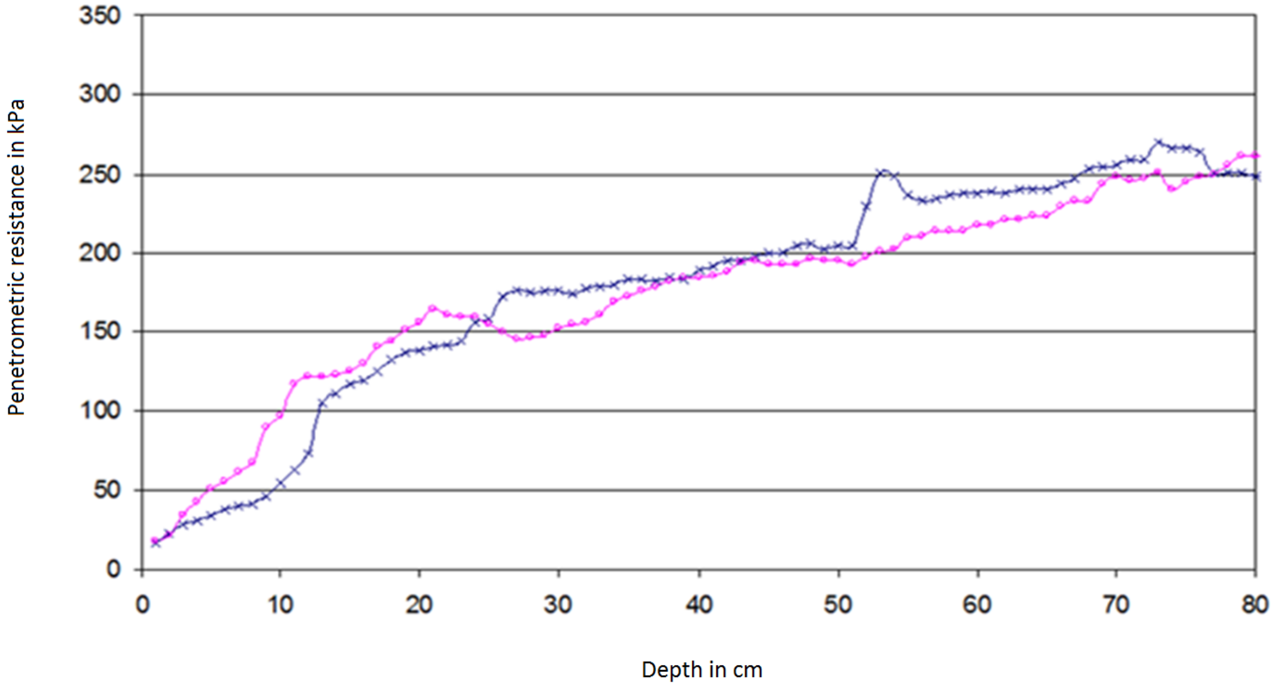


Fig. 13 Penetrometric results as comparison between no subsoiled soil with singly subsoiled soil after one-year of observation (2014, winter barley). ----------- no subsoiled soil ----------- singly subsoiled soil.

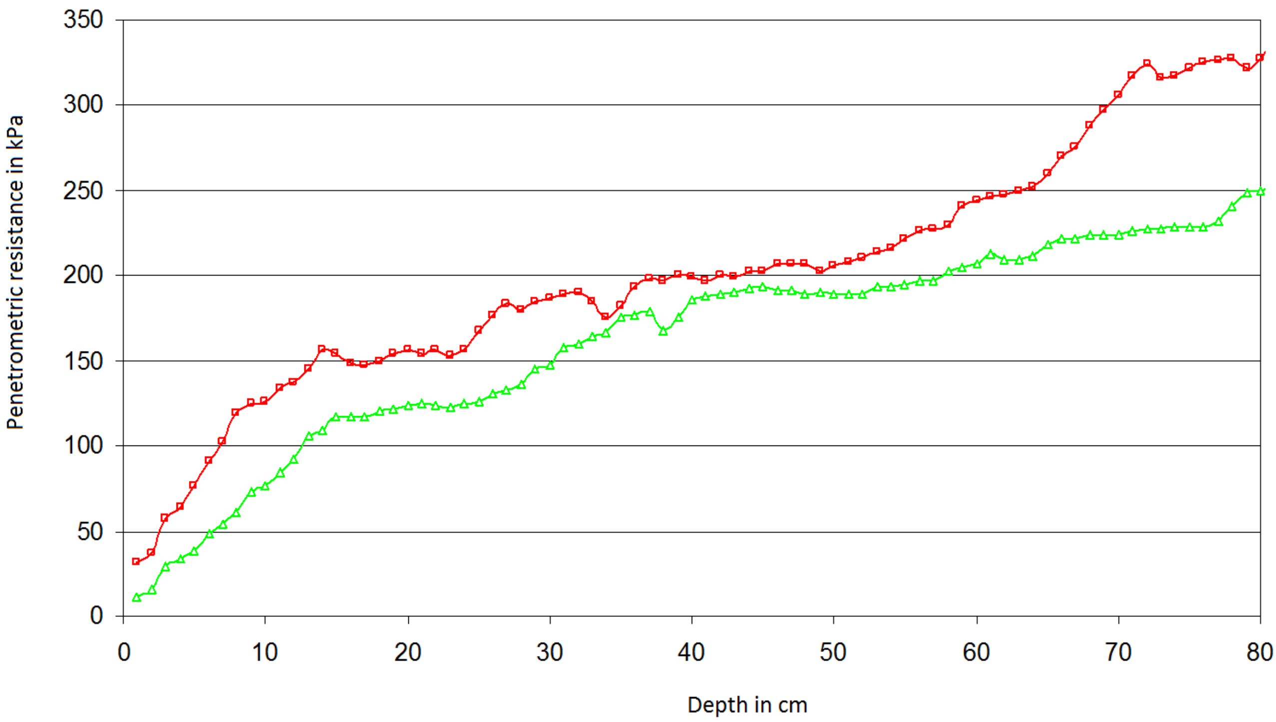


Fig. 14 Penetrometric results as comparison between cross-subsoiled soil and singly subsoiled soil (2014, winter barley). ----------- cross-subsoiled soil ----------- singly subsoiled soil

subsoiling have been applied (red line) in comparison to no subsoiled field (blue line). But it is necessary to add that those fields have been set up in the year 2013 and subsoiling has been applied in spring 2013 (results are from 2014). We can conclude that effects of subsoiling are significantly decreasing by time what is argument for necessity of repeated subsoiling application after 3 or 4 years (when we want to have positive effects from subsoiling application).

Fig. 14 is an argument for not so much higher water infiltration possibilities in cross-subsoiled field in comparison to singly subsoiled soil. But seems to be that under cross-subsoiling we can expect longer time of received positive effects than in case of singly subsoiled soil.

In another observations (Slovenia) it was determined that composting tillage (to depth 10 cm) caused more compaction than plough treatment. Subsoiling decreased compaction but it was no significant after 3 years of application.

In Slovenia measurement showed that the composting tillage (E) caused more compaction than plough treatment (0) at the both sites, indicating a slight compaction few cm below the disk tool action (E), which was 10 – 12 cm at the both sites. Subsoiling, which was done in summer 2011, had no significant effect in the soil compaction readings 3 years later in the summer 2014. More compacted soil under the composting tillage (E) was not negatively influenced the rapeseed yield, nor the infiltration capacity. It can be beneficial in terms of better traffic-ability of the field. The compaction of the soil at (E) was observed also by the root growth pattern (Fig. 15), which was not as vertical as it was by the plough treatment (O).

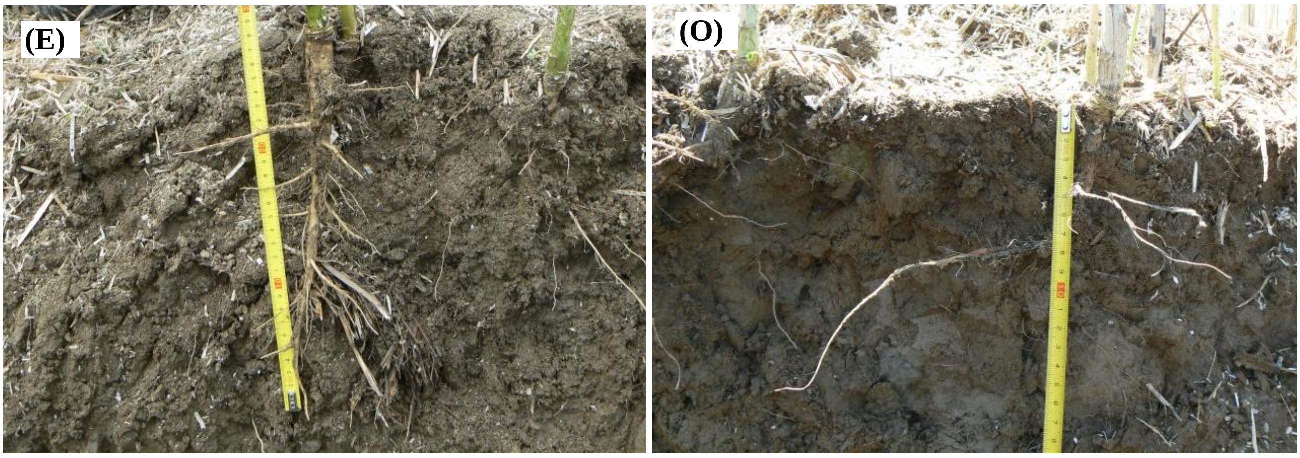


Fig. 15 Soil under the Composting Tillage (E) is more compact, but still intensively rooted than in case of conventional tillage (O). The main roots of oilseed rape under the shallow tillage layer (ca. 10 cm) are following the soil cracks and earthworm furrows.

4.2 WATER INFILTRATION INTO THE SOIL PROFILE OBSERVED BY A SIMPLE EXPERIMENTAL METHOD

This experiment was done only in Slovakia in the year 2013 on both experimental plots (in spring subsoiled and no subsoiled) by especially prepared experimental conditions (see 3.2.2.). There was confirmed that before artificial (experimental) water infiltration into the soil, the soil moisture has been significantly lower in both fields (subsoiled and no subsoiled) than after the infiltration. Moreover, before artificial water infiltration, in subsoiled soil a higher content of water occurred in deeper layers of soil profile (depth 60 and 75 cm) in comparison to no subsoiled soil. It is an argument for higher water content accumulated before artificial infiltration in subsoiled soil. But generally, after the three weeks of dry period no significant results have been observed.

But after water infiltration into the soil profile significantly more water penetrated into the subsoiled soil and higher moisture we observed in every layer of subsoiled soil profile in comparison to no subsoiled soil. Here we have to emphasise that 1% of moisture difference means about 10 l of water per 1 ton of soil what is at least 30 thousands litres of water per 1 ha of soil (to the depth of 30 cm). Simply, this experiment confirmed that subsoiling could be effective measure for higher water accumulation in soil.

Table 1 Soil moistures (in %) before and after infiltration experiments

	Before infiltration		After infiltration	
Depth in cm	Subsoiled	No subsoiled	Subsoiled	No subsoiled
0-15	15.98	15.11	29.78	25.07
15-30	17.42	17.88	20.52	19.87
30-45	17.49	18.71	20.81	19.44
45-60	18.98	17.98	19.42	19.01
60-75	19.7	18.9	19.48	18

4.3 SATURATED HYDRAULIC CONDUCTIVITY AND WATER HOLDING CAPACITY RESULTS

Observations were performed in all participating countries. Many results are collected and presented in national final reports of those countries.

From Czech Republic following results are summarizing the findings of saturated hydraulic conductivity for each variant at experimental plots. For better clarity, the results are given in per cent and always relates to the value for the variant of conventional tillage, which is considered as 100%. Values of water retention capacity are given in volume percentage. As it is evident from the Fig. 16 higher value of saturated hydraulic conductivity (K_{sat}) determined by double ring infiltrometer was recorded for the variant of sub-soiling technology at Ouběnice site and Prachov as well. In the Fig. 16 as well, the positive influence of organic farming on water infiltration rate into soil has been clearly observed, especially in comparison with conventional technology. This can be explained by higher ratio of cover crops in this variant of soil management.

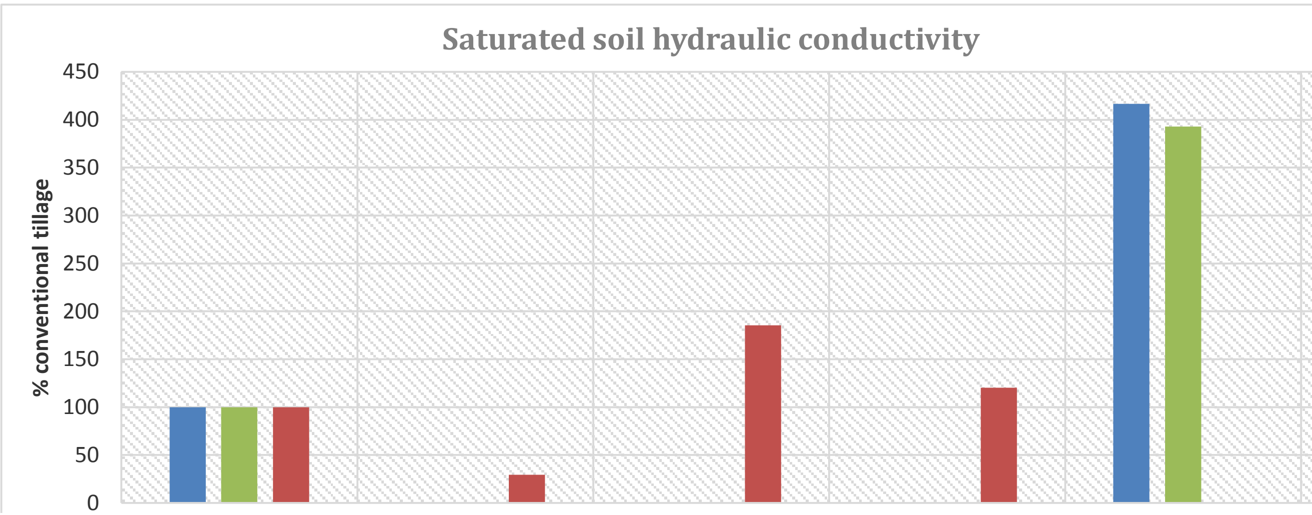


Fig. 16 Results for different ways of soil cultivation at the site Ouběnice, Prachov and Třebsín.

In case of the soil retention capacity expressed as water holding capacity, significant differences between the variants have not been observed. Water holding capacity of the soil in the Prachov study site is relatively high

- the highest of all monitored study plots. High values are primarily due to the soil texture (loamy topsoil, clay loamy subsoil).

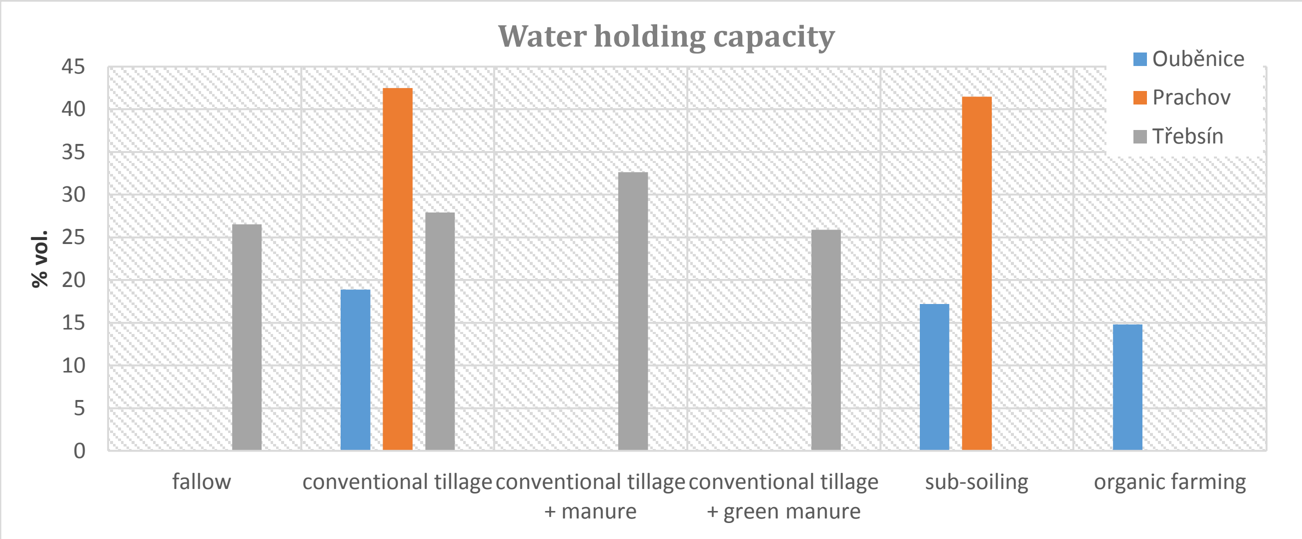


Fig. 17 Results for water holding capacity for different type soil cultivation at the site Ouběnice, Prachov and Třebsín.

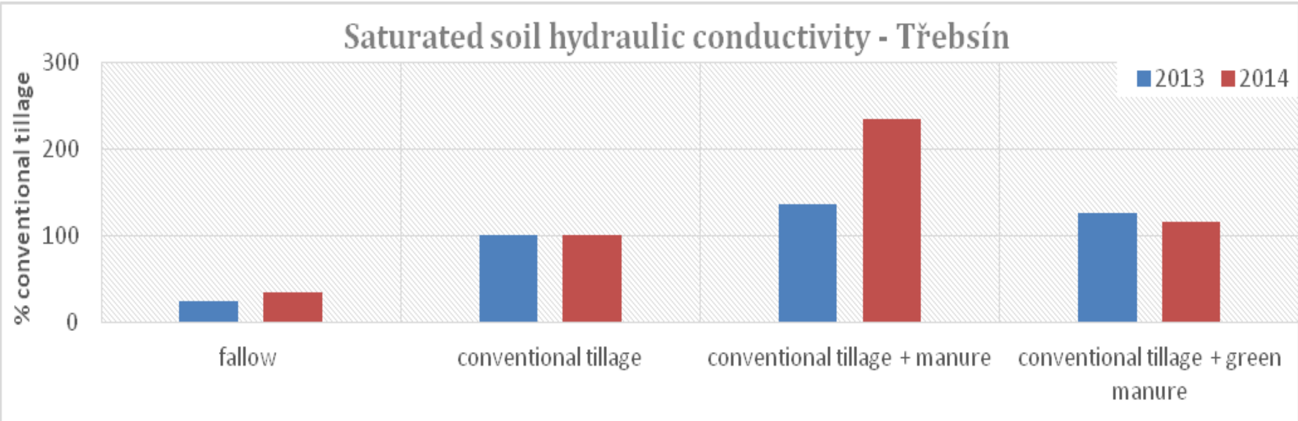


Fig. 18 Results for different ways of soil cultivation and organic fertilizer use at the Třebsín site.

The Figures 17 and 18 compare the average values of the measurements for two years. As it was expected, the lowest hydraulic conductivity values are detected on fallow land where the soil was not processed, only chemically treated against weeds. The best results were achieved in the variant with the addition of manure. It was proved by literature and 2-year experiment, that application of farmyard manure has positive influence on soil structure and stability of soil aggregates, which positively influence water infiltration into soil profile.

It is shown that the supply of organic matter to the soil through the application of farmyard manure has positive effects on soil infiltration capacity. The variant with farmyard manure has been shown every year the highest water holding capacity (Fig. 19) of the observed variations but in general the result are not significantly different (except year 2013). The exception is a variant with farmyard manure in 2013. An increase of the retention capacity resulted in difference of 7.25% in comparison with conventional tillage.

This seemingly small difference can bring about 63.5 cubic meters more water retained per hectare (the depth of the soil profile 0.5 m).

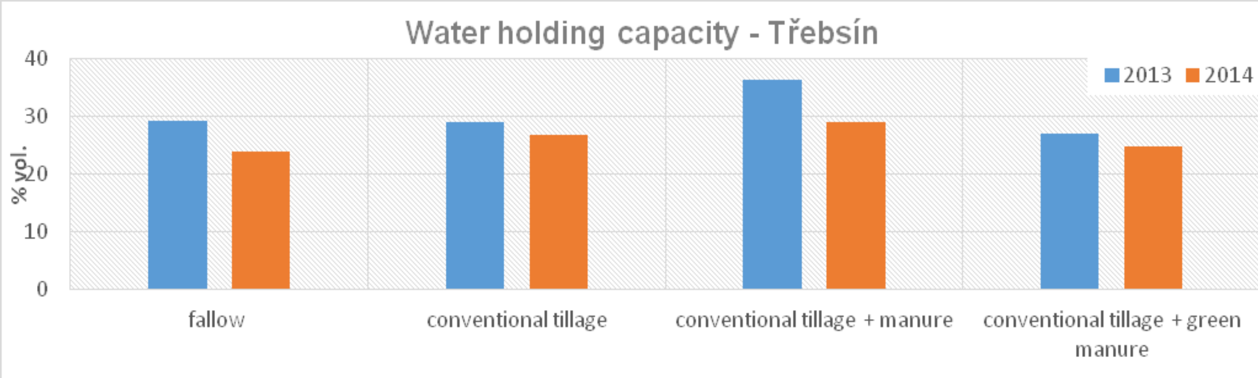
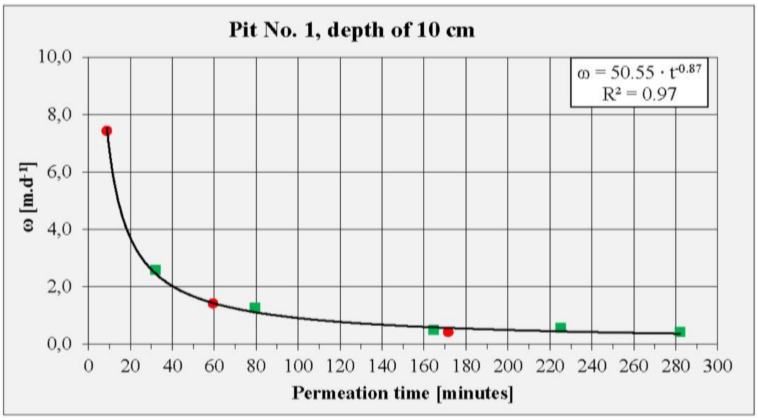


Fig. 19 Results for water holding capacity for different ways of soil cultivation at the site Třebsín.

From results obtained in Slovakia we can generally conclude the significant improved conditions for water penetration into the subsoiled soil profile in comparison to no subsoiled soils. It is concluded from steady state data from different depths (see as example Fig. 20, 21, 22).

Sonda Nr. 1

Time (t) [min]	ω [m.d^{-1}]	Classes of infiltration
10	6.82	Very high
20	3.73	Medium high
30	2.62	Medium high
40	2.04	Medium high
50	1.68	Medium high
60	1.43	Average
70	1.25	Average
80	1.12	Average
90	1.01	Average
100	0.92	Average
110	0.85	Average
120	0.78	Average
220	0.46	Average small
240	0.43	Average small
260	0.40	Average small
280	0.38	Average small



Time (t) [min]	ω [m.d^{-1}]	Classes of infiltration
10	10.85	Very high
20	6.23	Very high
30	4.51	High
40	3.58	Medium high
50	3.00	Medium high
60	2.59	Medium high
70	2.29	Medium high
80	2.06	Medium high
100	1.72	Medium high
110	1.59	Medium high
120	1.49	Average
140	1.31	Average
160	1.18	Average
180	1.08	Average
200	0.99	Average
220	0.92	Average

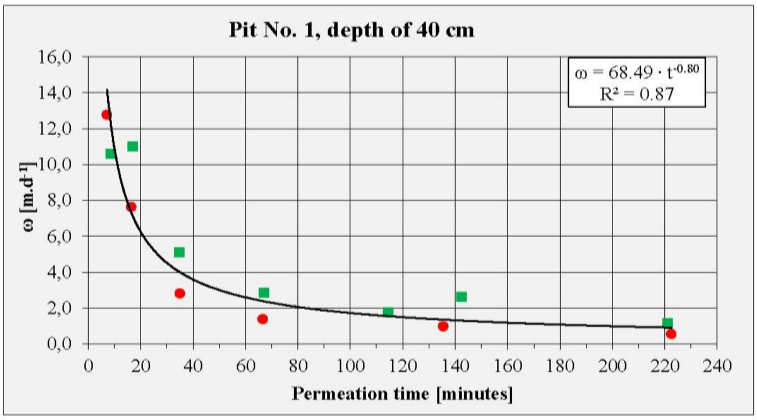
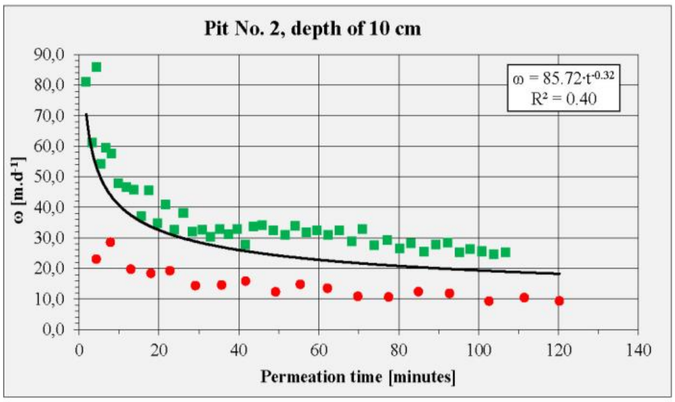


Fig. 20 Water infiltration into the no cultivated and no subsoiled soil profile (out of experiments).

Sonda Nr. 2

Time (t) [min]	ω [m.d^{-1}]	Classes of infiltration
10	40.26	Very high
20	32.48	Very high
30	28.64	Very high
40	26.20	Very high
50	24.45	Very high
60	23.10	Very high
70	22.02	Very high
80	21.13	Very high
100	19.72	Very high
110	19.14	Very high
120	18.63	Very high



Time (t) [min]	ω [m.d^{-1}]	Classes of infiltration
10	12.38	Very high
20	9.92	Very high
30	8.71	Very high
40	7.94	Very high
50	7.40	Very high
60	6.98	Very high
70	6.64	Very high
80	6.36	Very high
100	5.92	Very high
110	5.75	High
120	5.59	High
210	4.67	High

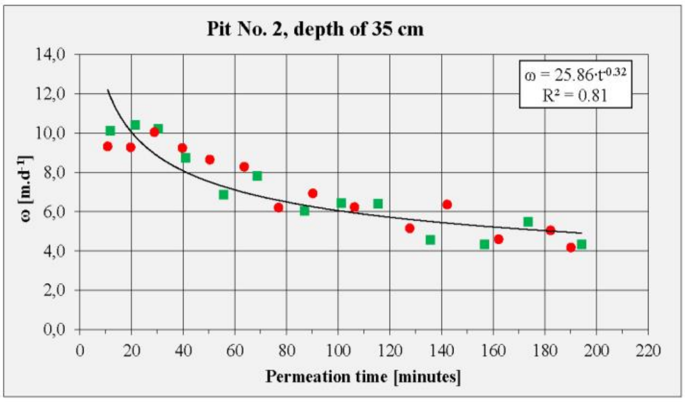
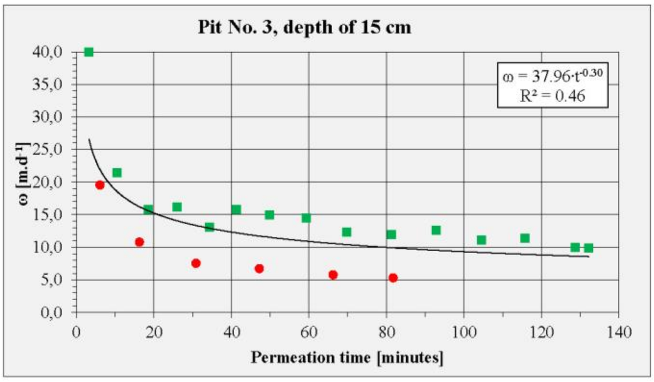


Fig. 21 Water infiltration into the subsoiled soil profile

Sonda Nr. 3

Time (t) [min]	ω [m.d^{-1}]	Classes of infiltration
10	19.03	Very high
20	15.45	Very high
30	13.68	Very high
40	12.55	Very high
50	11.74	Very high
60	11.11	Very high
70	10.61	Very high
80	10.20	Very high
100	9.54	Very high
110	9.27	Very high
120	9.03	Very high
140	8.62	Very high



Time (t) [min]	ω [m.d^{-1}]	Classes of infiltration
10	7.23	Very high
20	5.33	high
30	4.46	high
40	3.93	Medium high
50	3.56	Medium high
60	3.29	Medium high
70	3.07	Medium high
80	2.90	Medium high
100	2.62	Medium high
110	2.52	Medium high
120	2.42	Medium high
140	2.26	Medium high
160	2.13	Medium high

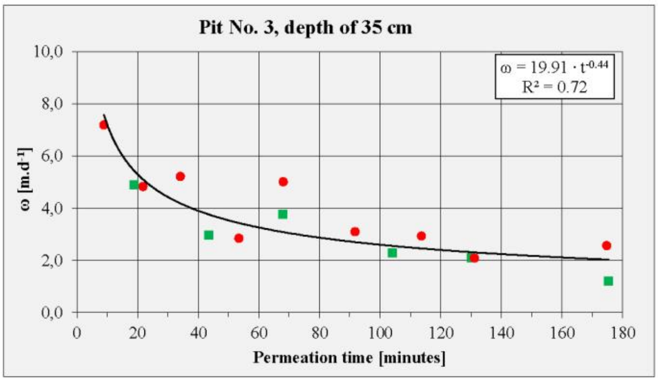


Fig. 22 Water infiltration into the no subsoiled soil profile

Generally we can say that subsoiling is significantly increasing soil water holding capacity in any soil where it has been verified. Important is that already mentioned higher content of water in soil mainly was accumulated in deeper layer of soil profile. It means that subsoiling really increase space in the soil where water can be penetrate, be accumulated and held in the nature. Results from Slovakia are generalized in Table 3. From presented results we can conclude higher water infiltration rates into the soil profile of singly subsoiled soil (from comparison of fields 1 and 2). Very good results have been achieved when soil was crossly subsoiled (field no.3).

Table 3 Generalized water collection in all plots of field experiments in Slovakia

Fields	**Infiltrated water** mm/time of experiment	**Potentials of infiltration** $m^3.ha^{-1}$	**Remarks to fields**
1	16,9	108,0	Singly subsoiled in spring 2013
2	16,1	89,6	No subsoiled in spring 2013
3	36,0	314.88	Cross-subsoiled in autumn 2013
4	15	53,3	Singly subsoiled in autumn 2013
Infiltration observed in August 11,2014			

In Slovenia it has been observed that water holding capacity was significantly improved in the upper 10 cm at conservation tillage (composting tillage) compared to conventional mouldboard system (17.6 vol. % and 14.9 vol. %). Below that depth the effects were opposite (Fig.23). It is due to the better soil structure in top 10 cm of soil profile in case of conservation tillage (determined after 12 years of conservation tillage application). A very important significant positive effect of conservation tillage system was on aggregate stability (82 % of aggregates remain stable in case of conservation tillage in comparison with 60 % at the traditional plots).

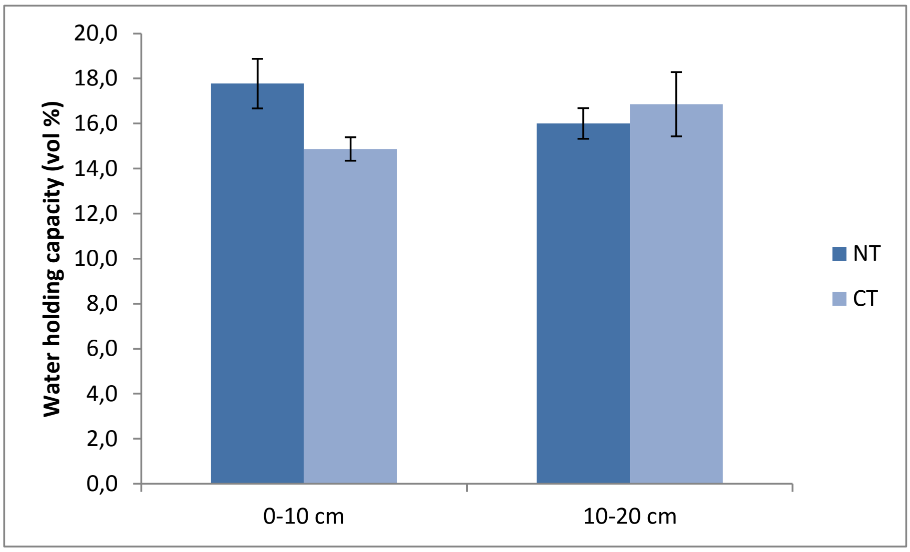


Fig. 23 Mean water holding capacity for conservation (N) and conventional (T) tillage at 0-10 cm and 10 – 20 cm soil depth

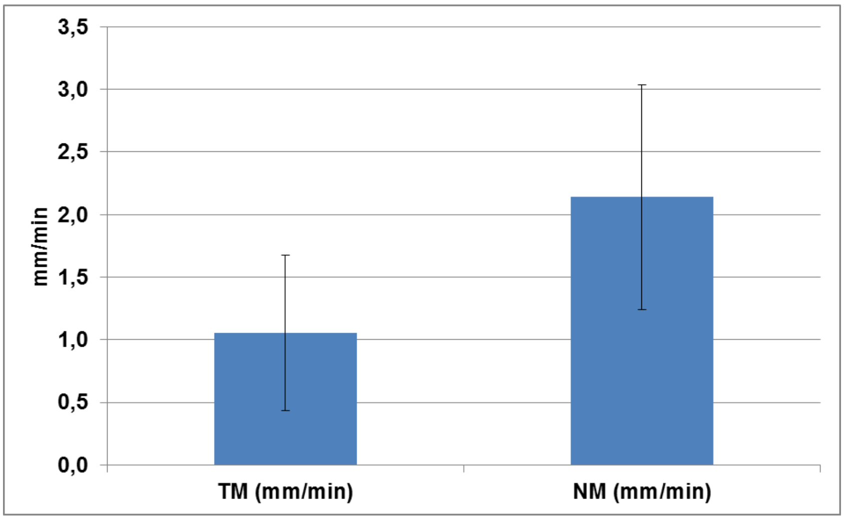


Fig. 24 Infiltration rate in conservation (N) and conventional (T) tillage plots using the double ring method

At the both locations (Slovenia), the composting tillage slightly improved the infiltration of water into the soil; in case of silt-clay soil of 'Kumrovo', the effect was significant (Fig.25). The effect was much less obvious at 'Mamino'. The infiltration results from autumn 2014 were compared to the results obtained in the spring 2012 at the location of long-term tillage experiment 'Rašica' which is located in the vicinity to 'Mamino' with the same soil type. Prolonged conservation tillage (12 years) caused a significant improvement of infiltration also in this soil type. Conservation tillage (NM) plots caused infiltration two times higher as plough treatment (TM).

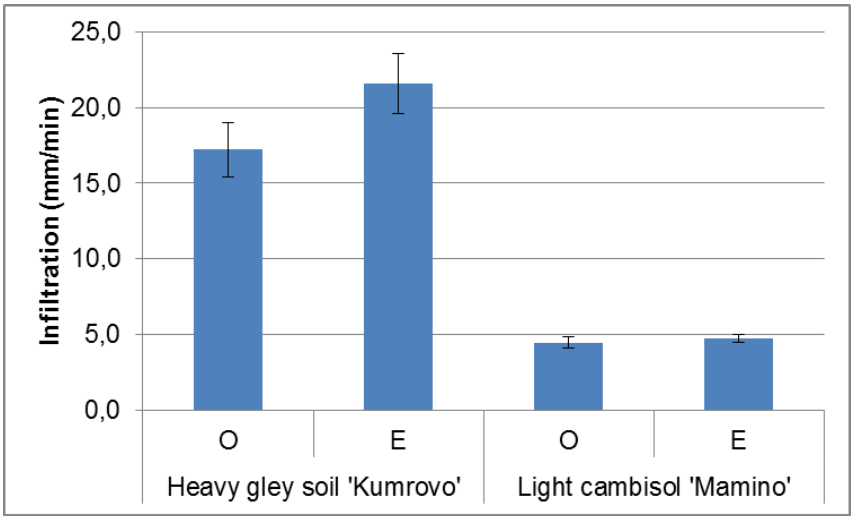


Fig. 25 Water infiltration at sites 'Kumrovo' and 'Mamino. O: Conventional tillage with plough; E: Composting tillage with the vario disc.

In Poland where the no tillage system was observed in comparison to conventional farming system, few times higher water infiltration was observed in no-tillage field. It is a result of pedofauna action. The earthworms improve the soil structure creating more mesopores in the soil. Very useful characteristic of infiltration is time required for 10 cm cumulative intake. For tillage field this parameter was about 50 hours while for no-tillage field it was about 12 hours.

A drastic difference in the density of earthworms (basically represented by one species typical for agriculture) dependent on the cultivation system was observed in the experimental fields in autumn 2013. Only in one case the presence of earthworms was observed in a field cultivated in the conventional system (tillage). In the field under no-tillage system dominates Allolobophora caliginosa (field worm), reaching high densities in both dates (respectively 132.5 and 82.8 ind.m-2 crawler) was recorded. The lower density of earthworms in November is the result of worm descent into the deeper layers of the soil before the period of hibernation. In addition to the two species of earthworms also insect larvae and imagos (Staphylinidae , Carabidae , Elateridae , Muscidae and Miridae) were found in the field. Their population in no-tillage field was of near 10-fold higher density than in traditionally cultivated field.

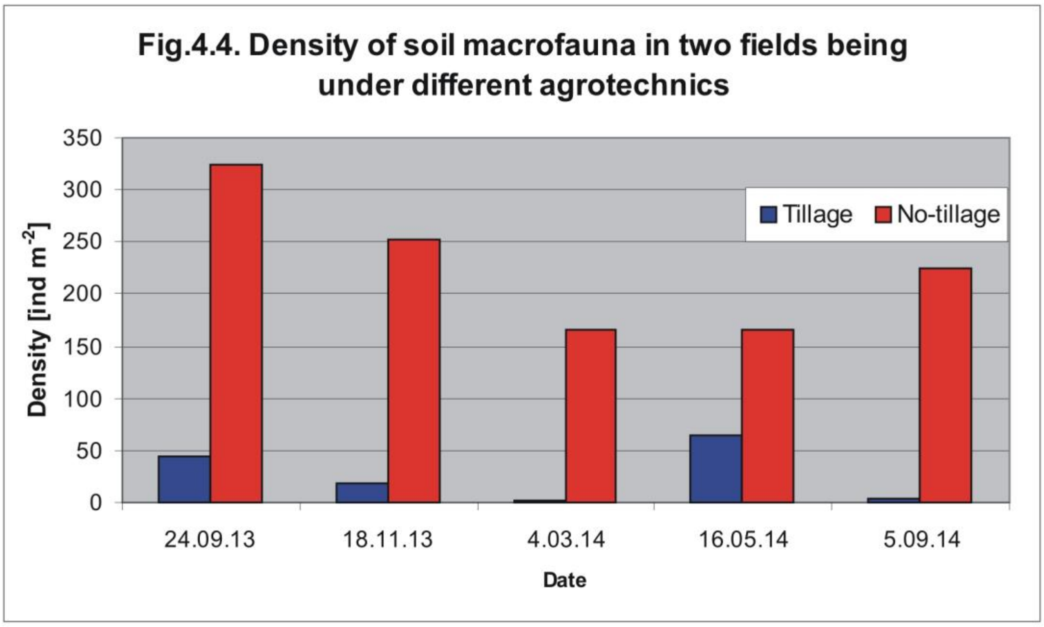


Fig. 26 Density of soil macrofauna under tillage and no-tillage soil use

4.4 YIELDS OF PLANTS

Results from Slovakia are presented in Table 4 (yields of maize). From results of average length of plants (10 for each field) we can conclude that maize plants cultivated on subsoiled soil have been longer in average (78.2 cm) in comparison to plants from no subsoiled field (66.7 cm). It supported the conclusion about better conditions in a subsoiled soil for plant growth and development during of growing season. Final parameters of maize yields are presented in Table 4.

Table 4 Average yield parameters of maize cultivated on subsoiled and no subsoiled soil

Yield parameters	Subsoiled soil	No subsoiled soil
Length of plants (m)	2.27	1.64
Weights of plants (kg/m^2)	2.43	1.51
Moisture of grains (%)	47.38	46.3
Yields of grains (t.ha^{-1})	9.25	8.28

From this table we can summarize that subsoiling has significantly positive effect on yield of maize. It was higher in comparison to no subsoiled soil by about 10 %. Bigger difference has been determined in weight of plants. In subsoiled soil it was higher almost about 40 %, what is very positive result when maize is cultivated as green forage.

In the year 2014 winter barley was cultivated in fields 1 and 2 and winter wheat in fields 3, 4 and 5. Results are available in Table 5. From this table is clear that subsoiling can be an increasing factor of yields but not so much in this second year after subsoiling operation (comparison 1 to 2). Cross-subsoiling is more active increasing measure than singly subsoiling and could be longer effective than singly subsoiled field.

Table 5 Yields of grain in the year of 2014.

Fields	Winter barley in $t.ha^{-1}$	Winter wheat in $t.ha^{-1}$
1	4.38	-
2	4.54	-
3	-	7.96
4	-	8.2
5	-	8.91

1– no subsoiled in spring 2013; 2 – subsoiled in spring 2013; 3 – no subsoiled in autumn 2013; 4– singly subsoiled in autumn 2013, 5 – cross-subsoiled in autumn 2013.

In Slovenia oilseed rape seeds production was observed in ploughed in comparison to subsoiled soil. Subsoiling caused evident subsequent positive effect on yield but it was more evident in the plough treatment (0), and not so much in the composting tillage (E).

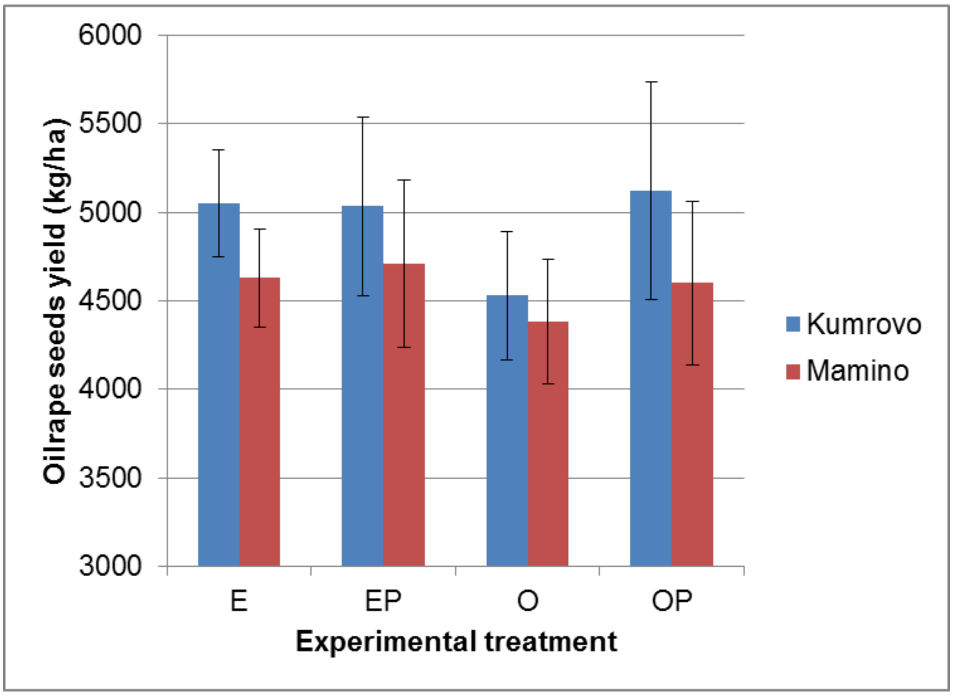


Fig. 27 Oilseed rape seeds yield at the experiments 'Mamino' and 'Kumrovo' in 2014. (0) conventionally ploughed tillage, (E) composting tillage, (EP) composting tillage and subsoiling, (OP) plough and subsoiling

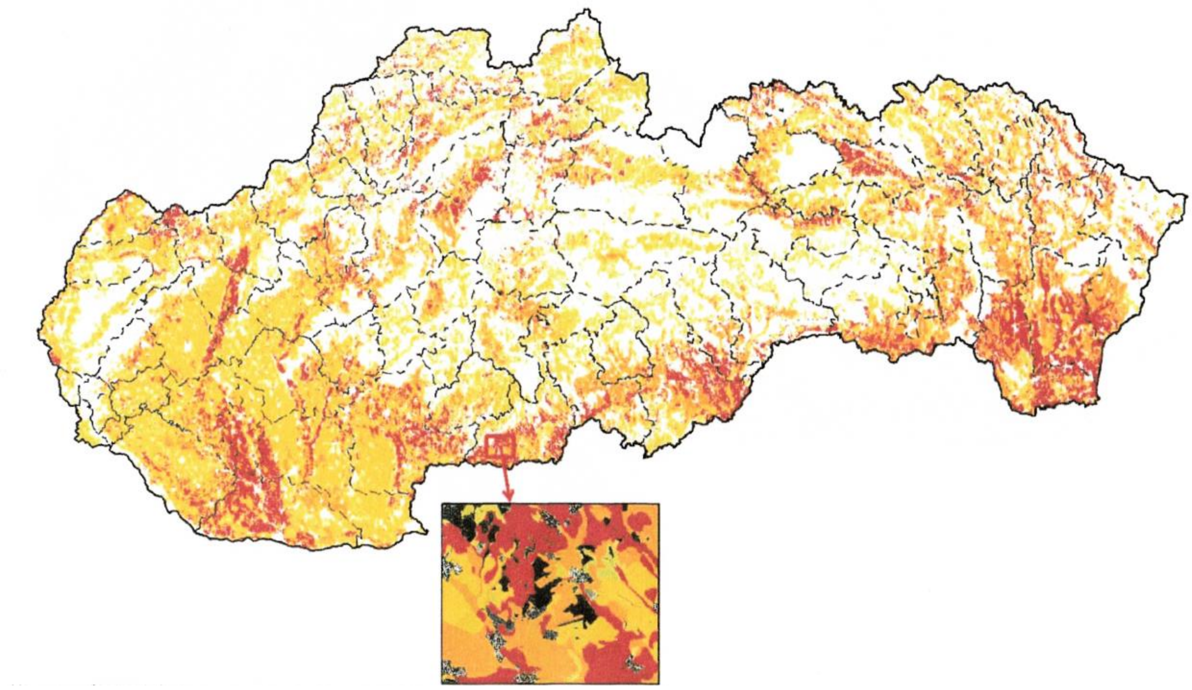
5. CONCLUSIONS

Research has been carried out in four countries (CZ, Pl, SK, SL) with the aim to propose some measures to increase soil water holding capacity and to combat drought and threats of floods as well. Following final conclusions can be presented:

- subsoiling decreased resistance of soil profile both for roots and water penetration into the soil profile (penetrometric experiments);
- subsoiling increased water infiltration into the soil profile (infiltration experiments), mainly when cross-subsoiling was applied;
- subsoiling increased the yields of maize, winter barley and winter wheat, but in second year it is not effective so much anymore;
- farmyard manure was clearly proved as the best organic soil amendments, which has improved all soil properties and soil water regimes as well (higher water infiltration into the soil and water holding capacity increase). As compensation for the absence of manure can be use a green manure, which also enriches the soil with organic matter;
- soil water holding capacity, infiltration rate, and aggregate stability significantly improved in case of composting tillage in comparison to conventional farming. Yields of plants under composting tillage are not lower, but achieved with less energy consumption and time for operations;
- composting tillage increased soil compaction below first 15 cm of soil profile. Subsoiling improved this situation but no longer than for 3 years;
- water infiltration and soil water holding capacity have been significantly increased in no-tillage fields in comparison to traditional farming system used. It is due to increased pedofauna actions (mainly more soil mesopores by earthworms activities) and as results of many relevant soil properties improvements (soil organic matter content increase, soil structure improvement, higher soil biodiversity);
- soil information systems can be used for implementation of technologies for soil water holding capacity increase into the agricultural practice (examples are presented in the following Chapter 6);
- general indicators for soils where water holding increase is needed have been developed as a guide (is it OK?) for water holding measures recommendations and use (see next Chapter 6);

6. PROPOSALS FOR PRACTICAL USE OF RESULTS

In Slovakia and the Czech Republic data are available from relatively good soil survey and they form a comprehensive information system with density of complex information for every 14 ha of agricultural soils. Now it is available as Soil Information System visualized on ortophotomaps and generalized separately for every agricultural field on territory of Slovakia and Czech Republic. Simply, every farmer, decision maker, and everybody who needs information about every arbitrary field in Slovakian territory have available it on www.vupop.sk or www.vumop.cz. Besides of data information, several generalized information are available as well. One of them is presentation of soil ecological unit what is single comprehensive data (code) about several soil properties and is identified and available for every field of Slovakian agricultural soils. This is very good background for creation of generalized information about fields, farms, cadastres, regions, and Slovakian territory too.



Map 1 Soil compaction potentials in Slovakia (Bielek, 2014). Natural preconditions for soil compaction (490 945 ha). Soil compaction by farming systems (438 971 ha). Both natural and farming threats for soil compaction (410 618 ha). No compacted soils 1 092 446 ha).

In relation to targets of this project we can use this information system for identification of all fields on territory of Slovakia which are suffering from soil compaction, which simultaneously have decreased water infiltration capacity, and which are suitable for subsoiling and other soil water holding increase technology. Every farmer can receive such information for every field where he is farming. It is possible with help of website and after that he can decide how to modify used farming systems to improve the situation in soil compaction. Proposals how to use the data could be as follows:

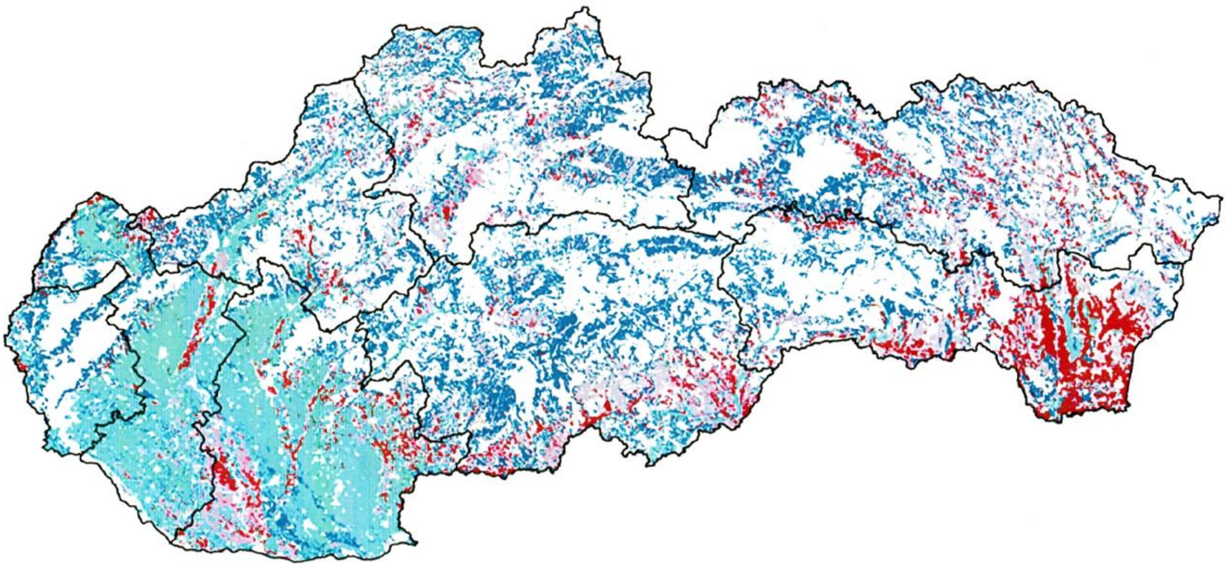
- to identify fields suffering from soil compaction (using website);
- to make decisions for subsoiling and/or another measures according to the categories of compaction;
- in case of simultaneous impacts of natural and artificial threats for soil compaction it is proposed: cross-subsoiling every 5 years or singly subsoiling every 3 years; two years clover or alfa-alfa growing immediately after the subsoiling within of 5 year of subsoiling cycle; at least every 3 years use of

organic fertilizers; generally is recommended to stop the soil ploughing and use only no-till sowing every year;

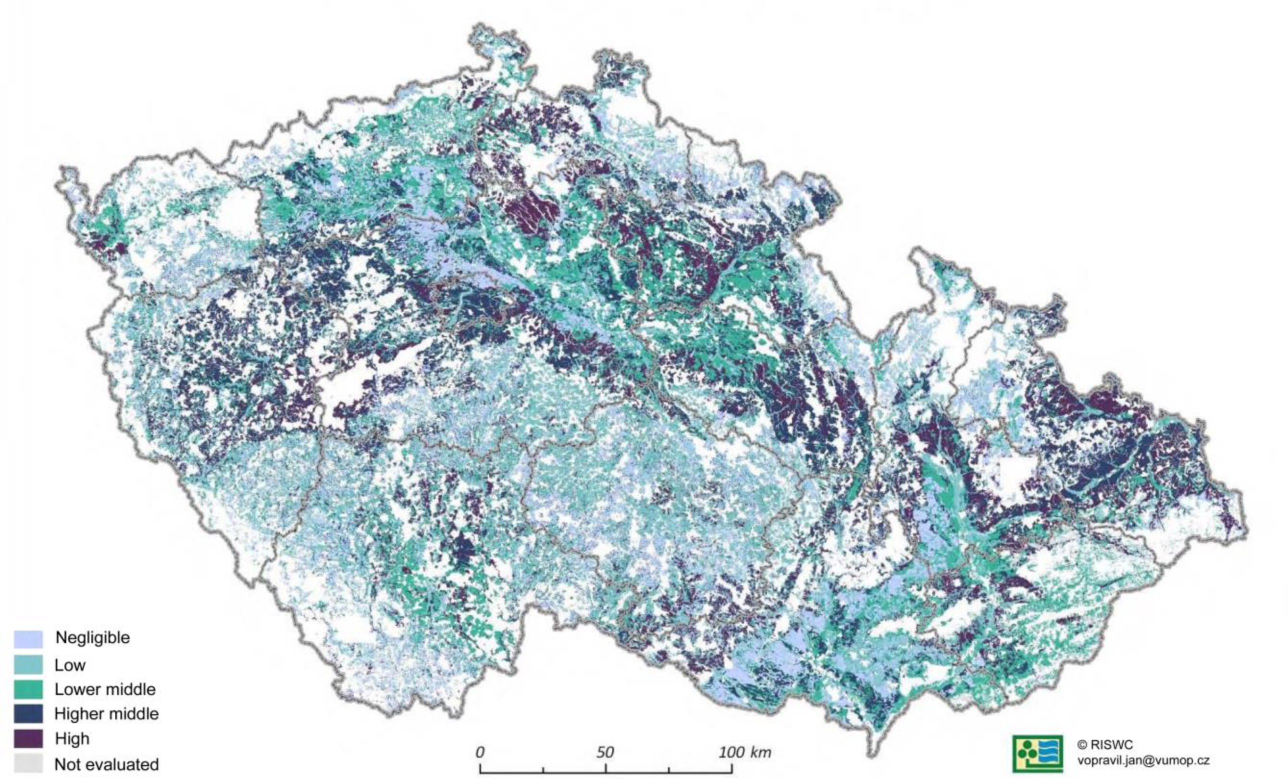
- in case of compaction by farming systems, deep soil cultivation (till 30-35 cm) use every year can be proposed instead of ploughing operations (no-till plant growing); it is recommended to use the single subsoiling every 3 years and organic fertilizers applications with the same frequency at least or deep root plant cultivation every 3 years (best after subsoiling immediately);
- in case of natural preconditions for soil compaction (e.g. heavy soils), it is recommended to change the ploughing systems of soil cultivation to deeper cultivated technologies (30-35 cm) every two years at least and organic fertilizers applications every 3 years; plants cultivation with deeper roots are recommended at least every 4 years;
- every farmer can select some options of farming system by his personal decision using of the measures presented here; this is needed because of specificity of farm types (according of plant, animal and another activities types), with respect to economy of farms and structure of production;

Operations for soil compaction decrease can bring the real advantages for farmers also from the yield production point of view. From Map 2 we can see territorial distribution of yields decrease due to soil compaction on territory of Slovakia. There are good arguments for farming corrections in areas where soil compaction is observed.

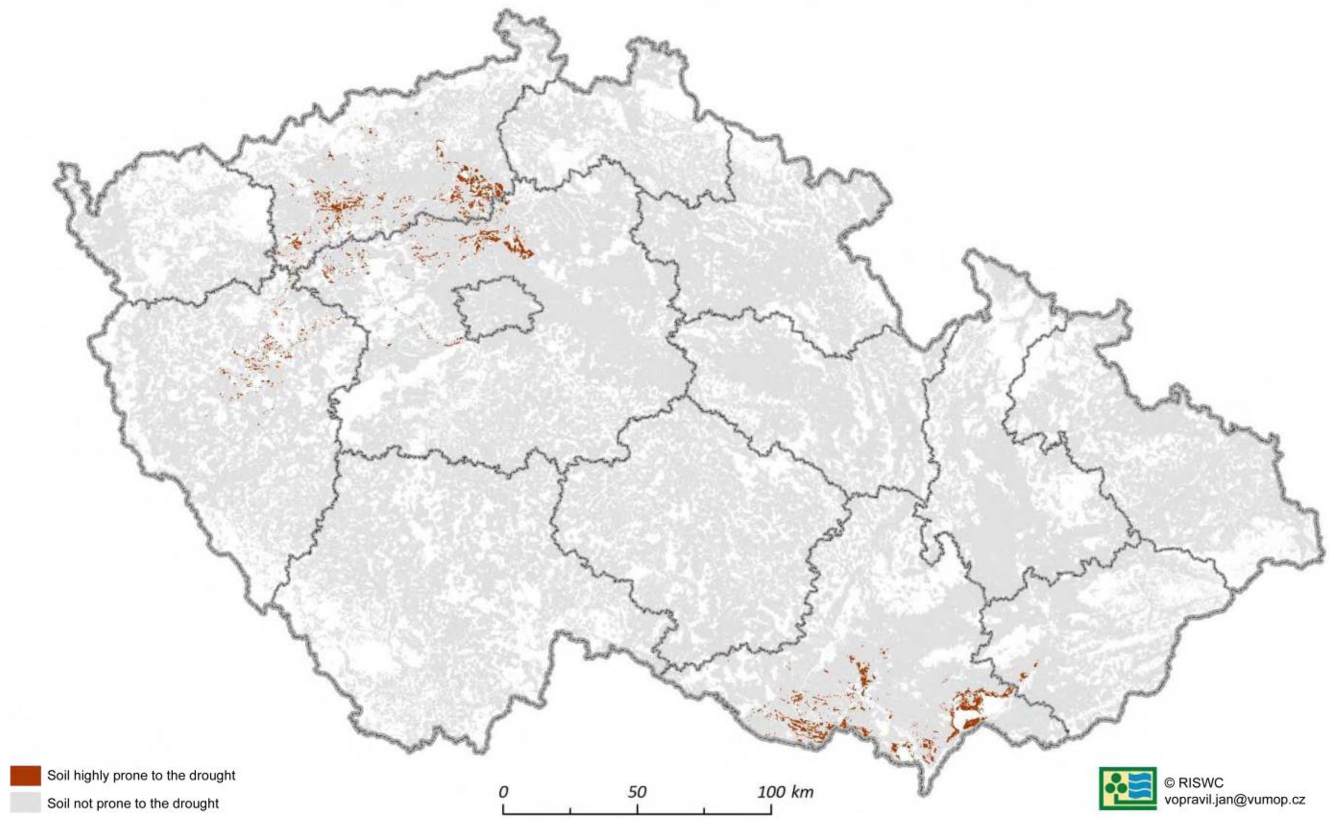
Higher water holding capacity of subsoiled soil can reduce a risk from water deficiency in agriculture, reduces irrigation needs, decreases flooding threats of due to better water infiltration into the soil profile, improves most important properties of soils including of essential soil functions and agri-ecosystem services of soil cover, improves water regimes of sites and regions in the country, and others. Simply subsoiling is very significant measure for agriculture, economy, ecology and social development of the country. From this point of view this is not only concern of farmers but it is the aim of all people from decision makers to common people everywhere.



Map 2 Decrease of soil production potential due to soil compaction in Slovakia (Bielek, 2014). About 30 % (11 % of total area of agricultural soils). About 20% (105). About 15 % (15 %). About 10% (25 %). No affected (35 %).



Map 3 Soil compaction potentials in Czech Republic based on soil information system.



Map 4 Areas prone to the drought in Czech Republic.

General field indicators of poor soil physical conditions (by Czech Republic) include:

1. Patchiness or absence of vegetation. This can be an obvious sign of degraded structure or other factors. When structural, it may reflect surface structure degradation or non-wetting characteristics which give rise to poor infiltration, or subsoil impermeability.
2. Weedy vegetation. Cyperaceae or Juncaceae may indicate soil structural decline because they flourish where water has been ponded on the surface, suggesting poor infiltration or an impermeable subsurface horizon.
3. Rill and sheet erosion. Erosive surface runoff may be symptomatic of poor surface structure. The turbidity of water in ponds and lakes after rain may be a good indicator of erosion.
4. Surface crusts.
5. Hard-setting surfaces. Poor infiltration and ponding. This may be indicated by puddles following rain in an area where one would expect rapid infiltration, or by wetting to only a shallow depth.
6. Pale surface soil colour and absence of organic matter. The surface of degraded soils may be brittle and pale, lacking organic matter and having lost clay either through eluviation (differential movement downwards) or by water or wind erosion.
7. Cloddiness. This may be apparent if after a single cultivation, large, tough clods are formed requiring further cultivation to form a reasonable seedbed.
8. Restricted root growth. This can be seen by digging with a narrow-faced spade and washing the roots free of soil. The root mass can be restricted to the upper soil or be constricted in particular places such as a less pervious layer, above and below which the roots may proliferate.

It is necessary to take into consideration that tillage is a labour-intensive activity in low-resource agriculture practiced by small land-holders, and a capital and energy-intensive activity in large-scale mechanized farming. For any given location, the choice of a tillage practice will depend on one or more of the following factors (by Czech Republic):

Soil factors

Relief (slope)

Erodibility and Erosivity

Rooting depth

Texture and structure

Organic-matter content

Climatic factors:

Rainfall amount and distribution

Water balance

Length of growing season

Temperature (ambient and soil)

Length of rainless period

Crop factors:

Growing duration

Rooting characteristics

Water requirements

Seed

Socio-economic factors:

Farm size, labour situation

Availability of a power source

Access to cash and credit facilities

Faem/family structure and composition

Other: Government policies and subsidies

Adopting organic farming, proper residue management, and complex crop rotations are examples of viable alternative cropping and management systems to conventional practices. The best combination of cropping practices for soil conservation must be determined for each soil and ecosystem. Cropping systems that are socially acceptable, economically profitable, and ecologically and environmentally compatible, and politically permissible must be designed for each ecosystem. In order to improve water management in the agricultural landscape there is a need to link the common agricultural policy and the management of water resources, which is formulated in plans for protection of water resources in Europe ("blue-print").

An application of good quality organic matter to maintain good physical properties of the soil has an important role as well. Cover crops are an integral component of cropping systems to conserve soil and water. All cover crops require water for growth, but usually winter cover crops have relatively little impact on soil moisture. Winter mixture of crops has the advantage in utilizing the autumn moisture. However, the earlier the cover crop is sown in the fall or the longer it is allowed to grow in the spring, the more water it will use. Summer annual cover crops use more water than winter annuals and may require irrigation. However, some species, such as Vigna unguiculata (cowpea) and Secale cereale L. (Cereal rye) or cool season grasses, are relatively drought tolerant. Legumes cover crops and cereals mixture enhance the performance of crop rotations to maintain the soil moisture. On the other hand, White Mustard cover crop (Sinapis alba – sometimes called Brassica alba or Brassica hirta) are a useful cover crop in vineyards, annual crop rotations, and home gardens as a winter cover but require rain or irrigation throughout the growing period.

Cover crops can be planted as a single species or in mixtures. The most common mixtures include a legume such as hairy vetch and a cereal grain such as rye. Mixtures provide both advantages and disadvantages over single species. Successful cover cropping requires the selection of a species or mixtures that will provide specific desired benefits and will be compatible with the overall farming system. Most growers who use cover crops derive multiple benefits from them.

From the viewpoint of maintaining the soil moisture, mulching is also very suitable. Mulches act as barriers to movement of moisture out of the soil. Usually they are organic (e.g. straw, peat, crop residues - corn, wheat, barley) materials which are subsequently by shallow tillage incorporate into the soil. Non-legume and legume winter cover crops are effective at improving soil fertility while providing abundant above- and below-ground biomass to the soil.

The support of farmers in the form of subsidies is suitable for support of cover crops, creating of buffer strips (strip cropping, buffer strips) on arable land or conversion of arable land to grassland – grassed waterways, grassed buffer strips etc. (e.g. In the Czech Republic GREENING program). On the other hand, targeted support of individual types of cropping systems (e.g. subsoiling, specific crops) is not completely effective. The choice of specific measures should be adapted to specific site conditions and soil type, which the support of one specific measures would not have contributed positively. Already allocation of Single Area Payment Scheme (SAPS) assumes that the farmer will follow practices of good agriculture and keep the "soil in good condition". For this purpose, the selection of the necessary technology will be done by farmer. It would be convenient to support the counselling for farmers and to acquaint farmers with the whole range of available technologies. Only farmer is able to assess applicability of available technologies to his land. But to adopt conservation technologies, farmers must know the impact of these technologies on soil water regime, crop production and other aspects. The knowledge will be transferred through counselling for farmers.

Conservation tillage systems to protect the soil and water reserves often have limited appeal to producers unless they offer economic advantages. Economic factors contributing to interest in conservation tillage include:

1. higher costs of fuel, labour, tractors, and other equipment;
2. higher equipment inventories and maintenance costs;
3. ability to use land at risk of erosion for more intensive crop production (rather than for pastures or in long-term rotations);
4. the opportunities offered for more intensive cropping, avoiding long fallow periods, because of greater water conservation; and
5. in many instances, higher crop yields.

6.1 POLICY DEVELOPMENT FOR WATER SAVING FARMING USE

Each member state of the European Union has subsidised agriculture. It is due to EU and member states concerns for food sufficiency, acceptable economy situation and ecology functions of agriculture and farmers. Because the subsoiling is in principle better than tillage measure used now, some supporting items must be incorporated into the Common Agriculture Policy (CAP EU). In case of opposite situation there is a real threat from no concern of farmers to be partners in water management practices in the country by farming and by soil management as generally. It can be expected that in spite of all positive effects of subsoiling on economy and profitability of farmers, they have not enough money for buying equipment and to cover the costs of subsoiling. Also other technologies suitable for soil water holding capacity increase (no-till, composting tillage) need to be supported because of higher cost of machines and expenses during their use.

Also general environmental concerns of EU and member states for using of those technologies must be taken into consideration. This is not only because of water regime regulations needs in the country but this is also an obligatory task to save properties and functions of soil as critical economy and environmental backgrounds of prosperity and profitability of countries and human life.

A big advantage is to make available expert systems for implementation of such a subsidiary principles (e.g. in Slovakia). Soil information system can immediately be used for acceptance and individual control of those items in subsidiary system on level of field and/or farmers. Because of the fact that soil water holding technologies have real agri-environmental impacts, the supports of farmers could be provided as financial subsidiary items in Agro-Environmental Programs.

National and EU concerns in water management practices need to mobilize all people who are acting towards these aims. Therefore advisory /extension services must be offered to all who need it and by all sectors responsible for it. Capacity is necessary to be built up and coordinated at cross-sectorial levels for all who are practically engaged and responsible in those problems.

Regulations of farming systems in favour of water retention in the country have crucial importance also as mitigation and adaptation measures against climate change threats. It is due to higher carbon sequestration into the soil by those technologies and as adaptation of environment, agriculture and living conditions to the expected climatic situations. From this point of view it is necessary to implement water saving technologies in soil use as an important part of EU and national climate change strategies as item of both mitigation and adaptation measures.

The practical implementations of water saving technologies in agriculture need a transition time due to economy potentials of farmers mainly. Therefore for every special farming system a concrete “chart curves” must be developed at EU and national levels, including identification of implementation time and mid-term control points for corrections of targets.

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