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Outputs from the project Visegrad fund:

Creating a platform to address the techniques used in creation and protection of environment and in economic management of water in the soil.

Content

Application of lysimeters in agricultural water management

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Abstract: A review of lysimeter research is presented involving the brief history of studies with lysimeters, describing the main lysimeter types and introducing the lysimeter related experiments carried out at (RIK) recently involving our main scientific achievements. Research activities with lysimeters have significant role in agricultural science in Europe: 2985 measuring devices (89.5% lysimeters) representing 148 stations and 20 countries are registered by the Lysimeter Research Group. The state-of-the-art of agricultural related lysimeter research involves the precise determination of the elements of the hydrological balance (even the amount of dew), water use efficiency studies (even for specific environmental conditions), irrigation and climate change relations, and nutrient loss and contamination issues.

Lysimeter researches have been carried out at RIK since 1983, in this paper some characteristic experiments and the results gained from them are reviewed in order to demonstrate the versatile utilization possibilities of lysimeters serving soil management researches. There three types of lysimeters operated at RIK making it unique in Hungary: 8 lysimeters with compensation system, 30 simple drainage lysimeters (26 were reconstructed and are used recently), and 6 electronic weighing lysimeters. On the base of the scientific and practical experiences gained during the long-term operation of the weighing lysimeters at Karcag, we figured out that the facilities provide very accurate data that can contribute to the better understanding of the salt- and water balance of the soil especially regarding the evaporation moderating effect of water preserving soil cultivation systems, the water use efficiency of different crops, the optimization of irrigation, and the mitigation of the harmful effect of secondary salinization.

Keywords: lysimeters, water balance, soil management, water use efficiency

INTRODUCTION

The Research Institute of Karcag, Institutes for Agricultural Research and Educational Farm, University of Debrecen (RIK) is situated in the Trans-Tisza Region of the Great Hungarian Plain, in the eastern part of Hungary. The ecological conditions of this region are unfavourable from several points of view. The low amount of annual precipitation (500 mm) and the high evapotranspiration result in a shortage of moisture of 100-300 mm in the vegetation period, which means a limiting factor of crop production by itself. But the so called "air-drought" makes the situation worse in the summer months. These effects cause considerable damages in quantity and quality for the regional crop production. The unfavourable soil conditions of our region must be mentioned as the third limiting factor. Significant rate of our heavy textured soils with bad water-, air- and heat regime is endangered by salinization. These unfavourable factors altogether give the reason why our institute emphasise the research of water- and salt balances of the soils of our region. In 1983-84 our institute established a compensation lysimeter station for the completion of the research results of our large-scale amelioration and water regulation experiments (Karuczka and Zsembeli, 1997). The main goal was the examination of vertical substance movements and calculation of water- and substance balances of soil monoliths. Because of the necessity of more accurate water balance measurements the lysimeter station was enlarged with 6 weighing lysimeter units in 1992-1993.

In this paper we give a review of lysimeter research presenting the brief history of studies with lysimeters, describing the main lysimeter types and introducing the lysimeter related experiments carried out at RIK recently involving our main scientific achievements.

MATERIAL AND METHODS

The term "*lysimeter*" was derived from the Greek words "*lysis*" and "*metron*" meaning dissolving and measuring, respectively. The term is thus applicable to any device utilized for studying the rate, amount and composition of percolation water through a porous medium. Indeed, many definitions refer to "instruments or devices that contain soil and receive natural rainfall or irrigation and are provided with an arrangement for collecting and measuring the percolate". Percolation is an important phase of the hydrologic cycle; it recharges groundwater and discharges into streams (Aboukhaled et al., 1982). For McIlroy and Angus (1963), a lysimeter consists of "a block of soil, together with vegetation, if any, enclosed in a suitable container and exposed in natural surroundings to permit determination of any one term of the hydrologic equation when the others are known". Similarly, Tanner (1967) refers to a "device in which a volume of soil, which may be planted to vegetation, is located in a container to isolate it hydrologically from the surrounding soil in order to assess or control various terms of the water balance equation". The WMO (1968) uses the term "evapotranspirometers" or "soil evaporimeters" for "containers of soil and vegetation from which the water loss is measured by weighing or accounting for all incoming water at the surface and all outflow from the bottom of the container". Hiller et al. (1969) defined lysimeters as "large containers filled with soil, generally located in the field to represent the field environment, and in which soil-water-plant conditions can be regulated and monitored more conveniently and accurately than in natural soil profile".

There several types of lysimeters, the main types are introduced here according to Aboukhaled et al. (1982). Basically we distinguish volumetric and weighing lysimeters.

1. Volumetric (non-weighing) lysimeters

a. Drainage lysimeters without water table

Provisions are made at the bottom of the lysimeter container to collect and measure volumetrically the deep percolation of superfluously supplied water. Precipitation and irrigation are measured by means of rain gauges and/or calibrated containers. The soil in the lysimeter is either maintained close to field capacity (daily watering or more) or saturated periodically. The evapotranspiration (ET) for a given period is considered as the difference between water applied and that drained.

b. Compensation lysimeters with constant groundwater table

A constant water table is maintained in the lower portion of the lysimeter. Upon evapotranspiration water from the water table moves into the root zone by capillary rise. The drop in water level is compensated automatically by a floating device and the amount necessary to maintain the constant level is measured volumetrically.

c. Compensation lysimeters with constant surface water level

A constant water level is maintained above the soil surface of the lysimeter either by periodic addition of water or by means of a floating regulating device. Evapotranspiration is determined directly from the amount of water needed to compensate the drop in water level.

2. Weighing lysimeters

Changes in weight of the lysimeter container are a direct measurement of incoming and outgoing water flow. An increase in weight refers incoming water through rainfall or irrigation. A decrease in weight refers to water loss through evapotranspiration and drainage. Drainage water is collected in containers attached to the lysimeter and measured periodically. Weighing lysimeters allow very accurate monitoring of crop evapotranspiration over short intervals. Their complexity in installation and higher construction costs, however, make their application rather limited to specialized research stations. A major difficulty is the accurate measuring and recording of small weight changes in relation to large and heavy soil masses. Different weighing principles and devices are applied with varying degrees of success.

a. Mechanical weighing lysimeters

Different types of mechanical balances are used to measure directly changes in weight of the container and soil mass due to evapotranspiration, precipitation or irrigation. The provision of an outer container or retaining walls allows free movement of the inner container enclosing the soil mass and crop. The inner container is either weighed periodically by lifting from its support or is placed directly on a specially designed mechanical balance which constantly records changes in weight of the container.

b. Electronic weighing lysimeters

Changes in weight of the inner container and soil mass are measured electronically using strain gauges or electric load cells. The inner container is often placed on a balancing frame which, through counterweights, reduces the actual weight on the strain gauge.

c. Weighing lysimeters with hydraulic load cells

The total weight of the lysimeter is distributed over hydraulic load cells (flexible bags, "pillows" or pressure bags) and the pressure of the fluid in the load cells is read on a manometer. Changes in weight of the lysimeter due to evapotranspiration, irrigation or precipitation cause a change in the height of the fluid in the manometer. The manometer readings require calibration, which is obtained either by static or dynamic calibration. The static procedure involves adding or removing known weights and finding the corresponding manometric height changes. The dynamic calibration (Bloemen 1964; Middleton 1972) is obtained by placing a container with a volume of water on the lysimeter from which water is discharged outside the lysimeter, at a constant rate. At equal time intervals the weight changes versus manometric changes are plotted.

d. Floating lysimeters

The soil container floats in a suitable liquid (H_2O or $ZnCl_2$) held in the outer container (hydrostatic floatation or Archimedes principle). Changes in the weight of the lysimeter due to evapotranspiration or irrigation are measured by changes in buoyancy and floatation of the liquid level. Lysimeters based on this principle have been reported by King, Tanner and Suomi (1956), Popov (1959), McMillan and Burgy (1960), Brooks and Pruitt (1966), Lourence and Goddard (1967) and WMO (1974). Hybrid systems using both buoyancy and mechanical balances have also been reported (Aslyng and Kristensen 1961).

The actual status of lysimeter stations and hydrology measuring sites operated in Europe was surveyed in a boarder scale by means of questioners in 2004. That time altogether 2390 lysimeters and seepage water samplers were operated in 178 stations in 18 countries. Among the 2440 lysimeters 84.2% were non-weighable (volumetric), while only 15.8% were weighing lysimeters, 46% within them were filled monolithically (Lanthaler and Fank, 2005).

Recent information on the lysimeter researches is available through the website of the Lysimeter Platform (I1). At this platform altogether 2985 measuring devices are registered (89.5% lysimeters) representing 148 stations and 20 countries. Three Hungarian lysimeter stations are registered: Karcag, Keszthely and Szarvas. The Lysimeter Platform is operated by the Lysimeter Research Group (LRG) founded in 1992 as a non-profit association and international scientific committee. Its main goals are the support of the interdisciplinary information exchange among the scientists and the extension of the scientific achievements to the public. LRG organises conferences, scientific excursions to visit different lysimeter stations and maintains the website. LRG has 500 registered members from 56 countries, though 72% of the members are from Europe (Cepuder et al., 2015).

The lysimeter conference organised by LRG every second year (Gumpensteiner Lysimetertagung) is an excellent platform to introduce novel scientific results achieved by the representatives of this research area. The last lysimeter conference was held in May of 2017, the presentations and posters represented the main experiments carried out by means of lysimeters. Research results gained from weighing lysimeter data like the hydrological balance of sealed surfaces

(Timm and Wessolek, 2017), evaporation and water use efficiency studies (Oberholzer et al., 2017), the determination of the amount of precipitation (Stephan et al., 2017), the determination of the amount of dew (Czellér et al., 2017). Specific environmental conditions can be also studied in more details by the application of lysimeters: Herndl et al. (2017) elaborated a method suitable for the determination of the amount of precipitation and evaporation in mountainous (alpine) regions, while the effect of tree species on the water balance in forest environment was established by Müller (2017). Climate change, as an important issue of nowadays, was also involved in the context of grassland management (Leitinger et al., 2017) and the substance and water balance of the soil (Köhn et al., 2017). Irrigation studies were also mentioned especially regarding its harmful effects like irrigation with saline water (Zsembeli et al., 2017, Kun et al., 2017) and the heavy metal (Baborowski et al., 2017) and herbicide (Strauß et al., 2017) contamination appears in leachate and groundwaters. The loss of nutrients are still an important issue that must be studied by means of lysimeters; leaching of P, K, Mg and S (Grunert, 2017) or N loss by leaching (Spiess et al., 2017; Murer et al., 2017). Plant nutrition can be also studied by means of lysimeters. Tauchnitz et al. (2017) studied the nitrogen use efficiency of maize, while Jancsó et al. (2017) determined the effect of different N-doses on the nitrogen use efficiency of winter wheat.

Lysimeter researches have been carried out at RIK since 1983. During those 35 years several information was gained concerning the water- and salt balance of the soils by means of these devices. There three types of lysimeters operated at RIK making it unique in Hungary: 8 lysimeters with compensation system, 30 simple drainage lysimeters (26 were reconstructed and are used recently), and 6 electronic weighing lysimeters. The photo of the lysimeter station of RIK is shown in Fig. 1.

Figure 1: The lysimeter station at RIK

Lysimeters with compensation system

The depth of the lysimeters is 120 cm, the surface area is 0.8 m^2. The type of the soil that was filled into the lysimeters is meadow chernozem salty in the deeper layers (vertisol). Some parameters of the investigated soil are shown in Table 1.

Table 1: Some parameters of the meadow chernozem soil filled into the lysimeters with compensation system

Depth	pH (H_2O)	pH (KCl)	K_A	Salt content	$CaCO_3$	Humus content	NO_3-N	P_2O_5	K_2O
cm				m/m%	%	m/m%	mg/kg	mg/kg	mg/kg
0-30	5.5	6.6	43	<0.02	< 0.05	2.8	9.1	79	243

	Particle size distribution (%)						
Depth cm	>0.25 mm	0.25-0,05	0.05-0.02	0.02-0.01	0.01-0.005	0.005-0.002	0.002-mm
0-30	0.39	4.66	19.59	15.44	10.29	10.46	39.19

Legends: K_A – Plasticity according to Arany

The parameters and their measurement frequency determined for the lysimeters with compensation system: amount of input and output waters (every 2-3 days), amount of input and output substances - macro-, microelements, nutrients, salts (biweekly).

Simple drainage lysimeters

The depth of the lysimeters is 120 cm, the surface area is 0.8 m^2. Three soil types were filled into the lysimeters: meadow chernozem salty in the deeper layers (vertisol) in 11 units, meadow solonetz (solonetz) in 12 units, and sand in 3 units. Some parameters of the investigated soils are shown in *Table 2-4*.

Table 2: Some parameters of the meadow chernozem soil filled into the simple drainage lysimeters

Depth	pH (H_2O)	pH (KCl)	K_A	Salt content	$CaCO_3$	Humus content	NO_3-N	P_2O_5	K_2O
cm				m/m%	%	m/m%	mg/kg	mg/kg	mg/kg
0-30	5.7	6.7	46	0.04	< 0.05	2.9	9.7	86	338
30-60	6.9	7.7	52	0.07	1.09	2.3	18.5	40	299
60-90	7.4	8.2	48	0.05	10.88	1.2	8.5	33	245

Particle size distribution (%)							
Depth cm	>0.25 mm	0.25-0.05	0.05-0.02	0.02-0.01	0.01-0.005	0.005-0.002	0.002-mm
0-30	0.5	6.4	11.4	15.4	13.6	11.5	41.2
30-60	0.2	5.8	7.2	16.3	14.1	10.6	45.9
60-90	0.1	3.5	9.0	13.4	16.0	11.0	47.0

Legends: K_A – Plasticity according to Arany

Table 3: Some parameters of the meadow solonetz soil filled into the simple drainage lysimeters

Depth	pH (H_2O)	pH (KCl)	K_A	Salt content	Humus content	NO_3-N	P_2O_5	K_2O	Ca
cm				m/m%	m/m%	mg/kg	mg/kg	mg/kg	mg/kg
0-20	7.48	7.00	46	0.13	2.31	68.6	1072	444	8710
20-40	8.20	7.23	52	0.12	1.43	14.6	653	247	19080
40-60	8.57	7.41	54	0.13	1.07	9.6	307	207	44160
60-80	8.90	7.64	52	0.16	0.71	6.2	188	185	52260
80-110	9.17	7.94	57	0.26	0.33	7.3	84	181	51000

Particle size distribution (%)							
Depth cm	>0.25 mm	0.25-0.05	0.05-0.02	0.02-0.01	0.01-0.005	0.005-0.002	0.002-mm
0-20	0.3	17.3	17.9	21.9	7.0	11.4	24.2
20-40	0.2	11.5	17.9	16.5	5.6	11.4	37.0
40-60	0.2	9.1	16.8	15.5	7.7	11.0	39.7
60-80	0.2	9.2	17.4	17.0	6.9	7.8	41.4
80-110	0.1	9.0	18.6	18.6	11.2	9.1	33.4

Legends: K_A – Plasticity according to Arany

Table 4: Some parameters of the sandy soil filled into the simple drainage lysimeters

Depth	pH (KCl)	K_A	Salt content	$CaCO_3$	Humus content	NO_3-N	P_2O_5	K_2O
cm			m/m%	%	m/m%	mg/kg	mg/kg	mg/kg
0-20	5.18	30	<0.02	<0.05	0.75	5.7	124	150
20-40	3.99	30	<0.02	<0.05	0.56	2.0	116	159
40-60	4.16	28	<0.02	<0.05	0.67	2.1	21	187
60-80	4.63	30	<0.02	<0.05	0.58	<2.0	20	144

	Particle size distribution (%)						
Depth cm	>0.25 mm	0.25-0.05	0.05-0.02	0.02-0.01	0.01-0.005	0.005-0.002	0.002- mm
0-20	16.2	77.6	1.8	1.1	0.2	1.9	1.2
20-40	27.6	64.4	3.2	0.2	0.3	1.0	3.3
40-60	27.6	62.8	3.0	1.4	0.6	0.5	4.0
60-80	28.6	61.4	3.5	1.8	0.8	1.6	2.4

Legends: K_A – Plasticity according to Arany

The parameters and their measurement frequency determined for the simple drainage lysimeters: amount of input and output waters (weekly), salt content of seepage (drain) waters (biweekly). Soil moisture content and temperature are constantly measured with the frequency of 3 hours in the 2 times 3 lysimeters filled with sandy and meadow chernozem soils at the depths of 0-10, 10-20, 20-30, 30-40 cm, respectively. In the 12 lysimeters filled with meadow solonetz soil moisture content and temperature are constantly measured with the frequency of 1 hour at the depths of 0-10, and 20-30 cm.

Weighing lysimeters

The depth of the lysimeters is 10 cm, the surface area is 1.6 m^2. The type of the soil that was filled into the lysimeters is meadow chernozem salty in the deeper layers, same as in the case of the soil filled into the simple drainage lysimeters (*Table 2*).

The parameters and their measurement frequency determined for the weighing lysimeters: change of weight (10 minutes), amount of seepage (drain) water (weekly), soil moisture content and temperature at the depths of 0-10, 10-20, 20-30, 30-40 cm (occasionally).

According to the principle of weighing lysimetry, our facility is suitable for the calculation of the water balance of each unit. The adequate water balance equation valid for the given situation is as follows:

$$P + I = E + D + WB$$

Where P = precipitation (mm), I = irrigation water (mm), E = evaporation (mm), D = drain water (mm), WB = water balance, change of soil moisture content (mm). As WB = ΔW, water balance equals the change of the weight of the soil column, its value can be expressed by reducing the input and output factors:

$$\Delta W = P + I - E - D$$

As all the factors of the water balance equation, except for evaporation, can be measured and expressed in mm, the evaporation value can be calculated as follows:

$$E = P + I - D + \Delta W$$

The accuracy of the calculation depends on the measurement accuracy of the components, which is 0.06 mm in the case of the change of weight. This accuracy ranges the lysimeter system to the category of high precision lysimeters.

Furthermore meteorological parameters (continuous), evaporation of open water surface (daily) are determined to all three lysimeter types, and soil samples are taken regularly (usually two times a year: at the beginning and at the end of the irrigation season).

RESULTS AND DISCUSSION

In this paper some characteristic experiments and the results gained from them are reviewed in order to demonstrate the versatile utilization possibilities of lysimeters serving soil management researches.

a. Determination of transpiration of fruit trees in compensation lysimeters

The compensation lysimeters used to serve the scientific establishment of drainage. Since this kind of research is not carried out at RIK any longer, new utilization of the compensation lysimeters was found. We planted fruit trees in the lysimeters in order to determine their transpiration values. 2 pear (Bosc kobak and William's) and 1 apple varieties (*Regal Prince*) were planted in 3 replications into 9 lysimeters with compensation system of the lysimeter station of RIK. The permanently maintained groundwater level was set at the depth of 90 cm serving as the water supply (subsurface irrigation) of the trees in dry periods. The soil surface was covered with plywood that impeded evaporation getting out and natural precipitation getting into the soil. Therefore the amount of water used from the supplying container equals the transpiration of the fruit trees (Riczu et al., 2010).

In 2011 the detecting of the transpiration values was begun at the end of June. The first intensive growing stage of canopy has approximately ended by this time and evolved the 70-80% of the foliage. The transpiration values were detected weekly till mid-October. The cumulative transpiration of the investigated fruit trees was compared (*Fig. 2*) in order to characterize the water use of them. The number (in parentheses) after the name of each fruit tree variety indicates the number of the lysimeter where the variety was planted.

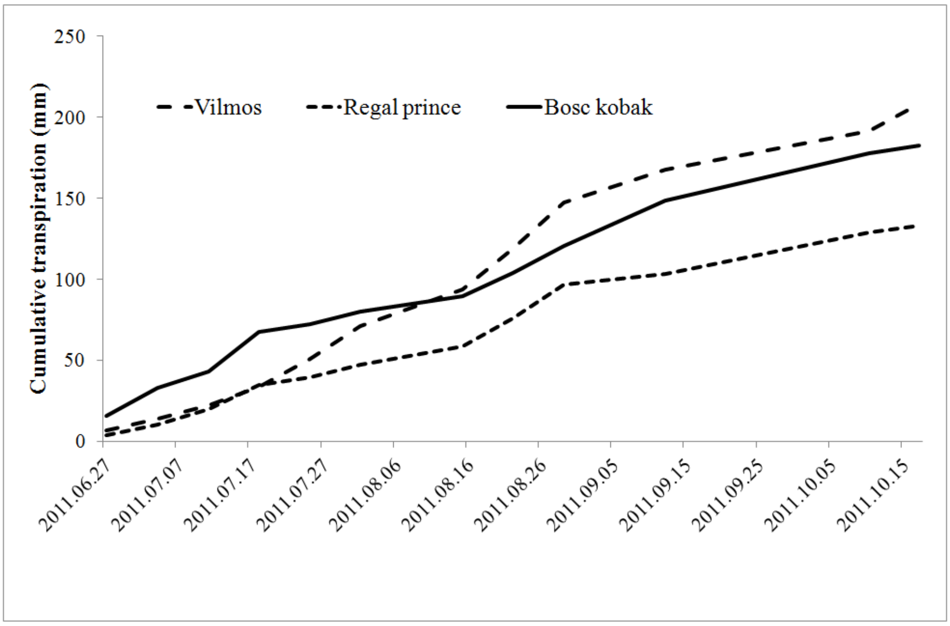

Figure 2: Cumulative transpiration of the investigated fruit trees (2011)

On the base of the cumulative transpiration values it could be established that the trees had a different transpiration characteristics. It is worth to compare the cumulative transpiration of investigated fruit trees with the leaf area, since the water loss practically happens only through the leaves. On the other hand, the individual development of the trees was different, thus the more developed trees have produced a bigger biomass and therefore their water use and transpiration were also higher. Expressing the transpiration values for 1 cm^2 leaf area, the transpiration values can be compared even better. If we divide the cumulative transpiration values of the fruit trees with the leaf area scanned with the ADC AM 100, their water loss per cm^2 can be got as the result. By calculating the average transpiration per a leaf area unit of the trees with the same variety, it can be established that *William's* had the highest (0.032 mm cm^{-2}) and *Regal Prince* with the largest leaf surface area had the lowest transpiration values (0.018 mm cm^{-2}) regarding the examined tree varieties. As the detecting frequency of transpiration was weekly, the increase of transpiration on July 18^{th} and on August 29^{th} must be correlated to the weekly heat amounts. Between these two dates no significant increase of transpiration could be detected, since a more than 8°C decrease of air temperature was experienced.

b. Study of secondary salinization in simple drainage lysimeters

An experiment was set in 12 simple drainage lysimeters at the lysimeter station of RIK in 2012 in order to simulate the conditions of irrigation characteristic in the region and to examine its effect on the soil and the indicator crops. The lysimeters were reconstructed in 2009 and filled with a slightly sodic (0.06% salt content) meadow solonetz soil. The lysimeters are 150 cm deep with a drain tube at 120 cm and have a surface area of 0.8 m^2.

In 2015 and 2016 irrigation with saline and deionised water were used. Two salt concentrations were applied: according to the broad survey of Zsembeli et al. (2011) the salt concentration of 1,800 mg/l is characteristic to the groundwater and the shallow wells of the area, while 600 mg/l salt concentration is characteristic to the deeper drilled wells utilizing the aquifers at 40-70 m depth. The salt concentration of the irrigation water of 600 mg/l was set by dilution: the 1,800 mg/l salt concentration of a groundwater well was mixed with deionised water in a 1:2 ratio. Irrigation was applied rationally and regularly, preferably in smaller amounts by every day when no natural precipitation occurred. The indicator crops were winter fodder pea and soya bean as there is an increasing demand from the farmers to produce these legumes induced by the change of the subsidizing system that remunerates the production of N-fixing legumes in the framework of 'greening'. The irrigation treatments were set in 4 replications combined with the 2 indicator crops giving the following arrangement of the 12 lysimeters (*Table 5*).

After the irrigation season of 2016, the yield of the indicator legume crops was determined and soil samples were taken from the soil of the lysimeters down to 40 cm and analysed in order to determine their salt content balance. The soil samples were analysed in the laboratory of RIK and their salt content was determined according to their electric conductivity. The total actual salt contents (mass of the total soluble salts expressed in grams) of the 0-10, 10-20, 20-30, 30-40 cm deep layers (most important in crop production) were calculated taking the soil mass of each layer into account (m/m%).

Table 5: Irrigation treatments in the simple drainage lysimeters (2015-2016)

Pea, deionised water replication 1	Pea, 600 mg/l water replication 1	Soya, deionised water replication 1	Soya, 600 mg/l water replication 1
Pea, 1800 mg/l water replication 1	Pea, deionised water replication 2	Soya, 1800 mg/l water replication 1	Soya, deionised water replication 2
Pea, 600 mg/l water replication 2	Pea, 1800 mg/l water replication 2	Soya, 600 mg/l water replication 2	Soya, 1800 mg/l water replication 2

The salt contents of the 4 investigated soil layers in the averages of the 4 replications of the 3 irrigation treatments are shown in *Fig. 3*. The horizontal line indicates the original salt content of the soil (0.06%) before irrigation was started.

It is obvious that irrigation with deionised water causes leaching of salts out of the upper layers, which is also shown by the salt contents increasing by depth. As no deep percolation (drain) water appeared in any of the lysimeters, the leached salts must have accumulated in the deeper layers and will be leached out when the soil columns of the lysimeters are oversaturated. In the lysimeters where irrigation water with 600 mg/l salt content was applied slightly negative salt balance was characteristic for the upper soil layers.

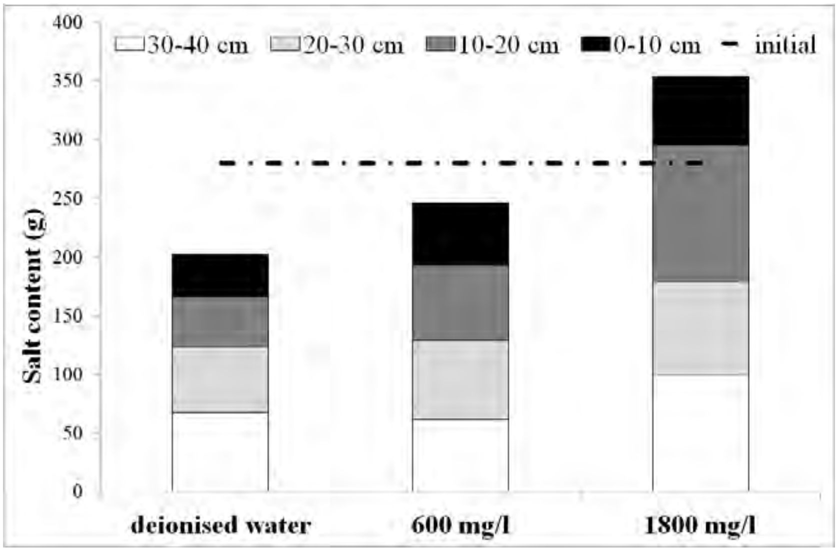

Figure 3: Total soluble salt content in the upper 40 cm soil layers of the lysimeters irrigated with waters of different salt concentrations

c. Determination of the evaporation moderating effect of soil cultivation methods with weighing lysimeters

The determination of the effects of technological elements influencing the soil water regime (mulch layer, heat isolating soil surface, mitigation of cracking, etc.) can contribute to the elaboration of water preserving technologies as the elements of up-to-date and sustainable crop production. The control of soil water regime is an effective environmental protective process at the same time, which is of great importance to prevent soil degradation and to mitigate the pollution of our water funds.

We numerically determined the half-year water balances (and their components) of the soil columns with different surfaces created by the modelling of various soil surface formation and covering methods. We figured out the probable reasons of the experienced differences and the effects of different periods, especially of the extremely dry or wet periods, on the water regime of the soil (Zsembeli, 1999; Zsembeli, 2002).

On the base of the half-year results we evaluated the effect of different soil surfaces created by the examined soil cultivation treatments on the soil water balance. By means of the method of regression analyses we tried to find a correlation between the amount of water input (precipitation, irrigation) and output by evaporation of the soil columns. We found close exponential correlation between the examined variables (*Fig. 4*).

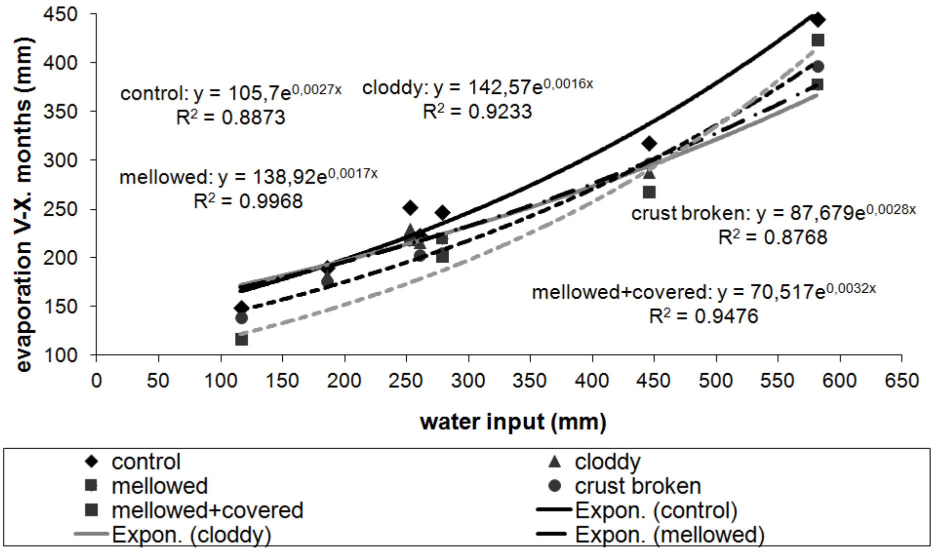

Figure 4: Correlation between water input and evaporation on the base of the half-year water balance data

According to the results we ranged the examined five treatments into three different groups. We established that probably there is a certain amount of water input, where practically there is no difference in the amount of water evaporated from the soil columns of the cultivated treatments. We also figured out that the treatments that have evaporation decreasing effect in the lower water input range, in case of water load higher than the average, loose more water by evaporation. We used indexes for the assessment of evaporation mitigating and infiltration increasing effect of the investigated treatments (*Table 6*). The higher is the rate of evaporation and the amount of input water, the lower is the mitigating effect of the given treatment (soil surface formation), while the higher is the rate of the amount of drain and input waters, the higher is the infiltration increasing effect.

Table 6: Assessment of the effect of five treatments on the water balance of the soil column

Treatment	Evaporation mitigating effect evaporation/input	Infiltration increasing effect drain water/input
control	94%	14%
cloddy	85%	17%
mellowed	84%	20%
mellowed + crust broken	77%	22%
mellowed + covered	77%	31%

d. Determination of water use efficiency of crops with weighing lysimeters

Various plants can be examined in weighing lysimeters, the practical limit is the size only. Since the establishment of the weighing lysimeter system at Karcag several plants have been applied in order to calculate their water use efficiency: millet, sunflower, maize, sorghum, energy willow, and recently Miscanthus. Either different plant species, varieties (hybrids), or various amounts water input were compared.

Some water use parameters of maize and sorghum of the investigated periods of 2009-2010 are shown in *Table 7*. The evapotranspiration in the function of the total water input index shows whether the water balance was negative or positive, in other words if the water supply was sufficient (100% or below) for the crop, or insufficient meaning that the crop decreased the moisture fund of the soil. In 2009 the water balances were negative, 5% of the water transpirated by maize originated from the soil moisture fund, while 17% in the case of sorghum. This result is in harmony with the literature data stating the soil drying capability of sorghum. In 2010 two sorghum hybrids had slightly negative water balance, while one hybrid showed positive balance, only 83 percent of the total water input was used for evapotranspiration. It must be mentioned that the hybrid Albita is a grain sorghum, while Berény and Sucrosorgo are sweet sorghum hybrids with much higher green mass (Zsembeli et al., 2011).

Table 7: Water use parameters of the indicator crops in the lysimeters

	Maize 2009	Sucrosorgo 2009	Sucrosorgo 2010	Berény 2010	Albita 2010
Precipitation (mm)	175.9	175.9	402.8	402.8	402.8
Irrigation (mm)	280	280	45	45	40
Total water input (mm)	455.9	455.9	447.8	447.8	442.8
ET (mm)	478.5	533.13	459.9	454.4	369.7
ET/water input (%)	105	117	103	101	83

In order to assess the effect of water input (irrigation) on the water balance of maize and sorghum further, the yield data were also used (*Table 8*). We measured the total biomass for all indicator crops, the corn-cob mass was determined for maize, while for sorghum the sugar content was measured. Naturally the biomass yields of the two crops cannot be compared directly, but they were used as the base of further calculations for determining the water use efficiency. As we experienced different values of ET, the question arose if the water use efficiencies of the two crops are different as well. In other words, some economic calculations can answer the question whether the bigger biomass or yield can compensate the higher input originating from the higher water consumption. As the hydrological approach of this question some indexes characterising the water use efficiency of the crops were calculated. These indexes can be the bases of further economic calculations.

Table 8: Water use efficiency indexes in the function of yields in 2009

Index	Maize	Sorghum
Total biomass (g/m^2)	3300	5100
Biomass/ET (g/mm)	6.9	9.6
Corn-cob mass (g)	2700	-
Sugar content (%)	-	18.9
Sugar yield (g/m^2)	-	964
Corn+cob mass/ET (g/mm)	5.64	-
Sugar yield/ET (g/mm)	-	1.8

The total biomass production of maize and sorghum in the function of ET describes how much plant biomass was built up by using 1 mm of water through evapotranspiration during the investigated period. The results of 2009 show a relatively higher water consumption of maize as it consumed less water in total, but approximately 30% more for producing the same amount of biomass. This difference obviously originates from the higher biomass production of sorghum, but also means a better water use efficiency of it.

In *Table 9* the water use efficiency indexes calculated for the yields of the sorghum hybrids in 2010 are shown. These values can be compared to other results gained under similar conditions and also to the results of other years. Hybrid Sucrosorgo was studied both years. There was considerable difference in the total biomass yield as the water supply was much satisfactory in the wet year of 2010 (positive water balance). The other two sorghum hybrids had lower biomass production, which was expected in the case of Albita, the grain sorghum hybrid. Berény, the other sweet sorghum hybrid had the highest sugar content, but still generated lower total amount of sugar due to its lower biomass yield. Albita, the grain sorghum hybrid generated 20-30% less sugar than the sweet ones, and although consumed 20% less water, still it needed the highest amount of water to generate 1 g of sugar.

Table 9: Water use efficiency indexes in the function of yields of sorghum in 2010

Index	Sucrosorgo	Berény	Albita
Total biomass (g/m2)	8900	7000	3400
Biomass/ET (g/mm)	19.4	15.4	9.2
Sugar content (%)	15	17	11.5
Sugar yield (g/m2)	1335	1190	391
Sugar yield/ET (g/mm)	2.9	2.6	1.1

e. Determination of the amount of dew with weighing lysimeters

The determination of the dewfall periods was done on the base of the weight data recorded by means of a weighing lysimeter system of RIK. The basis for calculation was a water balance equation with measured quantities on the left-hand side and the (yet unknown) boundary fluxes between soil and atmosphere on the right-hand side:

$$\Delta W + SW = P + I - ET$$

where ΔW = change of profile water content, SW = seepage water at lysimeter outlet, P = precipitation on the lysimeter, I = irrigation on the lysimeter, ET = evapotranspiration from the lysimeter; all dimensions are lengths.

The fundamental dataset contained 10-min-data of lysimeter mass (changes equalling changes of water content) and seepage water collected at the bottom outlet of the lysimeters, from which a nominal time series (W+SW) was calculated. The determination of the dewfall periods was done on the base of the weight data recorded by means of the weighing lysimeter system. Those periods are considered dewfall periods when positive weight changes are recorded by the lysimeters and at the same time neither natural precipitation nor irrigation occurred. The amount and duration of the natural precipitation data were determined on the base of the records with 10 minutes frequency of the meteorological station (belonging the official national network operated by the National Meteorological Service of Hungary) located in the territory of RIK at approximately 250 m distance from the lysimeter station. During the investigation period (1st April 2015 – 30th September 2016) the measurement frequency of the weight data of the lysimeters was also 10 minutes in order to harmonize them with the meteorological data. The weight changes of two weighing lysimeters – a grass covered and another with bare soil surface – were determined for each day of the investigation period and put an Excel data base.

Analysing all the weighing data of our data base we signed those periods when positive weight changes were characteristic regardless their extent. All these periods were compared to the precipitation data gained by means of the meteorological station and we determined such periods when positive weight changes are recorded by the lysimeters and at the same time neither natural precipitation nor irrigation occurred. For those periods we calculated the daily water balances of the soil columns of the lysimeters taking all the relevant inputs and outputs into consideration according to equation described above.

By means of this dewfall identification method based on the filtering we determined the daily amounts of dew fallen on the grass covered and bare soil lysimeters during all the 549 days of the whole investigation period and calculated the total values. Altogether 43.11 mm dew was detected on the grass covered surface calculated on the base of the water balance data during the 18 months of the investigation period. In order to judge this amount being high or low, we can compare it to the literature data, but unfortunately we have no data for a complete year from January to December yet.

According to the relevant literature the largest chance of dew formation is during the summer months as the conditions of the condensation of water vapours. The dew formation is more when the sky is clear and less when it is cloudy. In a typical summer day, when the sky is clear and the ground and plant surfaces are cooler at nights, there is more evaporation of water and hence more dew formation. When it is cloudy, the ground and plant surfaces do not get cool in the night and hence there is less dew formation. Contrary to these, the amount of dew measured on the grass covered soil surface in the 6 summer months (June, July, August of 2015 and 2016) was only 6.58 mm giving 15% of the total 18 months (*Fig. 5*). The dewiest period was detected on the grass covered surface in the three-month-long period between November 2015 and January 2016 with its 13.77 mm (40% of the total amount). Obviously most of the dew precipitated during this period was frost.

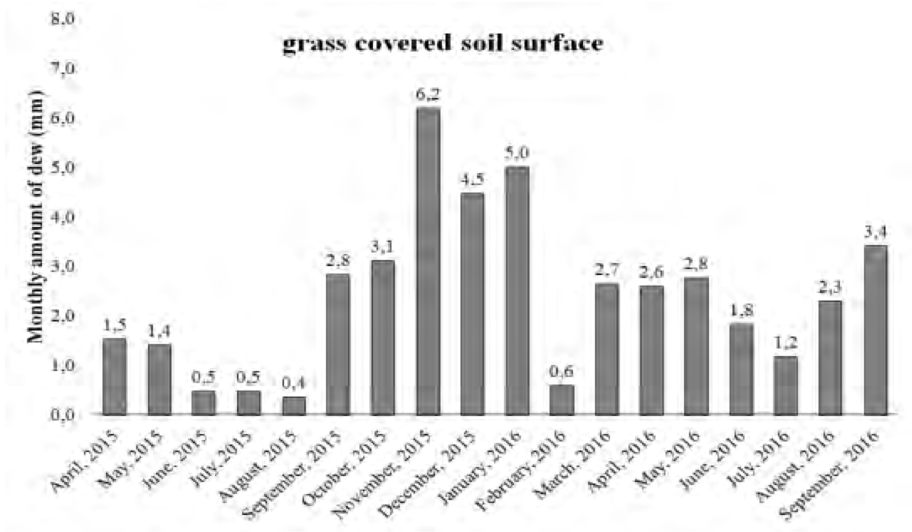

Figure 5: Monthly dew amounts measured on the grass covered lysimeter

In the case of the bare soil surface a bit more even time distribution of dew formation was characteristic (*Fig. 6*). The amount of dew measured on bare soil surface in the 6 summer months (June, July, August of 2015 and 2016) was 14.11 mm giving 28% of the total 18 months. The dewiest period was also during the period from November 2015 to January 2016, but with somewhat lower amount (9.65 mm) and percentage (20% of the total amount). Extreme amount of dew was detected in September 2016 with its 7.29 mm.

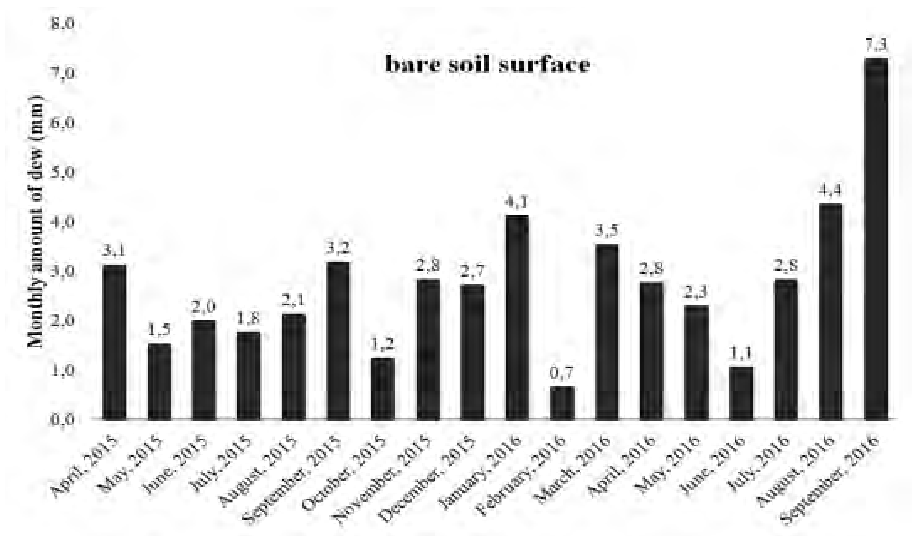

Figure 6: Monthly dew amounts measured on the lysimeter with bare soil surface

CONCLUSION

In the Great Hungarian Plain the most important ecological factor determining the development of agricultural production is water. There is long tradition of the efforts focus on saving water in agricultural use of water. Irrigation researches of the last century made it obvious that irrigation can be used only conditionally (strictly taking its environmental impacts as secondary salinization, soil degradation, etc into consideration) on large areas due to the special ecological and soil conditions of the Great Hungarian Plain. Therefore other approaches (water saving soil cultivation, application of crops with high drought tolerance) can be the solution of this problem. Researches focus on the control of the water- and salt regime in order to improve the efficiency of water use are of great importance. In accordance with the combat against drought damages and soil degradation the conventional soil cultivation methods are prospectively replaced by conservation tillage, which aims the decrease of the depth of the regularly cultivated soil layer and the formation of a topsoil rich in organic matter. The scientific establishment of the hydrological impacts of these new methods can absolutely be considered actual and needs further efforts. The determination of the effects of technological elements influencing the soil water- and salt regime can contribute to the elaboration of water preserving technologies as the elements of up-to-date and sustainable crop production. The control of soil water regime is an effective environmental protective process at the same time, which is of great importance to prevent soil degradation and to mitigate the pollution of our water funds.

Lysimeters are delineated soil columns with a known volume and surface area. The column can be either filled manually with disturbed soil material or be equipped with an undisturbed soil monolith excavated from the site of investigation. Lysimeter experiments can be either conducted in the laboratory (laboratory lysimeter) or in the field (field lysimeter). The lysimeter technique has been improved constantly and has been applied to even more complex research topics ever since. RIK is the only research base in Hungary where 3 types of lysimeters are operated. All the experiments described above prove that lysimeters are very versatile tools suitable for the precise quantification of the processes determining the water- and salt balance of the soil.

We determined the advantages and disadvantages of the weighing lysimeter system operated at Karcag, and figured out its application possibilities and limits for the examination of soil water balance. Our conclusion is that this weighing lysimeter system, with its given size parameters, provides very accurate data for the comparison analysis of the differences arising in the water balance of soil columns with different surface formation and covering treatments. Weighing lysimeters are very suitable tools for the determination of the water balance of the soil providing the possibility of the precise calculation of evapotranspiration, especially as the differences can be precisely quantified.

Our results call the attention the practical problems of agriculture of the region. One of those is the necessity of water preservation. Knowing the effect of different tillage systems of the water balance of the soil can contribute to the development of them. The determination of the effects of technological elements influencing the soil water- and salt regime can contribute to the elaboration of water preserving technologies as the elements of up-to-date and sustainable crop production. On the base of our results gained from the study the evaporation moderating effect of soil surface formations characteristic to the different tillage systems, we established that by the application of soil protective cultivation systems like reduced tillage significant amount of water can be preserved in the soil as soil protective mulch layer is formed on the surface. We suggest the application of reduced tillage under the agroecological conditions of Nagykunság region of Hungary as a good agricultural practice of soil management.

The other main problem in the region is irrigation. The use of saline water for irrigation cause secondary salinization, especially on soils susceptible to that. In our opinion the optimization of irrigation can mitigate the extent of secondary salinization, even though it definitely occurs. Our results concerning the use of saline water for irrigation are incredibly important as in Hungary for such a soil no irrigation is permitted with waters in which the total soluble salt content is over 500 mg/l. Our results show that the regulation is too strict as no salt accumulation occurred even after a long-term of irrigation with water of 600 mg/l salt content. In the case of irrigation with water of 1,800 mg/l salt content definite salt accumulation took place, especially in the 10-20 cm deep soil layer. On the other hand the determination of the water use efficiency of different crops can contribute to the proper selection of the crops more suitable for a specific region and to the optimization of irrigation. As a concrete example sorghum vs. maize can be mentioned. We established that under our circumstances the examined sweet sorghum hybrids (Sucrosorgo and Berény) payed better for the sufficient water supply, while the grain sorghum hybrid (Albita) probably showed better water use efficiency in dry years providing potential substitution of maize as a fodder crop.

For the development of soil management, the better understanding of all the elements of the hydrological cycle is essential. As the lysimeter technique is improving, recent advances allow measuring water balance components – including precipitation and dew as a fraction of it – with high accuracy and high temporal resolution. Our results concerning the measurement of the amount of dew for a longer term are novel and unique as only calculated data were available in this respect so far.

On the base of the scientific and practical experiences gained during the long-term operation of the weighing lysimeters at Karcag, we figured out that the facilities provide very accurate data of moisture content changes of the lysimeter units. These changes caused by the different water regime of the different soil surface formations and plant covers can be compared and expressed numerically, and can serve as the base of the further development of a hydrologically more effective soil management practice.

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REFERENCES

ABOUKHALED, A., ALFARO, A., SMITH, M. (1982): Lysimeters. FAO Irrigation and Drainage Paper. Rome. 68 p.

ASLYNG, H.C., KRISTENSEN, K.J. (1961): Water balance recorder. ASCE Proc. 87 (IRI). pp. 15-21.

BABOROWSKI, M., RUPP, H., WENDT-POTTHOFF, K., TAUCHNITZ, N., BEDNORZ, D., MEIßNER, R. (2017): Variation der Elementkonzentrationen im Drainagewasser zweier unterschiedlich genutzter landwirtschaftlicher Flächen der Norddeutchen Tiefebene. 17. Gumpensteiner Lysimetertagung, Austria, pp. 165-168. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

BLOEMEN, G.M. (1964): Hydraulic device for weighing large lysimeters. Trans. Amer. Soc. Agr. Eng 7(3) pp. 279-299.

BROOKS, F.A., PRUITT, W.O. (1966): Investigation of energy, momentum and mass transfers near the ground. Final Report USAEC, Davis, California. 259 p.

CEPUDER, P., BAUMGARTEN, A., BOHNER, A., KLAMMLER, G., MURER, E., WIMMER, B., NOLZ, R. (2015): Lysimeter Research Group - A scientific community network for lysimeter research

CZELLÉR K., ZSEMBELI J., SINKA L., KOVÁCS GY., STREDA, T., STREDOVA, H., CEPUDER, P., NOLZ, R. (2017): Determination of the amount of dew using weighing lysimeter data. 17. Gumpensteiner Lysimetertagung, Austria, pp. 181-184. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

GRUNERT, M. (2017): Auswirkung differenzierter Bodenbearbeitung auf verschiedenen Böden auf die P-, K-, Mg- und S-Verlagerung in der Lysimeteranlage Leipzig. 17. Gumpensteiner Lysimetertagung, Austria, pp. 65-70. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

HERMDL, M., SLAWITSCH, V., VON UNOLD, G. (2017): Eine Methode zur Quantifizierung von Niederschlag und Verdunstung im Winter unter Klimawandelbedingungen. 17. Gumpensteiner Lysimetertagung, Austria, pp. 131-136. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

HILLER, D., GAIRON, S., FALKENFLUG, V., RAWITZ, E. (1969): New design of low-cost hydraulic lysimeter system for field measurement of evapotranspiration. Israel J. Agric. Res. 19(2) pp. 57-63.

JANCSÓ M., SZALOKI T., SZÉKELY A., SZIRA F., MONOSTORI I., VÁGÚJFALVI A., HOFFMANN B., MEGYERY SZ., ONCSIK M.B. (2017): Characterization of 4 winter wheat cultivars with different Nitrogen Use Efficiency (NUE): A lysimeter study. 17. Gumpensteiner Lysimetertagung, Austria, pp. 103-106. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

KARUCZKA A., ZSEMBELI J. (1997): Construction, Operation and Experiences of the Karcag Lysimeter Station. Einldung zur 7. Gumpensteiner Lysimetertagung, Austria. pp. 37-39.

KING, K.M., TANNER, C.B., SUOMI, V.E. (1956): A floating lysimeter and its evaporation recorder. Trans. Amer. Geophys. Union 37. pp. 738-742.

KÖHN, J., MEIßNER, R., RUPP, H., REINSTORF, F. (2017): Sind die Wirkungen des Klimawandels auf den Boden anhand von Langzeit-Lysimeteruntersuchungen nachweisbar? 17. Gumpensteiner Lysimetertagung, Austria, pp. 57-64. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

KUN Á., BOZAN CS., ONCSIK M.B., BARTA K. (2017): Analysis of leachate from wastewater irrigation experiment with sorghum. 17. Gumpensteiner Lysimetertagung, Austria, pp. 213-216. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

LANTHALER, C., FANK, J. (2005): Lysimeter station and soil hydrology measuring sites in Europe – Results of a 2004 survey. 11. Gumpensteiner Lysimetertagung, Austria, pp. 19-24.

LEITINGER, G., FRENCK, G., TAPPEINER, U., OBOJES, N., NEWESELY, C., WELLSTEIN, C., SCANDELLARI, F., THOMA, M., TAGLIAVINI, M., TASSER, E. (2017): Valorization of grassland management for the water supply in context with climate change. 17. Gumpensteiner Lysimetertagung, Austria, pp. 145-148. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

LOURENCE, F.J., GODDARD, W.D. (1967): A water-level measuring system for determining evapotranspiration rates from a floating lysimeter. J. Appl. Meteorol. 6(3) pp. 487-492.

MCILROY, I.C., ANGUS, D.A. (1963): The Aspendale multiple weighed lysimeter installation. Div. Meteorol. Physics Paper No. 14, CSIRO, Australia. 27 p.

MCMILLAN, W.D., BURGY, R.H. (1960): Interception loss from grass. J. Geophys. Res. 65(8) pp. 2389-2394.

MIDDLETON, J.E. (1972): A quick weighing lysimeter system check. Agric. Eng. pp. 14-15.

MURER, E., KUDERNA, M., SELTENHAMMER, K., FUCHS, G. (2017): Lysimeteruntersuchungen als Unterstützung zum Grundwasserschutz. 17. Gumpensteiner Lysimetertagung, Austria, pp. 49-56. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

MÜLLER, J. (2017): Die forstökologische Forschung mit Lysimetern: Möglichkeiten und Grenzen ihres Einsatzes. 17. Gumpensteiner Lysimetertagung, Austria, pp. 137-144. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

OBERHOLZER, S., HUND, A., PRASUHN, V. (2017): Auswertung von Lysimeterdaten über sieben Jahre zur Bestimmung von Evapotranspiration, Wassernutzungseffizienz und Pflanzenkoeffizienten. 17. Gumpensteiner Lysimetertagung, Austria, pp. 201-204. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

POPOV, O.V. (1959): Lysimeters and hydraulic soil evaporimeters. Colloque de Hannoversch-Munden. Associate. Int. D'Hydrol. Sci. Publ. 49. pp. 26-37.

RICZU, P., ZSEMBELI J., TAMÁS, J. (2010): Evaluation of water balance of apple and pear trees. Journal of Agricultural Sciences. Acta Agraria Debreceniensis, Debrecen, Suppl. 193-198. ISSN: 1588-8363.

SPIESS, E., PRASUHN, V., HUMPHRYS, C. (2017): Einfluss des umbruchtermins und des Alters einer Ansaatwiese auf die Nitratauswaschung. 17. Gumpensteiner Lysimetertagung, Austria, pp. 87-92. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

STEPHAN, E., RUPP, H., MEIßNER, R. (2017): Niederschlagsmessungen in der sibirischen Kulunda Steppe – Vergleich von Niederschlagsmessern verschiedener Bauart mit wägbaren Lysimetern. 17. Gumpensteiner Lysimetertagung, Austria, pp. 185-188. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

STRAUß, C., BAYER, A., OBERNOLTE, M. (2017): Lysimeteruntersuchungen zum Austragsverhalten von im Maisanbau eingesetzten Herbiziden unter Freilandbedingungen (Standort Wielenbach). 17. Gumpensteiner Lysimetertagung, Austria, pp. 27-32. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

TANNER, C.B. (1967): Measurement of evapotranspiration. In: Irrigation of Agricultural Lands. Amer. Soc. Agron. 11. pp. 534-574.

TAUCHNITZ, N., SCHRÖDTER, M., SCHMIDT, G., HAUSER, B., KASIMIR, P., MEIßNER, R. (2017): Quantifizierung von Pflanzenschutzmittel(PSM)-Einträgen in Oberflächengewässer in einem

Kleineinzugsgebiet (Querne/Weida). 17. Gumpensteiner Lysimetertagung, Austria, pp. 11-16. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

TIMM, A., WESSOLEK, G. (2017): Studying the hydrological balance of (partially) sealed surfaces using high precision weighable lysimeters. 17. Gumpensteiner Lysimetertagung, Austria, pp. 157-162. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

WMO (1968): Measurement and estimation of evaporation and evapotranspiration. Tech. Note No. 83, Genova. 121 p.

WMO (1974): Guide to hydrological practices. WMO No. 168, Genova. 4th ed. 770 p.

ZSEMBELI J. (1999): Effect of Different Soil Surface Formations on the Moisture Content of the Unsaturated Zone in Weighing Lysimeters. Einldung zur 8. Gumpensteiner Lysimetertagung. Austria. 205.

ZSEMBELI J. (2002): Evaporation moderating effect of soil cultivation methods simulated in lysimeters. I. Alps-Adria Scientific Workshop. Opatija, Croatia. pp. 170-174.

ZSEMBELI J., CZELLÉR K., TUBA G., SZÜCS L., SINKA L. (2017): Effect of irrigation with saline water on the soil and legumes in simple drainage lysimeters. 17. Gumpensteiner Lysimetertagung, Austria, pp. 189-192. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

ZSEMBELI J., KOVÁCS GY., DEÁK D. (2013): Water use efficiency of energy willows determined in weighing lysimeters. Lysimeter research as an instrument for decision support. 15. Gumpensteiner Lysimetertagung, Austria, pp. 181-184. ISBN: 978-3-902559-90-6 ISSN: 1818-7722

ZSEMBELI J., KOVÁCS GY., MÁNDOKI A. (2011): Water use efficiency of maize and different sorghum hybrids under lysimeter conditions. 14. Gumpensteiner Lysimetertagung, Austria, pp. 227-229. p. ISBN: 978-3-902559-61-6 ISSN: 1818-7722

ZSEMBELI, J., SZŰCS L., BLASKÓ L. (2011): Secondary salinization by irrigation from drilled wells in Karcag area. DOI: 10.1556/Novenyterm.183 60.2011.Suppl.3. pp. 305-308.

I1: http://www.lysimeter.at/en/Lysimeter_Platform

Modern approaches to groundwater analysis results

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Abstract: Groundwater plays ussualy a major role in the water supply and ekology of arid ands emiarid regions. Recently, in the period of unprecedented dry season, its importance has begun to emerge in Central Europe. The quality of ground water is important in order to support life. In natural hydrological procesess, groundwater und river water interacts with the surrounding rocks causing a variety of hydrogeochemical processes that alter groundwater components. The groundwater chemistry depends on different hydrogeochemical processes that the ground water undergoes over rocks and time. Many researches of the hydrogeochemical processes has been an area of interest in the past times, as chemical variation of groundwater can reveal the interaction between groundwater and environment and provide a basis for water management used as a source of drinking or irrigation water.

This work shows the different methods used in presenting hydrochemical data of water samples. These techniques include the Bar charts, Stiff diagrams, and the Piper diagram. Equally important is the appropriate interpretation of pH and ORP. An indispensable part of modern work should be the use of appropriate indexes. These indexes help clarify the origin of the water and its evolution in the geological environment.

Key words: groundwater, SAR, pH, ORP

INTRODUCTION

Usually, groundwater plays a major role in the water supply and ecology of arid and semi-arid regions. Recently, in the period of unprecedented dry seasons, its importance has begun to emerge in Central Europe. The quality of groundwater is important in order to support life. In natural hydrological processes, groundwater und river water interact with the surrounding rocks causing a variety of hydrogeochemical processes that alter groundwater components. The groundwater chemistry depends on various hydrogeochemical processes that groundwater undergoes different rocks and time. In the past, many studies were conducted on hydrogeochemical processes, as chemical variation of groundwater can reveal the interaction between groundwater and environment and provide a basis for water management used as a source of drinking/ irrigation water.

pH

Hydrogen ion exponent – "pH" – indicates the acidity of water. This variable is defined as the negative decimal logarithm of hydrogen ion activity, or, alternatively, pH = –log [H+].

Neutral solutions always contain the same amount of H+ as that of OH-. In this case, pH = 7. This value can be derived from the equilibrium constant equation:

$Kw = [H+][OH–] = 10^{-14}$ at 25°C

When setting $[H+] = [OH–] = x$, we obtain $Kw = x^2 = 10^{-14}$ $x = 10^{-7}$ mol/l H^+

$pH = -\log [10^{-7}] = 7$

At pH values > 7, solutions are referred to as *alkaline solutions*, while at pH < 7, they are termed *acid solutions*.

Redox potential (ORP, Eh)

Oxidation-reduction potential specifies the ability to transform one of the reaction partners into an oxidised state. Oxidation-reduction potential can be expressed as “Eh” (redox potential) or “pe” (negative decimal logarithm of electron activity).

Redox potential can be calculated using Nernst Equation:

$Eh = Eh0 + (2.3RT/nF)\log([Ox]/[Red])$

$pe = pe0 + 1/n.\log ([Ox]/[Red])$

(Šráček, Kuchovský, 2003)

When intending to use surface water for irrigation and water supply purposes, factors necessary to consider include the daily oscillations of pH and ORP. Oscillations of values are caused by aquatic plants and algae, phytoplankton, and physical/chemical factors (Schwoerbel 1987; Liu *et al* 2005; Winde, 2002). In the warm summertime period, when biota reaches the peak of its activity and the process of photosynthesis is the most intense, redox potential is lesser than in the cooler seasons. Low ORP levels occur in autumn, when biota is subject to a significant process of dying-off and decomposition while generating large quantities of CO_2.

RESULTS AND DISCUSSION

Checking the results of the analysis must always be the first step before continuing the processing activity. However, this check is often ignored.

The dataset must be screened based on the charge balance error (CBE), as calculated according to Freeze and Cherry (1979), to identify samples that were electrically imbalanced.

$$CBE = \frac{\sum v m_c - \sum v m_a}{\sum v m_c + \sum v m_a} \times 100\%$$

Here, *v* is the absolute value of the ionic balance, *mc* is the molarity of the cationic species and *ma* is the molarity of the anionic species. CBE values were calculated at each site using the concentrations of the cations Na, K, Ca, Mg and the anions HCO_3, Cl and SO_4. Other analytes (e.g. NH_4, NO_3, Fe, Mn) can be excluded from CBE calculations. The difference in results should be up to 10% (Fetter 2000, Mathhess, 1982).

Possibilities of expressing concentrations

The results of chemical analyses are always presented or reported in concentration units. Different types of concentrations are used for different uses.

Concentration by weight

The concentrations of the common ions found in groundwater are reported by weight per volume units of milligrams per litre (mg/l).

Mass concentration

Defined as mass of solute dissolve in a specified unit volume of solution, the units in use include „kg/m^3“. Gram per litre (g/l) is the permitted unit as well, but „milligrams per litre i.e. (mg/l)“ is the most common mass concentration unit reported in the groundwater literature.

Chemical equivalence

Positively charged cations and negatively charged anions combine and dissociate in definite weight ratio. By expressing ion concentrations in equivalent weights, these ratios are readily determined because one equivalent weight of a cation will exactly combine with one equivalent weight of an anion. The combining weight of an ion is equal to its formula weight divided by its charge.

Molarity

Defined as the number of solutes in $1m^3$ of a solution. The unit for molarity is designated as mol/m^3.

Molality

Defined, *inter alia*, as the number of moles of solutes dissolved in a kilogram mass of a solution. The unit is mol/kg. As a result, one mole of a compound is the equivalent of one molecular weight.

Graphical methods

There are several variants of graphical techniques that have been developed for the presentation of chemical components of water. The major chemical constituents are usually used for the presentation. An important task of water investigation is the compilation and presentation of chemical data in a convenient manner for visual inspection. Graphs are used in comparing the similarities and differences in the concentration of the chemical constituents in each water sample analysed; they also find application in detecting the different composition of mixed water samples and identifying chemical processes that occur as water passes through the aquifer system. For this purpose, a variety of data presentation techniques exist and include those listed below.

Bar Charts

The bars are plotted with concentration values in milli equivalent per litre. The technique is widely used in portraying chemical quality. Each analysis is presented as a vertical bar having a height proportional to the total concentration of anions or cations. These graphs show the relative and total concentration of the dissolved constituents present.

Stiff Diagram

The procedure as proposed by Stiff (1951) involves plotting four cation concentrations to the left of the vertical zero axis and four anions to the right; all the values are expressed in milli equivalent per litre. When connected, the resulting point forms,an irregular polygonal pattern; waters of a similar quality define a distinctive shape from other of different quality. Stiff's method may be useful in comparing samples of water - particularly one highly mineralised, is easy to use and can be modified to fit the water being studied.

Piper Diagram

Piper (1944) used the abundance of calcium, magnesium, sodium and potassium cations and bicarbonate, sulphate and chloride anions. He proposed that ionic solutions of water could be treated as if they contained three cations groups and three anion groups. The less-abundant cation and anion constituents are summed with the major constituents in accordance with common physical properties, thus are accounted for in the plotting method. To convert the result of chemical analysis into a form appropriate for graphical interpretation, all results expressed in milligram per litre are converted to milli equivalent per litre by multiplying it with a conversion factor. For a complete analysis the total equivalent weight of cations and anions in solution must be equal; in this case the chemical character can be shown graphically by a single point on the Piper diagram.

Identification of hydrochemical processes

The chemical components of water do not only indicate the quality of water; they also help identify the geology of the area. Hydrochemistry deals with chemical analysis of water, which involves determination of the concentration of the inorganic constituents present. In describing units and expressions for water quality, standards exist and are used to interpret the quality for suitability for the particular purpose. Concentrations of different ions are expressed by chemical equivalent or weight (Dauda, Habib 2015).

Sodium absorption ratio - SAR

Excess sodium in water produces undesirable effects of changing soil properties and reducing soil permeability. Crops of low salt tolerance are chloride sensitive. The chlorinity index of the groundwater sources was calculated using the measured chloride ion concentration in water. Waters forming high sodium deposits are generally not suitable for irrigating soils as rather high sodium levels may deteriorate the soil characteristics. Sodicity index was calculated using the sodium absorption ratio (SAR). SAR can be calculated using SAR equation as shown below (Kalra and Maynard, 1991). SAR measures the relative proportion of sodium ions in a water sample to proportions of calcium and magnesium. SAR is used to predict the sodium hazard of high carbonate waters, particularly if they contain no residual alkali. For considering the suitability for irrigation the assessment of sodium concentration is essential. The sodium or alkali hazard in the use of water for irrigation is determined by absolute and relative concentration of cations. The relative activity of sodium ions in the exchange reaction with soil is expressed in terms of sodium adsorption ratio (SAR).

$$SAR = \frac{Na^{+}}{\sqrt{((Ca^{2+} + Mg^{2+})/2)}}$$

Residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) influences the suitability of groundwater for irrigation uses as well. Residual sodium carbonate can be estimated by subtracting the quality of alkaline earths $(Ca^{2+} + Mg^{2+})$ from the carbonate $(CO_3^{2-} + HCO_3^{-})$. When the sum of carbonates is in excess of calcium and magnesium, a possibility may be present of complete precipitation of calcium and magnesium. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate; this excess, identified by RSC, is calculated as follows (Eaton 1950; Ragunath 1987): $RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$. The concentration of ions is expressed in meq/L. According to the US Department of Agriculture, water having more than 2.50 meq/L of RSC is not suitable for irrigation purposes.

Soltan classification

Soltan (1999) classified groundwater as two types –base-exchange indices (r1) and meteoric genesis indices (r2), as shown below, $r1 = (Na^{+} - Cl^{-})/SO_4^{2-}$ $r2 = [(K^{+} + Na^{+}) - Cl^{-}]/SO_4^{2-}$, where ion concentrations are expressed in meq/L. If $r1 < 1$ and $r2 < 1$, groundwater sources are of Na^{+}–SO_4^{2-} and deep meteoric type, respectively, while $r1 > 1$ and $r2 > 1$ indicates that the sources are of Na^{+}–HCO_3^{-} and shallow meteoric type, respectively.

CONCLUSION

This work shows the different methods used in presenting hydrochemical data of water samples. These techniques include Bar Charts, Stiff Diagram, and Piper Diagram. Equally important is the appropriate interpretation of pH and ORP. The use of appropriate indices should be an indispensable part of modern work. These indices help clarify the origin of the water and its evolution in the geological environment.

ACKNOWLEDGEMENT

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REFERENCES

Dauda, M., Habib G. A. 2015: Graphical Techniques of Presentation of Hydro-Chemical Data, Journal of Environment and Earth Science, 5, 4, 65-75.

Eaton FM (1950) Significance of carbonates in irrigation waters. Soil Sci 39:123–133

Fetter, C.W., 2000. Applied Hydrogeology, 4th ed. Upper Saddle River, Prentice Hall Inc., New Jersey, pp. 598.

Freeze, R. A. and Cherry, J. A.: Groundwater, Prentice-Hall, New Jersey, 1979.

Kalra,Y. P. and Maynard, D. G.: 1991, Methods Manual for Forest Soil and Plant Analysis, Information. Report NOR-X-319, Northwest Region, Northern Forestry Centre, Forestry Canada.

Liu Z., et al. 2005: Diurnal Variations of Hydrochemistry in a Travertine-depositing Stream at Baishuitai, Yunnan, SW China —Aquatic Geochemistry 12

Mathhess, G.: 1982: The Properties of Ground Water, 1st ed., John Wiley & Sons, New York

Piper, A. M., 1944. A graphical procedure in the geochemical interpretation of water analyses. Trans. Amer Geophysics Union Pp 914-923.

Ragunath HM (1987) Groundwater. Wiley Eastern, New Delhi, p 563.

Schwoerbel J. 1987: Handbook of Limnology. – Ellis Horwood Ltd. Chichester

Soltan ME (1999) Evaluation of groundwater quality in Dakhla Oasis (Egyptian Western Desert). Eviron Monit Assess 57, 157–168.

Stiff, H. A., 1951. Interpretation of Chemical water analysis by means of pattern. Journal of petrol Technology, 3, 10, 15-17.

Šráček, O., Kuchovský, T. 2003: Základy Hydrogeologie – Masarykova univerzita v Brně, Brno.

Winde F. 2002: Uranium contamination of fluvial systems-mechanisms and processes, PIII:Diurnal and event-related fluctuations of stream chemistry-Pitfalls from mining affected streams in South Africa, Germany and Australia – Cuadernos de Investiacion Geografica

Evaluation of the system for improvement of microclimate in a greenhouse

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Abstract: The paper presents the results of initial research on the heating and cooling system, which was a semi-passive element of greenhouse heating. The research of the innovative system was carried out from 10th November 2017 to 23rd March 2018, during intensive strawberry growing. Analysis of the temperature and humidity distribution was reduced to the daily profile, which was determined on the basis of 5-min. average values. On the basis of the daily profile, one can notice the beneficial effect of the innovative system on the microclimate, this is temperature and humidity in plants. 2.4 kg of water has been condensed in the accumulator during the storage of excess heat. The obtained results are already satisfactory from the producer's perspective, despite the fact that the amount of avoided heat was not analyzed due to the process of dehumidifying the indoor air.

Keywords: energy, greenhouse, heating system, heat storage, air dehumidification, energy efficiency.

INTRODUCTION

When analyzing the greenhouse production in Poland and other countries it is easy to notice that most of the cultivated plants require more attention in terms of maintaining humidity in the greenhouse. The most common solution to this problem is airing greenhouses. It is associated with large heat losses. There are a number of more or less effective solutions, which are provided by a number of authors (Chauhan, Kumar, 2018; Patil, Gawande 2016; Tiwari, Tiwari, Al-Helal 2016). Most of them use refrigeration aggregates combined with forced air movement. Very often these are devices whose operation is relatively expensive, especially in large buildings. This is a reason of looking for new solutions which will meet the expectations, and their use and efficiency will be rewarding. Due to the desired air composition in the plant vegetation zone, a beneficial effect occurs when the temperature in the lower vegetation zone is slightly higher, than in the upper zone - under the shade (curtain). The condition mentioned above guarantees a slow upward movement of the air and thus lowering the humidity with the prolonged presence of CO_2 in the plant zone. Each increased air movement means greater heat loss and reduced CO_2 absorption. In currently used systems for reducing air humidity in greenhouses, the air from the upper zone is pushed to the sleeve placed in the lower zone of plants (Yildirim, Bilir 2017; Azaizia, Kooli, Elkhadraoui, et. al. 2017; Montoya, Guzmán, Rodríguez, et.al. 2016; Kıyan, Bingol, Melikog, et. al. 2013,). The air drawn from the upper zone is often mixed with the outside air. If at the same time, there are low outside temperatures in this period, the flow of external air into the greenhouse causes higher heat losses in the greenhouse. In extreme cases, in order to lower the humidity in the greenhouse, the air pushed into the sleeve is first preheated with recuperators.

Aim of the research

The aim of the research is to evaluate the innovative drying and heating system installed in the production greenhouse with an area of 1 ha. The assessment covered the temperature and humidity parameters in selected height zones of the facility. Obtained results of measurements will allow for evaluating the system in a spatial arrangement of a greenhouse and in time. In addition, the assessment covered the energy effects of the innovative system.

Research object

The research was carried out in a greenhouse in which intensive cultivation of strawberries was carried out. The greenhouse is located in Kalisz in the Greater Poland region. The greenhouse has two cultivated areas - 4 608 m^2 and 5 120 m^2, respectively. The greenhouse was built in 2005 in line with the Dutch documentation, with a height of 4.25 m and a width of 6.4 m. The roof of the greenhouse is made of single glass (4 mm) and the walls of double glass (2 x 4 mm). Elements connecting the glass panels are made of aluminum profiles.

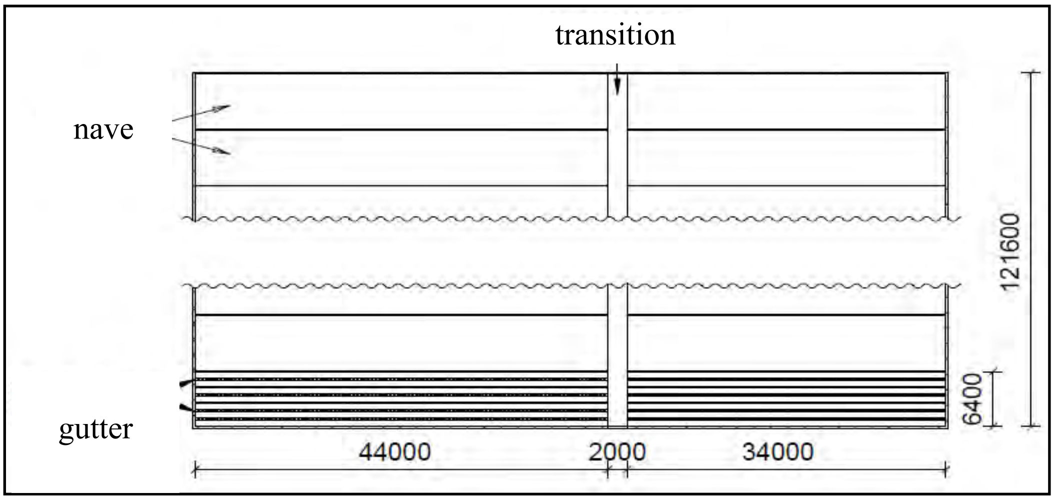

Fig. 1. Cross-section of the greenhouse

The greenhouse is divided into aisles, which are marked in Figure 1. The cultivation area of the object (hall) is separated by a 2 m wide passage. The length of the left part of the greenhouse is 44 m, while the right one is 34 m. The first hall has 9 naves and the other 10. There are 6 gutters on each aisle, on the longer part of the hall, there are 110 flower pots on the gutter.

Phot. 1. Partial view of the nave with the visible place of cultivation gutters and elements of the air conditioning system

The 200 mm wide cultivation gutters are suspended 1.5 m above the ground. The heating system consists of two circuits: the first one being the lower heating pipes (surface system) with a diameter of 60 mm, and the second one consisting of two loops of the vegetation heating (for one aisle = six cultivation gutters), which is the so-called active system. The bottom heating pipes are connected in a U-shape so that the supply and return collectors are on one side. There are 12 heating pipes for the bottom heating and four heating pipes for the vegetation heating for each aisle. In addition, there is an air heating sleeve under each tube, which is a semi-passive element (Photograph 1). The stretched foil sleeve has a diameter of 0.6 m, in which openings are cut in the upper part to allow free air discharge. The sleeve itself acts only as an element of air distribution during heating or drying of the object – depending on the microclimate parameters. The full diagram of the elements of the air system acting as an air dryer in the greenhouse, and the heat storage system is shown in the diagram (Figure 2). The basic elements of the tested drying-storing system are: the intake made of a PP pipe with a diameter of 160 mm, a blower (their total number on the greenhouse is 114 per one side), a drying and storing element (made of a PP pipe with a diameter of 160 mm), a condensate tank and the previously described sleeve distributing conditioned air. The drying-storage pipe is placed at a depth of 0.7 m below the level of the greenhouse with a 1% slope towards the condensation tank. The element that enforces air circulation in the tested system is a blower with a rated power of 145 W and a nominal efficiency of 1000 m^3/h.

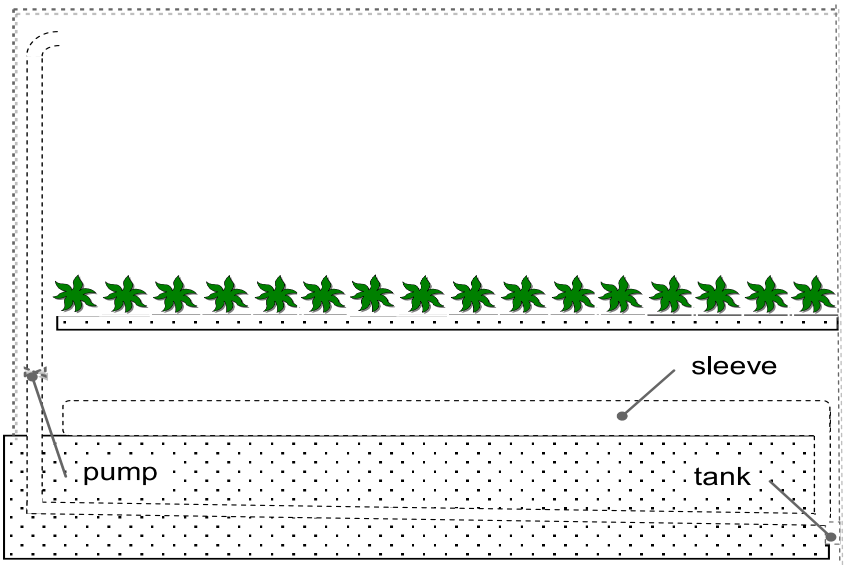

Fig. *2. Arrangement of the elements of the air heating-drying system*

The diagram (Figure 2) presents the cross-section of the nave and the arrangement of elements of the drying-heat storage system. The dehumidifier is designed to capture and remove the excess of water accumulated in the air. Warm air with increased humidity, from the upper zone of the greenhouse is sucked in by the fan, which directs it through a pipeline to a cooler condenser in the form of a pipe placed in the ground. When the dew point is exceeded, excess water evaporates and dehumidified air is discharged through the sleeve into the cultivation gutters, while condensate is discharged into the condensation tank. The air flowing through the condenser emits heat which is temporarily stored in the ground of the greenhouse. The heat accumulated in the condenser which comes from the cooled air and the condensation of the steam is used to support the basic heating of the greenhouse.

MATERIAL AND METHODS

The greenhouse production of the autumn and winter period is determined by plants' demand for heat, while heat and temperature is very various within a day time. Hence, the evaluation of an innovative system for drying the air and supporting greenhouse heating was carried out from 10th November 2017 to 23rd March 2018. It is very important to keep proper values of temperature and humidity because the created microclimate should provide plants with optimal development conditions, the most effective use of devices, and as low consumption of heat and auxiliary materials (plant protection products) as possible (Rutkowski 2010).

The tests were carried out on a station designed and build specially for this purpose. An essential element of the station is a measuring card equipped with 32 analogue channels, and a digital transducer with resolution of 12-bit. In addition, the measurement system was equipped with a data acquisition unit, and temperature and humidity sensors in class 1 respectively. Real-time temperature and humidity measurements had an interval of 30 seconds, so dynamic analyzes of these parameters could also be carried out. The diagram (Figure 3) shows the spatial arrangement of individual temperature and humidity sensors. Measurements of these parameters were carried out in two planes, i.e. in the middle of the nave and at the end of the nave; this choice was in part dictated by the need for safe and long-term distribution of sensors, without causing difficulties in performing ongoing works in the facility.

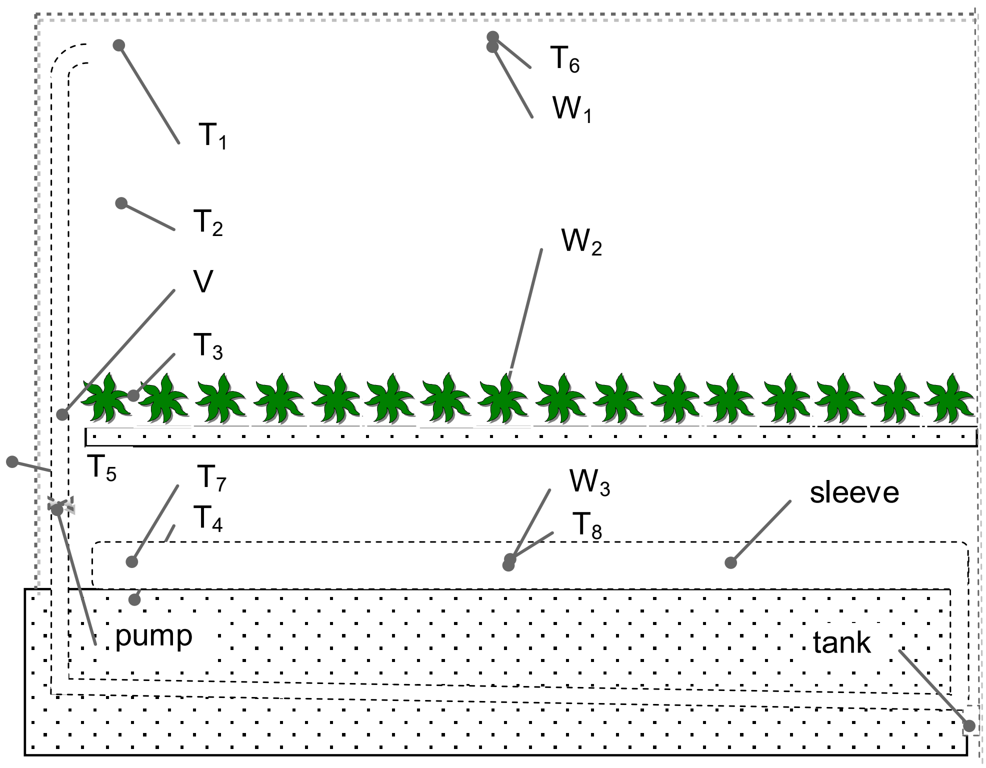

Fig. 3. Layout of the measuring system components: T1 - temp. above the shade, T2 - temp. at a height of 3m, T3 - plants temp., T4 - temp of ground in a greenhouse, T5 - environment temp., T6 - temp. above the shade in the middle of the hall, T7 - temp in the sleeve, T8 - temp. in the sleeve-middle, W1 - humidity above the shade, W2 - plant humidity, W3 - humidity in the sleeve

The analysis of the work parameters of the system was based on the average daily profile determined from the averaged values directly registered to the 5-minute interval. The five-month study period was divided into periods from 2 to 4 weeks for which the daily profile was determined, whereas the seven-week time of winter cooling of the plantation (dormancy in growing strawberries) was treated as one research period.

Based on the developed parameters of the daily profile, the value of power returned by the subject system to the greenhouse (1) was determined:

$$Q' = \dot{m} \cdot c_{pw} \cdot \Delta T \qquad (1)$$

where:

$\dot{m}$ – mass flow of air through the system,

ΔT – temperature difference between air sucked in from the upper zone of the greenhouse and air in the middle of the sleeve,

c_{pw} – specific heat of humid air.

The specific heat of the humid air was determined from the dependence (2):

$$c_{pw} = c_{ps} + c_{pp} * x \qquad (2)$$

where:

c_{ps} – specific heat of dry air, for the conditions prevailing in the facility,

c_{pp} – specific heat of water vapor,

x – current moisture content in the air.

An important parameter of the mentioned system is the stream of condensed water vapor, which was determined from dependence (3):

$$\dot{m}_w = \dot{m} \cdot (x_1 - x_2) \qquad (3)$$

where:

$\dot{m}$ – mass flow of air through the system

x_1 – moisture content in the intake air,

x_2 – moisture content in the air leaving the sleeve.

RESULTS AND DISCUSSION

The initial analysis of the system was carried out from 10th to 24th November 2017. This period included intensive cultivation of strawberries. Based on the recorded temperature parameters (Figure 4) and humidity (Figure 6), charts were made in accordance with the methodology; the daily period analysis was carried out with determining the average values in the interval of 5 minutes.

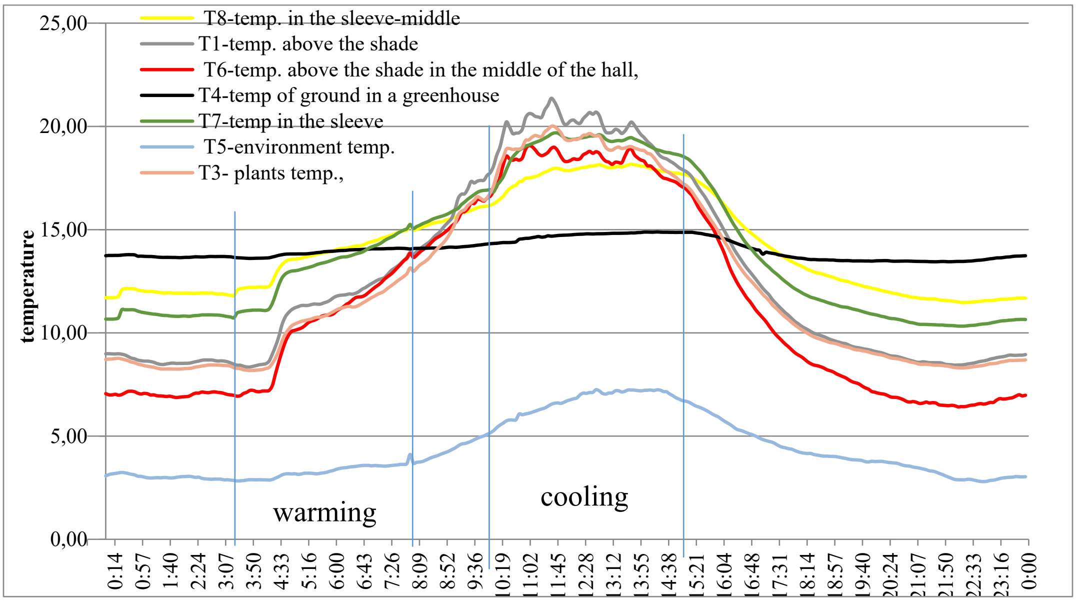

Fig. 4. The course of temperature changes of the climate in the greenhouse at the characteristic points of the semi-passive heating and cooling system.

At the graph (Figure 4) presenting the daily course of temperature changes in a greenhouse and the system under examination two periods can be noticed: the first one is marked as "heating" and the second as "cooling".

The time determination (start time and duration) of the listed periods was defined by the producer who took under consideration the energy effects of the project. Determination of the periods was determined by favorable prices of the electricity consumed. The first period of "heating" begins at 3:10 and ends at 8:00, when the temperature difference between the air leaving the sleeve and sucked was about 1^{O}C (Figure 5). After turning on the semi-passive heating and cooling system in the first hour of its operation, there is a slight increase in temperature difference dT1 (0,5^{O}C), then there is a sharp drop in this difference, which is the effect of the basic heating as shown in the diagram (Figure 4) by a sharp increase of all temperatures in the greenhouse excluding the temperature of the ground (T4).

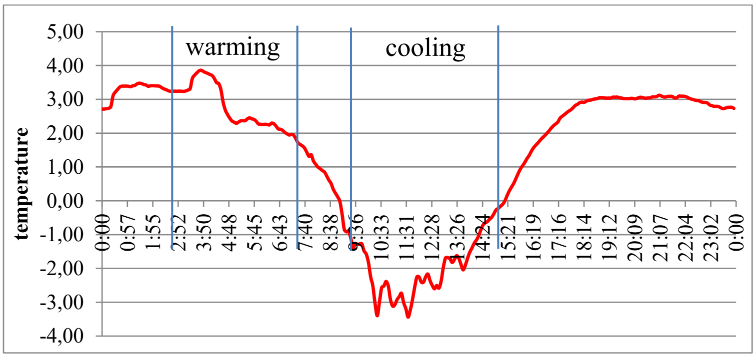

Fig. 5. The course of changes in the temperature difference between the air leaving the sleeve and this one sucked dT1

In the final stage of the first period of operation of the system (heating), the more stable work is observed when the temperature difference (dT1) drops quite slowly to 2^{O}C. It should also be noted that after the tested system is switched on, the air humidity leaving the sleeve is set at the level of the humidity of the intake air and this condition is maintained throughout the first "heating" period (Figure 6).

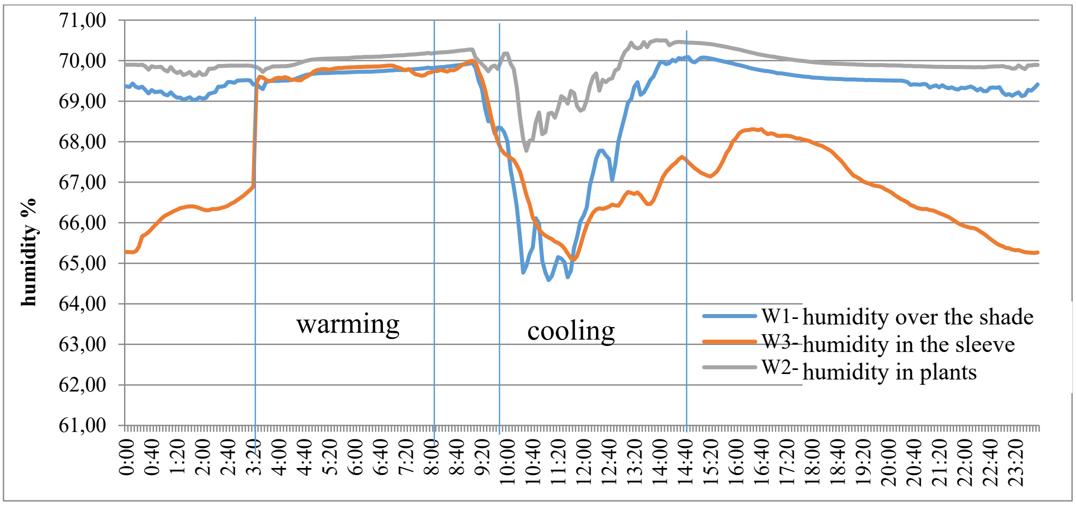

Fig. 6. The course of changes in humidity for the climate in the greenhouse at the characteristic points of the semi-passive heating and cooling system

In the second period of operation of the examined system (cooling) more complex situation occurs, which is caused by the inclusion of the ventilation system and basic heating, whose simultaneous operation allows for maintaining the humidity at a level not exceeding 70%, which favors intensive cultivation of plants. During this period, the temperature above the shade is the highest (T1) (Figure 4) and this lasts until the end of the work of the system, which is a very beneficial phenomenon. However, temporarily switching on the heating and cooling system, in this case at 9:50, is not the best solution – as it can be seen in the analysis of the graphs (Figures 4 and 6) – because earlier at 9:10 ventilation is turned on, which caused a reduction in humidity in the greenhouse. Hence, after switching on the system, the temperature difference dT1 (Figure 5) drops sharply to the value of -3.3^{O}C, but the difference in humidity of the air sucked from the above of shade and air which is leaving the sleeve (dW1) is insignificant (Figure 7), which gives the basis for saying that in the first part of the "cooling" period (regeneration of the ground accumulator) there is no drying effect and this condition lasts until 12:15. This is definitely caused by the earlier switching on of ventilation and its activation at this stage. The full effect of air drying and battery regeneration takes place in the second part of the analyzed period when the difference in humidity is set at 2.5% (Figure 7), and the temperature difference dT1 go towards $0^{O}C$ – this is caused by a change in external conditions and a slow drop in temperature above the shade T1 (Figure 4).

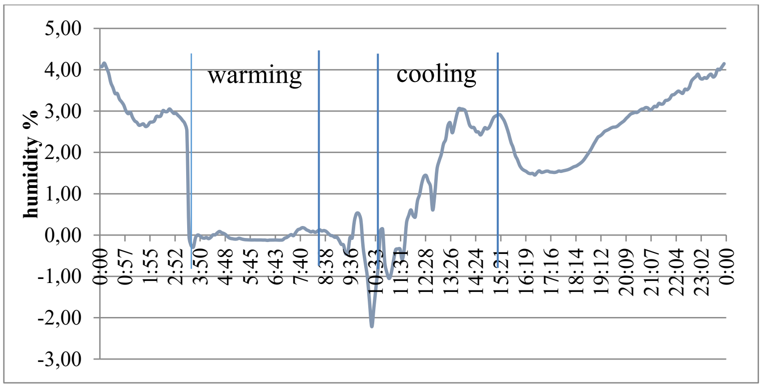

Fig.7. The course of changes in the humidity between the air sucked in and the air outgoing from the sleeve-dW1

In addition, in the second period, 2.4 kg of condensate was theoretically discharged from the tested heating and cooling system, which (calculated on the value of condensation heat) gives an additional 1.45 kWh of energy stored in the ground. On this basis, after summing up the heat of condensation and heat recovered from humid air, it can be stated that in the ground in the second period 7.36 kWh was stored, which gives the overall heat storage capacity in the ground at the level of 80%. The results obtained during the research with use of the described heating and cooling system installed in the greenhouse are optimistic, especially keeping in mind the recent quite strong trend of coal price growth, which usually is the basic source of heat in the Polish energy sector. At the initial stage of the research, the effect coming from increased heat consumption during greenhouse ventilation aimed at reducing air humidity was not analyzed. This effect can, to some extent, be achieved by applying the innovative system which is under the research.

CONCLUSIONS

On the basis of initial studies of the innovative semi-passive heating-cooling system implemented in a greenhouse which was supporting the basic heating system, it can be stated:

The efficiency of a natural accumulator in a daily cycle for an average day is 80%.

It is necessary to associate the second "cooling" period with the basic climate control system so that the tested system switches on before the ventilation is turned on. It will allow achieving a greater amount of stored energy, for example through more effective drying.

The theoretical amount of condensate obtained from one circuit of the heating-cooling system with a length of 44 m is 2.4 kg, and after integration of the system with a climate computer this amount should increase at least 50%.

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REFERENCES

Azaizia Z., Kooli S., Elkhadraoui S., Hamdi S., Guizani A. 2017 Investigation of a new solar greenhouse drying system for peppers International Journal of Hydrogen Energy Volume 42, Issue 13, 30 March 2017, pp. 8818-8826.

Chauhan PS., Kumar A.; 2018 Thermal modeling and drying kinetics of gooseberry drying inside north wall insulated greenhouse dryer Applied Thermal Engineering 130 2018 pp. 587-597.

Kıyan M., Bingol E., Melikog M., Albostan A. 2013. Modelling and simulation of a hybrid solar heating system for greenhouse applications using Matlab/Simulink; Energy Conversion and Menagement 72; pp. 147-155.

Montoya A.P., Guzmán J.L., Rodríguez F., Sánchez J.A. 2016. -Molina A hybrid-controlled approach for maintaining nocturnal greenhouse temperature: Simulation study;; Computers and Electronics in Agriculture 123; pp. 116-124.

Patil R., Gawande R. 2016 Areview on solar tunnel greenhouse drying system Renew Sustain Energy Rev, 56 (2016), pp. 196-214.

Rutkowski K. 2010. Energy and technological analysis of greenhouses [Analiza energetyczno-technologiczna szklarni]. Inżynieria Rolnicza 2(120)2010. pp. 157-163.

Tiwari S., Tiwari G.N., Al-Helal I.M. 2016 Development and recent trends in greenhouse dryer: a review Renew Sustain Energy Rev, 65 (2016), pp. 1048-1064

Yildirim N., Bilir L. 2017. Evaluation of a hybrid system for a nearly zero energy greenhouse;; Energy Conversin and Menagement 148; pp. 1278-1290

Possible threats to groundwater through executing Skalička Dam located near Hranice Karst and Hranice Abyss

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Abstract: The River Bečva basin is amongst the areas with the greatest exposure in the Czech Republic in terms of flood risk. The disastrous flooding of July 1997 had a devastating effect on the human settlements along the River Bečva as well as those found in the subsequent stretch of the River Morava. During the 1997 flood the level of the River Bečva increased by 6 m in the territory of Hranice Karst while there was an increase in the level of mineral waters in the karstic cavities and an eruptive outflow of mineral waters from an unused borehole. This made the flooding a major impetus for searching a concept of protection against floods in the studied area.

Building a water reservoir or a polder in the surroundings of Teplice nad Bečvou has been subject to discussions since around mid twentieth century; the possible benefits included enhanced minimum flow rates of the River Morava, water supply for the existing as well as prospective industries in the basin, and irrigation of arid regions of South Moravia. On the basis of the 1997 analysis of the situation, the territory was defined by the Plan of Key Basins of the CR document as a priority area for addressing protection against floods (approved by the Government Resolution No. 562 of 23 May 2007).

The planned Skalička Dam is located around 2.5 km from the edge of the Hranice Karst and around 3.5 km from the Hranice Abyss as the crow flies. The Hranice Abyss is the largest speleology object of the Hranice Karst. In 2016, the abyss was declared to be the world's deepest flooded cave. The genesis of mineral waters of the Hranice Karst - as well as the limestone thickness and spatial distribution below the overlay bedrocks are not yet fully clarified. In the territory of interest, there are preconditions for shallow circulation of groundwater of the zone of active water exchange, bound to the pore-permeable setting of alluvial plain sediments, the zone of surface karstification and secondary disconnection of bedrocks of the rocky massif; preconditions also exist for deep circulation of groundwater. The underlay of limestone rocks in the Hranice Karst still has not been reached by drilling or geophysical techniques. Based on the immediate observation of hydraulic influence of mineral water levels as part of the 1997 flood as well as the evaluation of the continuous measurement of levels of mineral waters and of their electrical conductivity in the Hranice Abyss, Zbrašov Aragonite Caves and balneology boreholes in the spa resort of Teplice nad Bečvou, these levels were found to be dependant of the water level of the River Bečva. Places where infiltration (source) regions of mineral waters have been identified include the area of the River Bečva near the settlement of Kamenec, i.e., directly within the area of Skalička WW. Drilling activities demonstrated Devonian limestone to occur in this area.

A polder can be considered a satisfactory means to address flood control and protection of mineral water. While the mineral water regimen will still be affected in the event of flood with this method of control, it will be only a temporary situation; after a certain time, the regimen will restore its initial status, depending on the specific situation, similarly as with the extreme flood in 1997. Contrary to the above, any permanent filling of Skalička WW with water and increased hydrostatic pressure by approx. 20 m may result in permanent and irreversible changes in the regimen as well as quality of mineral waters.

Key words: Hranice Karst, Hranice Abyss, Teplice nad Bečvou Spa, River Bečva, Skalička Dam

INTRODUCTION

The history of floods along the River Bečva and the importance of the proposed dam

The River Bečva basin is amongst the areas with the greatest exposure in the Czech Republic in terms of flood risk. The disastrous flooding of July 1997 had a devastating effect on the human settlements along the River Bečva as well as those found in the subsequent stretch of the River Morava. During the 1997 flood the level of the River Bečva increased by 6 m in the territory of Hranice Karst while there was an increase in the level of mineral waters in the karstic cavities and an eruptive outflow of mineral waters from an unused borehole. This made the flooding a major impetus for searching a concept of protection against floods in the studied area. This also restored the plan coming from the first half of the 20th century to construct a water work in the surroundings of the spa in Teplice nad Bečvou and the municipality of Skalička.

The River Bečva basin is situated in the eastern portion of the basin of the River Morava. It is a considerably varied area in terms of elevation; in the headwater region, the main tributaries are rapids in nature which they retain even in their lower stretches. A dangerously increased outflow is something to be taken into regard already at 40-50 mm of the daily sum of rainfall. The July 1997 flood went on in an unexpectedly rapid and ravenous manner with a huge destructive force. As part of the upper stretches, there was total destruction of watercourse channels. The water reached extreme levels (in Teplice nad Bečvou the difference of levels at culmination was approximately 7.3 m above the standard); the extent of inundation area and depth was above any value known so far. With its parameters, the flood which carried disastrously large quantities of floating solids was beyond any possibilities of measuring and monitoring. As well, the retention capacity of the landscape significantly reduced due to previous prolonged precipitation as became manifest through the flood of May 2010.

ilding a water reservoir or a polder in the surroundings of Teplice nad Bečvou has been subject to discussions since around mid twentieth century; the possible benefits included enhanced minimum flow rates of the River Morava, water supply for the existing as well as prospective industries in the basin, and irrigation of arid regions of South Moravia. The Skalička Dam now planned builds on the earlier, long-term plan for what is called “Teplice Polder”. On the basis of the 1997 analysis of the situation, the territory was defined by the Plan of Key Basins of the CR document as a priority area for addressing protection against floods (approved by the Government Resolution No. 562 of 23 May 2007). In 2015, the territory of the possible construction of the retention area was incorporated in the Regional Development Policy. The final version of the reservoir/polder design has not yet been formally adopted; the versions that are currently under assessment cause the other stakeholders to seek alternative solutions - such as such those that do not require any damming of the River Bečva channel (Krejčí, 2016). Any major intervention in the landscape conditions entails both the environmental and the socio-economic impact. While the environmental impacts are linked with altering the natural sites and ecosystems, the socio-economic impacts are bound to increased tourism potential of the territory (a new location factor). While any benefits of tourism potential are difficult to quantify, yet in the field of tourism water areas are considered an important element contributing to the development of tourism in the territory (Vystoupil et al. 2006; Navrátil et al. 2011; Bína, 2012)

The River Bečva basin and the parameters of the proposed dam

The River Bečva basin is situated in the eastern part of the main basin of the River Morava and bounded by the southern slopes of the hills of Oderské vrchy to the north and by the ridge of the

Moravian-Silesian portion of the Beskid Mountains. The basin is irregular in terms of shapes and highly diverse in terms of elevation. The headwater area of the River Bečva belongs to moist territories of the Czech Republic; the central portion of the basin is a slightly wet territory. In the headwater region, the main tributaries are rapids in nature which they retain even in their lower stretches. The River Bečva is a gravel-bed watercourse throughout its length up to the point it joins the River Morava.

The total length of the river is 120 km. From the source to the confluence with the River Rožnovská Bečva (58.8 km), the stream is called *Vsetínská Bečva*; downstream of the area, it is referred to as *Spojená Bečva*. This last stretch is 61.2 km long. The site that is subject to discussion is located at river kilometre 40 approximately. The basins of the tributaries of the River Spojená Bečva are of oblong shapes; the streams have not any significant influence on the hydrological regime of the river. The territory along the River Spojená Bečva has the character of cultural agri-forest landscapes of alluvial plains and terraces of the River Bečva. While in the basins of the stretches of Rožnovská Bečva and Vsetínská Bečva forest soils are prevalent (57% and 63%, respectively) and the percentage of arable land there is only 2-5%, in the basin of the River Spojená Bečva the proportion of forests is significantly lower (28%) while that of arable land increases to 46%.

Key factors of flooding in the basins of the River Morava and River Bečva involve precipitation totals and intensity as well as the length of duration of precipitation and the surface extent of its occurrence. A dangerously increased outflow is something to be taken into regard already at 40-50 mm of the daily sum of rainfall; the threat of flood damage increases with every other 50 millimetres. This was also manifest during the flood of May 2010 when the retention capacity of the landscape significantly reduced due to previous prolonged precipitation. Although this flood was far from reaching the parameters of the flood of 1997, it again caused severe damage and significantly affected a large number of people.

The proposed water work at the Skalička site is presumed to transform a flood wave as experienced in 1997, culminating at 950 $m^3.s^{-1}$, to a harmless outflow of 660–700 $m^3.s^{-1}$ (i.e., c. Q20). Designed parameters: dead dyke level (Ms) = 256.0 m above sea level, useful capacity level (Mz): 261.0 above sea level, max. water work level (Mr): 265.0 m above sea level.

Geological conditions

The planned Skalička Dam is located around 2.5 km from the edge of the Hranice Karst and around 3.5 km from the Hranice Abyss as the crow flies. The Hranice Abyss is the largest speleology object of the Hranice Karst. In 2016, the abyss was declared to be the world's deepest flooded cave (Guba, 2016). The Hranice Karst is a hypogenic karstic area situated on the eastern tip of the Maleník fault block between the municipalities of Hranice, Teplice nad Bečvou and Černotín, c. 40 km ESE of Olomouc. On the surface, the karst covers around 3 x 5 km and has evolved in Devonian carbonates. The Hranice Karst - including the entire fault block of Maleník - is part of the Palaeozoic sedimentary cover of Brunovistulicum. Brunovistulicum is represented by medium to high metamorphic Proterozoic acid igneous rocks that were deformed during the Variscan orogeny (Kalvoda *et al.* 2008). On this underlay there is a sequence of sedimentary rocks represented by Middle Devonian (Eifelian) rocks up to the rocls of Carbon age (Mississippian/Viséan); the sequence reaches overall thickness of up to 7 km (Schulmann - Gayer 2000; Kalvoda *et al.* 2008). The karst alone has evolved in Devonian carbonates - grade Givet to grade Tournai - which are included in the Macocha and Líšeň groups of strata (Dvořák – Friáková 1978). The total thickness of limestone rocks forming the Karst has not yet been detected and their underlay was never reached by drilling work. The Palaeozoic rocks are covered by the overthrusts of the flysch units of the Western Carpathians of Palaeogene age, non-deformed strata of Miocene marine sediments, and, finally, loesses and loess loams of the Quaternary age. These marine clastic sediments also filled the then already existing karstic depressions and caves (Geršl, 2009).

The tectonic structure throughout the territory was heavily affected by moving overthrusts of the Western Carpathians. On the eastern foreground of the Bohemian Massif, at the line of contact between the structures of the Western Carpathians (SW-NE direction) and structures of the Elbe lineament (SE-NW direction), the influence of moving overthrusts of the Western Carpathians modelled the late Mesozoic structure of the Nysa-Morava zone in the eastern part of which the

Hranice Karst is located. The zone is renowned for the local springs of carbonated mineral waters found in the SE-NW lines (Špaček *et al.* 2015). The weakened zones were also associated with the outcrops of Plio-Pleistocene alkaline-basic volcanic rocks (Ulrych *et al.* 2013).

In the territory of interest, there are preconditions for shallow circulation of groundwater of the zone of active water exchange, bound to the pore-permeable setting of alluvial plain sediments, the zone of surface karstification and secondary disconnection of bedrocks of the rocky massif; preconditions also exist for deep circulation of groundwater (Vrba 1960). The Hranice abyss is filled with carbonated mineral water high in carbon dioxide (Geršl, 2016).

MATERIAL AND METHODS

GIS methods

valuation of the geological situation at the proposed site of the reservoir was carried out using cartographic methods assisted by geo-information software (ArcGIS) that enables placing the selected data layers over each other and performs the synthesis of the characteristics handled. On the basis of the available proposed variant solutions of the Skalička Dam, a line layer was created of the water reservoir with use of the georeferencing method (Longley *et al.* 2011); the course of the line of the level was processed in two spot height options: 261 m above sea level (useful capacity level) and 265 m above sea level (retention volume level). As part of the next step, data layers were added to the created line layer; the data were available from the map portal of the Czech Geological Survey in the form of WMS service - geological map scale 1: 25 000 as well as from survey boreholes. The map synthesis enabled evaluating the geological conditions and locating the boreholes that reached the limestone localised as part of the surface area of the proposed work.

Long-term monitoring of groundwater parameters in the Hranice Karst

he modern monitoring of parameters of groundwater/mineral waters has been underway since 2002. Manometric probes with continuous recording are used for the monitoring of the levels. Monitoring the temperatures, electrical conductivity and pH used instruments WTW MultiLine P4 and Greisinger GMH 5450 placed on floats and featuring optimised HW allowing approximately 6 months of automatic operation. Initially, the parameters were recorded on an ad hoc basis in anticipation of the flood condition. Over the years the numbers of measurement were concentrated. On the River Bečva, in Zbrašov Aragonite Caves and in the Hranice Abyss, the measurements are already carried out on a continuous basis - more specifically, in recording intervals of 60 or 10 minutes.

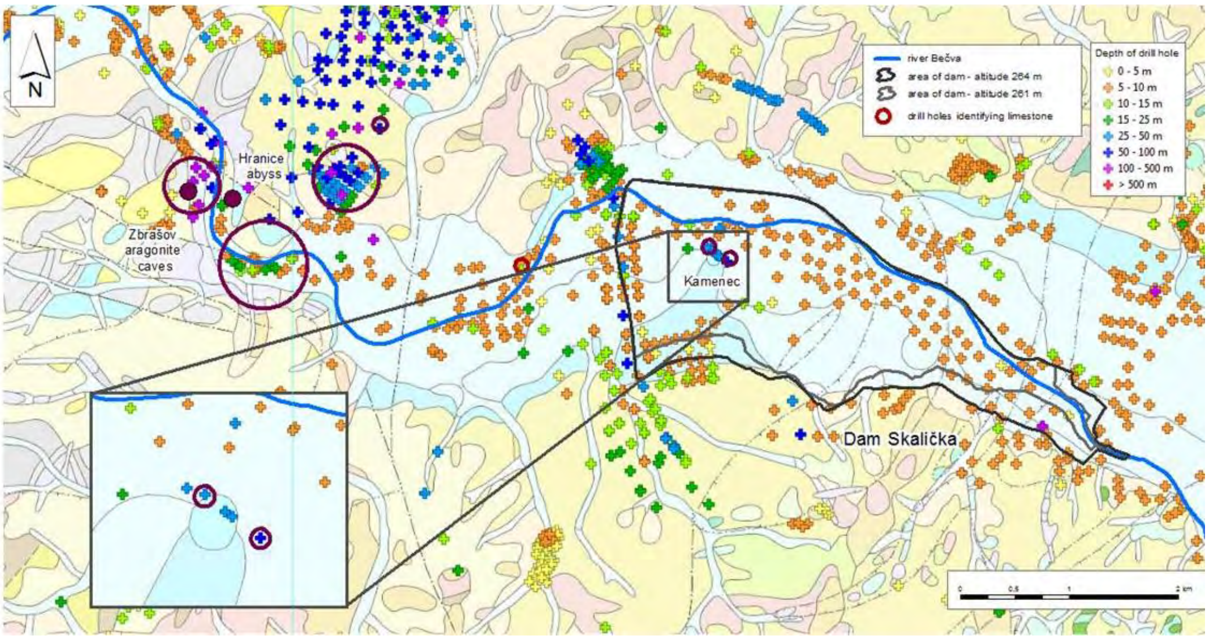

Fig. 1. Map synthesis evaluating the geological setting and distribution of the boreholes within the proposed Skalička dam.

RESULTS AND DISCUSSION

The genesis of mineral waters of the Hranice Karst - as well as the limestone thickness and spatial distribution below the overlay bedrocks are not yet fully clarified. The carbonate sediment sequence thickness and spatial distribution can only be inferred indirectly from the data obtained by borehole explorations in the wider area (e.g. Potštát-1 Borehole confirmed the presence of carbonates to the depth of 4,200 m; Choryně-9 Borehole confirmed the presence of Devonian carbonates to the depth of 1,462 m while reaching underlay para-gneisses in the range from 1,596 to 1,711 m. Branky Borehole confirmed the presence of Devonian limestone to the depth of 2,546 m; below the limestone, it reached underlay para-gneisses. Valašské Meziříčí Borehole confirmed the presence of Devonian limestone to the depth of 3,036 m; again, it reached the crystalline complex below the limestone. Palaeozoic bedrocks are deformed into very thin-walled stacks of pull structures separated by N-NW faults (Čížek – Tomek 1991), which makes any approximation between the boreholes greatly complicated or even impossible.

In the territory of interest, there are preconditions for shallow circulation of groundwater of the zone of active water exchange, bound to the pore-permeable setting of alluvial plain sediments, the zone of surface karstification and secondary disconnection of bedrocks of the rocky massif; preconditions also exist for deep circulation of groundwater. Karstic cavities were widely reached by the drilling operations. The reached caverns have the vertical dimensions of 3-7 m; a cavern was reached at a depth of 70 m. In general, the karstification depth depends on the depth of the generation of mineral waters - something that can be expected only approximately. Usually, karstification is reported to be going to end on an impermeable underlay of limestone. Realistically, however, karstic channels, or washed-off crack paths, can be considered to penetrate - albeit to a limited extent - all the way down to the underlay crystalline complex given the proven deep origin of the sourcing fluids.

In the course of the 20th century, numerous research reports were drawn up for the purposes of decision making concerning the planned water work; for instance, J. Vrba (1960) mentions in his final report conclusions made by O. Hynie as early as 1951, who rejected the idea of use of existing RI and RI wells (today referred to as Kropáč Spring and Gallaš Spring) through bringing their heads above the backwater level since ‘the fluctuating hydrostatic pressure will be always to the detriment of the dynamic stability of the spring’. Vrba (1960) also notes that the column of water resulting from the permanent damming will be an intervention that will absolutely change the current regimen of the springs. Initially, the definition of the situation referred to the so-called lower dam profile of “D”, due to the presence of highly-developed karstic channels; as regards the communication of groundwater proven later, these conclusions are possible to be extended to the entire territory of presence of limestone. The author defined “D”, “H” and “T” profiles as impossible to implement while suggesting the possibilities placed more to the east, where he however adds that a substantial part of the flooded area at these sites can be considered impermeable in all cases. From this point of view, there is only a small and seemingly irrelevant area in the proposed Skalička WW consisting of limestone outcrops (Fig. 1).

The setting where mineral groundwater generates and accumulates involves non-metamorphic, heavily karstified Devonian limestone of the Maleník fault block. Part of the springs is dispersed within Quaternary fluvial deposits of the River Bečva; places of carbon dioxide discharge are mainly located along the left bank of the river. A significant outgoing path of hot acidulous water also exists on the right slope of the River Bečva valley in the bottom of the Hranice Abyss (Krásný, 2012).

Under extreme conditions caused by the 1997 floods there was a significant increase in the hydraulic pressure drop between the level of groundwater of the carbonate massif and the level of the surface water of the River Bečva due to changes in the level of the River Bečva. The increase in the hydrostatic pressure caused the reopening of already destroyed Borehole D-II with a subsequent eruptive discharge of mineral waters. Borehole D-II was finished in 1956; the final depth was 67.5 m, Devonian limestone was found in the depths of 42.0 to 67.5 m below the ground. Forcibly open by the pressure of water, therefore, the borehole became an overpressure valve of the second aquifer. The spontaneous overflow, or the springing of mineral waters, continued to be active for approximately 1 month and was observed to rise around 1.1-1.5 m above the adjacent ground. The presence of mineral water was confirmed through geochemical analyses (unpublished reports).

Since 2002, the continuous measurements of the electrical conductivity of groun-dwater has repeatedly demonstrated that in the event of an increase in the water level of the River Bečva there is also a delayed increase in the level of mineral water while no change in its chemistry or conductivity occurs (Fig. 2). Mineral waters never become diluted by surface water - whether it is a river water or precipitation water with lower electrical conductivity. This phenomenon demonstrates the hydraulic connection of the surface water of the River Bečva and groundwater. Increased water level in the river means an increase in the hydrostatic pressure applied to the mineral groundwater. After the period of withholding water in the aquifer lapses, the hydraulic link necessarily creates chemical changes in the composition of water.

Factors quite difficult to predict include any influence on the microclimatic and mesoclimatic regimen of the area. As documented by Rožnovský et al. (2010) using the example of the Moravian Karst, or by Středová *et al.* (2015) based on the example of serpentinite steppes, climatic and mesoclimatic conditions are significantly influenced by the use of the wider neighbourhood, which applies not only to the peripheral portions of the karst relief.

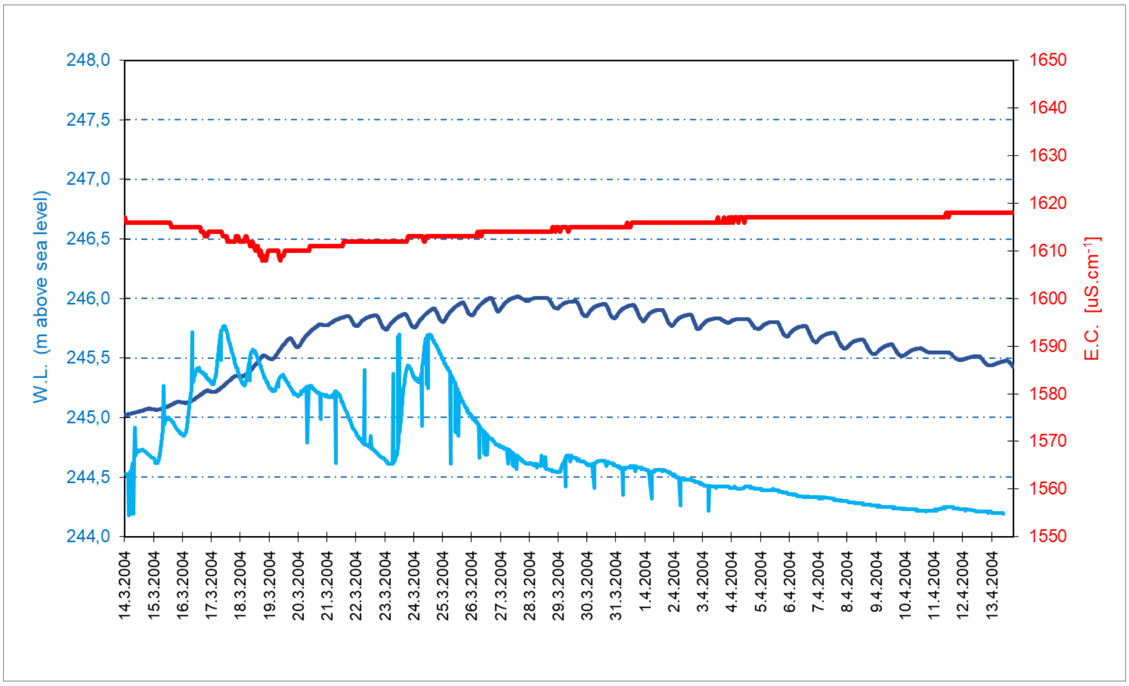

Fig. 2. An example of flood wave record on the Bečva River and its impact on mineral waters in 2004. Light blue – water level (WL) on the River Bečva; Dark blue – water level (WL) in Zbrašov Aragonite Caves, Cave of Death; Red – electrical conductivity (EC) of mineral waters in Zbrašov Aragonite Caves, Cave of Death.

CONCLUSION

Despite the considerable extent of exploratory efforts in the territory of interest, which involves more than 100 years of the region attracting experts from the fields such as hydrogeology, balneology, structural geology, deposit geology and others, not all of the issues concerning the structure of the Hranice Karst have been satisfactorily resolved. So far, geophysical and drilling explorations have provided just vague ideas of the thickness and distribution of Devonian limestone. The underlay of limestone rocks in the Hranice Karst still has not been reached by drilling or geophysical techniques. The deep-based origin of hydrothermal fluids, as demonstrated through the isotopic composition of carbon, ^{3}He and ^{4}He helium isotope ratios and increased thermal gradient, shows that well-permeable karstic channels are well developed throughout the thickness of the carbonate rocks and that outgoing paths of fluids transition as far as the granitoid underlay of carbonate rocks. Based on the immediate observation of hydraulic influence of mineral water levels as part of the 1997 flood as well as the evaluation of the continuous measurement of levels of mineral waters and of their electrical conductivity in the Hranice Abyss, Zbrašov Aragonite Caves and balneology boreholes in the spa resort of Teplice nad Bečvou, these levels were found to be dependant of the water level of the River Bečva. Places where infiltration (source) regions of mineral waters have been identified include the area of the River Bečva near the settlement of Kamenec, i.e., directly within the area of Skalička WW. Drilling activities demonstrated Devonian limestone to occur in this area.

A polder can be considered a satisfactory means to address flood control and protection of mineral water. While the mineral water regimen will still be affected in the event of flood with this method of control, it will be only a temporary situation; after a certain time, the regimen will restore its initial status, depending on the specific situation, similarly as with the extreme flood in 1997. Contrary to the above, any permanent filling of Skalička WW with water and increased hydrostatic pressure by approx. 20 m may result in permanent and irreversible changes in the regimen as well as quality of mineral waters.

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REFERENCES

Čížek, P. –Tomek, C. (1991): Large-Scale Thin-Skinned Tectonics in the Eastern Boundary of the Bohemian Massif. Tectonics, 10, 273-286.

Bína J. Hodnocení potenciálu cestovního ruchu v obcích České republiky. Urbanismus a územní rozvoj, 2002. 5, 1, s. 1-11

Dvořák, J. – Friáková, O. (1978): Stratigraphy of the Palaeozoic near Hranice na Morave. – Výzk. Práce Ústř. Úst. Geol., 18, 1-50.

Geršl, M. (2016): Rozlišení vod Hranického krasu na základě archivních analýz. – Zpr. geol. Výzk. v Roce 2015, 49, 247-252.

Geršl, M. (2009): Hranický kras. – In: Hromas, J. (ed.), Jeskyně ČR. Chráněná území ČR, vol. 15. Agentura ochrany přírody a krajiny ČR & EkoCentrum Brno, p. 362, Praha.

Guba, M. (2016): Tisková zpráva k hloubkovému průzkumu Hranické propasti a dosažení nové maximální hloubky -404m. http://www.hranickapropast.cz/

Kalvoda, J. – Bábek, O. – Fatka, O. – Leichmann, J. – Melichar, R. – Nehyba, S. – Špaček, P. (2008): Brunovistulian terrane (Bohemian Massif, Central Europe) from late Proterozoic to late Paleozoic: a review. – Int. J. Earth. Sci., 97, 497–518.

KRÁSNÝ, Jiří. Podzemní vody České republiky: regionální hydrogeologie prostých a minerálních vod. Praha: Česká geologická služba, 2012.

Krejčí, I. 2016. Poldr Skalička. Unie pro řeku Moravu, 16 s.

Longley, P., A., Goodchild, M., Maguire, D., J., Rhind, D.,W. (2011): Geographic Information Systems and Science. Wiley: Hoboken, 539 s.

Navrátil, J., Pícha, K., Knotek, J., Kučera, T., Navrátilová, J., Rajchard, J. (2013): The comparison of attractiveness of tourist sites for ecotourism and mass tourism: The case of waters in mountainous protected areas. Tourismos: An international multidisciplinary journal of tourism, 8(1), 35-51.

Rožnovský, J. – Středa, T. – Litschmann, T. – Pokladníková, H. – Fukalová, P. (2010): Mesoclimate as a part of recreation potential of the landscape on the example of the Moravian Karst. In: Recreation and Environmental Protection. Mendel University in Brno, 60–64.

Schulmann, K. – Gayer, R. (2000): A model for a continental accretionary wedge developed by oblique collision: the NE Bohemian Massif. – J. Geol. Soc. Lond., 157, 401–416.

Středová, H. – Knotek, J. – Středa, T. (2015): Microclimate monitoring for evaluation of management effect on Mohelno Serpentine Steppe. In: Public recreation and landscape protection – with man hand in hand! Brno: Mendel University in Brno, 157-160.

Špaček, P. – Bábek, O. – Štěpančíková, P. – Švancara, J. – Pazdírková, J. – Sedláček, J. (2015): The Nysa–Morava Zone: an active tectonic domain with Late Cenozoic sedimentary grabens in the Western Carpathians' foreland (NE Bohemian Massif). – Int. J. Earth Sci. (Geol. Rundsch.), 104, 963–990.

Vrba, J. (1960): Hydrogeologické posouzení území mezi Teplicemi nad Bečvou, Černotínem a dvorem Kamenec, se zřetelem na výstavbu přehrady na řece Bečvě. – MS, Závěrečná zpráva, Vodní zdroje. Praha.

VYSTOUPIL, J. a kol. Atlas cestovního ruchu České republiky. Praha: Ministerstvo pro místní rozvoj, 2006. 157 s.

Ulrych, J. – Ackerman, L. – Balogh, K. – Hegner, E. – Jelínek, E. – Pécskay, Z. – Přichystal, A. – Upton, B.G.J. – Zimák, J. – Foltýnová, R. (2013): Plio-Pleistocene basanitic and melilititic series of the Bohemian Massif: K–Ar ages, major/trace element and Sr–Nd isotopic data. – Chemie der Erde 73, 429–450.

Climate change at local level on the base of the air temperature and precipitation data of the weather station of Karcag

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Abstract: On the base of the analysis of the temperature and precipitation data recorded in Karcag between 2005 and 2017 it can be concluded that our climate is very changeable, unpredictable making agricultural production, especially crop production more risky and complicated. The change of temperature tends to warming up on the base of the data recorded in the last 13 years. We do not consider the precipitation data recorded from 2005 to 2017 sufficient to judge the tendency of the change in that respect, though the increasing changeability is obvious as found real extremes even a relatively short investigation period.

Key words: temporal variability, climate, air temperature

INTRODUCTION

Large spatial and temporal variability, changeability and hard predictability characterize the climate and weather of Hungary taking any climate factor into consideration (OMSZ, 2005). Nevertheless it is predictable that the frequency, probability, duration and intensity of weather extremes and their impacts (floods, excess water, drought etc.) are increasing even within the same year and area. The reasons of that are the large spatial and temporal variability of atmospheric precipitation, the increasing frequency of showers of high intensity, the unfavorable soil conditions, the improper land use and crop rotation (VÁRALLYAY, 2010).

The climate of planer Earth has been changing since it existence, sometimes faster, sometimes slower. Nevertheless the recent situation of our days is new as human activities influence not only the micro- and macroclimate, but the global climate as well (HARNOS, 2005). In order to know the climatic status of a region, precise measurements and observations in sufficient spatial and temporal resolution are crucial (WMO, 2010).

Beside the description and characterization of the climatic status of a region, the determination of the tendencies of the changes is also of great importance. To monitor the changes and determine their tendencies sufficiently long data series as the bases of the assessments are necessary (KONKOLYNÉ et al., 2008).

The increasing frequency of climatic extremes was predicted by scientists long time ago, and these predictions are already proven by now. During the last decades several weather extremes and unusual events with increasing frequency of occurrence were reported from all over the world (CAROLYN F., 2008). According to the Summary for Policymakers of IPCC, observations since 1950 prove the change of degree and occurrence frequency of some climatic extremes. Due to the increase of the concentration of the greenhouse gases the daily maximum and minimum values of air temperature have increased all over the world. In total the number of cold days and nights decreased, and parallel to this the number of hot days and nights increased. Phenomena concerning precipitation have higher uncertainty, though the increase of the frequency of heavy rains and floods can be observed in many regions. At the same time droughts also occur more frequently (IPCC, 2011).

On the base of the 2013 report of IPCC, the global average of surface temperature increased 0.89°C between 1901 and 2012. Each of the last three decades had been warmer than the former decades since 1850. The linear trend line fitted on the annual mean temperature data recorded in Hungary shows an obvious increase, the change of the annual mean temperature during the last 116 years is +1.10 °C, while for the last 30 years it is +1.38°C (RIESZ, 2017).

MATERIAL AND METHODS

Karcag, the capital of Great Cumania, is located in the north-east part of Hungary, in the centre of the Great Hungarian Plain. The subregion called Great Cumania is one of the driest areas of Hungary with high fluctuation of temperature and the most continental characteristic. Summers are dry, warm with low cover of clouds. The total number of annual sunshine hours is between 1970 and 2020. The annual mean temperature is 10.2-10.4°C, the mean temperature of the vegetation period is 17.4-17.6°C. The annual amount of precipitation is between 490 and 510 mm (DÖVÉNYI, 2010).

The Research Institute of Karcag RIEF University of Debrecen (RIK) has been carrying out meteorological measurements since its foundation in 1947. In July of 2004 a weather station belonging to the network of the National Meteorological Service was settled there (Figure *1*).

Figure 1: The weather station of Karcag

The measurement frequency of the weather station is 10 minutes, the data are recorded by data logger (QLC-50 by VAISALA). The measured meteorological parameters are summarized in *Table 1*.

Table 1: *The meteorological parameters measured in the weather station of Karcag*

PARAMETER	UNIT
air temperature	°C
mean temperature	°C
maximum temperature	°C
minimum temperature	°C
soil surface temperature	°C
minimum of soil surface temperature	°C
relative air humidity	%
air pressure	hPa
velocity of wind	m/s
direction of wind	°
maximum wind waft	m/s
direction of maximum wind waft	°
minute of maximum wind waft	minute
second of maximum wind waft	second
precipitation	mm
solar radiation	W/m
soil temperature at 10 cm depth	°C

RESULTS AN DISCUSSION

Air temperature

Annual mean air temperature data measured in Karcag from 2005 to 2017 were analyzed in order to figure out if there is s tendency of change in this parameter (*Fig. 2*). In the investigated period the average of the means is 11.3°C, 1.3°C higher than the 50 year average (10°C). The maximum of annual mean air temperature values was detected in 2014 (12.2°C), while the minimum value was calculated for 2005 (9.8°C), this latter year was the only one among the investigated 13 years when the annual mean value was below the 50-year average.

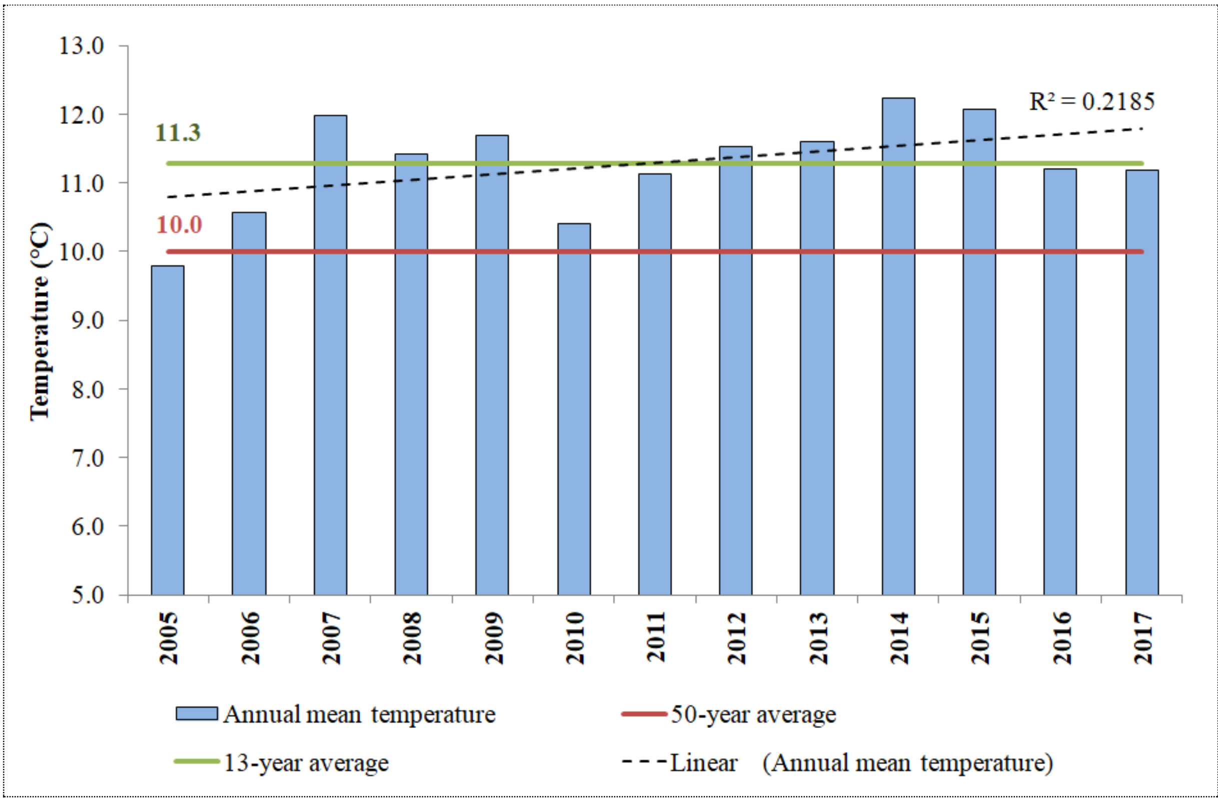

Figure 2: Annual mean air temperature in Karcag, 2005-2017

The linear trend line fitted on the data of the diagram shows obvious and gradual increase of the annual mean air temperature in Karcag in the period of 2005-2017. In the region of Karcag the importance of this trend is significant, it is even sensible by the local people.

Beyond the annual mean air temperature, the annual minimum and maximum values are worth to be analyzed too. The minimum values differed in a very wide interval within the investigated period, the lowest value was -23.3°C, while the highest minimum was -7.5°C. The maximum air temperature value reached 40°C in one year.

Precipitation

Precipitation is the most changeable among the climatic parameters. During the investigation period of 2005-2017 both droughty and very wet years took place (*Fig. 3*). The lowest value of the annual amount of precipitation was detected in 2012 with its 344 mm, while there were two years among the 13 when more than 700 mm fell. The absolute record was detected in 2010 with its 889.1 mm rainfall, no observation of higher amount can be found in our database going back to 1948. After the extremely wet year of 2010 extremes were characteristic in the following two years again, but extreme dryness; in 2011 385.7 mm, while in 2012 only 344.5 mm was the amount of annual precipitation. Then a year came with average amount of annual precipitation. If we fit a trend line on the data series, a decreasing tendency is figured out regarding the total amounts of annual precipitations. Nevertheless it cannot be concluded that this tendency has started, since the average of the investigated 13 years is 62 mm higher than the 50-year average.

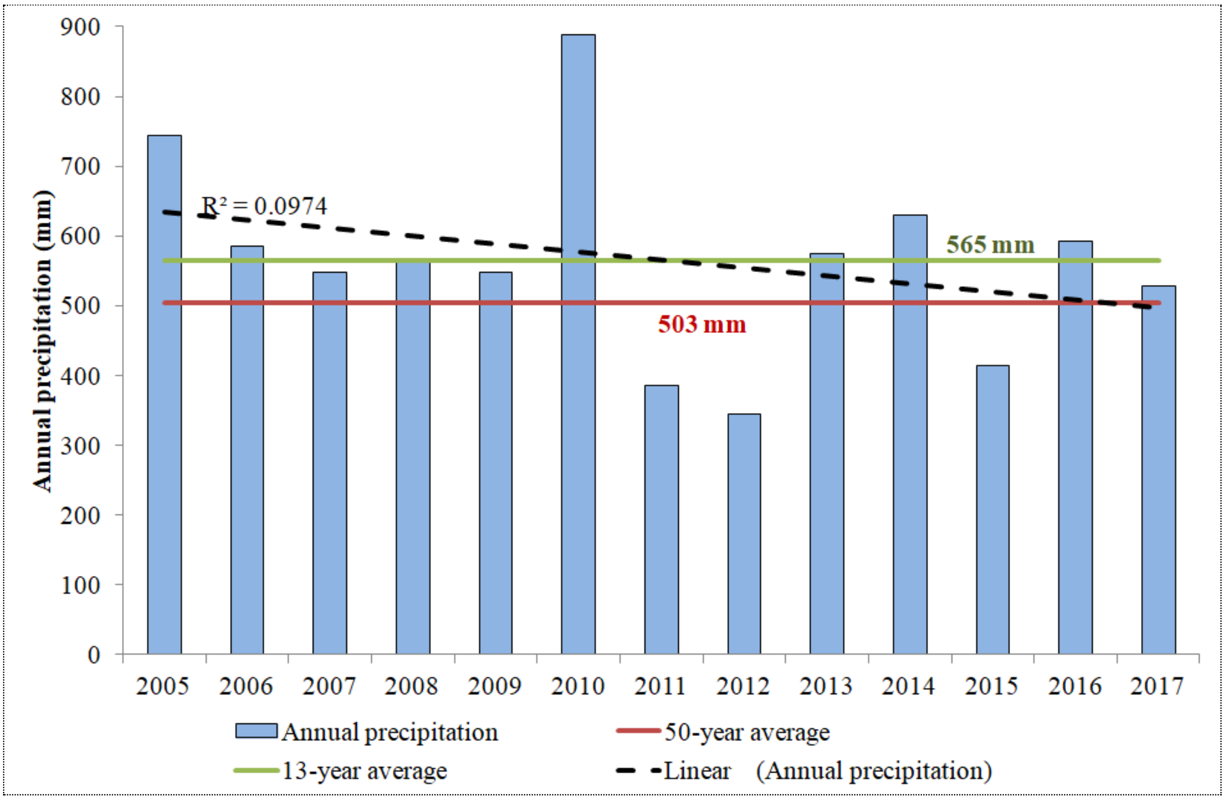

Figure 3: Annual amounts of precipitation in Karcag, 2005-2017

From agricultural point of view the temporal distribution of precipitation is very unfavorable in Great Cumania. The number of days with precipitation over 20 mm is increasing, even rainfall intensity over 60 mm/day occurred in 2005 and 2010. In *Table 2* we summarized the greatest point rainfalls observed in Karcag between 2005 and 2017.

Table 2: Annual record rainfall intensities observed in Karcag (2005-2017)

	Date	**mm/week**	Date	**mm/day**	Date	**mm/hour**	Date	**mm/10 min**
2005	05.07-11. 07	**71.5**	15.08	**62.7**	15.08	**22.2**	05.07	**12.0**
2006	30.07-06. 08	**44.3**	01.08	**28.7**	29.06	**20.9**	29.06	**8.5**
2007	22.10-28.10	**55.6**	27.05	**37.7**	27.05	**30.1**	05.10	**10.1**
2008	13.06-19.06	**50.2**	13.06	**41.8**	13.06	**14.6**	08.08	**8.0**
2009	04.11-10. 11	**68.1**	11.06	**29.7**	11.06	**25.1**	28.06	**9.5**
2010	20.07-26.07	**78.1**	25.07	**60.9**	14.06	**32.6**	06.08	**15.4**
2011	26.07-01.08	**52.5**	30.07	**32.0**	08.08	**13.4**	08.08	**7.8**
2012	05.06-11.06	**30.6**	25.25	**25.6**	09.06	**13.9**	09.06	**5.6**
2013	10.10-16.10	**40.8**	16.10	**29.8**	22.06	**21.2**	26.08	**12.1**
2014	09.09-15.09	**107.6**	13.09	**32.9**	23.07	**11.4**	15.09	**7.9**
2015	18.08-24.08	**60.5**	20.08	**27.5**	18.08	**12.6**	18.08	**9.3**
2016	21.06-27.06	**64.3**	27.06	**40.0**	03.07	**18.8**	03.07	**10.0**
2017	19.09-25.09	**51.6**	21.09	**40.4**	03.09	**20.0**	03.05	**6.6**

High intensity rainfalls are especially unfavorable in the region where heavy textured clay soils with low infiltration rate are characteristic. Due to the shrinking characteristic of these clay soils their pores are blocked, no infiltration and deep percolation of the water can take place. The excess water appearing on the soil surface results in water loggings that worsens the living conditions of crops through the shortage of air in the soil and the high evaporation loss.

Table 3 shows the results of the statistical analysis of our database regarding the mean temperature and precipitation values of the investigated 13 years. Temperature data varied in a large interval (2.4°C), the average of all means is 11.4°C, the standard deviation is 0.7°C. The difference between the lowest and largest amounts of precipitation is 544 mm, the standard deviation is143.7 mm showing large variability.

Table 3: Results of the statistical analysis of mean temperature and precipitation data

	Annual mean temperature 2005-2017	**Annual precipitation 2005-2017**
Mean	11.3	565.3
Standard error	0.2	39.9
Median	11.4	567.9
Standard deviation	0.7	143.7
Variance	0.5	20648.5
Kurtosis	0.3	1.2
Skewness	-0.8	0.7
Range	2.4	544.6
Minimum	9.8	344.5
Maximum	12.2	889.1
Sum	146.8	7348.9
N	13	13
Confidence level (95.0%)	0.4	86.8

CONCLUSIONS

Human society cannot feel climate change tendencies directly as they are relatively slow. Nevertheless the more frequently occurring extreme meteorological events have direct and indirect impacts on society and agriculture. Since the frequency and intensity of temperature extremes are increasing, their spatial and temporal occurrence is getting more and more variable, one of the biggest challenges of our society is to accommodate to them.

On the base of the analysis of the temperature and precipitation data recorded in Karcag between 2005 and 2017 it can be concluded that our climate is very changeable, unpredictable making agricultural production, especially crop production more risky and complicated. The change of temperature tends to warming up on the base of the data recorded in the last 13 years. We do not consider the precipitation data recorded from 2005 to 2017 sufficient to judge the tendency of the change in that respect, though the increasing changeability is obvious as found real extremes even a relatively short investigation period.

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REFERENCES

Carolyn F.: 2008. A klímaváltozás. A XXI. sz. legnagyobb kihívása. (The Impact of Climate Change). Budapest. 12-128p.

Dövényi, Z.: 2010. Magyarország kistájainak katasztere. MTA Földrajztudományi Kutatóintézet, Budapest.

Harnos N.: 2005. A klímaváltozás hatásának szimulációs vizsgálata őszi búza produkciójára. In: "AGRO-21" Füzetek. (Szerk.: Csete L.) AKAPRINT, Budapest, 31, 56-73 p.

IPCC, 2011: Intergovernmental Panel on Climate Change..Az Éghajlatváltozási Kormányközi Testület (IPCC) 2011. évi Tematikus Jelentése a szélsőséges éghajlati események kockázatáról és kezeléséről. ISBN 978-92-9169-131-9

IPCC, 2013 IPCC*: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Konkolyné Bihari Z., Lakatos M., Szalai S., 2008: Magyarország éghajlatáról. Változékonyság térben és időben. OMSZ-kiadvány.

OMSZ, 2005: Országos Meteorológiai Szolgálat tevékenysége, 2004-2005, Budapest

Riesz L. 2017: A Magyarországon megfigyelt éghajlati változások. pp. 155-159. In: Magyarország Környezeti Állapota 2016 (Szerk. HOLES A.) Herman Ottó Intézet, Budapest 262 p.

Várallyay Gy.: 2010. A talaj, mint víztározó; talajszárazodás. „Klíma-21” füzetek. MTA KSZI Klímavédelmi kutatások koordinációs iroda, Budapest.

WMO, 2010: A Meteorológiai Világszervezet állásfoglalása az éghajat 2009. évi állapotáról (magyar fordítás OMSZ, 2010)

Influence of seepage of water from domestic waste water treatment plants on groundwater

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Abstract: Domestic sewage treatment plants are a rapidly evolving phenomenon in the Czech Republic. This is especially the case where there is no sewer network available. There are, however, places where the water can not be drained into the river. Porom this must be solved by sinking into groundwater.

This paper is concerned with verifying the functionality of domestic wastewater treatment plants soaking in the Tišnov region. The theoretical section describes methods of waste water within the houses, their distribution, utilization characteristics. There is also described the technology selected domestic wastewater treatment plants method of operation. There are mentioned legislative provisions relating to wastewater treatment plants discharging to do their groundwater. The work includes hydro-geological description of the site, in which monitored Domestic wastewater treatment plant is located. Within the practical part was to validate the effectiveness of wastewater treatment. Samples of wastewater were regularly for six months removed from individual domestic wastewater treatment plants BAT and analyzed in the laboratory of the Institute of Agricultural, Food and Environmental Engineering Faculty of Agronomy, Mendel University in Brno. Measured parameters determining the quality of wastewater were compared with relevant legislation, the values guaranteed by the manufacturer of the individual household wastewater. Results of the analyzes of waste waters were evaluated interpreted. On the basis of their recommendations was established.

Key words: sewage water, legislation, domestic sewage treatment plants

INTRODUCTION

Domestic sewage treatment plants are a rapidly evolving phenomenon in the Czech Republic. This is especially the case where there is no sewer network available. There are, however, places where the water can not be drained into the river. Porom this must be solved by sinking into groundwater.

This paper is concerned with verifying the functionality of domestic wastewater treatment plants soaking in the Tišnov region. The theoretical section describes methods of waste water within the houses, their distribution, utilization characteristics. There is also described the technology selected domestic wastewater treatment plants method of operation. There are mentioned legislative provisions relating to wastewater treatment plants discharging to do their groundwater. The work includes hydro-geological description of the site, in which monitored Domestic wastewater treatment plant is located. Within the practical part was to validate the effectiveness of wastewater treatment. Samples of wastewater were regularly for six months removed from individual domestic wastewater treatment plants BAT and analyzed in the laboratory of the Institute of Agricultural, Food and Environmental Engineering Faculty of Agronomy, Mendel University in Brno. Measured parameters determining the quality of wastewater were compared with relevant legislation, the values guaranteed by the manufacturer of the individual household wastewater. Results of the analyzes of waste waters were evaluated interpreted. On the basis of their recommendations was established.

In the Czech Republic, over 1.5 million people are not connected to municipal sewerage systems. Leakage reservoirs cause poor quality of surface and groundwater. In the villages, we can still face the phenomenon of so-called ditches and the drainage of uncleaned wastewater into the environment. For this reason, the purchase of a household sewage treatment plant, which would clean household wastewater, could seem like an ideal solution.

The aim of this thesis is to verify the functionality of domestic sewage treatment plants in the Tišnov region. Describe the origin, distribution and properties of sewage.

Sink water

Sewage effluents are considered to be water produced in households and other urban amenities such as restaurants, hotels, shopping centers, etc. The amount of wastewater is almost the same as drinking water.

Sewage water consists of a certain amount of drinking water, human excrement, urine and products of human activity in households. Pollutants are made up of about 50% organic and 50% organic, most of which are urine and faeces (MALÝ, J., MALÁ, J., 2006; PITTER, P., 1999).

Other sources of organic substances include, for example, animal and vegetable kitchen residues consisting of proteins, carbohydrates and lipids). Dry matter of faecal matter consists of bacteria, fats, proteins and polysaccharides. The most widespread component of inorganic compounds are, for example, nitrogen compounds, sulfur phosphide, chlorides, etc. These substances occur in both urine and detergents and cleaning agents (MALÝ, J., MALÁ. J., 2006).

Specific amount of sewage water qspec. (ie per capita per day) ranges between 80 and 200 liters per person per day. In practice, this value is slightly overestimated and 150 dm3 per person per day is used. It includes a safety margin (GRODA, B. a kol., 2007).

Gray water

Gray water is considered to be water from dishwashing, bathing, showering and laundry. We divide the gray water into four categories:

1. Unshared gray water,
2. Gray water from kitchens and dishwashers,
3. gray water from washbasins, bathtubs and showers, and
4. gray water from washing machines (BIELLA, R., 2011)

Domestic sewage treatment plant

Domestic sewage treatment plants (WTPs) are facilities for pre-treatment of waste water and subsequent discharge into underground or surface waters. Depending on the principle and technology of waste water treatment, it is divided into so-called packed and root.

Discharging waste water from domestic WWTPs into surface or underground water is subject to many legal regulations.

Basic legislation includes:

1. Act No. 254/2001 Coll. on Water and on the Amendment to Certain Acts (Water Act), as amended.
2. Government Regulation No. 57/2016 Coll. on indicators and values of permissible waste water pollution and on the permit requirements for the discharge of waste water into underground waters.
3. Act No. 254/2001 Coll. on Water and on the Amendment to Certain Acts (Water Act), as amended.

Domestic sewage treatment plant

Domestic sewage treatment plants (WTPs) are facilities for pre-treatment of waste water and subsequent discharge into underground or surface waters. Depending on the principle and technology of waste water treatment, it is divided into so-called packed and root.

For our work, we chose the AQUATEC household wastewater treatment plant type AT 6 and AT8. It is an all-plastic mechanical waste water treatment plant for 2-5 equivalent inhabitants (EO) in the case of type AT 6 and for 3-7 EO in the case of type AT 8. The Biological Institute for Biological

Treatment removes organic pollution from waste waters and nitrogen forms to a guaranteed level according to the valid legal regulations of the Czech Republic. For 1 EO, the daily wastewater production is 135 l / s. / day. WWTP AT 6 and AT 8.

It meets the requirements of ČSN 75 6402, ČSN 75 0905 and ČSN EN 12566-3. On the outflow from wastewater treatment plants, the producer guarantees the efficiency of wastewater treatment by legislation.

WWT 1

Two adults, two children and a baby are living in the house. At the beginning of the measurement, the UCC was in operation for only one month. This situation has allowed us to monitor the whole process from the beginning. The family spends mostly seven days a week at home. Short-term showering prevails over bathtub bathing. Here is a conventional house drug store that did not change during the measurement. At the start of the startup, the ICU started more often per day. This, however, caused excessive infiltration of PCBs. Currently, a maximum of one washing machine is per day and washing. is spread over several days a week. Manual dishwashing is done every day, with so-called "delicacies". The dishwasher was used on average three times per week, during visits and celebrations.

WWT 2

It is a domestic waste water treatment plant type AT 8, ie for 3-7 EO. Blasting of ULC is discontinuous. As a source of drinking and service water, the family uses the municipal water supply system. This WWTP was launched in 2013. The family usually spends six days a week at home, one day away from home. The house uses a combination of a conventional and environmentally friendly drugstore to the environment, while the environmentally friendly drugstore is used in the form of toilet gel and dishwashing gel.

WWT 3

It is a domestic wastewater treatment plant type AT 6, ie for 2-5 EO. WWTP was launched in 2014. Aeration is continuous here. The family has its own source of drinking water, while the water in the house is treated through a water treatment reducing the excess concentration of manganese and iron in the water. The Frosch eco-friendly drugstore is used in the household. There are 2 adults and 2 children in the house. The dry cleaner is in operation for two years.

RESULTS

Tab. 1 Comparison of results of individual measurements BSK5 for WWT 1.

Sample number	Moon	BOD5 (mg.l-1)	Evaluation
1	October	127	Poor
2	January	25,4	Good
3	March	81,7	Poor

Tab. 2 Comparison of results of individual measurements BSK5 for WWT 2.

Sample number	Moon	BOD5 (mg.l-1)	Evaluation
1	October	120	Poor
2	January	120	Poor
3	March	77,5	Poor

Tab. 3 Comparison of results of individual measurements BSK5 for WWT 3.

Sample number	Moon	BOD5 (mg.l-1)	Evaluation
1	October	175	Poor
2	January	59,5	Poor
3	March	74,7	Poor

CONCLUSION

Sewage treatment plants should be treated as living organisms, which need to provide favorable living conditions. It is necessary to carry out the operation of the WWTP regularly and to follow the instructions given by the producer of domestic WWTPs. If the operators of the WWTPs are to be managed, the wastewater treatment should be carried out correctly and the wastewater values at the exit from the WWTP should be satisfactory. This is mainly about the access of the operators to the WWTPs, which plays a key role here. However, given the time capacities of water authorities, it is still difficult to get ICP operators to periodically check the effectiveness of waste water treatment.

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REFERENCES

GRODA, B. a kol.; 2007; Čištění odpadních vod jako nástroj k ochraně životního prostředí v zemědělské praxi a na venkově

MALÝ, J., MALÁ, J.; Chemie a technologie vody. 2. doplněné vydání. Údolní 56, 602 00 Brno, Česká republika: ARDEC s.r.o., 2006, 329 s. ISBN 80-86020-50-9

Identification of spatial variability of moisture and soil compaction

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Abstract: The paper presents the research was to identify selected physical properties of the soil after cereal harvest in a field of 100 ha. The scope of work included the measurement of soil compaction and humidity in a field of 100 ha, enabling spatial visualization (digital maps) of the measured size on the testing ground. The depth of soil penetration through the penetrometer cone was 0.7 m, while the soil moisture was measured at the depth of 0.1 m and 0.25 m. The number of measuring points was determined by a virtual grid with a side of 30 m, which was applied to the contour of the tested field. Significant relations between the soil compaction and its moisture within the area of the tested field were observed, where the variability of the amount of water was very large. It has been noted that the range of variability of soil compaction at the working depth of machines for basic cultivation is at the level of 60%, which justifies the attempt to conduct precise soil cultivation. Whereas the range of oscillation of the compaction value oscillated between 0.1 MPa and 5 MPa, nevertheless the highest values of compaction were recorded at a depth of 0.45 m, which indicates the presence of the plow sole.

Keywords: spatial variability, GIS, GPS, soil compaction, soil moisture, overall soil porosity, the plow sole, precise soil cultivation.

INTRODUCTION

The total area of sowing of basic cereals with cereal mixtures in 2016 amounted to approx. 7.4 million ha. In the structure of sowing, total cereal grains accounted for 69.6% of the total sown area. The number of farms engaged in cereal cultivation amounted to 1064.9 thousand, i.e. 89.4% of all farms that cultivated crops. The share of farms cultivating grain in the total number of farms with crops increased from 68.8% in the group of 0-1 ha of usable agricultural land to over 92.7% starting from the group of 5-10 ha, reaching the highest value among farms with an area of 15-20 ha (93.9%). The share of cereal sown area in the total sown area in individual area groups of usable agricultural land ranged from 62.4% in the group of 100 ha and more and 64.4% in the 50-100 ha group to 79.3% in the 5-7 ha group. The average area of sown cereal crops in one agricultural holding engaged in their cultivation amounted to 6.95 ha. In farms with 5 to 50 ha of usable agricultural land, there were 56.1% of the total cereal growing, and these farms accounted for approx. 50% of all farms cultivating cereals. The largest number of farms cultivating cereals, i.e. 70.7% of all farms cultivating grain, ranged from 1 to 10 ha of usable agricultural land, however, on these farms only 27.5% of total cereal crops were available (www.agropogoda.pl). The set of post-harvest and pre-harvest crops for cereal crops may be modified depending on the follow-up plant and the physical properties of the soil. Currently, in high-performance agriculture, the optimization of the production process in post-harvest and pre-harvest cultivation phase makes it possible to identify selected physical properties of the soil. Knowledge of soil parameters important from the point of view of cultivation enables the preparation of maps presenting spatial diversity of soil and consequently the use of precise technological activities that use highly technologically advanced electronic and satellite systems, which tools are: farm machines equipped with artificial intelligence, automatic data collection systems, Geographic Information Systems (GIS) for their processing and extensive systems and procedures for computer data analysis and production decision support (Faber 1998). In modern agriculture, the machines used are becoming heavier and heavier and they cooperate with high-power tractors, which makes the wheels of these machines and tractors and natural processes are the source of forces that cause kneading of agricultural soils. Technical development especially in recent years, which lagged behind the development of technology has intensified the number of journeys of agricultural aggregates. The consequence of this state of affairs is the progressive degradation of soils, that is, the change of their physical properties, which eliminates the achievement of high yields.

On the basis of research in mechanized farms Walczykova (1995) found that the average size of the surface of wheel tracks aggregates is, depending on the plant species, from 3.2 to 6.9 hectares per one hectare of field. Minimizing the damage to the soil caused by the passing of agricultural aggregate wheels requires the development of a strategy to travel across the field. The solution to this problem is presented, among others, by a controlled traffic farming system (CTF), which involves such management of aggregates in order to limit all field rides to the smallest possible area of permanent traffic lanes (Walczykova, Zagórda 2017). The research carried out by Walczyk and Zagórda (2017) showed that small changes in the machinery park and production technology in the cultivation of winter wheat with the use of simplified cultivation will increase the area free from wheel rides to about 71% of the area. Agricultural soil has two contradictory requirements: - ensuring conditions for plant growth and development, thus loose soil, containing a lot of free space, - providing a suitable ground for agricultural vehicles traffic, i.e. a durable soil, transferring mechanical loads without excessive deformation. Through the interaction of natural factors and means of agricultural technology, the structure and volumetric weight change. The structure defined as a system of soil aggregates will have a decisive influence on how the soil reacts to external loads. With different sizes of soil aggregates, there are many points of their contact, which reduces volumetric changes due to the displacement of particles. This means less kneading, i.e. less deterioration of the ratio of the pore volume to the volume of the skeleton. Mechanically formed large pores, the most important for root growth and water movement, will be permanent only when the aggregates located in their surroundings are stable. The reason for the breakdown of the structure and the loss of large pores is, inter alia, the soil load of agricultural equipment. The optimum pore and air volumes in the main soil components are for the light soil 40% of the pore volume and 15% air, for the soil medium 45% pores and 10% air, for heavy soil 47% pores and 12% air. As a result, sometimes a few dozen kilometers of furrows cover every hectare of arable fields, some of the furrows are repeatedly kneaded with wheels of tractors and machines, resulting in changes in the shape of the field's surface. Furrows can have a depth of several or even several dozen of centimeters (horizontal). The second result of the action of the wheels are soil deformations, often difficult to remove despite the multiple subsequent cultivation of such soil, vegetation and yields differ significantly. That is why the problem empowers the soil to grow to the rank of one of the most important. Thus the pressure reduces the volume of the air pores, thereby affecting the air conditions prevailing in the soil. As you know, plant roots can not penetrate into pores with a diameter of less than 1 mm. The density and changes in pore structure may, therefore, significantly reduce the penetration of roots, and thus the uptake of nutrients and water. In studies on the impact of kneading on the formation of the root system of plants, it is commonly concluded that the concise soil creates mechanical resistance to growing roots and causes unfavorable conditions for the roots to supply oxygen, water and minerals (Dexter, 1986; Bengough and Mullins, 1990; Taylor and Brar, 1991; July and Stępniewski, 1995; Cook et al., 1996). The most frequent reaction of the roots to soil compaction is the reduction of their length, concentration in the top layer and reduction of the depth of roots (Lipiec et al., 1991, July et al., 2003). Roots growing in heavily crushed soil are characterized by a larger diameter, a higher degree of flattening, and an irregular surface of the epidermis, in which there are hollows on soil particles (Lipiec et al., 1991). Technological progress forces (enables) the development of sophisticated agricultural production technologies that, through their innovation and efficiency, lead to a better use of soil production potential. Achieving such a condition is possible only by learning about physical parameters of the soil and their impact on machine aggregates. Walczykova et al. (2016) presented a comprehensive list of sensors used in measuring various physical soil parameters used in agriculture. Knowledge of the strength characteristics is very important, because often this property changes, for example, due to the change in soil volume in the kneading process. Soil compaction is the result of an increase in its density and strength. To determine the soil strength, i.e. the characteristics dependent on humidity and variable in time, the soil compactness (penetration resistance) is measured. The strength measured by the penetrometer gives a picture of the load capacity of the ground. It is important in determining the soil compaction, which is caused by the passage of agricultural machinery. These probes are characterized by considerable diversity (Potter, Chichester 1993). The measuring cone itself was analyzed (Lejman, Owsiak 1996) from the point of view of the value of the apex angle and the base area of the cone. Walczykova and Walczyk (1992) constructed a probe with an electronic recorder. The influence of the probe's movement speed on the obtained test results was also examined (Buliński, Majewski 1998). Currently, conical penetrometers are commonly used in which the ASAE standards are applied to measure and construct the penetrometer cone. Kroulik et al. (2004) state that the variability of crop yielding may be due to the variability of soil properties, and the observed variability may be the basis for precise soil cultivation (Kroulik, Prosek 2000). Walczykova et al. (2005) presented a spatial distribution of variability of soil physical properties using a mobile cartographic recorder for positioning. Using the knowledge of basic physicochemical soils and the method of their measurement (Bajla et al., 2005), they developed a method of continuous measurement of penetration resistance with a horizontal penetrometer with the intention of its use in precision agriculture, the resistance force measured with a piezoelectric sensor. Conical penetrometers are the most commonly used meters because they are easily accessible, easy to use and due to their accuracy of measurement. The results obtained from these tools can be used to build models that help in a comprehensive way to find the correlation between penetrometric resistance and the density, type or soil moisture.

The purpose and scope of research

The aim of the study was to determine the spatial diversity of soil moisture and compaction within the field which was under investigation at different depth levels of the soil profile and surface extraction of identified anomalies. In addition, the overall soil porosity was determined. The following measurements were made to achieve the goal:

- *soil compaction*
- *soil moisture*
- *overall soil porosity*

The scope of work included the measurement of soil compaction and humidity in a field of 100 ha, enabling spatial visualization (digital maps) of the measured size on the testing ground. The depth of soil penetration through the penetrometer cone was 0.7 m, while the soil moisture was measured at the depth of 0.1 m and 0.25 m. The number of measuring points was determined by a virtual grid with a side of 30 m, which was applied to the contour of the tested field. The subject of the research was to identify selected physical properties of the soil after cereal harvest in a field of 100 ha (Fig. 1).

Fig.1. View of the part of the field covered by the research

Field irregularities and terrain unevenness were not found on the surface of the field. The stubble being an experimental field was created after wheat harvest, which cultivation technology is currently used in commercial farms. The research was carried out in the area of Głubczyce, which is characterized by very good soils, most often the parent rock is loess. These soils contain a large amount of humus, where its thickness sometimes reaches 1 m in depth. Class I-III soils account for 74% of the total arable land area, the climate is beneficial for the development of agriculture, which is the dominant branch of the economy in this commune. In the structure of crops, cereals account for approx. 80% of the crop area.

MATERIAL AND METHODS

Methodology for measuring soil compaction

The SiRF III GPS mobile receiver built into the Fujitsu-Siemens palmtop was used to precisely determine the points in which the sounding and humidity measurements were carried out. The microcomputer has been equipped with the 3R-Map application that allows to determine the location of points, to record the course of the polygon's lines and boundaries. The probing was performed pointwise at intervals of 30 m on the surface of the field, where the measurement sites were the vertices of "squares" (Fig. 2). The exception was field areas where there was a reasonable suspicion of high variability of compactness, where the grid of measurment points was concentrated. For further spatial processing, the measurement data was transferred to a desktop computer equipped with the 3R-GIS eXpres programme, where it was converted to the base format "shp" for the ArcView 3.3 programme, in which digital maps of spatial differentiation of the measured quantities were generated.

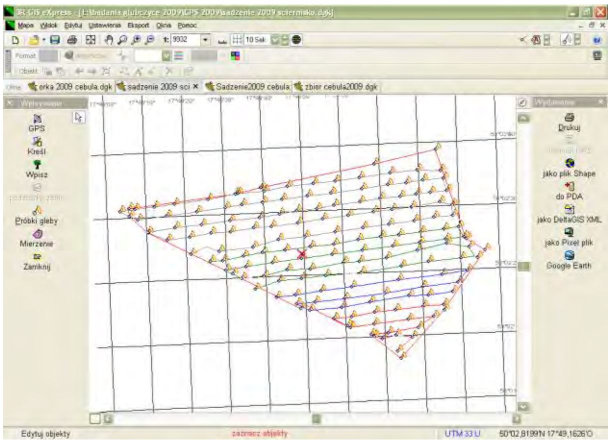


Fig. 2. The 3R-GIS eXpres programme interface

There were 9 penetrometer probes per one measurement point distributed in accordance with the shape of the letter X [PN-R-04031]. The measurement of soil compactness was made using a conical penetrometer, the Penetrologger Eijkelkamp model with ThetaProbe probe designed to measure soil compactness and moisture on arable land acc. To ASAE standards (currently ASABE). The penetrometer casing was equipped with an internal GPS receiver by means of which the coordinates of the measurements were determined and recorded. The probing depth was 0.8 m when recording the value of the soil compactness measured at 0.01 m intervals. The measurements were carried out using a cone with a nominal diameter of 11.28 mm and an aperture angle of 30 °. The device was leveled using a spirit level installed in the casing, keeping probe deviation tolerance from the vertical not exceeding 3.5o during probing. The depth was measured with an ultrasonic sensor cooperating with the reference plate. The measurements of brevity were made with the average pressing speed of the penetrometer cone of 5 cm · s-1. Graphical and numerical analysis was carried out using the Penetro Wiever programme (Fig. 3).

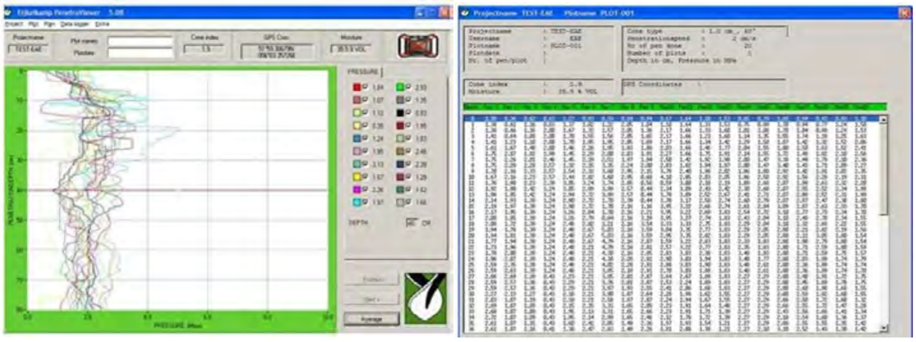


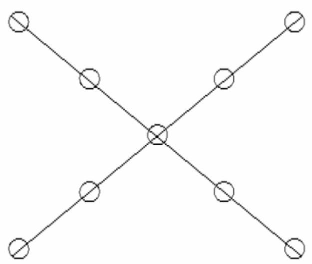
Fig. 3. Graphical and numerical course of soil compaction presented with the use of the Penetro Wiever programme

Methodology of measuring soil moisture

Soil moisture was determined using the ThePaProbe probe being part of the Penetrologger Eijkelkamp. In addition, soil moisture measurement was measured in randomly chosen measuring places using the drying method (Fig. 4). Measuring places of soil compaction were also places where soil moisture was measured. In order to determine the moisture profile of soil moisture measurement was made at three depths, i.e. 0.1 m, 0.25 m.

Fig. 4. A soil excavator enabling soil sampling and a soil sampling apparatus

Samples for laboratory tests concerning granulometric composition and soil richness in nutrients were located and collected only in places with significant differentiation resulting from maps of spatial variation of the working resistance of a reference tool. One sample consisted of samples taken from 9 places, arranged in the shape of a cross (Fig. 5) with the center at the point determined by the virtual grid of the geographical coordinates of the point. Soil laboratory analysis was carried out at the District Chemical and Agricultural Station in Krakow.



Source: BN-78/99180-11

Fig. 5. Sampling scheme at the measuring point

Methodology for determining overall porosity

Soil samples with an intact structure were collected annually before proceeding to the experimental cycle at three depths of the soil profile, i.e. 0-0.1, 0.1-0.2 and 0.2-0.3 m, within each experimental field. The characteristics of the water retention of the soil were determined in Richards pressure chambers, on ceramic plates (Klute, Dirksen 1986), taking moisture measurements for 7 different water potential values (-3,9, -15.6, -31.0, -77,9, -194.7, -491.7 and -1554.8 kPa). The moment of achieving the water potential balance in the samples was assessed on the basis of the water outflow registered by the burette system. The curves of soil water retention characteristics were determined based on the equation:

$$\theta = \frac{\theta_s}{\left[1+(\varphi h)^n\right]^{\left(1-\frac{1}{n}\right)}} \quad (1)$$

where: θ - water content [cm^3 cm^{-3}], h - water potential [kPa], θs - saturation water content [cm^3 cm^{-3}], calculated on the basis of total soil porosity, φi n - estimated parameters of the model.

The van Genuchten (1) model was adapted to the obtained water potential / moisture data by the non-linear estimation method. On the basis of the obtained soil retention characteristics, differential porosity was determined, with 5 pore fraction determined according to the Greenland classification (1981)

(Tab. I):
- binding pores (BS, bonding space),
- residual pores (RP, residua pores),
- water storage pores (SP, storage pores),
- water-permeable pores (TP, transmission pores),
- cracks and fissures (FS, fissures).

Based on the obtained data, the following was calculated:
- useful water retention (RU) for plants, as the difference in humidity between the field's water capacity (at water potential - 15.5 kPa) and the humidity of permanent wilting (at the water potential of -1554 kPa),
- production water (RP) retention, as the difference in moisture between the field's water capacity (at the potential of -15.5 kPa) and the humidity of the total inhibition of plant growth (at the potential of -491,7 kPa).

Table I. Classification of soil pores by diameter and the corresponding range of water potential.

Name	Diameter[µm]	Water potential [kPa]
Binding pores (BS, bonding space)	< 0,005	> -60 000
Residua pores (RP, residual pores)	0,005 – 0,5	-60000 – -600
Water storage pores (SP, storage pores)	0,5 – 50	-600 – -6,0
Water-permeable pores (TP, transmission pores)	50 – 500	-6,0 – -0,6
Cracks and fissures (FS, fissures)	> 500	< -0,6

Source: Greenland 1977

RESULTS AND DISCUSSION

Soil moisture

One of the soil parameters that is most often taken into account in the case of treatments included in the basic crop is the soil moisture. To a large extent depending on the humidity, the final effect of a given treatment depends on the energy expenditure of a given activity resulting from resistance to the active elements of tools and machines working in the soil. In the experiment, soil moisture was measured at a depth of 0.1 m and at a depth of 0.25 m, the depth to which spring soil cultivation usually reaches. The average value of soil moisture at a depth of 0.1 m was 15.5%, characterized by a small spatial diversity, at a level of 9%. The spatial distribution of soil moisture values within the studied field is shown in Figure 6.

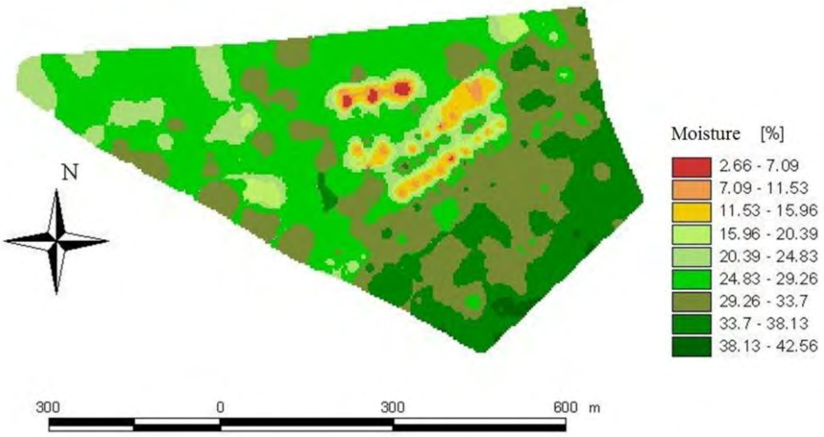


Fig. 6. Spatial distribution of soil moisture values at a depth of 0.1 m

Analyzing the spatial distribution of humidity at a depth of 0.1 m (Fig. 6), it was noted that the maximum humidity values (dark green color) were located in the south-eastern and southern part of the field. The lowest values (red and bright orange color) occurred in several places of the field, occupying in total a negligible area of the studied area. Similar observations are related to soil moisture (Fig. 7) recorded at a depth of 0.25 m.

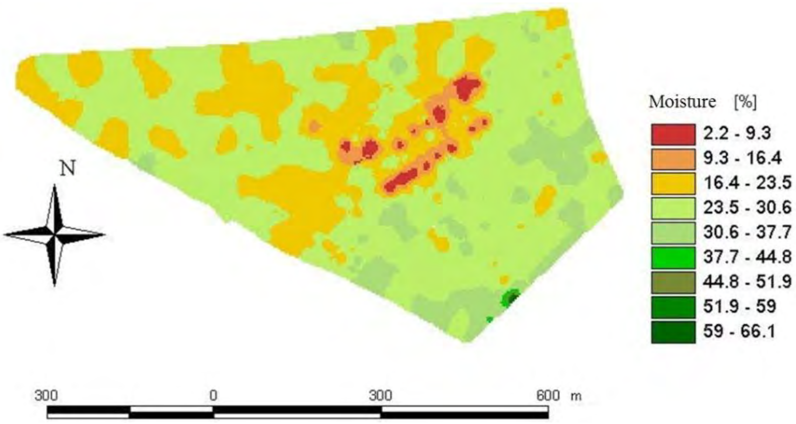


Fig. 7. Spatial distribution of soil moisture recorded at a depth of 0.25 m

It was observed that the average value of soil moisture was 18, characterized by a small spatial diversity of 7%. The lowest humidity values of 2.22% were consolidated in analogous points as in the case of soil moisture at a depth of 0.1 m (Fig. 6), however, they had a smaller surface overall. It can be observed that the variation in values of soil moisture is a derivative of the variation in humidity recorded at a depth of 0.1 m.

Soil compaction

The most important soil parameter that translates to a large extent on the resistance of the soil center to cutting tools is the compactness which can be measured with conical penetrometers. The advantage of such a measurement is that it is possible to assess the soil profile in terms of brevity in a relatively quick and minimally invasive way, and assigning geographical coordinates to measuring points enables digital maps of spatial differentiation of the field from the point of view of compaction. In the case of soil compaction at a depth of 0.05 m, it was noted that the average value of soil compactness was 0.4 MPa (Fig. 8) with a very high variation coefficient of 147%.

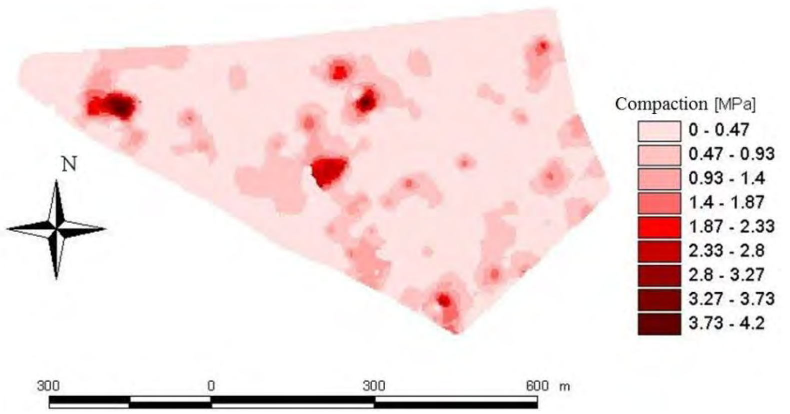


Fig. 8. Spatial distribution of soil compactness recorded at the depth of 0.05m

The range of oscillation of soil compaction at depth was 3.7 MPa, which was a significant value, especially at a depth of 0.05. Nevertheless, analyzing the spatially visualized distribution of compaction within the studied field, it was noted that the maximum values of the parameter analyzed (dark-red color) were of incidental character and were located in four points of the central and north-western part of the field. The lowest values of compaction (approx. 0.5 MPa), marked with a light pink color, dominated the majority of the tested field. Figure 9 shows the spatial differentiation of soil compactness recorded at a depth of 0.1 m, it should be noted that at the analyzed depth crop harvesting is most often carried out. The average value of soil compaction at the analyzed depth of the soil profile was at the level of 0.64 MPa, characterized by a 121% coefficient of variation. It was observed that the range of the measured value was 3.7 MPa, similarly as at the depth of 0.05 m. The lowest values of compaction occurred in the majority of the field, the color (light pink). On the other hand, the highest values occurred in several places of the field located mainly in the central and north-western part, however, they occupied a larger area in relation to the area occupied at a depth of 0.05m.

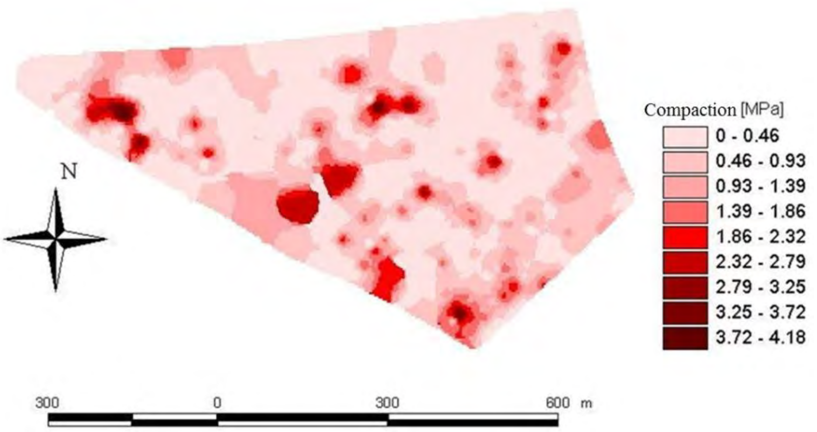


Fig. 9. Spatial distribution of soil compaction recorded at a depth of 0.1 m

Similar observations concern soil compaction (Fig. 10) recorded at a depth of 0.15 m.

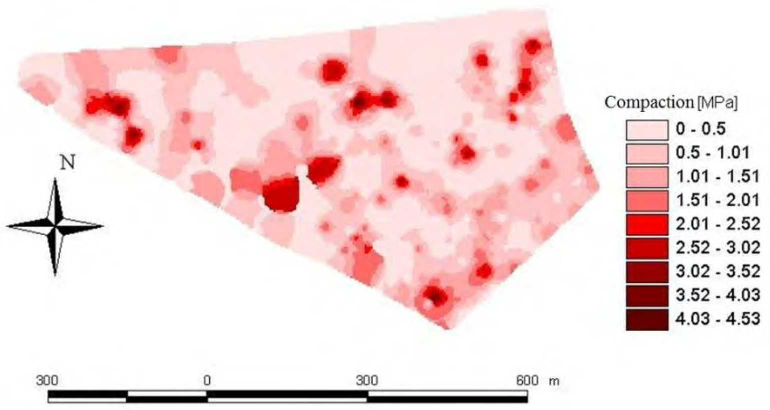


Fig. 10. Spatial distribution of soil compaction recorded at a depth of 0.15m

It was noted that the average value of soil compaction recorded at a depth of 0.15 m was 0.77 MPa and 47% higher than the average soil compaction recorded at a depth of 0.05 m. The range of reported compaction values was from 0.25 MPa to 4.53 MPa, which translates into more than 100% coefficient of variation. It proves a great diversity of soil compaction within the examined field. The structure of spatial diversity of soil compaction is a derivative of soil compaction recorded at a depth of 0.1 m (the highest values of compaction of over 2 MPa were consolidated at several points in the central and north-western part of the field, and the lowest were recorded in the northern and north-eastern part of the study area Fig. 11 presents spatial distribution of soil compaction, recorded at a depth of 0.2 m, that is at the depth of plowing.

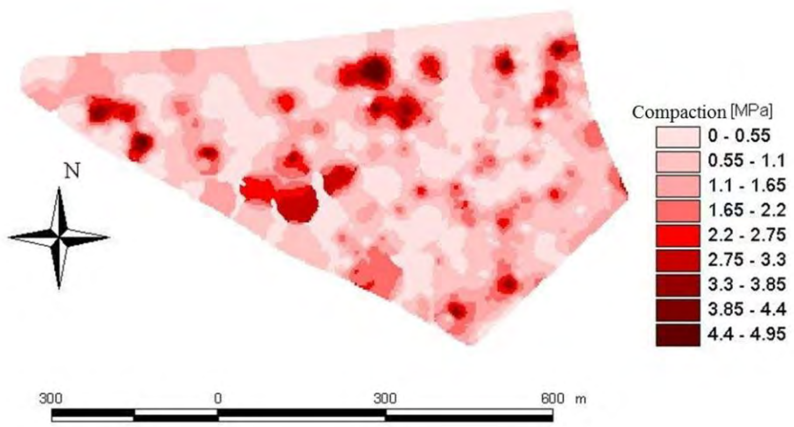


Fig. 11. Spatial distribution of soil compaction recorded at a depth of 0.2 m

It was observed that the mean value was 1.04 MPa with a variation coefficient of 103%, which indicates a wide variation of the soil center in which the experiment was performed. The lowest values of compaction occurred in the northern and north-eastern part (light red color), and the highest values of compaction were consolidated in several small areas located in the central part of the field (dark red color). At a depth of 0.25 m, soil compaction (Fig. 12) was higher by 26%, amounting to 1.36 MPa in relation to soil firmness recorded at a depth of 0.2 m.

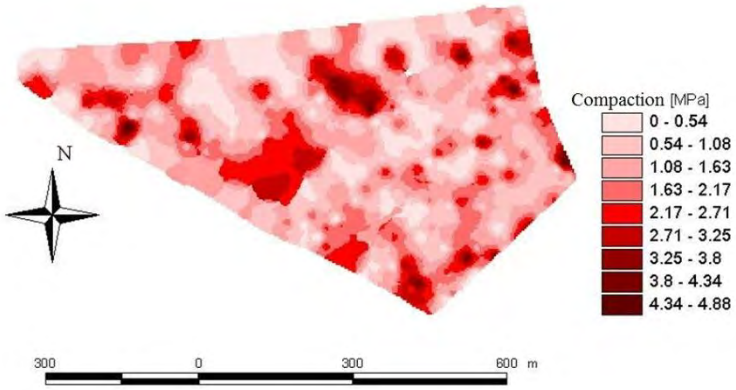


Fig. 12. Spatial distribution of soil compaction recorded at a depth of 0.25m

The range of oscillation of the compaction value was 4.2 MPa with a variation coefficient of about 80%. The lowest values of soil compaction were characterized by north-western and northern parts of the field. It should be noted, however, that the maximum values of compaction (dark red color) were of incidental character and were located in the central-western and northern part of the field, occupying a larger area in relation to the occupied surface at the smaller depths of the soil profile. In the case of soil compaction at a depth of 0.3 m (Figure 13), it was noted that the average value of soil compaction was 1.72 MPa.

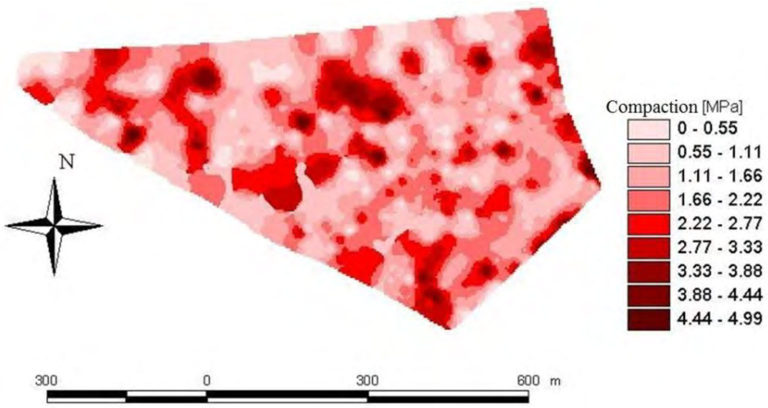


Fig. 13. Spatial distribution of soil compaction recorded at a depth of 0.30m

A slightly higher soil compaction value of 1.96 MPa was characterized by the soil profile to a depth of 0.35 m (Fig. 14). The coefficient of variation was at the level of 60%, indicating a relatively significant differentiation of the soil center in terms of the measured size, taking into account the depth of the soil profile. The highest values of compaction were recorded in the southern and north central part of the field as well as western areas of the studied area. On the other hand, the lowest values of soil compaction were consolidated in small points of the northern and north-eastern part of the field.

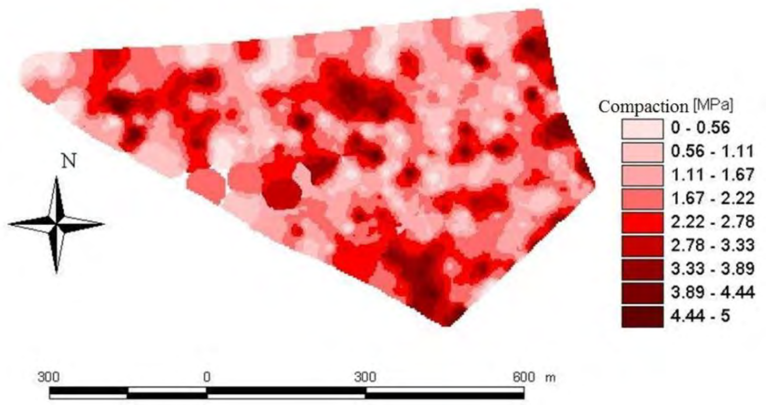


Fig. 14. Spatial distribution of soil compaction recorded at a depth of 0.35 m

Figure 15 shows the visualized distribution of compaction at a depth of 0.4 m, which is the depth to which basic cultivation reaches.

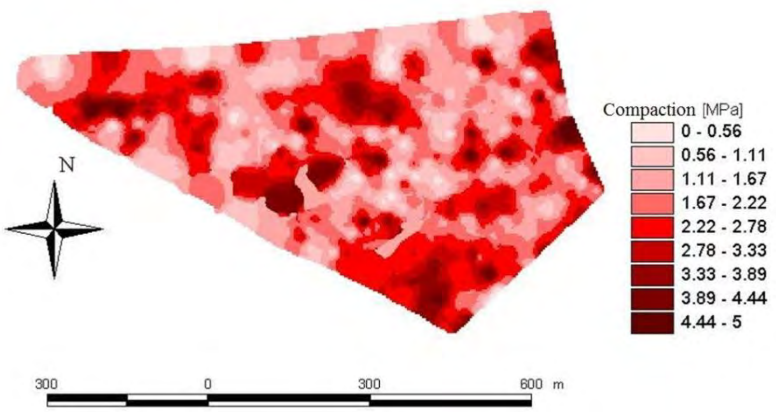


Fig. 15. Spatial distribution of soil compaction recorded at a depth of 0.40 m

It was noted that the average value of soil compaction was at the level of 2.0 MPa, while the range of soil compaction oscillation was similar to the depth of 0.35 m over 4.5 MPa, which indicates a relatively large variation in the measured value, but it should be noted that spatial analysis does not confirm a large spatial diversity and the range of variation was influenced by individual points of the tested field in which the compaction was significantly different but in terms of area of the above-mentioned. the points occupied a negligible area. A further increase in the penetration depth of the soil profile translated into an increase in soil compaction, the mean value of which at the depth of 0.45 m was 2.2 Mpa (Fig. 16) with a variation coefficient of 53%.

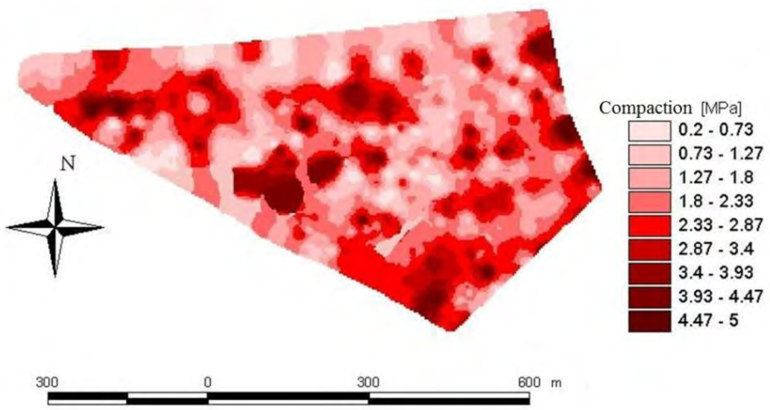


Fig. 16. Spatial distribution of soil compaction recorded at a depth of 0.45M

The highest value of soil compaction was characterized by the southern and north-central and eastern areas of the field under investigation. The lowest values of soil compaction were consolidated at small points in the north and north-west and the central part of the field. Slightly lower soil compaction of 2.08 MPa was found at a depth of 0.5 m, which would indicate the occurrence of the so-called plots, which depth would oscillate between 0.45 m and 0.5 m. Figure 17 shows the spatial variation of soil compaction observed at a depth of 0.6 m

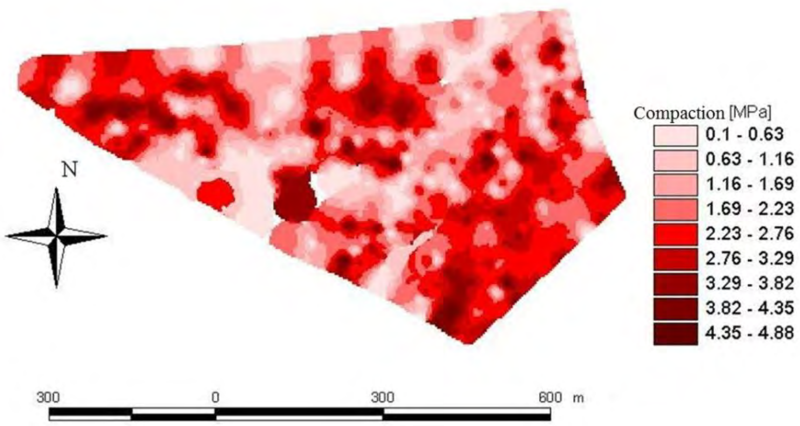


Fig. 17. Spatial distribution of soil compaction recorded at a depth of 0.60 m

In the case of soil compaction at a depth of 0.60 m, it was noted that the average value of compaction was 2.07 MPa with a variation coefficient of 50%. The range of oscillation of the value of soil compaction at depth was over 4.5 MPa. Analyzing the spatial distribution of compaction (Fig. 17), it was noted that the maximum values of soil compaction occur in the south-eastern central and north-western part of the field. However, the lowest values of compaction occupy a small area (light pink color), concentrating in the northern part of the field, especially on its outskirts.

Soil porosity

The soil differential porosity was determined on the basis of water retention curves of the examined soil (Fig. 18) plotted for three depths of the soil profile, i.e. 0.1 m, 0.2 m and a depth of 0.3 m. It was observed that so-called pF curves after exceeding 10 kPa overlap and there are no differences between them up to the maximum pressure.

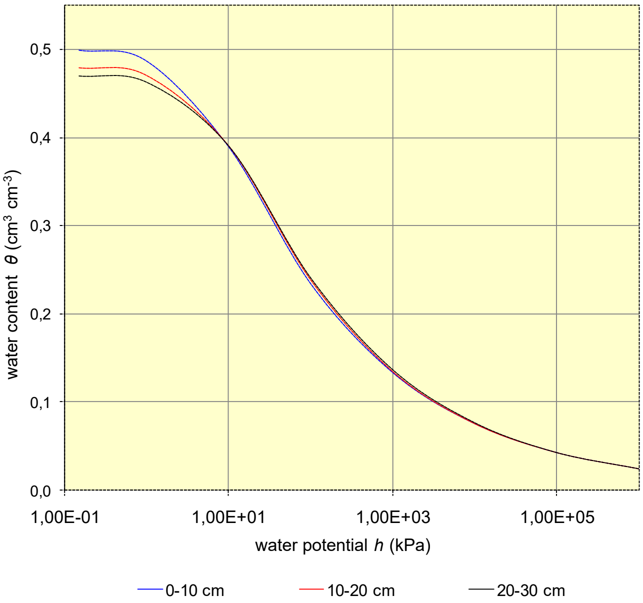


Fig. 18. Water retention curves

Analyzing the content of mesopores (Fig. 19) at individual depths of the soil profile, there were no significant differences in average values, which ranged at 24%.

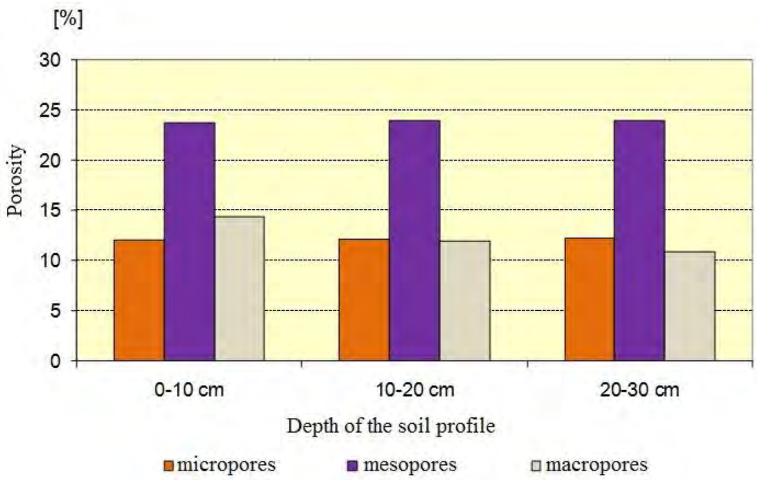


Fig. 19. Water retention curves

The highest content of macropores, amounting to almost 15%, was characterized by soil in the layer up to 0.1 m, while in layers of deeper soils, the macropore content decreased and in the soil layer at the depth above 0.2 m it was about 11%. However, in the case of micropores, an opposite trend was observed in relation to macropores, i.e. the highest micropore content of 12% was found in the deepest layer of soil and the lowest was recorded at the depth of 0.1 m, where the value of micropores was 11%.

CONCLUSION

Significant relations between the soil compaction and its moisture within the area of the tested field were observed, where the variability of the amount of water was very large. It has been noted that the range of variability of soil compaction at the working depth of machines for basic cultivation is at the level of 60%, which justifies the attempt to conduct precise soil cultivation. Whereas the range of oscillation of the compaction value oscillated between 0.1 MPa and 5 MPa, nevertheless the highest values of compaction were recorded at a depth of 0.45 m, which indicates the presence of the plow sole. The studies justified the need to highlight the so-called limit soil compaction, which qualifies the given soil layer as the one with the established plow sole. The issue is complicated by the diversity of the degree of compaction within different soils, which enforces an individual approach in principle to each analyzed field. On the fields covered by the research, the soil belonged to the species: "silt dust" [NB-78 / 9180-11], giving on the one hand great opportunities for exploitation research, but on the other hand very limited by the "minute" duration of the experiment. Heterogeneity of the soil on the entire field area is conducive to the presence of plow plows in some areas, which in addition to local soil anomalies is also the result of crop errors, which underlines the necessity to identify and spatial separation of such areas within the field's surface.

ACKNOWLEDGEMENTS

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REFERENCES

Bajla, J., Walczykova, M., Štrba, M., Benda, I. 2005. The evaluation of the horizontal soil resistance with an application of stochastic process theory [in Polish: Ocena poziomego oporu gleby z wykorzystaniem teorii procesów stochastycznych]. Inżynieria Rolnicza, 10(70):13-21.

Bengough, A. G., Mullins, E. C., 1990. Mechanical impedance to root growth: a review of experimental techniques and root growth responses. Journal of Soil Science, 40: 341-358.

Buliński, J., Majewski, Z. 1998. Evaluation of discrepancies in soil compactness measurement results in different test conditions [in Polish: Ocena rozbieżności wyników pomiaru zwięzłości gleby w różnych warunkach wykonywania badań], Problemy Inżynierii Rolniczej. 2: 5-12.

Cook, A., Marriott, C. A., Seel, W., Mullins, E.C. 1996. Effects of soil mechanical impedance on root and shoot growth of *Lolium perenne* L., *Agrostis capillaris* and *Trifolium repens* L. Journal of Experimental Botany, 47: 1075-1084.

Dexter, A. R. 1986. Model experiments on the behaviour of roots at the interface between a tilled seed bed and a compacted subsoil. Plant and Soil, 95: 123-133.

Faber, A. 1998. The precise agriculture system is an opportunity to reduce the threats to the natural environment [in Polish: System rolnictwa precyzyjnego szansą na ograniczenie zagrożeń dla środowiska przyrodniczego]. Frag. Agron, 79(3): 52–64.

Greenland, D. J. 1977. Soil damage by intensive arable cultivation: temporary or permanent? Phil. Trans. R. Soc. Lond. B 1977. 281: 193-208; DOI: 10.1098/rstb.1977.0133.

Greenland, D. J. 1981. Soil management and soil degradation. J. Soil Sci., 32: 301-322.

Klute, A., Dirksen, C. 1986. Water retention. Laboratory methods. In: A. Klute (Ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. SSA Book Series: 5.

Kroulík, M., Kumhála, F., Mimra, M., Prośek, V. 2004. Possibilities for determination of interdependence between soil properties and yield. AgEng, Leuven 2004, Book of abstracts. 80-81.

Kroulík, M., Prošek, V. 2000. Uplatní se možnost lokálne diferencovaného zpracowani pudy. Mechanizace zemedelství. Mechanizace zemedelství, 3.

Lejman, K. , Owsiak, Z. 1996. Analysis of the parameters of the cone's cone [in Polish: Analiza parametrów stożka zwięzłościomierza]. Zeszyty Problemowe Postępów Nauk Rolniczych, 425: 121-126.

Lipiec, J., Hakansson, I., Tarkiewicz, S., Kossowski, J. 1991. Soil physical properties and growth of spring barley related to the degree of compactness of two soils. Soil and Tillage Research, 19: 307-317.

Lipiec, J., Stępniewski, W. 1995. Effect of soil compaction and tillage system on uptake and losses of nutrients. Soil and Tillage Research, 35: 37-52.

Lipiec, J., Medvedev, V.V., Birkas, M., Dumitru, E., Lyndina, T. E., Rousseva, S., Fulajtar, E. 2003. Effect of soil compaction on root growth and crop yield in Central and Eastern Europe. International Agrophysics, 17: 61-70.

Potter, K. N., Chichester, F. W. 1993. Physical and Chemical Properties of a Vertisol with Continuous Controlled-traffic, No-till Management. Transactions of the ASAE. 36(1): 95-99. (doi: 10.13031/2013.28319) @1993.

Taylor, H. M., Brar, G. S. 1991. Effect of soil compaction on root development. Soil and Tillage Research, 19: 111-119.

Walczykova, M. 1995. Selected technical and technological aspects of kneading agricultural soils with tractor aggregates [in Polish: Wybrane techniczne i technologiczne aspekty ugniatania gleb rolniczych agregatami ciągnikowymi]. Zeszyty naukowe Akademii Rolniczej w Krakowie. Nr 202.

Walczykova, M., Walczyk, J. 1992. Application of computer technology in studies on soil compactness [in Polish: Zastosowanie techniki komputerowej w badaniach zwięzłości gleby]. Zeszyty Naukowe Akademii Rolniczej w Krakowie, 268: 3-12.

Walczykova, M., Zagórda, M., Aboud, Z. 2005. Spatial soil volatility in the aspect of its selected physical properties [in Polish: Zmienność przestrzenna gleby w aspekcie jej wybranych właściwości fizycznych]. Inżynieria Rolnicza, 10(70): 385-394.

Walczykova, M., Kiełbasa, P., Zagórda, M. 2016. Acquisition and use of information in agriculture: monograph [in Polish: Pozyskanie i wykorzystanie informacji w rolnictwie: monografia]. Polskie Towarzystwo Inżynierii Rolniczej ISBN 978-83-64377-03-7.

Walczykova, M. , Zagórda, M. 2017. The possibilities of reducing the compacted field area in selected crop rotation, EJPAU 20(4), #13. [Online]. Available at: http://www.ejpau.media.pl/volume20/issue4/art-13.html. [Accessed: 2018, August 25].

[Online]. Available at: www.agropogoda.pl/powierzchnia-zasiewow-zboz-w-201. [Accessed: 2018, August 23].

PN-R-04031. 1997. Soil chemical and agricultural analysis - Sampling [in Polish: Analiza chemiczno-rolnicza gleby - Pobieranie próbek].

New techniques in agricultural water management

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Abstract: A review of lysimeter research is presented involving the brief history of studies with lysimeters, describing the main lysimeter types and introducing the lysimeter related experiments carried out at (RIK) recently involving our main scientific achievements. Research activities with lysimeters have significant role in agricultural science in Europe: 2985 measuring devices (89.5% lysimeters) representing 148 stations and 20 countries are registered by the Lysimeter Research Group. The state-of-the-art of agricultural related lysimeter research involves the precise determination of the elements of the hydrological balance (even the amount of dew), water use efficiency studies (even for specific environmental conditions), irrigation and climate change relations, and nutrient loss and contamination issues.

Lysimeter researches have been carried out at RIK since 1983, in this paper some characteristic experiments and the results gained from them are reviewed in order to demonstrate the versatile utilization possibilities of lysimeters serving soil management researches. There three types of lysimeters operated at RIK making it unique in Hungary: 8 lysimeters with compensation system, 30 simple drainage lysimeters (26 were reconstructed and are used recently), and 6 electronic weighing lysimeters. On the base of the scientific and practical experiences gained during the long-term operation of the weighing lysimeters at Karcag, we figured out that the facilities provide very accurate data that can contribute to the better understanding of the salt- and water balance of the soil especially regarding the evaporation moderating effect of water preserving soil cultivation systems, the water use efficiency of different crops, the optimization of irrigation, and the mitigation of the harmful effect of secondary salinization.

Keywords: lysimeters, water balance, soil management, water use efficiency

INTRODUCTION

The Research Institute of Karcag, Institutes for Agricultural Research and Educational Farm, University of Debrecen (RIK) is situated in the Trans-Tisza Region of the Great Hungarian Plain, in the eastern part of Hungary. The ecological conditions of this region are unfavourable from several points of view. The low amount of annual precipitation (500 mm) and the high evapotranspiration result in a shortage of moisture of 100-300 mm in the vegetation period, which means a limiting factor of crop production by itself. But the so called "air-drought" makes the situation worse in the summer months. These effects cause considerable damages in quantity and quality for the regional crop production. The unfavourable soil conditions of our region must be mentioned as the third limiting factor. Significant rate of our heavy textured soils with bad water-, air- and heat regime is endangered by salinization. These unfavourable factors altogether give the reason why our institute emphasise the research of water- and salt balances of the soils of our region. In 1983-84 our institute established a compensation lysimeter station for the completion of the research results of our large-scale amelioration and water regulation experiments (Karuczka and Zsembeli, 1997). The main goal was the examination of vertical substance movements and calculation of water- and substance balances of soil monoliths. Because of the necessity of more accurate water balance measurements the lysimeter station was enlarged with 6 weighing lysimeter units in 1992-1993.

In this paper we give a review of lysimeter research presenting the brief history of studies with lysimeters, describing the main lysimeter types and introducing the lysimeter related experiments carried out at RIK recently involving our main scientific achievements.

MATERIAL AND METHODS

The term "*lysimeter*" was derived from the Greek words "*lysis*" and "*metron*" meaning dissolving and measuring, respectively. The term is thus applicable to any device utilized for studying the rate, amount and composition of percolation water through a porous medium. Indeed, many definitions refer to "instruments or devices that contain soil and receive natural rainfall or irrigation and are provided with an arrangement for collecting and measuring the percolate". Percolation is an important phase of the hydrologic cycle; it recharges groundwater and discharges into streams (Aboukhaled et al., 1982). For McIlroy and Angus (1963), a lysimeter consists of "a block of soil, together with vegetation, if any, enclosed in a suitable container and exposed in natural surroundings to permit determination of any one term of the hydrologic equation when the others are known". Similarly, Tanner (1967) refers to a "device in which a volume of soil, which may be planted to vegetation, is located in a container to isolate it hydrologically from the surrounding soil in order to assess or control various terms of the water balance equation". The WMO (1968) uses the term "evapotranspirometers" or "soil evaporimeters" for "containers of soil and vegetation from which the water loss is measured by weighing or accounting for all incoming water at the surface and all outflow from the bottom of the container". Hiller et al. (1969) defined lysimeters as "large containers filled with soil, generally located in the field to represent the field environment, and in which soil-water-plant conditions can be regulated and monitored more conveniently and accurately than in natural soil profile".

There several types of lysimeters, the main types are introduced here according to Aboukhaled et al. (1982). Basically we distinguish volumetric and weighing lysimeters.

Weighing lysimeters

Changes in weight of the lysimeter container are a direct measurement of incoming and outgoing water flow. An increase in weight refers incoming water through rainfall or irrigation. A decrease in weight refers to water loss through evapotranspiration and drainage. Drainage water is collected in containers attached to the lysimeter and measured periodically. Weighing lysimeters allow very accurate monitoring of crop evapotranspiration over short intervals. Their complexity in installation and higher construction costs, however, make their application rather limited to specialized research stations. A major difficulty is the accurate measuring and recording of small weight changes in relation to large and heavy soil masses. Different weighing principles and devices are applied with varying degrees of success.

a. Mechanical weighing lysimeters

Different types of mechanical balances are used to measure directly changes in weight of the container and soil mass due to evapotranspiration, precipitation or irrigation. The provision of an outer container or retaining walls allows free movement of the inner container enclosing the soil mass and crop. The inner container is either weighed periodically by lifting from its support or is placed directly on a specially designed mechanical balance which constantly records changes in weight of the container.

b. Electronic weighing lysimeters

Changes in weight of the inner container and soil mass are measured electronically using strain gauges or electric load cells. The inner container is often placed on a balancing frame which, through counterweights, reduces the actual weight on the strain gauge.

c. Weighing lysimeters with hydraulic load cells

The total weight of the lysimeter is distributed over hydraulic load cells (flexible bags, "pillows" or pressure bags) and the pressure of the fluid in the load cells is read on a manometer.

Changes in weight of the lysimeter due to evapotranspiration, irrigation or precipitation cause a change in the height of the fluid in the manometer. The manometer readings require calibration, which is obtained either by static or dynamic calibration. The static procedure involves adding or removing known weights and finding the corresponding manometric height changes. The dynamic calibration (Bloemen 1964; Middleton 1972) is obtained by placing a container with a volume of water on the lysimeter from which water is discharged outside the lysimeter, at a constant rate. At equal time intervals the weight changes versus manometric changes are plotted.

d. Floating lysimeters

The soil container floats in a suitable liquid (H_2O or $ZnCl_2$) held in the outer container (hydrostatic floatation or Archimedes principle). Changes in the weight of the lysimeter due to evapotranspiration or irrigation are measured by changes in buoyancy and floatation of the liquid level. Lysimeters based on this principle have been reported by King, Tanner and Suomi (1956), Popov (1959), McMillan and Burgy (1960), Brooks and Pruitt (1966), Lourence and Goddard (1967) and WMO (1974). Hybrid systems using both buoyancy and mechanical balances have also been reported (Aslyng and Kristensen 1961).

Lysimeter researches have been carried out at RIK since 1983. During those 35 years several information was gained concerning the water- and salt balance of the soils by means of these devices. There three types of lysimeters operated at RIK making it unique in Hungary: 8 lysimeters with compensation system, 30 simple drainage lysimeters (26 were reconstructed and are used recently), and 6 electronic weighing lysimeters. The photo of the lysimeter station of RIK is shown in Fig. 1.

Figure 1: The lysimeter station at RIK

The depth of the lysimeters is 10 cm, the surface area is 1.6 m^2. The type of the soil that was filled into the lysimeters is meadow chernozem salty in the deeper layers, same as in the case of the soil filled into the simple drainage lysimeters (*Table 2*).

The parameters and their measurement frequency determined for the weighing lysimeters: change of weight (10 minutes), amount of seepage (drain) water (weekly), soil moisture content and temperature at the depths of 0-10, 10-20, 20-30, 30-40 cm (occasionally).

According to the principle of weighing lysimetry, our facility is suitable for the calculation of the water balance of each unit. The adequate water balance equation valid for the given situation is as follows:

$$P + I = E + D + WB$$

where P = precipitation (mm), I = irrigation water (mm), E = evaporation (mm), D = drain water (mm), WB = water balance, change of soil moisture content (mm). As WB = ΔW, water balance equals the change of the weight of the soil column, its value can be expressed by reducing the input and output factors:

$$\Delta W = P + I - E - D$$

As all the factors of the water balance equation, except for evaporation, can be measured and expressed in mm, the evaporation value can be calculated as follows:

$$E = P + I - D + \Delta W$$

The accuracy of the calculation depends on the measurement accuracy of the components, which is 0.06 mm in the case of the change of weight. This accuracy ranges the lysimeter system to the category of high precision lysimeters.

Furthermore meteorological parameters (continuous), evaporation of open water surface (daily) are determined to all three lysimeter types, and soil samples are taken regularly (usually two times a year: at the beginning and at the end of the irrigation season).

RESULTS AND DISCUSSION

In this paper some characteristic experiments and the results gained from them are reviewed in order to demonstrate the versatile utilization possibilities of weighing lysimeters serving soil management researches.

Determination of the evaporation moderating effect of soil cultivation methods with weighing lysimeters

The determination of the effects of technological elements influencing the soil water regime (mulch layer, heat isolating soil surface, mitigation of cracking, etc.) can contribute to the elaboration of water preserving technologies as the elements of up-to-date and sustainable crop production. The control of soil water regime is an effective environmental protective process at the same time, which is of great importance to prevent soil degradation and to mitigate the pollution of our water funds.

We numerically determined the half-year water balances (and their components) of the soil columns with different surfaces created by the modelling of various soil surface formation and covering methods. We figured out the probable reasons of the experienced differences and the effects of different periods, especially of the extremely dry or wet periods, on the water regime of the soil (Zsembeli, 1999; Zsembeli, 2002).

On the base of the half-year results we evaluated the effect of different soil surfaces created by the examined soil cultivation treatments on the soil water balance. By means of the method of regression analyses we tried to find a correlation between the amount of water input (precipitation, irrigation) and output by evaporation of the soil columns. We found close exponential correlation between the examined variables (*Fig. 4*).

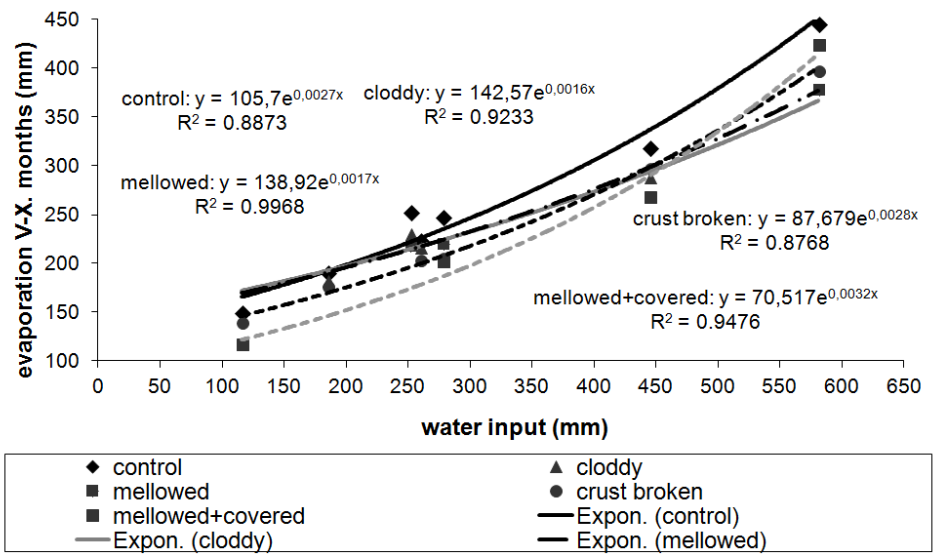

Figure 4: Correlation between water input and evaporation on the base of the half-year water balance data

According to the results we ranged the examined five treatments into three different groups. We established that probably there is a certain amount of water input, where practically there is no difference in the amount of water evaporated from the soil columns of the cultivated treatments. We also figured out that the treatments that have evaporation decreasing effect in the lower water input range, in case of water load higher than the average, loose more water by evaporation. We used indexes for the assessment of evaporation mitigating and infiltration increasing effect of the investigated treatments (*Table 6*). The higher is the rate of evaporation and the amount of input water, the lower is the mitigating effect of the given treatment (soil surface formation), while the higher is the rate of the amount of drain and input waters, the higher is the infiltration increasing effect.

Table 6: Assessment of the effect of five treatments on the water balance of the soil column

Treatment	**Evaporation mitigating effect evaporation/input**	**Infiltration increasing effect drain water/input**
control	94%	14%
cloddy	85%	17%
mellowed	84%	20%
mellowed + crust broken	77%	22%
mellowed + covered	77%	31%

d. Determination of water use efficiency of crops with weighing lysimeters

Various plants can be examined in weighing lysimeters, the practical limit is the size only. Since the establishment of the weighing lysimeter system at Karcag several plants have been applied in order to calculate their water use efficiency: millet, sunflower, maize, sorghum, energy willow, and recently Miscanthus. Either different plant species, varieties (hybrids), or various amounts water input were compared.

Some water use parameters of maize and sorghum of the investigated periods of 2009-2010 are shown in *Table 7*. The evapotranspiration in the function of the total water input index shows whether the water balance was negative or positive, in other words if the water supply was sufficient (100% or below) for the crop, or insufficient meaning that the crop decreased the moisture fund of the soil. In 2009 the water balances were negative, 5% of the water transpirated by maize originated from the soil moisture fund, while 17% in the case of sorghum. This result is in harmony with the literature data stating the soil drying capability of sorghum. In 2010 two sorghum hybrids had slightly negative water balance, while one hybrid showed positive balance, only 83 percent of the total water input was used for evapotranspiration. It must be mentioned that the hybrid Albita is a grain sorghum, while Berény and Sucrosorgo are sweet sorghum hybrids with much higher green mass (Zsembeli et al., 2011).

Table 7: Water use parameters of the indicator crops in the lysimeters

	Maize 2009	Sucrosorgo 2009	Sucrosorgo 2010	Berény 2010	Albita 2010
Precipitation (mm)	175.9	175.9	402.8	402.8	402.8
Irrigation (mm)	280	280	45	45	40
Total water input (mm)	455.9	455.9	447.8	447.8	442.8
ET (mm)	478.5	533.13	459.9	454.4	369.7
ET/water input (%)	105	117	103	101	83

In order to assess the effect of water input (irrigation) on the water balance of maize and sorghum further, the yield data were also used (*Table 8*). We measured the total biomass for all indicator crops, the corn-cob mass was determined for maize, while for sorghum the sugar content was measured. Naturally the biomass yields of the two crops cannot be compared directly, but they were used as the base of further calculations for determining the water use efficiency. As we experienced different values of ET, the question arose if the water use efficiencies of the two crops are different as well. In other words, some economic calculations can answer the question whether the bigger biomass or yield can compensate the higher input originating from the higher water consumption. As the hydrological approach of this question some indexes characterising the water use efficiency of the crops were calculated. These indexes can be the bases of further economic calculations.

Table 8: Water use efficiency indexes in the function of yields in 2009

Index	Maize	Sorghum
Total biomass (g/m^2)	3300	5100
Biomass/ET (g/mm)	6.9	9.6
Corn-cob mass (g)	2700	-
Sugar content (%)	-	18.9
Sugar yield (g/m^2)	-	964
Corn+cob mass/ET (g/mm)	5.64	-
Sugar yield/ET (g/mm)	-	1.8

The total biomass production of maize and sorghum in the function of ET describes how much plant biomass was built up by using 1 mm of water through evapotranspiration during the investigated period. The results of 2009 show a relatively higher water consumption of maize as it consumed less water in total, but approximately 30% more for producing the same amount of biomass. This difference obviously originates from the higher biomass production of sorghum, but also means a better water use efficiency of it.

In *Table 9* the water use efficiency indexes calculated for the yields of the sorghum hybrids in 2010 are shown. These values can be compared to other results gained under similar conditions and also to the results of other years. Hybrid Sucrosorgo was studied both years. There was considerable difference in the total biomass yield as the water supply was much satisfactory in the wet year of 2010 (positive water balance). The other two sorghum hybrids had lower biomass production, which was expected in the case of Albita, the grain sorghum hybrid. Berény, the other sweet sorghum hybrid had the highest sugar content, but still generated lower total amount of sugar due to its lower biomass yield. Albita, the grain sorghum hybrid generated 20-30% less sugar than the sweet ones, and although consumed 20% less water, still it needed the highest amount of water to generate 1 g of sugar.

Table 9: Water use efficiency indexes in the function of yields of sorghum in 2010

Index	Sucrosorgo	Berény	Albita
Total biomass (g/m2)	8900	7000	3400
Biomass/ET (g/mm)	19.4	15.4	9.2
Sugar content (%)	15	17	11.5
Sugar yield (g/m2)	1335	1190	391
Sugar yield/ET (g/mm)	2.9	2.6	1.1

e. Determination of the amount of dew with weighing lysimeters

The determination of the dewfall periods was done on the base of the weight data recorded by means of a weighing lysimeter system of RIK. The basis for calculation was a water balance equation with measured quantities on the left-hand side and the (yet unknown) boundary fluxes between soil and atmosphere on the right-hand side:

$$\Delta W + SW = P + I - ET$$

where ΔW = change of profile water content, SW = seepage water at lysimeter outlet, P = precipitation on the lysimeter, I = irrigation on the lysimeter, ET = evapotranspiration from the lysimeter; all dimensions are lengths.

The fundamental dataset contained 10-min-data of lysimeter mass (changes equalling changes of water content) and seepage water collected at the bottom outlet of the lysimeters, from which a nominal time series (W+SW) was calculated. The determination of the dewfall periods was done on the base of the weight data recorded by means of the weighing lysimeter system. Those periods are considered dewfall periods when positive weight changes are recorded by the lysimeters and at the same time neither natural precipitation nor irrigation occurred. The amount and duration of the natural precipitation data were determined on the base of the records with 10 minutes frequency of the meteorological station (belonging the official national network operated by the National

Meteorological Service of Hungary) located in the territory of RIK at approximately 250 m distance from the lysimeter station. During the investigation period (1st April 2015 – 30th September 2016) the measurement frequency of the weight data of the lysimeters was also 10 minutes in order to harmonize them with the meteorological data. The weight changes of two weighing lysimeters – a grass covered and another with bare soil surface – were determined for each day of the investigation period and put an Excel data base.

Analysing all the weighing data of our data base we signed those periods when positive weight changes were characteristic regardless their extent. All these periods were compared to the precipitation data gained by means of the meteorological station and we determined such periods when positive weight changes are recorded by the lysimeters and at the same time neither natural precipitation nor irrigation occurred. For those periods we calculated the daily water balances of the soil columns of the lysimeters taking all the relevant inputs and outputs into consideration according to equation described above.

By means of this dewfall identification method based on the filtering we determined the daily amounts of dew fallen on the grass covered and bare soil lysimeters during all the 549 days of the whole investigation period and calculated the total values. Altogether 43.11 mm dew was detected on the grass covered surface calculated on the base of the water balance data during the 18 months of the investigation period. In order to judge this amount being high or low, we can compare it to the literature data, but unfortunately we have no data for a complete year from January to December yet.

According to the relevant literature the largest chance of dew formation is during the summer months as the conditions of the condensation of water vapours. The dew formation is more when the sky is clear and less when it is cloudy. In a typical summer day, when the sky is clear and the ground and plant surfaces are cooler at nights, there is more evaporation of water and hence more dew formation. When it is cloudy, the ground and plant surfaces do not get cool in the night and hence there is less dew formation. Contrary to these, the amount of dew measured on the grass covered soil surface in the 6 summer months (June, July, August of 2015 and 2016) was only 6.58 mm giving 15% of the total 18 months (*Fig. 5*). The dewiest period was detected on the grass covered surface in the three-month-long period between November 2015 and January 2016 with its 13.77 mm (40% of the total amount). Obviously most of the dew precipitated during this period was frost.

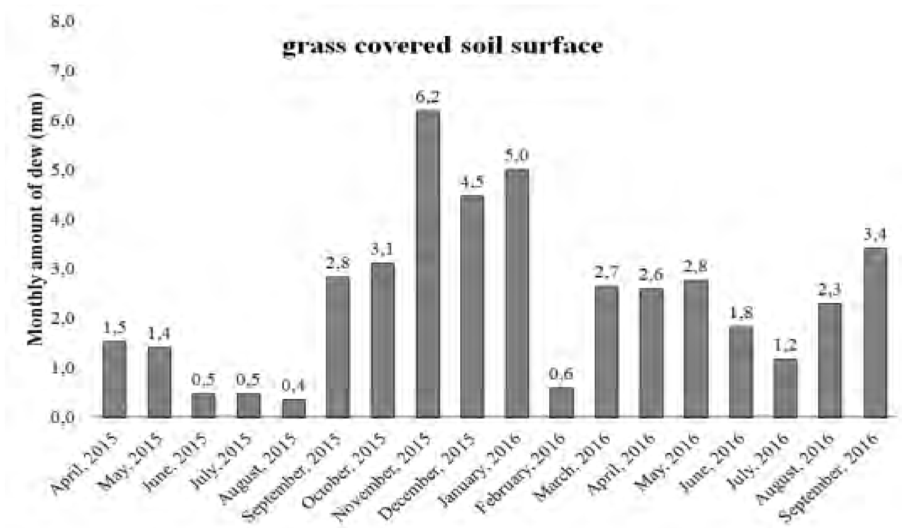

Figure 5: Monthly dew amounts measured on the grass covered lysimeter

In the case of the bare soil surface a bit more even time distribution of dew formation was characteristic (*Fig. 6*). The amount of dew measured on bare soil surface in the 6 summer months (June, July, August of 2015 and 2016) was 14.11 mm giving 28% of the total 18 months. The dewiest period was also during the period from November 2015 to January 2016, but with somewhat lower amount (9.65 mm) and percentage (20% of the total amount). Extreme amount of dew was detected in September 2016 with its 7.29 mm.

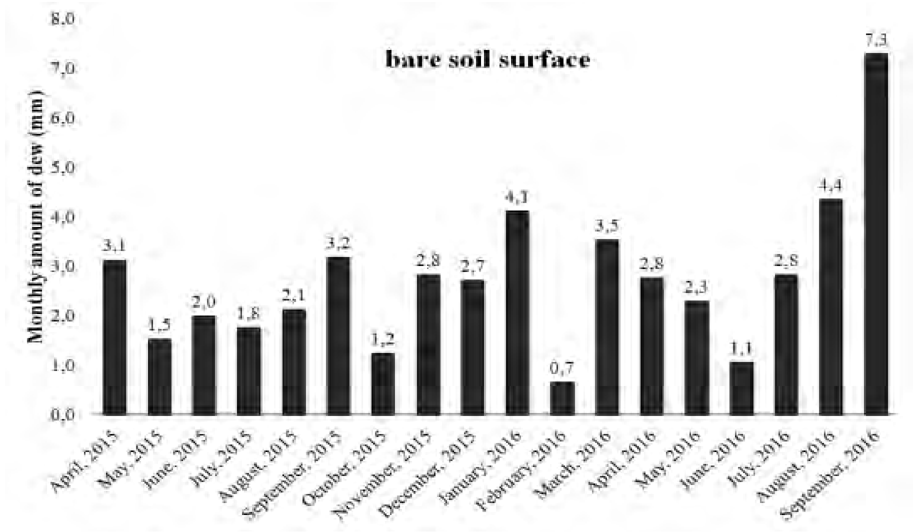

Figure 6: Monthly dew amounts measured on the lysimeter with bare soil surface

CONCLUSIONS

In the Great Hungarian Plain the most important ecological factor determining the development of agricultural production is water. There is long tradition of the efforts focus on saving water in agricultural use of water. Irrigation researches of the last century made it obvious that irrigation can be used only conditionally (strictly taking its environmental impacts as secondary salinization, soil degradation, etc into consideration) on large areas due to the special ecological and soil conditions of the Great Hungarian Plain. Therefore other approaches (water saving soil cultivation, application of crops with high drought tolerance) can be the solution of this problem. Researches focus on the control of the water- and salt regime in order to improve the efficiency of water use are of great importance. In accordance with the combat against drought damages and soil degradation the conventional soil cultivation methods are prospectively replaced by conservation tillage, which aims the decrease of the depth of the regularly cultivated soil layer and the formation of a topsoil rich in organic matter. The scientific establishment of the hydrological impacts of these new methods can absolutely be considered actual and needs further efforts. The determination of the effects of technological elements influencing the soil water- and salt regime can contribute to the elaboration of water preserving technologies as the elements of up-to-date and sustainable crop production. The control of soil water regime is an effective environmental protective process at the same time, which is of great importance to prevent soil degradation and to mitigate the pollution of our water funds.

We determined the advantages and disadvantages of the weighing lysimeter system operated at Karcag, and figured out its application possibilities and limits for the examination of soil water balance. Our conclusion is that this weighing lysimeter system, with its given size parameters, provides very accurate data for the comparison analysis of the differences arising in the water balance of soil columns with different surface formation and covering treatments. Weighing lysimeters are very suitable tools for the determination of the water balance of the soil providing the possibility of the precise calculation of evapotranspiration, especially as the differences can be precisely quantified.

Our results call the attention the practical problems of agriculture of the region. One of those is the necessity of water preservation. Knowing the effect of different tillage systems of the water balance of the soil can contribute to the development of them. The determination of the effects of technological elements influencing the soil water- and salt regime can contribute to the elaboration of water preserving technologies as the elements of up-to-date and sustainable crop production. On the base of our results gained from the study the evaporation moderating effect of soil surface formations characteristic to the different tillage systems, we established that by the application of soil protective cultivation systems like reduced tillage significant amount of water can be preserved in the soil as soil protective mulch layer is formed on the surface. We suggest the application of reduced tillage under the agroecological conditions of Nagykunság region of Hungary as a good agricultural practice of soil management.

The other main problem in the region is irrigation. Determination of the water use efficiency of different crops can contribute to the proper selection of the crops more suitable for a specific region and to the optimization of irrigation. As a concrete example sorghum vs. maize can be mentioned. We established that under our circumstances the examined sweet sorghum hybrids (Sucrosorgo and Berény) payed better for the sufficient water supply, while the grain sorghum hybrid (Albita) probably showed better water use efficiency in dry years providing potential substitution of maize as a fodder crop.

For the development of soil management, the better understanding of all the elements of the hydrological cycle is essential. As the lysimeter technique is improving, recent advances allow measuring water balance components – including precipitation and dew as a fraction of it – with high accuracy and high temporal resolution. Our results concerning the measurement of the amount of dew for a longer term are novel and unique as only calculated data were available in this respect so far.

On the base of the scientific and practical experiences gained during the long-term operation of the weighing lysimeters at Karcag, we figured out that the facilities provide very accurate data of moisture content changes of the lysimeter units. These changes caused by the different water regime of the different soil surface formations and plant covers can be compared and expressed numerically, and can serve as the base of the further development of a hydrologically more effective soil management practice.

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REFERENCES

ABOUKHALED, A., ALFARO, A., SMITH, M. (1982): Lysimeters. FAO Irrigation and Drainage Paper. Rome. 68 p.

ASLYNG, H.C., KRISTENSEN, K.J. (1961): Water balance recorder. ASCE Proc. 87 (IRI). pp. 15-21.

BABOROWSKI, M., RUPP, H., WENDT-POTTHOFF, K., TAUCHNITZ, N., BEDNORZ, D., MEIßNER, R. (2017): Variation der Elementkonzentrationen im Drainagewasser zweier unterschiedlich genutzter landwirtschaftlicher Flächen der Norddeutchen Tiefebene. 17. Gumpensteiner Lysimetertagung, Austria, pp. 165-168. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

BLOEMEN, G.M. (1964): Hydraulic device for weighing large lysimeters. Trans. Amer. Soc. Agr. Eng 7(3) pp. 279-299.

BROOKS, F.A., PRUITT, W.O. (1966): Investigation of energy, momentum and mass transfers near the ground. Final Report USAEC, Davis, California. 259 p.

CEPUDER, P., BAUMGARTEN, A., BOHNER, A., KLAMMLER, G., MURER, E., WIMMER, B., NOLZ, R. (2015): Lysimeter Research Group - A scientific community network for lysimeter research

CZELLÉR K., ZSEMBELI J., SINKA L., KOVÁCS GY., STREDA, T., STREDOVA, H., CEPUDER, P., NOLZ, R. (2017): Determination of the amount of dew using weighing lysimeter data. 17. Gumpensteiner Lysimetertagung, Austria, pp. 181-184. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

GRUNERT, M. (2017): Auswirkung differenzierter Bodenbearbeitung auf verschiedenen Böden auf die P-, K-, Mg- und S-Verlagerung in der Lysimeteranlage Leipzig. 17. Gumpensteiner Lysimetertagung, Austria, pp. 65-70. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

HERMDL, M., SLAWITSCH, V., VON UNOLD, G. (2017): Eine Methode zur Quantifizierung von Niederschlag und Verdunstung im Winter unter Klimawandelbedingungen. 17. Gumpensteiner Lysimetertagung, Austria, pp. 131-136. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

HILLER, D., GAIRON, S., FALKENFLUG, V., RAWITZ, E. (1969): New design of low-cost hydraulic lysimeter system for field measurement of evapotranspiration. Israel J. Agric. Res. 19(2) pp. 57-63.

JANCSÓ M., SZALOKI T., SZÉKELY A., SZIRA F., MONOSTORI I., VÁGÚJFALVI A., HOFFMANN B., MEGYERY SZ., ONCSIK M.B. (2017): Characterization of 4 winter wheat cultivars with different Nitrogen Use Efficiency (NUE): A lysimeter study. 17. Gumpensteiner Lysimetertagung, Austria, pp. 103-106. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

KARUCZKA A., ZSEMBELI J. (1997): Construction, Operation and Experiences of the Karcag Lysimeter Station. Einldung zur 7. Gumpensteiner Lysimetertagung, Austria. pp. 37-39.

KING, K.M., TANNER, C.B., SUOMI, V.E. (1956): A floating lysimeter and its evaporation recorder. Trans. Amer. Geophys. Union 37. pp. 738-742.

KÖHN, J., MEIßNER, R., RUPP, H., REINSTORF, F. (2017): Sind die Wirkungen des Klimawandels auf den Boden anhand von Langzeit-Lysimeteruntersuchungen nachweisbar? 17. Gumpensteiner Lysimetertagung, Austria, pp. 57-64. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

KUN Á., BOZAN CS., ONCSIK M.B., BARTA K. (2017): Analysis of leachate from wastewater irrigation experiment with sorghum. 17. Gumpensteiner Lysimetertagung, Austria, pp. 213-216. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

LANTHALER, C., FANK, J. (2005): Lysimeter station and soil hydrology measuring sites in Europe – Results of a 2004 survey. 11. Gumpensteiner Lysimetertagung, Austria, pp. 19-24.

LEITINGER, G., FRENCK, G., TAPPEINER, U., OBOJES, N., NEWESELY, C., WELLSTEIN, C., SCANDELLARI, F., THOMA, M., TAGLIAVINI, M., TASSER, E. (2017): Valorization of grassland management for the water supply in context with climate change. 17. Gumpensteiner Lysimetertagung, Austria, pp. 145-148. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

LOURENCE, F.J., GODDARD, W.D. (1967): A water-level measuring system for determining evapotranspiration rates from a floating lysimeter. J. Appl. Meteorol. 6(3) pp. 487-492.

MCILROY, I.C., ANGUS, D.A. (1963): The Aspendale multiple weighed lysimeter installation. Div. Meteorol. Physics Paper No. 14, CSIRO, Australia. 27 p.

MCMILLAN, W.D., BURGY, R.H. (1960): Interception loss from grass. J. Geophys. Res. 65(8) pp. 2389-2394.

MIDDLETON, J.E. (1972): A quick weighing lysimeter system check. Agric. Eng. pp. 14-15.

MURER, E., KUDERNA, M., SELTENHAMMER, K., FUCHS, G. (2017): Lysimeteruntersuchungen als Unterstützung zum Grundwasserschutz. 17. Gumpensteiner Lysimetertagung, Austria, pp. 49-56. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

MÜLLER, J. (2017): Die forstökologische Forschung mit Lysimetern: Möglichkeiten und Grenzen ihres Einsatzes. 17. Gumpensteiner Lysimetertagung, Austria, pp. 137-144. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

OBERHOLZER, S., HUND, A., PRASUHN, V. (2017): Auswertung von Lysimeterdaten über sieben Jahre zur Bestimmung von Evapotranspiration, Wassernutzungseffizienz und Pflanzenkoeffizienten. 17. Gumpensteiner Lysimetertagung, Austria, pp. 201-204. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

POPOV, O.V. (1959): Lysimeters and hydraulic soil evaporimeters. Colloque de Hannoversch-Munden. Associate. Int. D'Hydrol. Sci. Publ. 49. pp. 26-37.

RICZU, P., ZSEMBELI J., TAMÁS, J. (2010): Evaluation of water balance of apple and pear trees. Journal of Agricultural Sciences. Acta Agraria Debreceniensis, Debrecen, Suppl. 193-198. ISSN: 1588-8363.

SPIESS, E., PRASUHN, V., HUMPHRYS, C. (2017): Einfluss des umbruchtermins und des Alters einer Ansaatwiese auf die Nitratauswaschung. 17. Gumpensteiner Lysimetertagung, Austria, pp. 87-92. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

STEPHAN, E., RUPP, H., MEIßNER, R. (2017): Niederschlagsmessungen in der sibirischen Kulunda Steppe – Vergleich von Niederschlagsmessern verschiedener Bauart mit wägbaren Lysimetern. 17. Gumpensteiner Lysimetertagung, Austria, pp. 185-188. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

STRAUß, C., BAYER, A., OBERNOLTE, M. (2017): Lysimeteruntersuchungen zum Austragsverhalten von im Maisanbau eingesetzten Herbiziden unter Freilandbedingungen (Standort Wielenbach). 17. Gumpensteiner Lysimetertagung, Austria, pp. 27-32. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

TANNER, C.B. (1967): Measurement of evapotranspiration. In: Irrigation of Agricultural Lands. Amer. Soc. Agron. 11. pp. 534-574.

TAUCHNITZ, N., SCHRÖDTER, M., SCHMIDT, G., HAUSER, B., KASIMIR, P., MEIßNER, R. (2017): Quantifizierung von Pflanzenschutzmittel(PSM)-Einträgen in Oberflächengewässer in einem Kleineinzugsgebiet (Querne/Weida). 17. Gumpensteiner Lysimetertagung, Austria, pp. 11-16. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

TIMM, A., WESSOLEK, G. (2017): Studying the hydrological balance of (partially) sealed surfaces using high precision weighable lysimeters. 17. Gumpensteiner Lysimetertagung, Austria, pp. 157-162. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

WMO (1968): Measurement and estimation of evaporation and evapotranspiration. Tech. Note No. 83, Genova. 121 p.

WMO (1974): Guide to hydrological practices. WMO No. 168, Genova. 4th ed. 770 p.

ZSEMBELI J. (1999): Effect of Different Soil Surface Formations on the Moisture Content of the Unsaturated Zone in Weighing Lysimeters. Einldung zur 8. Gumpensteiner Lysimetertagung. Austria. 205.

ZSEMBELI J. (2002): Evaporation moderating effect of soil cultivation methods simulated in lysimeters. I. Alps-Adria Scientific Workshop. Opatija, Croatia. pp. 170-174.

ZSEMBELI J., CZELLÉR K., TUBA G., SZÜCS L., SINKA L. (2017): Effect of irrigation with saline water on the soil and legumes in simple drainage lysimeters. 17. Gumpensteiner Lysimetertagung, Austria, pp. 189-192. ISBN: 978-3-902849-45-8 ISSN: 1818-7722

ZSEMBELI J., KOVÁCS GY., DEÁK D. (2013): Water use efficiency of energy willows determined in weighing lysimeters. Lysimeter research as an instrument for decision support. 15. Gumpensteiner Lysimetertagung, Austria, pp. 181-184. ISBN: 978-3-902559-90-6 ISSN: 1818-7722

ZSEMBELI J., KOVÁCS GY., MÁNDOKI A. (2011): Water use efficiency of maize and different sorghum hybrids under lysimeter conditions. 14. Gumpensteiner Lysimetertagung, Austria, pp. 227-229. p. ISBN: 978-3-902559-61-6 ISSN: 1818-7722

ZSEMBELI, J., SZŰCS L., BLASKÓ L. (2011): Secondary salinization by irrigation from drilled wells in Karcag area. DOI: 10.1556/Novenyterm.183 60.2011.Suppl.3. pp. 305-308.

I1: http://www.lysimeter.at/en/Lysimeter_Platform

Irrigation of potatoes and its impact of infiltration

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Abstract: In this article we focused of on the evaluation of soil infiltration ability during the application of additional irrigation. The area of the location was 6.23 ha and was cultivated the early variety potatoes of GALA. Number of the monitoring points was 9. The whole process was monitored from the planting potatoes up to the stubble ploughed under, which was realized after the gathering. The initial infiltration value was 12.43 $cm.s^{-1}$. This value has been affected by the residual winter soil moisture. After the first irrigation and processing of soil, the value of infiltration rapidly rose. There is caused a small precipitation and a low irrigation dose. On the third measurement there was a reduction of infiltration rate and that to value 24.43 $cm.s^{-1}$. Consequently, there were applied another irrigation rates during the vegetation period. The results were only changed partially, which was caused by the right application of irrigation rates. Before the gathering the irrigation rate was not applied. The last measurement showed a decrease in infiltration caused by atmospheric precipitations three days prior to measurement. In conclusion, the irrigation dose and its influence on the infiltration capacity of the soil are not negligible. Therefore, it should be examined not only in relation to the intensity of supplementary irrigation, but also in relation to other factors closely related to the infiltration capacity of the soil.

Key words: potatoes, water penetration, infiltration

INTRODUCTION

Infiltration can be measured by several methods such as block furrow infiltrometer, ring infiltrometer, respectively by devices that measure the inflow and outflow of water (Davis and Frey, 1963). The most commonly used became a ring infiltrometer (Hills, 1970).

One of the main reasons for soil conservation technologies integration into the system of soil management is currently decrease in the flooding of the surface layer of soil and its drainage (Shipitalo et al., 2000).

The process of water penetration into the soil is called infiltration and it happens mostly through its surface. From the hydrological point of view the most interesting infiltration is from precipitation. From the intensity of infiltration the formation of surface runoff depends and it’s associated with soil erosion. The aim is to create such a conditions which allows that the greatest amount of rainfall are infused into the soil so needed for plants growth (Velebný et al., 2000).

Infiltration is the process through which the water enters the soil and it can be described by infiltration rate which in soil science is the rate at which the soil is able to absorb water from rainfall or irrigation. Infiltration rate (capacity) of the soil is measured by the rate of water column displacement in mm per unit of time ($mm.s^{-1}$), or in millilitres per time unit ($mL.s^{-1}$). Overall, the more water soil absorbs, the more it rate reduces in advance. If rainfall exceeds the infiltration rate, drainage of water into the soil will be slower. Infiltration rate can be measured by device called infiltrometer (Kukan et al., 2008).

Among modern measurement methods includes the measurement by Minidiscs infiltrometer. The advantage of this measurement of infiltration is its low water consumption of about 135 ml per one measurement. The water infiltrates into the soil through a semi-permeable and stainless steel membrane and on water infiltration into the soil is read on the scale.

MATERIAL AND METHODS

The aim of the study was to observe the effect of irrigation dose and others working operations on infiltration rate during growing season. On a given plot area of 6.23 ha were cultivated potato, Gala varieties. There were selected 9 observation points on the selected field where infiltration measurement were conducted by MiniDisc Infiltrometer (DECAGON DEVICES, Figure 1A). For recording of the field boundaries and position of observation points were used handheld satellite navigation system Garmin Oregon 450 (Figure 1B).

***Figure 1** MiniDisc Infiltrometer (A) and GPS unit (B)*

MiniDisc Infiltrometer consists of polycarbonate tubes with a diameter of 31 mm and a height of 327 mm. The tube is divided into two parts which are filled with water. The upper part is for setting air intake using adjustable steel tube (depending on soil type). The water from the lower part is infiltrated into the soil through a semi-permeable stainless steel membrane disposed on the bottom of the tube. The lower part is also equipped with a scale in millilitres from which are subtracted the volume of infiltrated water. Measurements were carried out following the procedure as described in procedure manuals. MiniDisc Infitrometer package provides also the software for processing results.

Hydraulic conductivity of the soil can be defined as: „how many meters of water per day seep down into the soil, namely by the gravity or pressure gradient unit"(Kirkham, 2005).

The hydraulic conductivity of the soil is calculable by various methods. One of them is the method for calculating infiltration and hydraulic conductivity of soil which was set by Zhang (1997).

After calculating hydraulic conductivity (k) for each monitoring point, a map of hydraulic conductivity of soil was constructed.

RESULTS AND DISCUSSION

Measurements were carried out on a plot where potato varieties Gala (early) were planted and owned by private farmer Zdenko Černay, located in Senec. The selected plot is part of a large estate with an area of 81 ha in the administrative territory of Veľký Biel. The land is under irrigation with built-in distribution of irrigation water which comes from the nearby lake - a former gravel pit. With regards to the soil and climatic conditions selected field belongs to corn production area. It is a very warm and very dry lowland region, where the main soil unit is typical black soil, carbonated on carbonate alluvial sediments, medium duty - loamy.

The outcome of our research was to evaluate the impact of irrigation dose and work activities during the growing season on the infiltration capacity of the soil expressed by hydraulic conductivity. The field was fertilized during the pre-plan cultivation by ammonium nitrate with dose of 300 $kg.ha^{-1}$. Fertilizers were incorporated into the soil by compactor, after which potatoes were planted by potatoes planter GRIME GL 34T (4-lines) and followed by turn-up operation by covering machine GRIME.

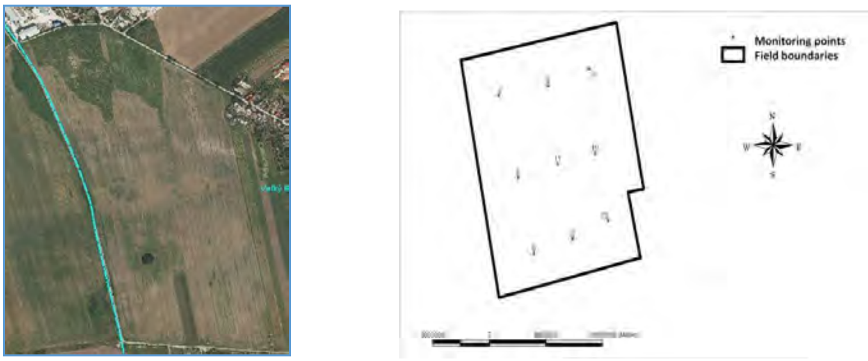

Figure 2 Selected field and monitoring points.

After these operations first measurement took place. Figure 3 shows the dependence of cumulative infiltration on the square root of time. The results are valid for the monitoring point 1. It showed almost a fluent change of cumulative infiltration with curve slope parameter C_1 determined according to the methodology as 0,0006. The value of van Genuchton´s parameter A, determined according to the methodology enclosed to MiniDisc infiltrometer, was 7 for given soil type. Negative values reflect deceleration during the infiltration which occurred in the monitoring point 4. In the monitoring point 8 was value of infiltration already positive as in the rest of field area. It is possible to conclude from mentioned figure that the field consist of areas passing through it with different characteristics in comparison to the edges of the field. The low value of the calculated weighted average of hydraulic conductivity (12.44 $cm.s^{-1}$) expresses the remaining reserve of winter moisture which was able to get into the shallow layers of the soil during extensive operations connected with potatoes planting and it's covering with additional soil.

Before the second measurement irrigation dose of 30 mm was applied. It was followed by another turn-up and covering potatoes with additional soil. Later, when the weeds emerged pesticide spraying took place and there we applied Sencor (dose of 1 $kg.ha^{-1}$) and Garland Forte (dose of 0.8 $l.ha^{-1}$). Weighted average of hydraulic conductivity at the second measurement has increased more than four times (50.25 $cm.s^{-1}$). Graphical display of the results can be seen in Figure 4. The measured values indicate reduced reserves of soil moisture in the shallow layers which resulted in increased hydraulic conductivity. Sometime after the second measurement it was followed by supplementary irrigation with dose 40mm. After the irrigation third measurement was conducted. The last two measurements (second and third) were performed three days apart. It means a significant effect of high doses of irrigation on hydraulic conductivity where the value of weighted average decrease from 50.25 $cm.s^{-1}$ on dry soil to 24.43 $cm.s^{-1}$ on soil saturated with irrigation water. The decrease in hydraulic conductivity has been 51%. After third irrigation dose was applied, fourth measurement was carried out with distance in time about 2 weeks. Weighted average of hydraulic conductivity was 25.26 $cm.s^{-1}$ what means only slight decrease in comparison with third measurement on 0.83 $cm.s^{-1}$. Measurements were not done immediately after irrigation dose however the value of hydraulic conductivity indicates that there were still sufficient reserves of soil moisture. It can be concluded that the distribution of irrigation doses for this period has been optimal.

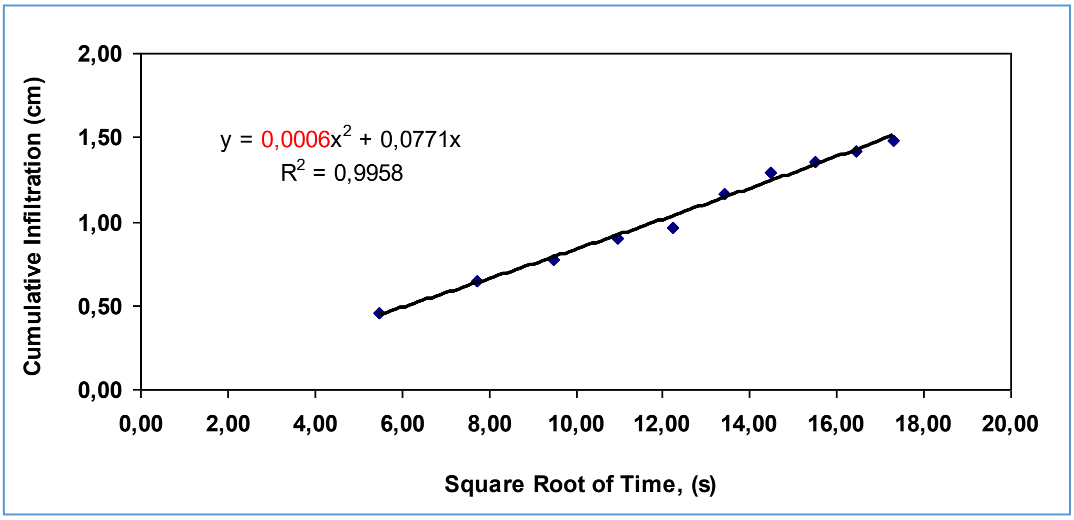

Figure 3 Dependence of cumulative infiltration on the square root of time (monitoring point 1, measurements 1)

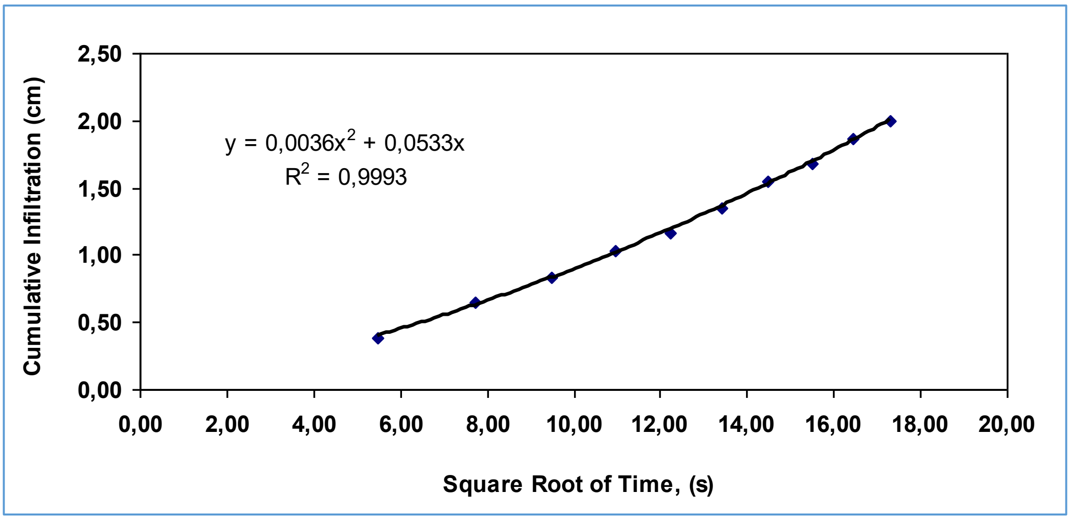

Figure 4 Dependence of cumulative infiltration on the square root of time (monitoring point 1, measurements 2)

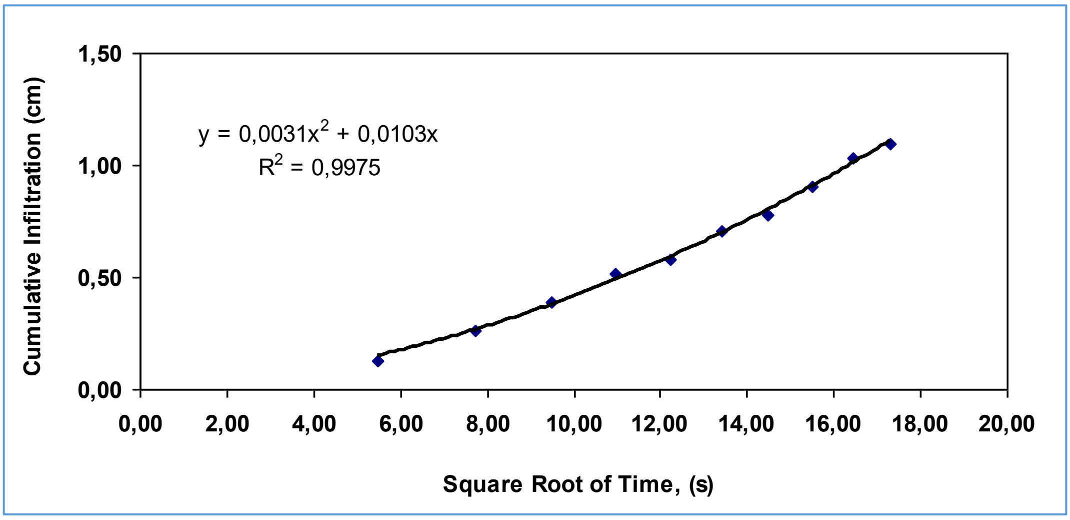

Figure 5 Dependence of cumulative infiltration on the square root of time (monitoring point 1, measurements 3)

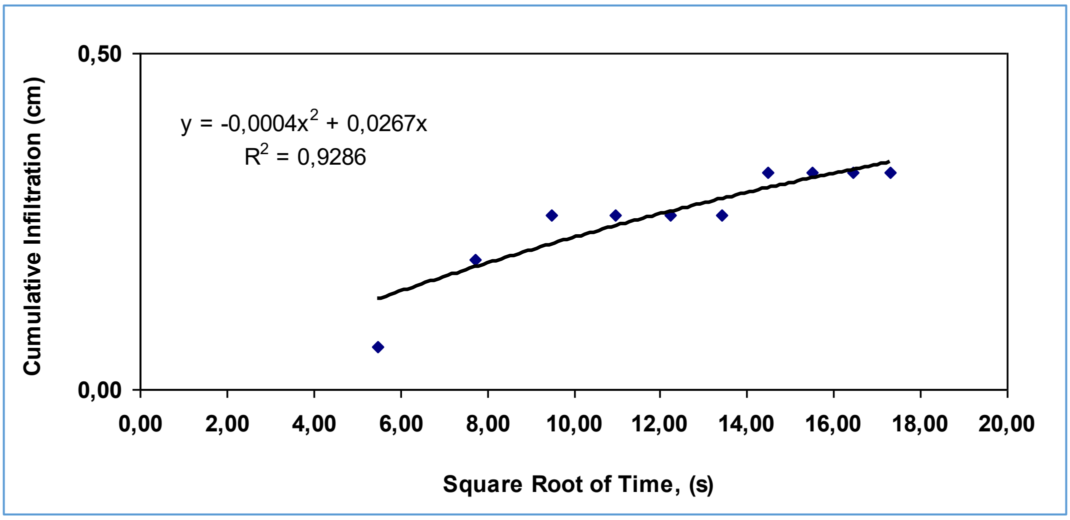

Figure 6 Dependence of cumulative infiltration on the square root of time (monitoring point 1, measurements 4)

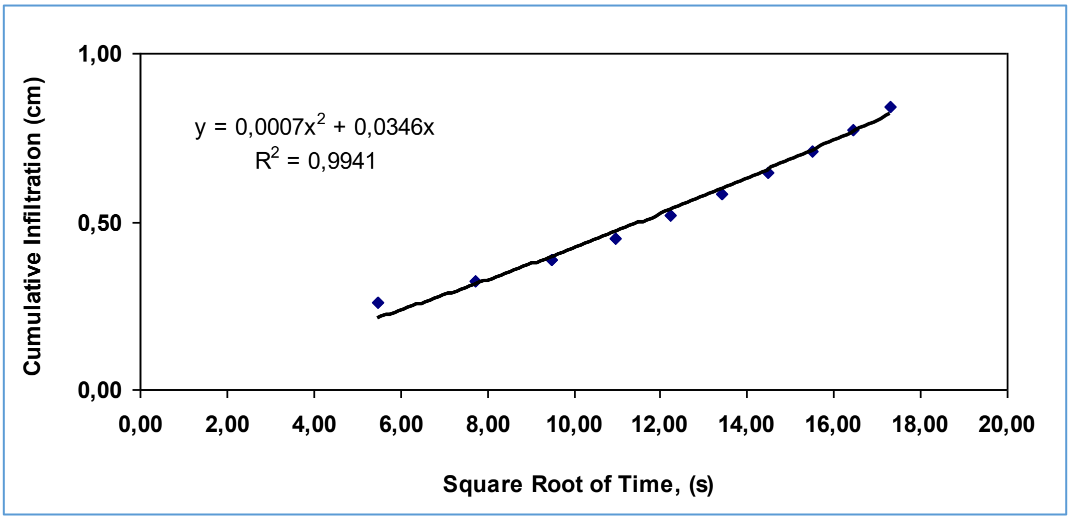

Figure 7 Dependence of cumulative infiltration on the square root of time (monitoring point 1, measurements 5)

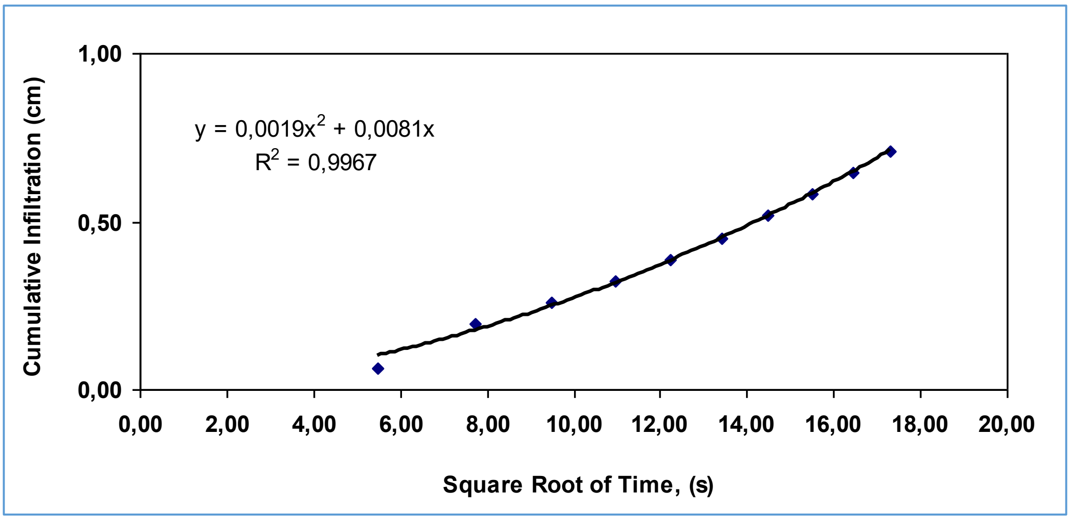

Figure 8 Dependence of cumulative infiltration on the square root of time (monitoring point 1, measurements 6)

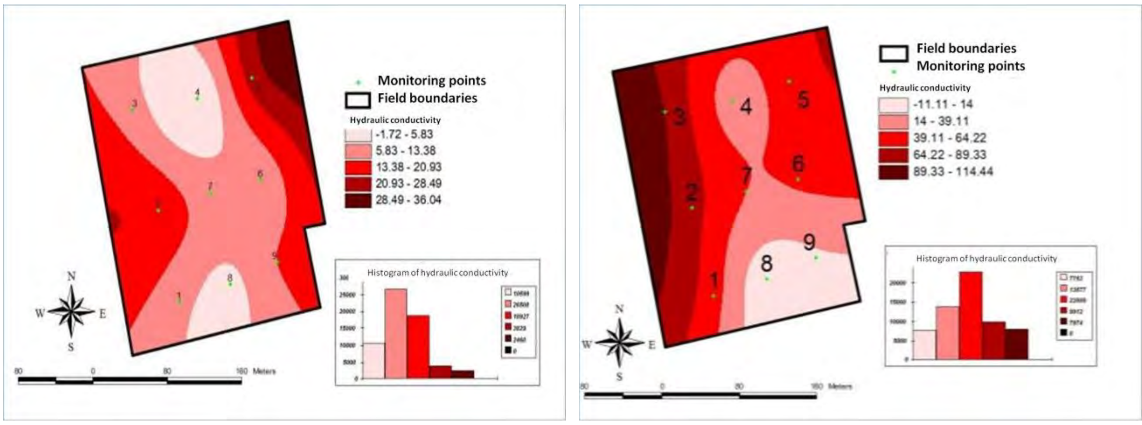

Figure 9 Map of hydraulic conductivity of soil (1st and 2nd measurement).

Before the fifth measurement there were no additional irrigation on the field and crops were harvested by potatoes harvesting machine GRIME SE 170 – 60. The fifth measure has taken place on the field without a crop and without post-harvest treatment of soil, containing crop residues. Average value of hydraulic conductivity in the fifth measurement was 41.01 $cm.s^{-1}$. Increased value of hydraulic conductivity indicates a reduction in soil moisture reserves and application of irrigation dose would be then recommended, what has not taken place with regard to the period of harvest.

The last working operation on the field was soil tillage and crop residues incorporation into the soil with disk-harrow Grégoire Bessou. After these operations the sixth measurement took place. Before the last measurement an increased hydraulic conductivity was expected due to the loosened soil surface but three days prior the measurement there were an excessive rainfall. Increased soil moisture was observed in soil layers and decreased hydraulic conductivity occurs (weighted average 24.66 $cm.s^{-1}$).

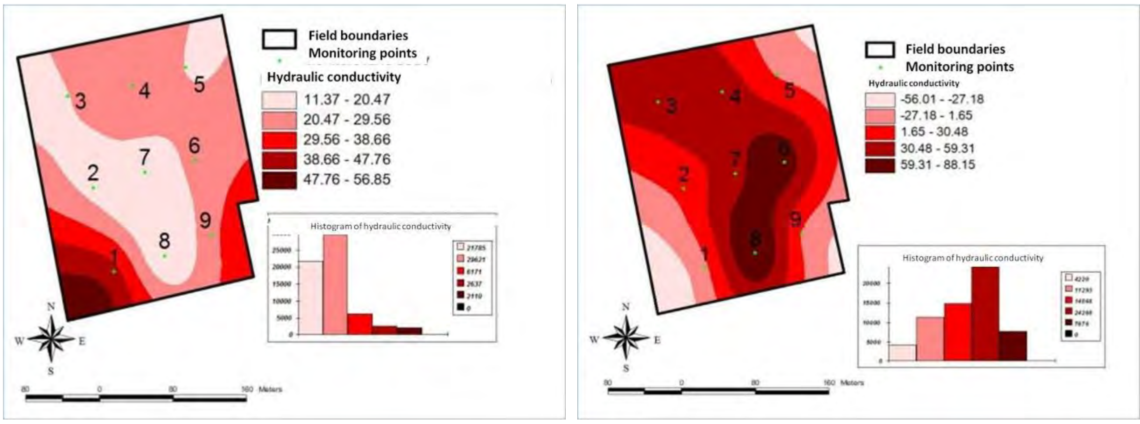

Figure 10 Map of hydraulic conductivity (3rd and 4th measurement).

Soil erosion is a major environmental threat to sustainability and production capacity of agriculture. In the last 40 years almost one third of the world's arable land was destroyed by soil erosion (Pimentel et al., 1995).

Soil erosion affects the dynamics of carbon in the soil. Ecological and environmental effect erosion indicated by changes in soil carbon ensures a serious and experimental reduction of soil carbon and minimize the transport of sediment to the world's water channels (Lal, 1995).

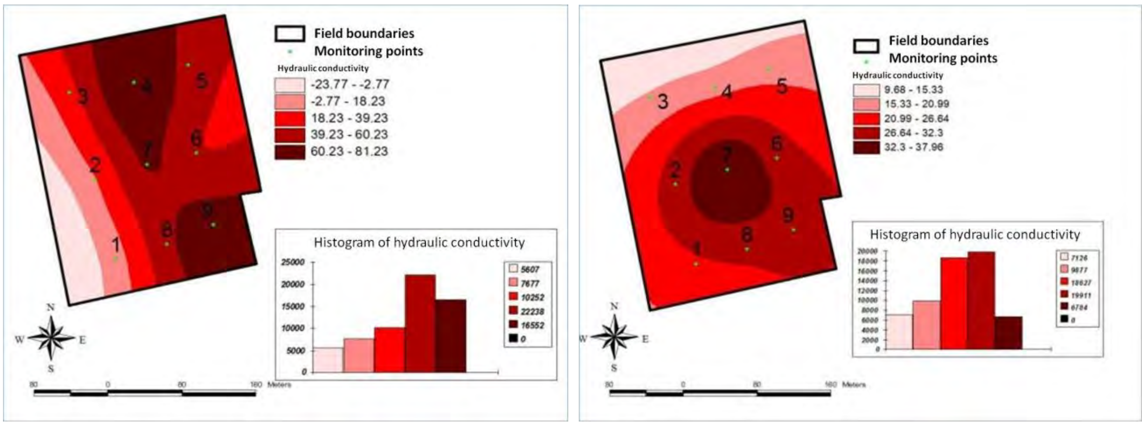

Figure 11 Map of hydraulic conductivity (5th and 6th measurement).

Measurements of infiltration rate are different in the method of water application to the soil surface. There are three most basic ways of measuring infiltration (Schulin, 1995) namely, reservoir method (water usually soak in from two concentric cylinders or large infiltrometers with different plan shape), tenziometric method (in this method the infiltration water passes through the porous plate with low permeability) and method of artificial rain (in this method, measurements of infiltration are made indirectly).

The infiltration of water into the soil is such a characteristic of the soil, which describes the ability of water penetration into the soil. To its specification a several methods exists. The measurement results will help to determine the effect of soil erosion and its control (Sindelar et al., 2007).

Economically effective way to prevent water pollution and its flush out is the tillage which leaves a crop residues on the soil surface (Ginting et al., 2003) also called conservation tillage.

In application of supplementary irrigation and determination of its doses it is needed to determine hydrolimits, soil moisture and monitoring of precipitation and address their effect on the erosion. One of the effects which can maintain the erosion is to keep sufficient infiltration capacity of the soil. Adversely effect on the infiltration capacity of the soil are an extremely high irrigation doses but also use of inappropriate machinery to its application. It can cause the degradation of soil surface by improper spraying of the irrigation water which is caused by kinetic energy of the drops falling on the soil surface.

CONCLUSION

The issue of the paper was to assess the effect of irrigation not only benefits but also work activities during the growing season on the infiltration capacity of the soil. The infiltration is closely related to the hydraulic conductivity of the soil and according to our findings is mainly dependent on soil moisture. It was clearly confirmed by measurements taken immediately before and immediately after supplementary irrigation when the soil hydraulic conductivity decreased by up to 51%. Progressively as the soil surface dries out hydraulic conductivity was increasing. The last measurement not confirmed our expectations whereas shown no elevation in hydraulic conductivity after the last measurement which should result in a change of soil structure by performing stubble breaking. This phenomenon could be caused by several factors such as rainfalls as a result of impact on the hydraulic conductivity which obscure the effect of stubble breaking. It would be interesting to examine, in this case, the whole soil horizon and to conclude further consequences.

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REFERENCES

DAVIS, J.R. - FREY, A.W. 1963. Measurement of infiltration rates in irrigated furrows. In: Transactions of the ASAE. Annual 6. 1963. Number 4.

GINTING, D. - MONCRIEF, J.F. - GUPTA, S.C. 2003. Performance of a variable tillage systems based on interaction with landscape and soil. Precision Agriculture Vol. 4. No.1. Kluwer Academic Publishers. Netherlands. 2003. ISSN 1385-2256. p. 19-34.

HILLS, C.R. 1970. The determination of the infiltration capacity of field soil using cylinder infiltrometer. In: British Geomorfological Research Group. Tech. Bull. No.3. 1970.

KIRKHAM, M.B. 2005. Principles of Soil and Plant Water Relations. Elsevier Academic Press: Burlington. MA. 2005. pp. 145-172.

KUKAN, P. – JOBBÁGY, J. – BUC, M. – FINDURA, P. 2008. Infiltration ability of soil as an indicator of its variability. In: X. Medzinárodná vedecká konferencia mladých. Zborník z medzinárodnej vedeckej konferencie. CD. Praha. 16.-18. Septembra 2008. s. 130-135. ISBN 978-80-213-1812-0.

LAL, R. 1995. Global soil erosion by water and carbon dynamics. In: Reicosky, D.C. – Lindstrom, M.J. – Schumacher, T.E. – Lobb, D.E. – Malo, D.D. 2005. Tillage-induced CO_2 loss across an eroded landscape. Soil & Tillage Research. Vol. 81. p 183–194.

PIMENTEL, D. – HARVEY, C. – RESOSUDARMO, P. – SINCLAIR, K. – KURZ, D. – MCNAIR, M. – CRIST, S. – SHPRITZ, L. – FITTON, L. – SAFFOURI, R. – BLAIR, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267. p. 1117–1123. Available on internet: http://www.sciencemag.org/cgi/content/abstract/sci;267/5201/1117

SCHULIN, R. 1995. Bodenschutz-Kutz. Institut f. Terrestrische ökologie. ETHZ. 1995.

SHIPITALO, M.J. – DICK, W.A. – EDWARDS, W.M. 2000. Conservation tillage and macropore factors that affect water movement and the fate of chemicals. Soil & Tillage Research. Vol. 53. Nos. 3-4. p. 167-183.

SINDELAR et al. 2007. Hodnocení infiltrace vody do půdy. In IX. Medzinárodná vedecká konferencia mladých 2007. Zborník z medzinárodnej vedeckej konferencie. CD. Nitra 10. – 11. Október 2007. ISBN 978-80-8069-946-8

VELEBNÝ et al. 2000. Vodný režim pôdy. STU Bratislava. 2000. ISBN 80-227-1373-2

ZHANG, R. 1997. Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. Soil Science Society of Aerica Journal. 61. p. 1024-1030.

The use of soil conditioner and its effect on soil physico-mechanical and hydraulic properties

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Abstract: The aim of the study was to assess and evaluate the effect of soil conditioner on the spatial variability of soil environment. Activator PRP-SOL conditioning soil properties was selected as a field of study. Assessment of soil environment was done through the evaluation of selected soil properties, namely, tensile resistance of the soil and soil infiltration ability. Two dose of PRP-SOL application was done twice in year 2015 (Autumn and Spring) and once in 2016 (Spring) with application rates 150 kg ha^{-1} and 140 kg ha^{-1}, respectively. The area was divided into blocks where stimulators were applied and none treated as a control. The evaluation of recorded values showed that treatability and tillage itself was significantly better on the area which was treated by application of PRP-SOL activators. In addition, tensile resistance was decreased by 5.71% in comparison with non-treated area of experimental field. Since the infiltration ability is among the very important soil properties which have an effect on soil moisture regime as well as surface runoff and therefore soil erosion. The evaluation of recorded values has revealed the effect of treatment by PRP-SOL activators on soil infiltration ability and therefore it results in increases infiltration of precipitation as well. Overall increase of infiltration was recorded at value 2 mm h^{-1}. It can be concluded that application of soil activators may increase the soil conditions and therefore not only conserve soil fertility but even increase it from the long term perspective.

Key words: soil conditioning, activators, PRP-SOL, infiltration, tension resistance, tillage.

INTRODUCTION

Worsening situation in crop production in Slovakia, where quality of agricultural land started to decline rapidly due to impacts of using more and more heavy and complex machinery, gradually forced both professionals and laymen to look for and propose new possibilities of solving of adverse effects and impacts of machinery technique on soil culture, what finally results in low crop yield. Soil compaction is one of the soil properties in question. Strudley et a. (2008) stated that soil tillage practices can affect soil hydraulic properties and processes dynamically in space and time with consequent and coupled effects on chemical movement and plant growth. It leads to loss in crop yield (Ahmadi & Ghaur, 2015), since the compaction prevents plants' root system to penetrate through to deeper soil layers to reach water/nutrients (Šařec & Novák, 2017a and 2017b). Soil compaction has also negative impact on the environment (Ball et al., 1999; Chyba et al., 2014) due to the reduced ability of the soil to absorb water (Angulo-Jaramillo et al. 2000). Chyba et al. (2014) verified significantly higher water infiltration rate in the non-compacted soil than in the compacted soil. Soil compaction, erosion and creation of spell of drought are factors which affect and cause soil degradation to the greatest extent, while they significantly influence its properties (Šařec & Novák, 2017a and 2017b). It for example increases soil bulk density, and thus leads to a reduction of soil water infiltration rate (Chyba et al., 2014). According to Strudley et al. (2008) understanding of soil pore geometry and structure is fundamental to identification of tillage effects on soil physical and hydraulic properties. Kay and Angers (2002) provided standard definitions (e.g., weak to strong soil structure), classifications (e.g., macropores >75 μm), and a useful discussion of factors affecting soil structure, including texture and mineralogy, organic matter, inorganic materials, pore fluid, microorganisms, soil fauna, plants, climate, and management. The organic matter may be applied in various forms (Šařec & Novák, 2016, 2017a, 2017b). Manure or compost is commonly used, but it is possible to use also other forms (Wang et al., 2015). Especially on heavy and decarburized soils, there is a problem with the decomposition of applied organic matter (Fontaine et al., 2003; Sarec et al., 2017). It remains in the soil without decomposition and does not affect positively other properties of the soil, e.g. the physical and chemical ones (Steinbeiss & Gleixner 2005). On numerous locations, negative effects are underestimated and their interaction causes irreversible damage to soil fertility (Wilhelm et al. 2007). As a result, there is also a decrease in biomass yield of crops and grasslands (Shahzad et al., 2012). Of course, the problem of soil organic carbon loss may be stopped by applying sufficient quantities of organic matter (Johnson et al., 2006). Manure (or other forms of organic matter) can be supplemented by activators of biological transformation (Šařec & Novák, 2016). The use of activators for the decomposition of organic matter was also recommended by Parr et al. (1986). In their case, activators were applied within the composting. Barzegar et al. (2002) confirmed a positive impact of the compost treatment of as well, i.e. increased wheat yields and improved soil physical properties. Soil compaction primarily affects the physical properties of soil, either in the short or long term (Šařec & Novák, 2017a and 2017b). For example at higher soil moisture levels, passes of farm machinery can lead to excessive soil compaction (Kroulík et al. 2009). The results of Vero et al. (2012) indicate that higher soil moisture deficits (SMD) at the time of machinery trafficking resulted in smaller changes to soil characteristics and more rapid recovery from surface deformation than when trafficking occurred at lower SMD. According to the results of Ahmadi & Ghaur (2015), gradual increase in soil water content generally resulted in an increase in soil bulk density after tractor wheeling. The negative effect of soil compaction is manifested through increased bulk density, soil cone index, and other variables (Blanco-Canqui et al. 2017). This all leads to reduction in porosity, hydraulic soil properties, stability and other variables (Alakukku, 1996). All these parameters are connected together and influence crop yields (Indoria et al. 2016). Celik et al. (2010) confirmed organic applications to significantly lower the soil bulk density and penetration resistance.

Currently, the main objective becomes increasing of soil fertility in line with selection of minimization technologies of soil treatment taking into account soil conditions (Peltre et al. 2015). Suitable selection of these technologies combined with their rational application also contributes to disruption of these adverse effects significantly (Šařec & Novák, 2017a and 2017b). Gradual use of obtained knowledge resulted in designing and development of protective measures which effectively not only restrain these adverse effects, but may also have positive impact on soil structure under certain conditions (Kay & Angers, 2002), so they directly affect fertility and expected yields of agricultural crops. Each soil structure has its own typical values of bulk density, porosity, hydraulic characteristics and other variables (Six et al., 1999; Šařec & Novák, 2017a). For example, sandy-loam soils have higher cumulative infiltration rate than clay-loam soils, the lowest values are observed in turn with clay soils (Ekwue & Harrilal, 2010). Liu et al. (2012) confirmed this positive effect in their further study where they showed a beneficial effect on maize growth, soil organic matter content, nutrients levels, and water-storage capacity in sandy soils. The most important thing for the future is to keep up the rising trend in this area and to search for new methods that could successfully eliminate these adverse effects in order to prevent further deterioration of soil environment (Ahmadi & Ghaur, 2015). Effect of the use of substances for soil amendment (activators) on soil properties is a relatively unexplored phenomenon (Šařec & Novák, 2017a and 2017b). Impact can be mainly expected on the physical and chemical properties of soil. Kroulík et al. (2011) suggested a beneficial effect of incorporation of organic matter on the physical properties of soil, on water infiltration into the soil and on partial elimination of the consequences of soil compaction beneath the tracks. It can be also assumed that changes in soil properties will be reflected in the long term rather than immediately after application (Šařec & Novák, 2017a and 2017b). According to Podhrázská et al. (2012), repeated conventional tillage and application of PRP Sol did not demonstrate any improvement in soil physical properties (density, porosity, soil compaction, reduced water content in soil). Another factor that influences the variables mentioned is soil structure and soil aeration. If the soil is loosened, water capacity is higher compared to the untilled soil (Ekwue & Harrilal, 2010). Each soil structure has its own typical values of bulk density, porosity, hydraulic characteristics and other variables. For example, sandy-loam soils have higher cumulative infiltration rate than clay-loam soils, the lowest values are observed in turn with clay soils (Ekwue & Harrilal, 2010). In terms of economy and operation, energy demand of soil tillage is one of the crucial elements (Liang et al. 2013). Tillage is the base operation in agricultural systems and its energy consumption represents a considerable portion of the energy consumed in crop production (Larson et al., 1995). McLaughlin et al. (2002), Liang et al. (2013) and Peltre et al. (2015) reported manure amendments to have significant effect on reduction in tillage implement draft. Prolonged application and higher rates brought advanced reduction.

The current pressure and need of increasing soil structure, its conservation and increase of soil fertility leads to increased research efforts and various soil biological activators were developed. According to this efforts it was addressed a field experimental research. The aim of the study was to assess and evaluate the effect of soil conditioner on the spatial variability of soil environment.

MATERIALS AND METHODS

Our research was carried out in 2015-2016 on one plot divided to two parts in the selected agricultural farm Agrodružstvo TP, ltd. Palárikovo, which consists of 57 soil units and a structure of soil fund represents 2,420 ha of agricultural land. One part was treated by the material (48.041713, 18.042425) for soil structure treatment and the other part was a control part (48.038541, 18.043567). PRP-SOL material for soil structure treatment was applied to the plot widely. In terms of the objective defined, field experiments were carried out in this selected location and measurements were carried out under operational conditions. A term material for soil structure treatment means activator of soil vital functions PRP SOL. Auxiliary soil materials do not remove consequences, but create favourable conditions for biological life in soil what reflects in lower consumption of used agricultural chemistry. Therefore, PRP SOL is suitable for minimization which supports biological life in the upper part of soil horizon. Infiltrometer consists of polycarbonate tube with a diameter of 31 mm and height of 327 mm which is divided into two parts. Both parts are filled with water. Upper part serves for setting of air suction. Water filled in the bottom part infiltrates to soil through semi-permeable stainless steel diaphragm. Suction of air can be set according to soil type. There is a scale in the bottom part of the tube of infiltrometer on which a value of water volume is read in ml after 30 seconds. Measured results are processed by PC. It is important to choose a suitable place for measurement. An important pre-requisite is to make measurement on surface of soil without cracks. After selection of a suitable place, it is important to prepare surface of soil for measurement carefully, because it must be flat and smooth, so the whole diaphragm will be in contact with soil surface (Decagon Devices, 2005). Speed of infiltration v_i is expressed by a ratio of water quantity absorbed through a unit of area of soil surface per a time unit (Velebný et al., 2000).

$$v_i = \frac{dV}{A\,.\,dt}\,,(mm\,s^{-1}) \qquad (1)$$

Where:

dV – elementary volume of infiltrated soil per time unit dt (m^3),

A – area through which water volume dV is infiltrated (m^2).

The result is not often expressed by height of water layer infiltrated to soil per time unit ($mm\ s^{-1}$). Total amount of water V infiltrated to soil per time Δt through unit of area of soil surface from the beginning infiltration is called cumulative (total) infiltration i (Velebný et al., 2000). Cumulative infiltration per time t can be expressed as follows:

$$i = \frac{V_{(t)}}{A}\,,(mm\,s^{-1}) \qquad (2)$$

Where:

$V_{(t)}$ – water volume (m^3),

A – area through which water volume dV is infiltrated (m^2).

Tension force was measured during ploughing by 5-mouldboard plough to the depth of 22 cm by a tensometric apparatus in two parts of the plot, while one part was treated by a material and the other part was a control. In technical practice, tensometric measurements present effective method for detection of actual operating tensions. In addition, tensometric apparatus is also widely used in design of sensors of force, pressure, torque, etc. A set for measurement of tension resistance contained measuring instruments and devices (Tractor John Deere 8300, fifth-wheel plough 5PHX 35 and measuring system Hottinger Baldwin Messtechnik Spider-8). Measurements were performed on the plot - both on treated part and control part. The apparatus records values of tension force in N in intervals of 0.2 seconds. Results were recorded during the same time of run in two repetitions with identical plough setting. HBM Spider 8 actuating device meets requirements of operating systems with the aim to ensure transfer of data and its operational accuracy. In case of trailing ploughs, dynamometer (tensometer) is located between a tractor and plough. Force measured on dynamometer directly corresponds to tension force *FT = FX (N)*.

RESULTS AND DISCUSSION

The measurements were conducted on field trial held in Agrodružstvo TP, ltd, Palárikovo. The field conditions were characterised as mostly flat relief with maximum elevation difference 1.1 m. The field has significant soil heterogeneity with a very good production potential and fertility. Majority of the field is formed by Chernozem and it is considered as heavy or very heavy soils. The measurements were conducted in years 2015 – 2016. Fig. 3 shows the climatic condition during the seasons of observation. As it is indicated at fig.1 the climatic conditions during the vegetation period was relatively stable and warm, however in case of precipitation year 2015 was significantly drier that year 2016 where the volume of precipitations were recorded significantly lower. Indoria et al. (2016) reviewed how the different management technologies like integrated nutrient management, tillage practices, mulching, addition of clay, surface compaction, conservation tillage, use of polymers, etc. can favourably modify the soil physical properties like bulk density, porosity, aeration, soil moisture, soil aggregation, water retention and transmission properties, and soil processes like evaporation, infiltration, run-off and soil loss for better crop growth and yield. Moreover, it was suggested that if appropriate soil management technologies are adopted in rained areas for the improvement of soil physical health, the productivity of rained crops can be significantly improved (Indoria et al. 2016).

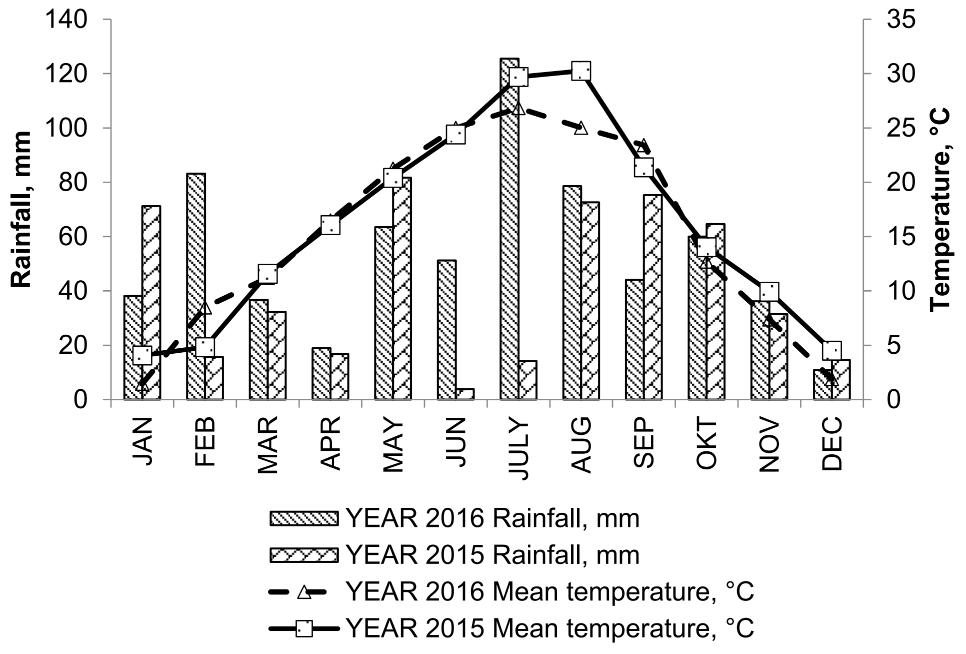

Figure 1 *Rainfall represented monthly as sum of precipitations and temperature records for Palárikovo, Slovakia*

During the first year of measurements the soil analysis was performed in order to define starting conditions of experiments and subsequent comparison of soil profile structure (Fig. 2). In the analysis of soil structure the soil clods diameters and distributions was considered according to Shaojie et al. (2016). The samples were collected from two horizons in depths from0.00–0.15 and 0.15–0.30 m in three replications. Every structural fraction was weighted individually and the percentages were calculated subsequently. For evaluation was introduced and calculated the coefficient of soil structure which characterise the relation between valuable from point of agronomical view (0.25–10 mm) and less valuable structural elements (>10 and <0.25 mm) shown in Table 1.

Figure 2 *Example of comparison of soil profiles (Control and PRP Sol) from year 2015*

Table 1 *Comparison of structural elements – in Palárikovo, autumn 2015*

Variant	Depth, m	Structural elements, %						Coefficient of structure
		>10	5–10	2–5	0.5–2	0.25–0.5	<0.25	
Control	0.00–0.15	38.22	20.22	16.98	15.95	1.69	5.32	1.32
	0.15–0.30	42.54	25.63	17.81	11.31	1.32	2.41	1.23
	Average	**40.38**	**22.92**	**17.40**	**13.63**	**1.50**	**3.86**	**1.27**
PRP SOL	0.00–0.15	24.75	30.70	22.53	17.50	1.62	3.90	2.60
	0.15–0.30	30.51	34.21	13.95	17.90	0.85	2.40	2.80
	Average	**27.63**	**32.45**	**18.24**	**17.70**	**1.23**	**2.56**	**2.34**

From the observed values it can be concluded that the soil conditioner PRP Sol has a positive effect on soil properties and arability and can positively affect the compaction of arable horizon down to 0.30 m. The greatest differences in case of soil structural analyses were observed at soil structural elements above 10 mm where in case of PRP Sol conditioner was calculated value 27.63% in comparison with control part at 40.38% which means the difference 12.75% in average. In case of smaller soil structural elements from 0.25 to 0.5 mm the differences in both parts of experimental areas were only small and not significant. Similar observation was obtained also in case of soil structural elements below 0.25 mm. In the case of utilization of biostimulators also biochar is considered as an alternative. For example, Blanco-Canqui (2017) has reported that biochar generally reduces soil bulk density by 3 to 31%, increases porosity by 14 to 64%, and has limited or no effects on penetration resistance. Biochar increases wet aggregate stability by 3 to 226%, improves soil consistency, and has mixed effects on dry soil aggregate stability. It increases available water by 4 to 130%. Further study shows that saturated hydraulic conductivity decreases in coarse-textured soils, and increases in fine-textured soils following biochar application (Blanco-Canqui, 2017). In addition, Sajjadi et al. (2016) investigated the relations between infiltration rate and soil texture, moisture and compaction and it was shown the effect of soil properties and their relations on infiltration rate by using non-linear regression.

Later on in our study the selected physical properties of soil were observed and are shown in Table 2.

Table 2 *Selected physical properties of the soil*

Variant	Depth of soil (m)	Density red. (g cm^3)	Porosity (%)	Current content		Max. capillary capacity	Min. air capacity
				Water	Air	% volume	
				% volume			
Control	0.0–0.1	1.27	51.77	10.66	40.87	37.56	14.77
	0.1–0.2	1.45	44.28	21.50	23.21	35.21	8.95
	0.2–0.3	1.51	40.75	24.92	14.99	35.12	5.90
	Average	**1.41**	**45.60**	**19.02**	**26.35**	**35.96**	**9.87**
PRP SOL	0.0–0.1	1.29	51.30	18.59	31.67	38.85	10.99
	0.1–0.2	1.55	43.95	25.21	18.98	34.61	8.10
	0.2–0.3	1.41	45.90	22.42	24.25	37.10	9.69
	Average	**1.42**	**47.05**	**22.07**	**24.96**	**36.85**	**9.59**

Measurements focused on comparison of speed of infiltration of water into soil. The plot area was 21 ha with 10 monitoring points where each monitoring point was calculated from ten repetitions. Volume of infiltrated water was measured in both parts of the plot, it means the part treated by PRP SOL material (48.041713, 18.042425) and control part (48.038541, 18.043567), and in ten repetitions during the same time period in the depth of 10 cm. Values of soil humidity were also measured in the control soil probes in 10 cm intervals. A measurement of volume soil humidity in surface zone to 10 cm was carried out in five repetitions for control.

Table 3 shows the statistical comparison of observed values for cumulative soil infiltration rate between untreated and treated part of the field experimental area by soil conditioner PRP Sol.

Table 3 *Descriptive statistics of cumulative infiltration*

Variant	Average	Max.	Median	Min.	Percentile 25	Percentile 75	Standard deviation
Control	0.14	0.23	0.15	0.03	0.10	0.19	0.06
PRP SOL	0.18	0.26	0.18	0.06	0.13	0.23	0.07

Result of measurements was a difference in average percentage of soil humidity content in the part of the plot treated by PRP SOL material with a value of 37.7% compared to the value of 39.4% in control part. Easy to say, water in treated area moved downwards vertically to lower zones of soil profile during the same time from the last rain more quickly. Speed of infiltration set according to retention curves and their trend lines from average measured values is graphically displayed in the Fig. 3.

Blanco-Canqui et al. (2017) has reported that tillage treatments affected pounded infiltration only. Mouldboard plough significantly increased pounded infiltration rate by 21.6 cm h^{-1} at 5 min and by 8.8 cm h^{-1} at 60 min compared with no-till. However, when compared with disk and chisel, mouldboard plough increased pounded infiltration rates at all measurements times, which lasted 3 h. Regarding cumulative infiltration, mouldboard plough increased cumulative infiltration by 26.9 cm to 39.0 cm after 3 h compared with other tillage systems. Similarities in tension infiltration suggest that the higher pounded infiltration for mouldboard plough was most likely due to the presence of voids or fractures (>125 μm) created by full inversion tillage. Total porosity, saturated hydraulic conductivity, and water retention among the treatments did not differ (Blanco-Canqui et al., 2017). In these relations, tillage affects the infiltration speed in soil levels and application of soil activators may also positively affects the speed of infiltrations as well.

It was also concluded by Šařec & Žemličková (2016) that concerning soil bulk density, a drop in values can be discerned with the application of cattle manure, and with majority of variants using pig manure where there are high dosage rates, but the drop was found also with PRP Sol alone. Moreover, Strudley et al. (2008) concluded that differences in temporal variability depend on spatial locations between rows, within fields at different landscape positions, and between sites with different climates and dominant soil types. Most tillage practices have pronounced effects on soil hydraulic properties immediately following tillage application, but these effects can diminish rapidly. Long-term effects on the order of a decade or more can appear less pronounced and are sometimes impossible to distinguish from natural and unaccounted management-induced variability (Golchin et al., 1994).

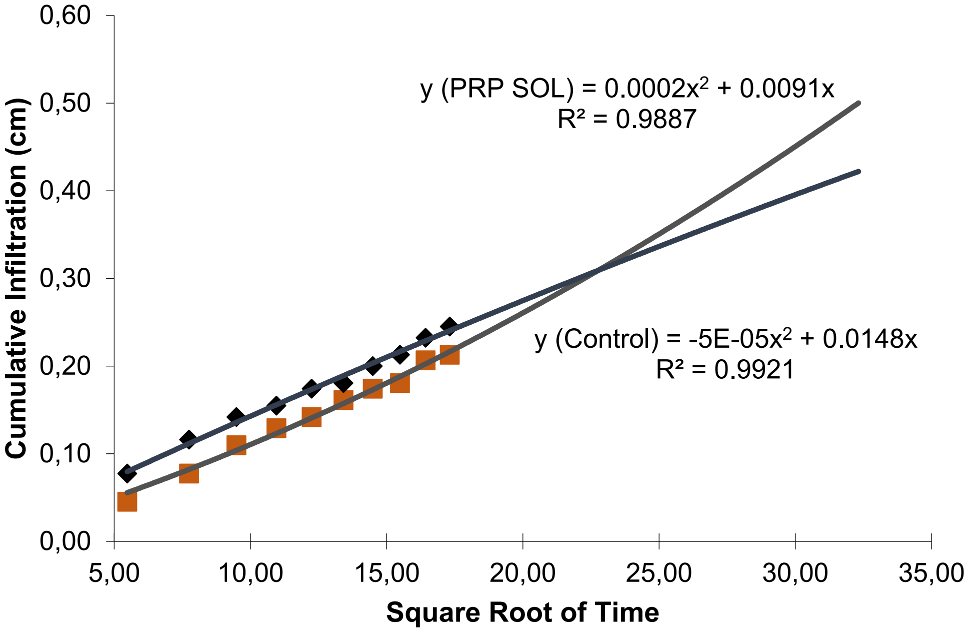

Figure 3. *Speed of infiltration*

Set values of retention curves and their trend lines point to the fact confirming a difference of soil humidity measurement in surface zone of soil profile that rain water in the surface treated by PRP SOL material was infiltrated more quickly. Difference in speed of infiltration to the depth after treatment by PRP SOL material was 2 mm per 1 hour. Sarec et al. (2017) observed the favourable effect of soil activators on the bulk density and other physical soil properties during the measurement of the physical properties of soil. Vegetation indices were another consideration for rating. They suggest a beneficial effect of application of bio-activators. The following values were measured by tensometer force sensors which recorded value (Table 4) of tension force and a measurement unit Hottinger Baldwin Messtechnik Spider-8. During driving of machinery, total measured tension force stopped on the value of 83,735 N in the plot which was used as a control part (Fig. 4). We measured lower values on the treated plot. Maximum tension force measured while driving on the plot treated by the material was 78,911 N (Fig. 5). Also Šařec & Žemličková (2016) has demonstrated the beneficial effect of substances for soil (PRP Sol) and manure amendment (PRP Fix) and of organic fertilisers of various origins on soil bulk density, cone index and on implement draft force reduction.

Table 4 *Descriptive statistics of tension force*

Variant	Average	Max.	Median	Min.	Percentil 25	Percentil 75	Standard deviation
Control	64.03	83.73	66.25	-5.94	63.11	68.84	12.55
PRP SOL	54.89	78.91	56.19	-0.40	50.88	62.10	13.10

In addition, Šařec & Novák (2017b) concluded that the impact of the manure and the activators on the value of saturated hydraulic conductivity is difficult to precisely define. One of the factors may be the duration of the experiment. Another, probably more relevant, is the soil texture of the trial field. All the variants treated with manure demonstrated increase of saturated hydraulic conductivity, namely with PRP Sol applied as well. Moreover, Bagarello et al. (2006) reported that difficulties of measuring saturated hydraulic conductivity on light soils were found. At high levels of conductivity, the effects of soil tillage, fertilization or the influence of cultivated crops cannot be clearly demonstrated. In accordance with authors' assumptions, Celik et al. (2010) confirmed organic applications to significantly lower the soil bulk density and penetration resistance. However, the assumption was not verified by the results so far. Beneficial effect of activated organic matter on soil properties and on production potential was confirmed by Barzegar et al. (2002). Bernal et al. (1998) pointed to the gradualness of changes in the soil and to the need for long-term exposure to carbon fixation and microbial activity.

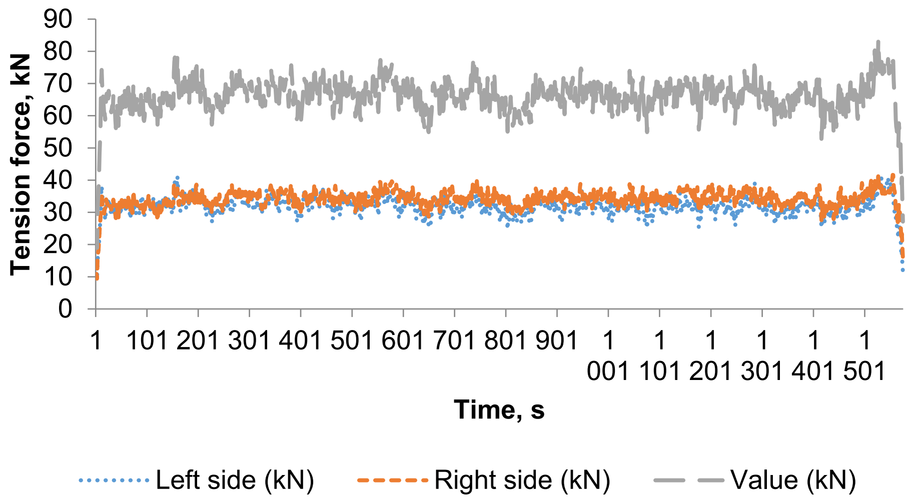

Figure 4. *Record about measurement of tension force during ploughing in the control part (maximum generated force is 83.7 kN)*

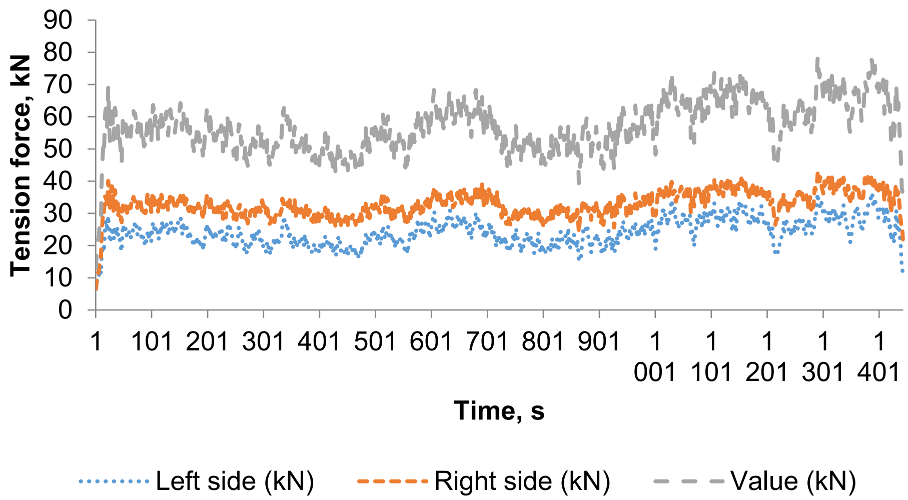

Figure 5. *Record about measurement of tension force during ploughing on the plot after application of the material (maximum generated force: 78.9 kN)*

By comparison of measured and calculated values of tension force caused by tools used in the soil and total need of work it was proven that degree of workability of soil is significantly better on the plot treated by the material than in the control part. Simple analysis of these results confirm a fact that improved function of biological activity and so structure of soil caused decrease of tension force for 5.71% compared to untreated plot (Table 4). According to Strudley et al. (2008) development of soil structure and aggregation are dynamic properties that depend upon soil parent material in addition to climate and management factors. Shrink/swell clays may play an important role in both the natural variability of soil structure and potential responses of soil hydraulic properties to management practices (Horn et al., 1994; McGarry et al., 2000). Changes in soil pore structure in swelling clays have been evidenced in studies of gas and water flow (Angulo–Jaramillo et al., 2000; Horn & Smucker, 2005) and solute transport (Bouma & Woesten, 1979). Swelling clays may also account for some reversal of soil disturbances, such as self-healing of cracks (Eigenbrod, 2003; McDonald et al., 2006) and re-formation of surface cracks upon drying (Radford et al., 2000). Smiles (1995, 2000) provided reviews of the physics of swelling soils, noted here for general reference. Moreover, as Strudley et al. (2008) pointed out, Smiles (2000) has never been cited before, which points to the lack of active advances in this area, with the exception of the few studies cited here on interactions of tillage with the shrink/swell behaviour of soils.

CONCLUSIONS

Tension force measurements were performed during ploughing by 5-mouldboard plough 5PHX 35 to the depth of 22 cm. The experiment itself was carried out in both parts of the plot, namely in the part treated by material and control part. The value of tension force was recorded by tensometer sensors and data were recorded by a measurement unit Hottinger Baldwin Messtechnik Spider-8. During driving of machinery, total measured tension force was 83,735 N in the plot which was used as a control part. We measured lower values on the treated plot. Maximum tension force measured while driving on the plot treated by the material was 78,911 N.

By comparison of measured values of tension force caused by tools used in the soil and total need of work it was proven that degree of workability of soil is significantly better on the plot treated by the material than in the control part. Simple analysis of these results confirms a fact that improved function of biological activity and so structure of soil caused decrease of tension force for 5.71% compared to untreated plot.

Infiltration of soil can be measured by several methods. One of the fastest and simplest methods is measurement by Minidisk infiltrometer. We can state that by using of infiltrometer we found out that speed of infiltration depends on compactness of soil, where some layers of soil infiltrate water faster, and parts of soil with compacted layer infiltrate water more slowly.

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REFERENCES

Ahmadi, I. & Ghaur, H. 2015. Effects of soil moisture content and tractor wheeling intensity on traffic-induced soil compaction. *Journal of Central European Agriculture* **16**(4), 489–502.

Alakukku, L. 1996. Persistence of soil compaction due to high axle load traffic. I. Short-term effects on the properties of clay and organic soils. *Soil and Tillage Research* **37**, 211–222.

Angulo-Jaramillo, R., Vandervaere, J.-P., Roulier, S., Thony, J.-L., Gaudet, J.-P. & Vauclin, M. 2000. Field measurement of soil surface hydraulic properties by disc and ring infiltrometers. A review and recent developments. *Soil and Tillage Research* **55**(1–2), 1–29.

ASABE Standards 2011. ASAE D497.7 MAR2011, *Agricultural Machinery Management Data*. ASABE, St. Joseph, MI, USA.

Bagarello, V., Elrick, D.E., Iovino, M. & Sgroi, A. 2006. A laboratory analysis of falling head infiltration procedures for estimating the hydraulic conductivity of soils. *Geoderma* **135**, 322–334.

Ball, B.C., Parker, J.P & Scott, A. 1999. Soil and residue management effects on cropping conditions and nitrous oxide fluxes under controlled traffic in Scotland. *Soil and Tillage Research* **52**, 191–201.

Barzegar, A.R., Yousefi, A. & Daryashenas, A. 2002. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. *Plant and Soil* **247**, 295–301.

Bernal, M.P., Sanchez-Monedero, M.A., Paredes, C. & Roig, A. 1998. Carbon mineralization from organic wastes at different composting stages during their incubation with soil. *Agriculture, Ecosystems & Environment* **69**, 175–189.

Blanco-Canqui, H. 2017. Biochar and soil physical properties. *Soil Science Society of America Journal* **81**(4), 687–711.

Blanco-Canqui, H., Wienhold, B.J., Jin, V.L., Schmer, M.R. & Kibet, L.C. 2017. Long-term tillage impact on soil hydraulic properties. *Soil and Tillage Research* **170**, 38–42.

Bouma, J. & Wosten, J.H.M. 1979. Flow patterns during extended saturated flow in two, undisturbed swelling clay soils with different macrostructures. *Soil Science Society of America Journal* **43**(1), 16–22.

Celik, I, Gunal, H., Budak, M. & Akpinar, C. 2010. Effects of long-term organic and mineral fertilizers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions. *Geoderma* **160**, 236–263.

Chyba, J., Kroulík, M., Krištof, K., Misiewicz, P. & Chaney, K. 2014. Influence of soil compaction by farm machinery and livestock on water infiltration rate on grassland. *Agronomy Research* **12**(1), 59–64.

DECAGON DEVICES. 2005. *Minidisk infiltrometer, User's manual*. Decagon devices, ltd.

Eigenbrod, K.D. 2003. Self-healing in fractured fine-grained soils. *Canadian Geotechnical Journal* **40**(2), 435–449.

Ekwue, E.I. & Harrilal, A. 2010. Effect of soil type, peat, slope, compaction effort and their interactions on infiltration, runoff and raindrop erosion of some Trinidadian soils. *Biosystems Engineering* **105**, 112–118.

Fontaine, S., Mariotti, A. & Abbadie, L. 2003. The priming effect of organic matter: a question of microbial competition? *Soil Biology and Biochemistry* **35**, 837–843.

Golchin, A., Oades, J.M., Skjemstad, J.O. & Clarke, P. 1994. Soil structure and carbon cycling. *Soil Research* **32**, 1043–1068.

Horn, R. & Smucker, A. 2005. Structure formation and its consequences for gas and water transport in unsaturated arable and forest soils. *Soil and Tillage Research* **82**(1), 5–14.

Horn, R., Taubner, H., Wuttke, M. & Baumgartl, T. 1994. Soil physical-properties related to soil-structure. *Soil and Tillage Research* **30**(2–4), 187–216.

Indoria, A.K., Sharma, K.L., Sammi Reddy, K. & Srinivasa Rao, C. 2016. Role of soil physical properties in soil health management and crop productivity in rainfed systems–II. Management technologies and crop productivity. Current Science 110(3), 320–328.

Johnson, J.F., Allmaras, R.R. & Reicosky, D.C. 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. *Agronomy Journal* **98**, 622–636.

Kay, B.D. & Angers, D.A. 2002. *Soil structure*. A.W. Warrick (Ed.), Soil Physics Companion, CRC Press, Boca Raton, FL (2002), pp. 249–295.

Kroulík, M., Kumhála, F., Hůla, J. & Honzík, I. 2009. The evaluation of agricultural machines field trafficking intensity for different soil tillage technologies. *Soil & Tillage Research*, **105**, 171–175.

Kroulík, M., Kvíz, Z., Kumhála, F., Hůla, J. & Loch, T. 2011. Procedures of soil farming allowing reduction of compaction. *Precision Agriculture* **12**, 317–333.

Larson, D.L. & Clyma, H.E. 1995. Electro-osmosis effectiveness in reducing tillage draft force and energy forces. *Transactions of ASAE* **38**, 1281–1288.

Liang, A., McLaughlin, N.B., Ma, B.L., Gregorich, E.G., Morrison, M.J., Burtt, S.D., Patterson, B.S. & Evenson, L.I. 2013. Changes in mouldboard plough draught and tractor fuel consumption on continuous corn after 18 years of organic and inorganic N amendments. *Energy* **52**, 89–95.

Liu, J., Schulz, H., Brandl, S., Miehtke, H., Huwe, B. & Glaser, B. 2012. Short-term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions. *Journal of Plant Nutrition and Soil Science* **175**, 698–707.

McDonald, A.J., Riha, S.J., Duxbury, J.M., Steenhuis, T.S. & Lauren, J.G. 2006. Soil physical responses to novel rice cultural practices in the rice-wheat system: Comparative evidence from a swelling soil in Nepal. *Soil and Tillage Research* **86**(2), 163–175.

McGarry, D., Bridge, B.J. & Radford, B.J. 2000. Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics. *Soil and Tillage Research* **53**(2), 105–115.

McLaughlin, N.B., Gregorich, E.G., Dwyer, L.M. & Ma, B.L. 2002. Effect of organic and inorganic soil nitrogen amendments on mouldboard plow draft. *Soil & tillage research* **64**, 211–219.

Parr, J.F., Papendick, R.I. & Colacicco, D. 1986. Recycling of organic wastes for a sustainable agriculture. *Biological Agriculture & Horticulture* **3**, 115–130.

Peltre, C., Nyord, T., Bruun, S., Jensen, L.S. & Magid, J. 2015. Repeated soil application of organic waste amendments reduces draught force and fuel consumption for soil tillage. *Agriculture, Ecosystems and Environment* **211**, 94–101.

Podhrázská, J., Konečná, J., Kameníčková, I. & Dumbrovský, M. 2012. Survey of the impact of PRP SOL subsidiary substance on the hydrophysical properties of soil at cultivation of sugar beet. *Listy cukrovarnické a řepařské* **128**, 128–133.

Radford, B.J., Bridge, B.J., Davis, R.J., McGarry, D., Pillai, U.P., Rickman, J.F., Walsh, P.A. & Yule, D.F. 2000. Changes in the properties of a Vertisol and responses of wheat after compaction with harvester traffic. *Soil and Tillage Research* **54**(3–4), 155–170.

Sajjadi, S.-A.-H., Mirzaei, M., Nasab, A.F., Ghezelje, A., Tadayonfar, G. & Sarkardeh, H. 2016. Effect of soil physical properties on infiltration rate. *Geomechanics and Engineering* **10**(6), 727–736.

Sarec, P., Novak, P. & Kumhalova, J. 2017. Impact of activators of organic matter on soil and crop stand properties in conditions of very heavy soils. *Engineering for Rural Development* **16**, 486–491.

Shahzad, T., Chenu, C., Repinçay, C., Mougin, C., Ollier, J.L. & Fontaine, S. 2012. Plant clipping decelerates the mineralization of recalcitrant soil organic matter under multiple grassland species. *Soil Biology and Biochemistry* **51**, 73–80.

Shaojie, H., Enheng, W., Xiangwei, C. & Song, L. 2016. Effects of tillage on compression and rebound behavior of topsoil in black soil region. *Acta Pedologica Sinica* **53**(3), 646–653.

Six, J., Elliott, E.T. & Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and notillage systems. *Soil Science Society of America Journal* **63**, 1350–1358.

Smiles, D.E. 1995. Liquid flow in swelling soils. *Soil Science Society of America Journal* **59**(2), 313–318.

Smiles, D.E. 2000. Hydrology of swelling soils: A review. *Australian Journal of Soil Research* **38**(3), 501–521.

Steinbeiss, S. & Gleixner, G. 2005. Variable contribution of soil and plant derived carbon to dissolved organic matter. In: *AGU Fall Meeting Abstracts*.

Strudley, M.W., Green, T.R. & Ascough II, J.C. 2008. Tillage effects on soil hydraulic properties in space and time: State of the science. *Soil and Tillage Research* **99**(1), 4–48.

Šařec, P. & Novák, P. 2016. Influence of biological transformation of organic matter on improvement of water infiltration ability of modal luvisol. *In: 6th International Conference on Trends in Agricultural Engineering*, TAE 2016, Sept 7, 2016, Prague. Prague: Czech University of Life Sciences Prague: 627–632.

Šařec, P. & Novák, P. 2017a. Changes in soil properties due to the application of activators in conditions of very heavy soils. *Research in Agricultural Engineering* **63**(special issue), S40–S45.

Šařec, P. & Novák, P. 2017b. Influence of manure and activators of organic matter biological transformation on selected soil physical properties of Modal luvisol. *Agronomy Research* **15**(2), 565–575.

Šařec, P. & Žemličková, N. 2016. Soil physical characteristics and soil-tillage implement draft assessment for different variants of soil amendments. *Agronomy Research* **14**(3), 948–958.

Velebný, V., Novák, V., Skalová, J., Štekauerová, V. & Majerčák, J. 2000. *Water regime of soil*. Slovak technical university, Bratislava, 2000, 208 pp. (in Slovak)

Vero, S.E., Antille, D.L., Lalor, S.T.J. & Holden, N.M. 2012. The effect of soil moisture deficit on the susceptibility of soil to compaction as a result of vehicle traffic. *American Society of Agricultural and Biological Engineers Annual International Meeting 2012*, ASABE 2012, Volume **7**, 2012, Pages 5419–5434.

Wang, K., Li, W., Li, X. & Ren, N. (2015): Spatial nitrifications of microbial processes during composting of swine, cow and chicken manure. *Scientific reports* **5**.

Wilhelm, W.W., Johnson, J.M., Karlen, D.L. & Lightle, D.T. 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. *Agronomy journal* **99**, 1665–1667.

Effect of seed position on the utilization water in the soil

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Abstract: Climate changes in the conditions of Slovakia at growing oilseed rape are also reflected. Agricultural term of sowing is according to the region August, which is characteristic by soil drought. In this period should we minimize number of working operations at the cultivation, to save water in the soil. Partly solution of this problem can solve a good choice of seeding machine, or rather good choice of seed position. It has been proven, that the longitudinal distribution of the seeds and the row spacing, size of the area affect the crop. Polygons with the same size of area can be distinguished in the shape of area corresponding to one plant. An ideal area should be a circle, but we are not able to reach that by currently used seeding machine. In the contribution we tried to evaluate the effect of the created living space around the plants on the mutual competition of the plants. As a result, we have found out, that the more positive results from the point of view of polygon formation have been achieved with the Monopill S. This claim is based on the obtained crops for each variant.

Keywords: polygon evaluation, water in the soil, crop

INTRODUCTION

During the cultivation brings the climate changes an unfavorable distribution of rainfalls (Fiala, 2016). The accumulation of these problems is in the final production results very negatively reflected. In connection with climate changes it is possible to expect an increase of extreme weather events. A major problem in soils in the Slovak Republic is a small supply of organic matter and too much compaction. Our efforts to increase production intensity are unfortunately counter-productive in that, we don´t respect the baselines processes running in soil, especially from point of view the biological activities (Kosolapova a kol., 2016). The soil structure is in the most cases disturbed by the low soil biological activity and the lack of organic matter. As a consequence these disturbances, the soil physical properties are significantly deteriorated. So it is creates the first assumption deterioration of rainfall water infiltration to the soil and its holding in the soil profile (Stefanovits, 1992; Badalíková a kol., 2018). These are factors that are closely intertwined with the management of moisture in the soil, or rather in the use of soil moisture by plants. A plant that has the required living space around the root system has better conditions for germination and emergence of plants. It is clear that the deployment quality of seed in the soil has a direct effect on the germination, plant emergence, the use of space by crops, but also the use of appropriate machinery in the sowing, chemical treatment and harvesting crops (Findura, 2005). Nearest to these requirements is the use of polygonal method. It uses the Delaunay´s triangulation and Voronoiov´s or Thiessen´s decomposition of polygons (Griepentrog, H., W. 1999). The above issues were addressed by other authors (Kuruc, 2013).

MATERIAL AND METHODS

Research was conducted on the farm Agrodružstvo Rišňovce. Under these measurements we tried to compare the different methods of sowing by polygonal method. We tried to compare the sowing of drillers with intermittent and continuous seeding.

Method for the description of quality spatial distribution of seeds reflects the area per one seed (plant), taking into accounts the parameters of a longitudinal layout, row spacing and quantities of the seeds. Described polygonal method should allow comparing different methods of sowing by defining the individual mean area (living spaces) for each crop. Since the detection of distance between the seeds immediately after sowing is difficult we have performed this procedure after the emergence of the plants and their subsequent digitizing and image analysis.

For the measurements we used drills using various methods of sowing and operating at various principles of work. Firstly, it was used AMAZONE ED 300 with continuous seeding system that uses Hooziera´s cylindrical system and were supplemented by a rotating chisel plough for seedbed preparation. Secondly, Kverneland Accord Monopill S driller with intermittent sowing system was used. It uses a mechanical scooping of seeds with the internal implementation of sowing holes. Driller are generally used for sowing of sugar beet and maize.

The methodology of work can be divided into:

- monitoring of the seeds properties,
- monitoring of the soil properties,
- evaluation of the quality of sowing by shape factor and real area of polygons.


Fig. 1 View of the soil profiles

Area per plant described by polygon is characterized by: area size, form (shape), plant position (eccentricity).

Size of the area per plant is of a great significance for the amount of the field germination and development of plants. Equal amounts of seeding result in the same average size of the area. It has been shown that the longitudinal distribution of seeds, row spacing and size of the area have an impact on the yield. Polygons with the same size of area can be distinguished in the shape of area corresponding to one plant. An ideal area should be a circle, but we are not able to reach that by currently used drills. Since the circle has the smallest area for a given perimeter, the ratio formed from ideal and the real circuit could be applied as a benchmark for describing the shape of the actual area deviations from the ideal measuring area (living space of plant). For evaluation of area shape were introduced so called form factor (equation 1).

$$\bar{T}_k = \frac{1}{n}\sum_{i=1}^{n}\frac{O_{ideal}.i}{O_{real}.i} \qquad (1)$$

where:

O_{ideal} – ideal perimeter of hexagonal polygon,

O_{real} – actual perimeter of measured polygon,

S_i – actual area of polygon.

Ideal perimeter will be then based on actual size of the polygon area as:

$$O_{ideal} = 3{,}7224\sqrt{S_i} \qquad (2)$$

The real area of a polygon (S_i) we get by the sum of the triangles areas which forms the polygon (fig. 2).

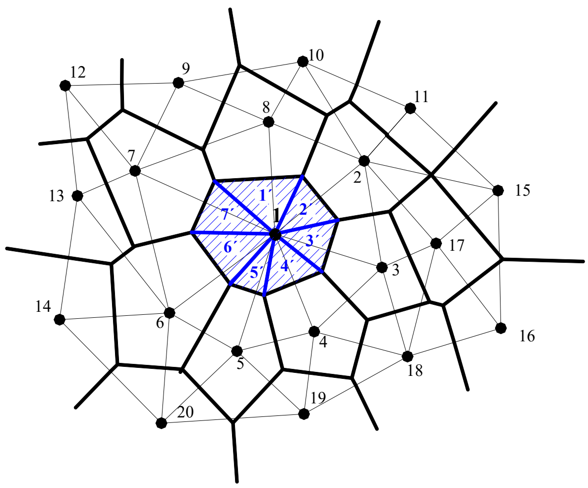

Fig.2 Polygonal distribution of points (plants): 1 to 20- distribution of pints (plants); 1´to 7´- triangles forming a polygon created around the point 1

In addition to the size and shape of the area will have its importance also position of plants within the polygon (the eccentricity), however, compared to these characteristics is less significant and there are not developed a methods for its determination.

From the above knowledge we used in the evaluation of individual photos of oilseed crop, while we used the software TfPoly M, produced by doc. Dr. Ing. Juraj Maga. When using the referred software, firstly it is needed to adjust the photos into BMP format and trim them to the size of capturing frame. Subsequently, individual plants shall be marked out and selects the function: mark the neighbouring plants (Fig. 3).

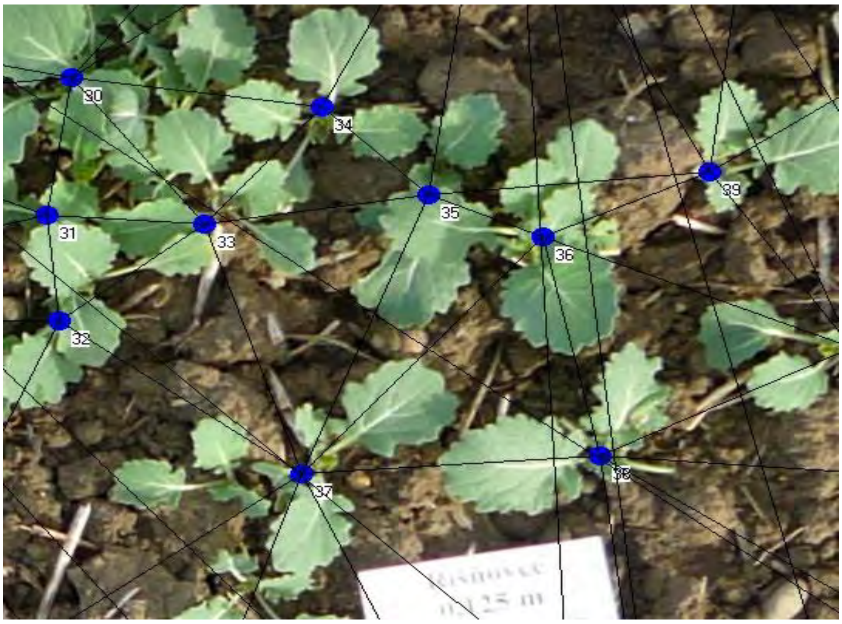

Fig.3 Detail of designation of neighbouring points and their interaction

Consequently, it is necessary to select a polygon feature creation and export of results, where the evaluation indicators are already such as shape factor, actual area or the actual circumference of living area around the plant. All those elements of the evaluation gives an overview of the use of living area around the plant, its potential competitiveness in comparison with other plants and also allows to compare the different methods of sowing.

Evaluation of spatial distribution of seeds has its justification in terms of future growth and development of plants. The area is more regular in shape of a circle thus more optimal is absorption of moisture, nutrients and sunlight.

RESULTS AND DISCUSSION

Measurements were carried out on loamy sand soils at the Agrodružstvo Rišňovce company. The research was requested by the practice, where the basic idea was if oilseed rape can be sown also by using of drills with intermittent seeding. For measurements, we used options of the company, where we compared the seed drill Amazone ED 309 with roller sowing mechanism seed drill Kverneland Monopill S – mechanical drill with the internal implementation of seeding holes. In the same conditions at different working speeds, different sowing rates, we focused on spatial distribution of seeds after sowing.

ISO 7256/1 and 7256/2 prescribe the characterization of conditions under which the measurements were conducted. It was a land with sloping 0-1°, BPEJ0145001, phosphorus 128 $mg.kg^{-1}$, potassium 145 $mg.kg^{-1}$, magnesium 159 $mg.kg^{-1}$, pH 7.3. After seedbed tillage we achieved the required finely crumbly texture. Soil samples were collected by Kopecky rollers.

Tab. 1 Results of the evaluation of soil properties in laboratory

RIŠŇOVCE				
weight of wet sample in g	weight of dry sample in g	depth of measurement in mm	bulk density of dry soil $t.m^{-3}$	moisture, %
146,79	122,28	15	1,2228	20,04416
129,42	105,51	30	1,0551	22,66136
125,76	101,41	45	1,0141	24,01144

We also tried to evaluate the penetrometric resistance through the digital penetrometer (Fig. 4).

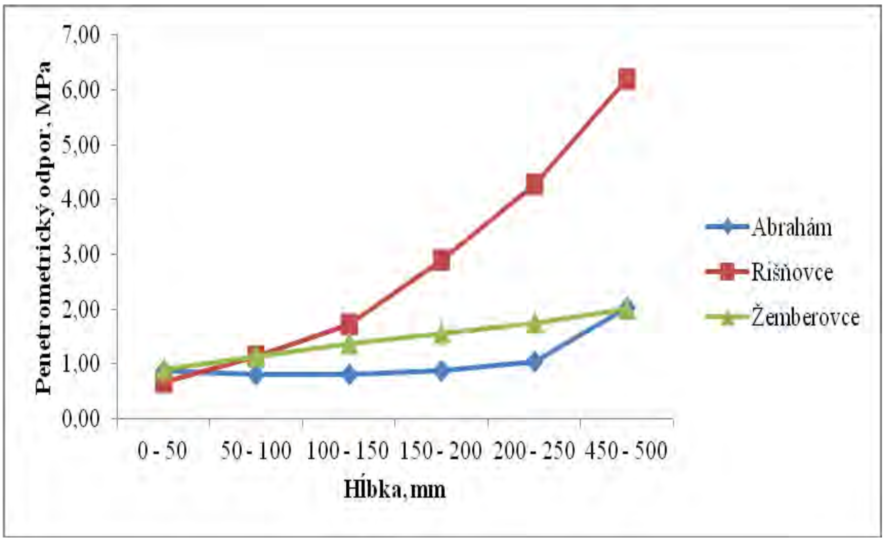

Fig.4 The course of penetrometric resistance measured at various sites

For measurements the seed PR46W20 were used produced by company of Pioneer. In terms of scoop process, it is important that seeds reached approximately spherical shape. The measured values of seeds dimensions were following: average length - 1.71 mm, average width 1.66 mm and the thickness as the smallest dimension - 1.65 mm. These values represent the basis of calculation of shape factors, where the smaller the difference between coefficients thus more spherical seed is.

Tab. 2 Comparison of the evaluated parameters the different options used in Rišňovce.

	Rišňovce	
	Amazone 125 mm	Monopill 450 mm
Seed rate per hectar	160 000	160 000
Yield of grains, t	2,4	2,9
Average shape factor	0,58	0,69
Average area of polygons, (mm^2)	5755,219	5902,247
Average number of stems, n	3,49	10,45
Average number of siliques, n	66,46	215,91
Average height of plants, cm	110,07	107,22

When measuring the horizontal storage of seeds in the soil, we proceeded in accordance with ISO standard 7256/2, which, although does not prescribe the area measuring layout of seeds but tells about drills in terms of assessing longitudinal deployment of seeds during the sowing. What are the working conditions under which the object of research is trying to tell is about minimum operating speed up to the maximum operating speed in grading by 0.5 ms^{-1}. We were trying in measurements to observed of speed prescribed by the standard but some have adjust their energy resource options used in other standards prescribes the test machine on level ground and on a slope. For our measurement we used the land with sloping up to 2°.

Based on measured data we can conclude that for seed drill Amazone ED 300 with row spacing 0.125 m was recorded maximum value of shape factor 0.91 at operating speed 6.2 $km.h^{-1}$ and the minimum value of 0.73 was achieved. Similar pattern was observed in assessing the actual area that has plant during the vegetation available. This course is shown in fig.3, the curve with the polynomial shape.

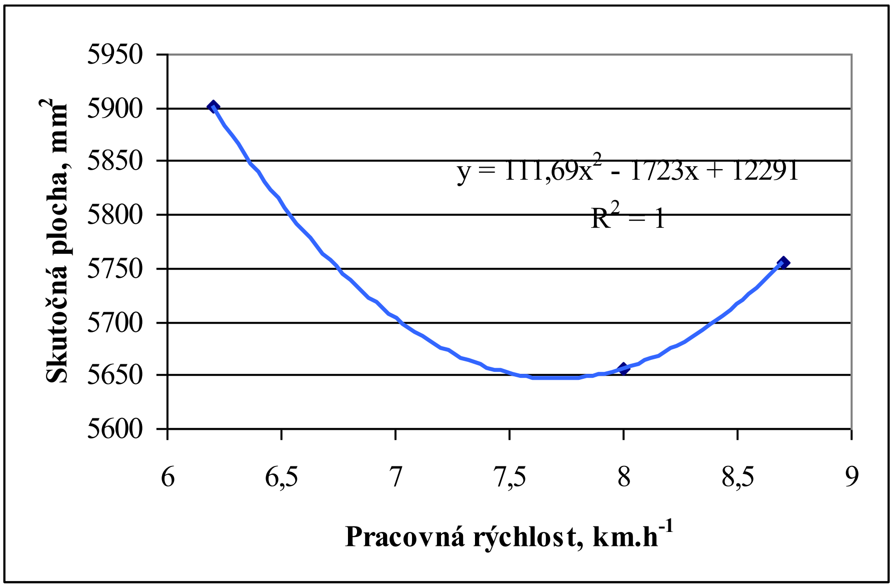

Fig.5 The dependence of the actual plants area on working speed of the machine Amazone ED

Based on measured and evaluated data it can be concluded that the seed drill Amazone ED 300 with swing chisel plough with row spacing 0.125 m has its best working speed 6.2 km h^{-1}. It must be said that the evaluation criterion of regularity polygon is shape factor. The ideal shape for the development of the plant is a circle which has the value 1. Therefore, the closer the value obtained through the measurement thus the more ideal sowing in terms of shape.

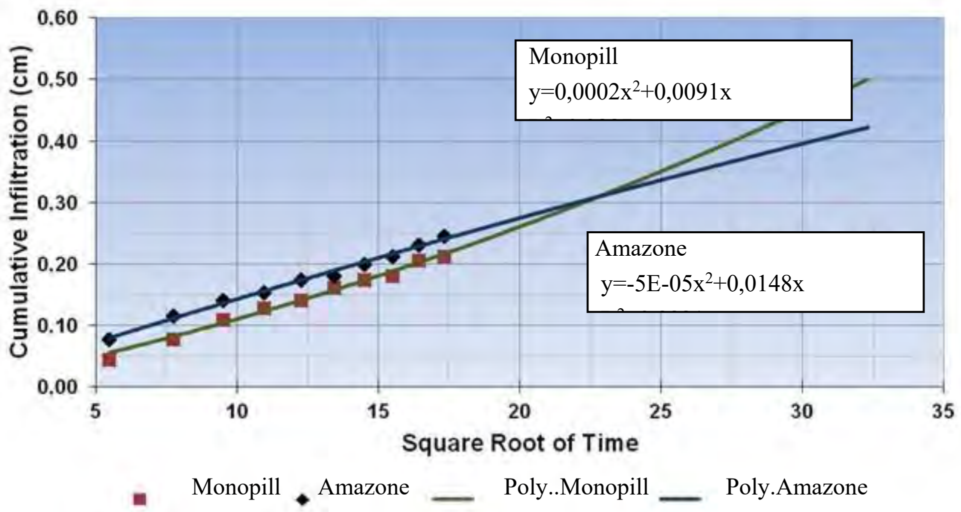

Fig. 6 Speed of infiltration depending on different methods of seeding

The difference in infiltration between more compation soil as a result of the impact of the parts Amazone seeding machine compared to the Monopill S was 2 mm per hour. It means, in this part is faster recovery of soil moisture before the dry season

It is a value that is identical, although the value of drill Amazone but in terms of driller Monopill S at all speeds was reached relatively high values of shape factor. From the obtained values, we can see that as the best globally based on 0.450 m distance where the value of shape factor is 0.886 in comparison with row spacing where reached a value of only 0.823. The benefit of drill Monopill S however, tells also saving of seed which is achieved in comparison with conventional AMAZONE ED.

CONCLUSION

Quality and precision sowing to maximize germination and plant emergence is an important factor in terms of minimizing inputs into the production process, but also in terms of maximizing yields, and hence the total valuation of work for all seasons. Already in our country are considering seeding of oilseed rape by drills with intermittent seeding. Finding the optimal number of individuals and ideal inter-row spacing between plants is among the main objectives. Manufacturers of seed breeding new hybrids to deploy stems shallow over the soil surface and also offer new opportunities in growing this important crop. Based on these results we can conclude that from the perspective of shape of plant living space and hence in terms of method of sowing a better results were achieved with driller with intermittent sowing Monopill S. The most appropriate row spacing distance was 0.450 m and especially at lower working speeds.

REFERENCES

Badalíková B., Novotná J. 2018: Nedostatek půdní vlahy vlivem úbytku organické hmoty v půdě. Úroda 2018. sv. 66, č. 8, s. 70-72. ISSN 0139-6013

Calvo P., Nelson L., Kloepper J. W. (2014). Agricultural uses of plant biostimulants. Plant Soil 383, 3–41. 10.1007/s11104-014-2131-8

DEMO, M. a kol. 1995. Obrábanie pôdy. Nitra: VŠP, 1995. 309 s. ISBN: 80-209-0048-9

Du Jardin P. (2015). Plant biostimulants: definition, concept, main categories and regulation. Sci. Hortic. 196, 3–14. 10.1016/j.scienta.2015.09.021

Fiala R., Kohut M., Chuchma F., Rožnovský J. 2016: Zemědělské sucho na území České republiky v roce 2015. Konference: In sborník příspěvků z mezinárodní konference "Půdní a zemědělské sucho v Kutné Hoře 2016. VÚMOP, Str.: 66-81. ISBN 978-80-87361-55-9

FINDURA, P. 2005. Sejba širokoriadkových plodín, In: *Moderná mechanizácia v poľnohospodárstve*,2005, č.3, s. 5-7.

GRIEPENTROG, H., W. 1999. Zur Bewertung der Flächenverteilung von Saat gut. In: Agrartechnische Forschung, 1999, Nr. 5, H 2, s. 117-124

JAMBOROVÁ, M. 1999. Olejniny: Situačná a výhľadová správa. Bratislava: VÚEPP, 1999. 23 s. ISBN: 80-8058-108-8

Kosolapova A., Yamaltdinova V., Mitrofanova E., Fomin D., a Teterlev I. 2016: Biological Activity of Soil Depending on Fertilizer Systems. *Bulgarian Journal of Agricultural Science*. 2016, **22**(6), 921-926. ISSN 13100351

KRAUSKO, A. a kol. 1992. Rastlinná výroba I. Nitra: VŠP, 1992. 207 s. ISBN: 80-7137-058-4

Lhotský J., 2000: Zhutnění půd a opatření proti němu. Studijní zpráva UZPI Praha, 61 s.

Miller, R. H., 1990. Soil microbiological inputs for sustainable agricultural systems. In: Edwards, C. A., Lal, R., Madden, P., Miller, R. H., House, G. (Eds.), Sustainable Agricultural Systems. Soil Water Conservation Society, pp. 614–623.

PÁLTIK, J., RATAJ, V., BAŠEK, P. 1994. Vplyv opotrebenia výsevnej pätky na rozmiestnenie semien v riadku. In: *Acta Technologica Agriculturae*. Nitra: VŠP, roč. 24, 1994, s. 67-77

Sotákova S. 1982: Organická hmota a úrodnost pôdy. Príroda, Bratislava, s. 234

Stefanovits P.; 1992. Soil sicence. Mezőgazda Kiadó. Budapest

Szűcs L., Zsembeli J.; 2014. Improvement of soil productivity by application of PRP-SOL in reduced tillage. Úroda 12/2014, vědecká příloha, roč. LXII, 119-126. ISSN 0139-6013.

ZUBAL, P. 1999. Vzájomné pôsobenie rozhodujúcich vkladov pri pestovaní olejnín – repka olejka forma ozimná, repka olejka forma jarná, horčica biela: Záverečná správa. Piešťany: VÚRV, 1999.19 s.

Impacts of soil activators aplications on basic soil conditions and water regime in soil

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Abstract: During 2011 - 2015 we observed the established experiment where the influence of soil support substances, products with a specific ratio of organic, mineral substances and trace elements for the soil environment. Experimental site is located in 210 m above sea level and is classified as the warmest T4 climate zone. The obtained results show that application of soil activators has positive impact on the soil physical properties - reduced compaction, increased porosity as well as the soil structure has improved. Better results were obtained by application soil activators. The yields were higher with this product compared to control.

Key words: soil conditions, soil degradation, water regime, produktivity, yield, soil activators

INTRODUCTION

Of the negative processes threatening soils, physical degradation is the most common and causes the most serious problems. Biological activity in the soil declines due to soil compaction and degradation of soil texture, thus reducing soil productivity (Stefanovits, 1975, Taylor, 1987). Soil compaction is also the cause of harmful dysfunction in terms of the soil's infiltration ability, air capacity and thermal behaviour (Stefanovits, 1992, Birkás, 2002). These unfavourable effects can be mitigated by soil conditions, i.e. by improving physical, chemical and biological properties of agricultural soils. Soil conditions can be improved by appropriate soil management or by applying various additives such as synthetic soil substances, organic fertilizer or polysaccharides of microbiological origin. Organic fertilizer is a valuable source of soil organic matter which plays an important role in sustaining the integrity of soil structure supporting numerous functions of soil, especially infiltration, water retention and resilience against erosion (Gregorich et al., 1994). The reduction in the amount of soil organic matter in agro-ecosystems closely relates to degradation of physical soil properties (Li et al., 2007). One of the possibilities to mitigate the unfavourable impact of climatic change is to use methods of protective soil management. Reducing soil tillage and its effect on physical, chemical and biological properties of soil were studied by Szűcs and Zsembeli (2014) in a long-term experiment in Karcag. Their study was based on monitoring the effectiveness of a soil conditioner which improved the condition and biological properties of soil.

Biological soil characteristics provide precious information on changes in other soil properties. Numerous microbiological and biological parameters can be assessed very quickly and precisely in laboratories; sometimes even in the field. Biological soil characteristics are especially sensitive to changes in farm management, to soil degradation and contamination (Brookes, 1995). For example, soils on erosion-damaged land have highly degraded biological characteristics and the soil has practically no biological vitality / is biologically passive (García et al., 2000). Nevertheless, it is very difficult to determine which particular physical or chemical soil property is damaged on the basis of biological characteristics alone. Therefore authors Tejada et al., 2006; and Wei et al., 2011, tried to correlate biological properties of soil with the physical and chemical characteristics to discover their mutual relationship. The authors focused on soils damaged by excessive compaction, i.e. with disturbed physical properties.

Beneficial soil microorganisms are directly or indirectly involved in promoting plant growth and Beneficial soil microorganisms are directly or indirectly involved in promoting plant growth and yield. The ameliorating effect of fly ash (FA) with reference to the microbial density and activity was sparsely studied (Parab et all, 2015) in acidic soil under field conditions. An experiment was conducted to assess the population dynamics of beneficial microorganisms at different levels of FA (25 Mg/ha, 50 Mg/ha, 100 Mg/ha and control with no fly ash. It was observed that population density of phosphorus solubilising bacteria (PSB) (1.33 x 10(6) cfu/100 g soil), Actinomycetes (3.11 x 10(5) cfu/100 g soil) and arbuscular mycorrhizal fungi (AM fungi) were maximum at 50 Mg/ha FA. However, the density of Azotobacter (6.27 x 10(4) cfu/100 g soil) was highest at 25 Mg/ha. AM fungi root colonization and soil microbial activity were significantly highest at 50 Mg/ha dose of FA in comparison to control. FA amendment significantly improved the physical-chemical properties of soil. Cation exchange capacity, water holding capacity, available P and available K were optimum at 50 Mg/ha. Heavy metal content in FA amended soil was found to be reduced with respect to the control.

Biochar is the product of thermal degradation of organic materials in the absence of oxygen (pyrolysis), and is distinguished from charcoal by its use as a soil amendment (Lehmann and Joseph, 2009). Biochar as a soil amendment is confronted with the challenge that it must benefit soil health as it can be by no means separated from soils once it is added. The available literature even though sparse and mostly based on short-term studies has been encouraging and the trend obtained so far has raised many hopes. Biochar has been reported to positively impact an array of soil processes ranging from benefiting soil biology, controlling soil-borne pathogens, enhancing nitrogen fixation, improving soil physical and chemical properties, decreasing nitrate (NO^{3-}) leaching and nitrous oxide (N_2O) emission to remediation of contaminated soils. However, very little biochar is still utilized as soil amendment mainly because these benefits are yet to be quantified, and also the mechanisms by which the soil health is improved are poorly understood. Due to the infancy of research regarding this subject, there are still more questions than answers. The future research efforts must focus on carrying out long-term experiments and uncover the mechanisms underlying these processes so that key concerns surrounding the use of biochar are addressed before its large scale application is recommended (Lone et all, 2015).

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Bennet et all. (2014) determines the influence of lime and gypsum on the rehabilitation of a degraded sodic soil in a semi-arid environment 12 years after application. The aim was to assess rehabilitation strategies for sodic soils as alternatives to the application of gypsum alone. An experimental site was used where lime and gypsum combinations (L0G0, lime 0 t ha (-1) and gypsum 0 t ha (-1); L0G1, L0G2.5, L0G5, L1G0, L2.5G0, L5G0, L1G1, L2.5G1) had been applied 12 years prior, in 1994. An earlier study had reported on the effects after 3 years of the chemical ameliorants and tillage on a range of soil physical and chemical properties at the site. The current study, sampled in 2006, assessed the effects after 12 years of lime and gypsum on soil chemistry, stability, hydraulics, vegetative growth and soil respiration. Calcium, primarily from lime, was observed to have a major effect on soil health. Significant Beneficial soil microorganisms are directly or indirectly involved in promoting plant growth and yield. The ameliorating effect of fly ash (FA) with reference to the microbial density and activity was sparsely studied (Parab et all, 2015) in acidic soil under field conditions. An experiment was conducted to assess the population dynamics of beneficial microorganisms at different levels of FA (25 Mg/ha, 50 Mg/ha, 100 Mg/ha and control with no fly ash. It was observed that population density of phosphorus solubilising bacteria (PSB) (1.33 x 10(6) cfu/100 g soil), Actinomycetes (3.11 x 10(5) cfu/100 g soil) and arbuscular mycorrhizal fungi (AM fungi) were maximum at 50 Mg/ha FA. However, the density of Azotobacter (6.27 x 10(4) cfu/100 g soil) was highest at 25 Mg/ha. AM fungi root colonization and soil microbial activity were significantly highest at 50 Mg/ha dose of FA in comparison to control. FA amendment significantly improved the physico-chemical properties of soil. Cation exchange capacity, water holding capacity, available P and available K were optimum at 50 Mg/ha. Heavy metal content in FA amended soil was found to be reduced with respect to the control.

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MATERIALS AND METHODS

When applying different doses of the preparation PRP SOL is possible that not only physical, chemical and biological properties of treated soil will be changed but that changes in its fertility and productivity (i.e. yield fluctuations will occur as well (PRP EBV, PRP T20). The experiment was established in the cadastre of the village Litobratrice (Agrocentrum Hrusovany) in the spring of 2011. The experimental field was used for growing maize for grain as a monoculture.

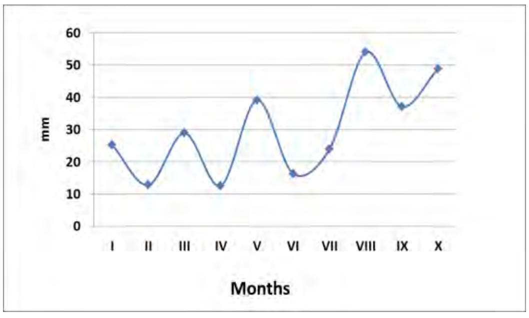
Climatic conditions: The experimental locality is situated in the maize-growing regions (altitude 210 m above sea level).and is classified as the warmest climatic zone T4. This locality is influenced by the rain shadow of the Ceskomoravská (Bohemian-Moravian) Highlands and the average annual precipitation is about 461 mm (of this, 302.3 mm are rainfalls occurring during the growing season). The average annual temperature is 8.9 °C, (of this, 15.3°C in the growing season).

Soil conditions: Modal chernozem on loess, meadium heavy, and loamy to claey-loamy. The depth of the topsoil layer is as much as 0.4 m.

Surveys of temperatures and sums of precipitation, as recorded in individual measuring sites in Litobratrice within the year 2015, are presented in Graphs 1 and 2. This year has been measured precipitation amount of 212 mm and an average temperature of 17.2^0 C during the growing season, which is 90 mm less rainfall and 1.9^0 C above the long term average.

Graph 1: Course of average monthly sums of temperatures (2015)

Graph 2: Sums of monthly precipitations (2015)



Within the framework of this experiment, physical, chemical, and biological properties of soil as well as yields of the main crop (maize for grain) were monitored.

Soil samples were collected in four variants of this experiment in the course of the growing season; the obtained results were used for the evaluation of effects of various doses of PRP SOL preparation of the soil environment (Experiment I). In one experimental variant the supporting effect of PRP T20 on microbial activities was studied as well.

Variant A – Control (without PRP SOL) – only the mineral form of the N fertiliser was spread by means of broadcasting (i.e. evenly and uniformly) on the experimental field; phosphorus (P) was applied simultaneously with the seed material (plough sole placing)

Variant B – N fertiliser + 100 kg of PRP SOL; plough sole placing (with a simultaneous application of seed material and fertiliser); without P and K

Variant C – N fertiliser + 150 kg PRP SOL; plough sole placing (with a simultaneous application of seed material and fertiliser); without P and K

Variant D – N fertiliser + 150 kg PRP SOL; broadcasting; without P and K

Variant T20 – 100 kg of PRP T20 preparation

In Experiment II, all variants were the same as in Experiment I; the only difference was that plants were sprayed with the liquid growth stimulator PRP EBV in the stage of the 3rd – 4th leaf. In Experiment II, only yields were monitored. In both experiments and in all variants, the maize crop was harvested by hand in three replications. The yield of grains was calculated as follows: ears (cobs) harvested from 15 plants were weighed and the moisture content in harvested grains was determined; thereafter these data were converted to the hectare yield with the standard moisture content of 14 % and TGW.

In 2013, a new experimental variant T20 was established, in which the preparation PRP T20 supporting the growth and propagation of microorganisms was applied in the dose of 100 kg. In this case, the following parameters were determined in three replications, both in control and in T20: germination, height of plants and their vitality after 14 and 28 days, planting density after 28 days, weight of biomass in the stage of 4-6 leaves – length and weight of roots, weight of stalk, and yield of kernels from 12 plants harvested by hand. As far as the grain yield was concerned, the following parameters were evaluated: number of rows on an ear, number of kernels in a row, number of kernels on an ear, weight of ears from 12 plants, and moisture content in kernels at the moment of harvest. All obtained data were evaluated in accordance with the predetermined methodology.

The width and length of one experimental variant were about 30 and 100 m, respectively. Plant protection measures were performed in a uniform manner with regard to the actual situation existing in the locality under study.

Methodology of soil analyses

Of physical soil properties, the following parameters were monitored: reduced bulk density, porosity, actual contents of water and air, maximum capillary capacity, minimum air-holding capacity, soil structure, water stability of soil aggregates, and penetrometric density of soil.

Physical properties were studied using the using Kopeck's stainless steel cylinders. Soil samples were collected in five replications from three different depths, viz. 0-0.10; 0.10-0.20 and 0.20-0.30 m.

Soil structure was estimated by means of screening dry soil samples on sieves with the average mesh size of 0.25; 0.5; 2.5; 10 and 20 mm. Soil samples were taken in three replications from two different depths, namely 0-0.15 and 0.15-0.30 m. Each structural fraction was weighed separately and converted to a percent value. For the evaluation itself, coefficients of structurality were calculated, which expressed the relationship between agronomically valuable (0.25-10 mm) and less valuable structural elements (>10 and <0,25 mm).

The degree of soil profile compactness was estimated by means of a mechanic penetrometer.

The penetrometric test is based on pushing a standardized steel cone into the soil. Its main advantage consists in a high expeditiveness and possibility of a rapid evaluation of results characterising the soil profile under study (in this case down to the depth of 0.40 m). In each variant, at least 5 replications were performed within the framework of the all topsoil profile.

The water stability (i.e. the stability of soil aggregates) was estimated in loose soil samples collected in the average depth of 0-0.20 m. When using this method, soil aggregates of the size of 1-2 mm were washed for 5 minutes in a wet washing sieve apparatus. The water stability of soil aggregates was estimated by means of the method of wet sieving (Kandeler 1996). Percentages of water-stable aggregates in the total sample were calculated using the formula:

$$\% SAS = ((M_2 - M_3) / \quad W - (M_3 - M_1)) . 100$$

where

% SAS is the percent of stable soil aggregates;

M_1	weight of the tray (g);
M_2	weight of the tray, stable aggregates and sand (g)
M_3	weight of the tray and sand (g)
$(M_2 - M_3)$	weight of stable aggregates
$M_3 - M_1)$	weight of sand
W	weight of the sample (4 g)

As far as the chemical properties were concerned, contents of essential nutrients (nitrogen, phosphorus, potassium, magnesium and calcium) were assessed together with the content of humus, its quality, and the ion-exchange reaction of soil.

Soil samples used in chemical analyses were taken from two different depths, namely 0-0.15 and 0.15-0.30 m together with those used for humus content estimations. The pH exchange reaction was estimated in a KCl eluate and measured with a pH-meter while contents of available phosphorus, potassium and magnesium were determined in the spectrophotometer using the Melich III method (expressed in mg per 1 kg of soil). The content of total nitrogen (in %) was assessed after the mineralisation by means of the Kjehdahl distillation method. Samples for estimations of the humus content and its quality were also taken from depths of 0-0.15 and 0.15-0.30 m. The total humus content (or, in other words, oxidable carbon) was determined using the Tjurin method as modified by Novák. Humus quality was determined on the base of humic and fulvic acids ratio using tabelar dependences of the colour coefficient Q4/6.

Of biological soil properties both quantitative and qualitative biological parameters of the topsoil layer till the depth of 0.10 m were studied.

Basal and potential respiration was expressed by means of qualitative biological parameters (as described by Černohlávková). This method is based on measurements of respiration activity expressing the amount of CO2-C (usually and most frequently expressed in g) produced within a certain time interval and related to one gram of dry soil. The microbial respiration of soil was monitored within a period of 7-30 day aerobic incubation. Results of these measurements of microbial respiration activity were expressed either as a cumulative content of CO_2-C released per unit of time or as the average diurnal production of CO_2-C (expressed in mg of CO_2-C per kg of DM.

Soil biomass (i.e. the quantitative content of microorganisms) was estimated by the fumigation-extraction method (Vance et al.). Soil samples were fumigated with chloroform for a period of 24 hours and the content of C_{bio} was determined on the base of the differences between fumigated and non-fumigated samples. Carbon was estimated either by means of the dichromate oxidation taking place in presence of a strong acid and combined with the subsequent titration with Mohr's salt or by means of spectrophotometry.

RESULTS AND DISCUSSION

Yield

The results for yield in grain maize, with the use of additives PRP SOL and PRP SOL + EBV, are given in Tables 1 and 2. Grain maize was harvested on 01.10.2015.

Yield was negatively influenced by the weather during the vegetation period this year, when it hardly rained at all from June to the end of August. Overall yield was only moderate.

The lowest yield was found in variant A (control) without application of PRP SOL. The highest yield was in variant D, which had up to 9.96 t.ha^{-1} greater yield than the control variant. On the whole, however, the heads of maize were smaller, as were the grains, which failed to develop in places. This applied to all variants.

From Table 2 it is evident that the liquid stimulator PRP EBV had a positive influence on yield, especially in variants C and D with a higher dosage of applied PRP SOL. The lowest yield was found in variant A, without application of PRP SOL. In this case, too, the heads of maize were dry and under-developed.

Table 1: Yields of maize grain - Variant with the application of PRP SOL (Litobratřice 2015)

Variant	Repetition	Yield of grain at harvest moisture t.ha^{-1}	Grain moisture content	Converted to standart moisture content 14% t.ha^{-1}	TKW g
A	1	12.91	19.00	12.16	232.00
	2	1.56	24.40	1.37	289.40
	3	8.85	23.60	7.86	276.73
	Average	7.77	22.33	7.13	266.04
B	1	12.95	22.70	11.64	317.90
	2	11.34	18.70	10.72	235.56
	3	17.49	23.80	15.50	239.56
	Average	13.93	21.73	12.62	264.34
C	1	13.52	20.50	12.50	240.92
	2	13.61	19.40	12.75	221.86
	3	15.38	18.30	14.61	195.85
	Average	14.17	19.40	13.29	219.54
D	1	21.32	24.00	18.84	269.75
	2	16.94	20.00	15.76	224.89
	3	14.93	18.80	14.10	334.78
	Average	17.73	20.93	16.23	276.47

Table 2: Yields of maize grain - Variant with the application of PRP SOL + PRP EBV (Litobratřice 2015)

Variant	Repetition	Yield of grain at harvest moisture t.ha^{-1}	Grain moisture content	Converted to standart moisture content 14% t.ha^{-1}	TKW g
A	1	8.86	16.90	8.56	188.08
	2	12.16	16.50	11.80	182.82
	3	8.43	17.50	8.08	190.51
	Average	9.81	16.97	9.48	187.14
B	1	21.09	22.90	18.91	273.68
	2	12.69	20.00	11.81	224.20
	3	10.21	17.70	9.77	212.60
	Average	14.66	20.20	13.49	236.83
C	1	17.08	18.30	16.23	231.58
	2	24.18	19.50	22.63	241.64
	3	17.97	20.00	16.71	226.26
	Average	19.74	19.27	18.52	233.16
D	1	11.56	17.40	11.10	214.42
	2	16.71	20.10	15.53	267.28
	3	15.45	20.70	14.25	274.92
	Average	14.57	19.40	13.63	252.21

Physical soil characteristics

Values for physical soil characteristics in 2015 are given in Table 3. The highest reduced bulk density (rBD) was recorded, on average, in control variant A. At 1.45 g.cm^{-3} this is a limit value according to Lhotský (2000). However, in the subsoil layer, 0.2 – 0.3 m, this limit was exceeded by 0.14 g.cm^{-3}. The lowest rBD was found in variant D, with an average of 1.29 g.cm^{-3}; in the surface layer (0 – 0.10 m) it was only 1.14 g.cm^{-3}. Similar results were found in terms of soil porosity and aeration. The lowest air capacity was measured in control variant A, and highest in variant D. The greatest differences in rBD between the surface layer and subsoil layer were detected in variants A and B. Current soil water content (CWC) was found to be highest, on average, in variant A, which was due to accumulation of water mainly in the subsoil layer due to greater soil compaction. In other variants there was no significant difference.

Table 3: Physical properties of soil (Litobratřice 2015)

Variant	Soil depth (m)	Bulk density (g.cm-3)	Total porosity (%)	Moment convent of		Max. capillary	Min. airholding
				water	air		
				% vol.		% vol.	
A	0 - 0.1	1.28	51.21	17.39	33.81	39.22	11.98
	0.1 - 0.2	1.47	43.88	24.90	18.97	33.76	10.12
	0.2 - 0.3	1.59	39.15	27.63	11.52	30.70	8.45
	Average	1.45	44.75	23.31	21.44	34.56	10.18
B	0 - 0.1	1.13	56.69	12.77	43.93	39.41	17.28
	0.1 - 0.2	1.42	45.82	26.52	19.30	34.46	11.37
	0.2 - 0.3	1.44	45.06	25.20	19.86	32.76	12.30
	Average	1.33	49.19	21.50	27.70	35.54	13.65
C	0 - 0.1	1.26	51.99	19.04	32.96	38.11	13.88
	0.1 - 0.2	1.50	42.71	24.78	17.93	31.23	11.48
	0.2 - 0.3	1.43	45.51	25.61	19.90	33.05	12.46
	Average	1.40	46.74	23.14	23.60	34.13	12.61
D	0 - 0.1	1.14	56.45	15.35	41.10	39.72	16.73
	0.1 - 0.2	1.34	48.83	24.22	24.61	33.11	15.72
	0.2 - 0.3	1.39	46.81	25.03	21.78	33.61	13.20
	Average	1.29	50.70	21.53	29.16	35.48	15.22

Soil structure

Table 4 gives soil structure values for 2015. Values for structural coefficient (SC) represent the quality of soil structure. The highest SC was found in variant D, and the lowest in control variant A. In variant D the coefficient was 0.32 point higher than variant A, which indicates that, despite the drought this year, the structural capability of the soil is retained due to the application of PRP SOL (var. C, D), especially in surface soil layers. SC this year did not exceed a value of 1 in any variant, which is a state of unfavourable structure. This was due to the drought at the time the soil samples were taken. Better SC was found in the surface layer in almost all variants.

Table 4: Percentages of structural elements (Litobratřice 2015)

Variant	Soil depth	Structural elements (% vol.)						Coefficient of structurality
		< 10	5 - 10	2 - 5	0.5 - 2	0.25 - 0.5	>0.25	
A	0 - 0.15	67.59	11.59	11.73	6.85	0.40	1.84	0.44
	0.15 - 0.30	78.94	8.29	6.03	5.86	0.17	0.71	0.26
	Average	73.26	9.94	8.88	6.35	0.28	1.28	0.34
B	0 - 0.15	61.10	14.58	11.80	10.07	0.49	1.97	0.59
	0.15 - 0.30	61.04	16.56	15.42	5.73	0.25	1.00	0.61
	Average	61.07	15.57	13.61	7.90	0.37	1.48	0.60
C	0 - 0.15	56.30	15.68	21.04	5.84	0.23	0.90	0.75
	0.15 - 0.30	64.56	14.86	13.52	5.97	0.22	0.88	0.53
	Average	60.43	15.27	17.28	5.91	0.23	0.89	0.63
D	0 - 0.15	54.48	17.66	13.43	13.00	0.30	1.13	0.80
	0.15 - 0.30	64.14	15.81	14.03	5.14	0.18	0.69	0.54
	Average	59.31	16.73	13.73	9.07	0.24	0.91	0.66

Water stability

As stated in Tab. 5, water stability values in 2015 were at a good level and no significant differences between variants were evident. The lowest values were found in control variant A. According to the classification scale for water stability in soil aggregates the structural quality was at medium level in all variants.

Table 5: Average values of soil aggregations water stability (Litobratřice 2015)

Variant	Repetition	(%)
A	1	39.43
	2	37.22
	3	37.99
	Average	**38.21**
B	1	38.23
	2	45.17
	3	42.09
	Average	**41.83**
C	1	43.15
	2	41.59
	3	42.02
	Average	**42.25**
D	1	40.54
	2	45.48
	3	42.15
	Average	**42.72**

Water content in soil

Gravimetric findings for water content in 2015 are given in Tab. 6. While greater soil moisture was recorded in the spring period in variants with PRP SOL, a higher level of moisture was found in control variant A (without PRP SOL) at the end of the vegetation period when more rain was recorded. This corresponds with the greater soil compaction in this variant and the lower ability to allow water to reach the subsoil. Variants where preparations were applied retained moisture at the same level throughout the soil profile.

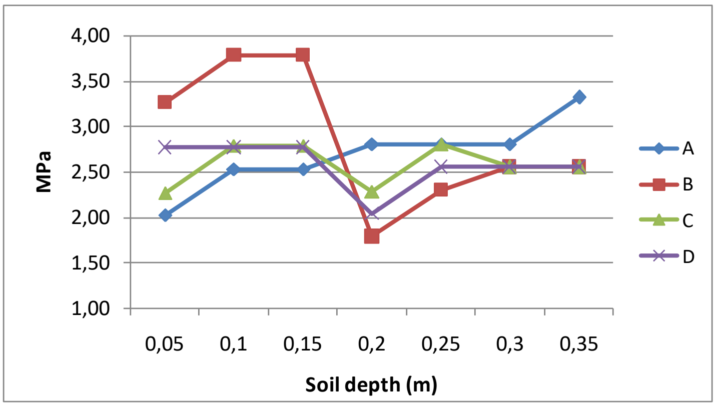
Table 6: Soil moisture (Litobratřice 2015)

Variant	Soil depth (m)	Sampling		Average
		Beginning of the growing season	End of the growing season	
A	0 - 0.1	13.61	15.34	14.48
	0.1 - 0.2	16.94	17.30	17.12
	0.2 - 0.3	17.33	17.20	17.27
	Average	15.96	16.62	16.29
B	0 - 0.1	11.25	17.33	14.29
	0.1 - 0.2	18.69	17.86	18.27
	0.2 - 0.3	17.51	15.86	16.69
	Average	15.82	17.02	16.42
C	0 - 0.1	15.14	17.13	16.13
	0.1 - 0.2	16.51	17.58	17.05
	0.2 - 0.3	17.94	16.37	17.15
	Average	16.53	17.03	16.78
D	0 - 0.1	13.46	14.97	14.21
	0.1 - 0.2	18.07	17.71	17.89
	0.2 - 0.3	17.96	18.04	18.00
	Average	16.50	16.90	16.70

Penetrometric resistance of soil

Values of penetrometric resistance of soil (PRS) measured at the beginning of the vegetation period are given in Graph 3, which indicates that, at the start of the vegetation period, soil compaction exceeded the critical boundary of 3.7 MPa in variant B at a depth of 0.10 – 0.15 m. Soil compaction increased with soil depth most of all in control variant A. In variants C and D penetrometric resistance increased gradually and was lowest on average, which is also due to the good structural condition of the soil, as shown by the structural coefficient values.

Graph 3: Penetrometric resistance of soil – beginning of the growing season (Litobratřice 2015)



Graph 4 evaluates the measured PRS values from the end of the vegetation period. Values for all variants were lower than in the springtime due to greater soil moisture. The highest PRS values were recorded, on average, in variant A, but in variants B and C in the subsoil layer (Tab 7).

Graph 4: Penetrometric resistance of soil – end of the growing season (Litobratřice 2015)

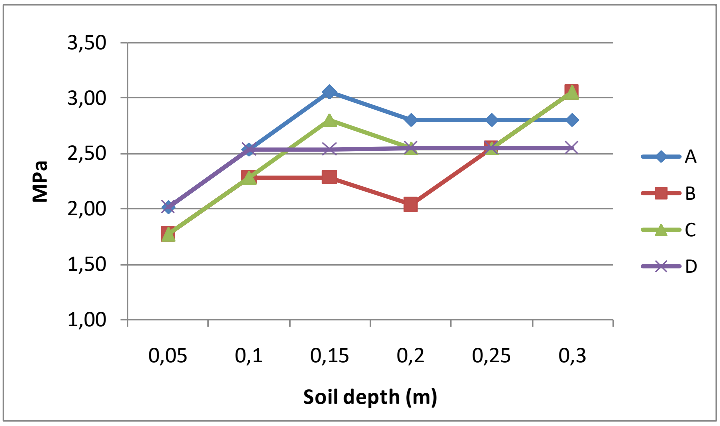


Table 7: Penetrometric soil resistance (MPa) – Litobratřice 2015

Variant	Soil depth (m)	Beginning of the vegetation period	End of the vegetation period	Variant	Soil depth (m)	Beginning of the vegetation period	End of the vegetation period
A	0.05	2.02	2.02	C	0.05	2.27	1.77
	0.10	2.53	2.53		0.10	2.78	2.28
	0.15	2.53	3.05		0.15	2.78	2.80
	0.20	2.80	2.80		0.20	2.28	2.55
	0.25	2.80	2.80		0.25	2.80	2.55
	0.30	2.80	2.80		0.30	2.55	3.05
	0.35	3.32	3.32		0.35	2.55	3.05
B	0.05	3.27	1.77	D	0.05	2.77	2.02
	0.10	3.78	2.28		0.10	2.77	2.53
	0.15	3.78	2.28		0.15	2.77	2.53
	0.20	1.78	2.03		0.20	2.03	2.55
	0.25	2.30	2.55		0.25	2.55	2.55
	0.30	2.55	3.05		0.30	2.55	2.55
	0.35	2.55	3.57		0.35	2.55	2.55

Chemical characteristics of soil

Table 8 gives the values for nutrient content of soil and exchange soil reactions detected during the vegetation period. From the recorded values it is evident that the level of available P is low, K content is good, Mg content is good, the overall level of N is moderate and Ca content is very high. There were no significant differences between variants. Soil reaction was evaluated as alkaline, and remained at the same level as the previous year.

Table 8: Nutrients content and the soil reaction (Litobratřice 2015)

Variant	Soil depth (m)	pH_{KCl}	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	N total (%)	Ca (mg/kg)
A	0 - 0.15	7.4	54	247	247	0.180	7584
	0.15 - 0.30	7.5	42	220	249	0.180	7533
	average	7.5	48	234	248	0.180	7559
B	0 - 0.15	7.5	38	256	260	0.180	7334
	0.15 - 0.30	7.5	24	205	238	0.160	6965
	average	7.5	31	231	249	0.170	7150
C	0 - 0.15	7.5	38	225	247	0.180	6694
	0.15 - 0.30	7.5	38	226	264	0.170	7259
	average	7.5	38	226	256	0.175	6977
D	0 - 0.15	7.5	38	244	254	0.160	7280
	0.15 - 0.30	7.5	28	186	245	0.160	7549
	average	7.5	33	215	250	0.160	7415

Humus content and quality

Table 9 gives values for content of Cox, humus (converted Cox) and its quality. It is apparent from Table 9 that a higher content of humus was found in variants C and D. In variants A and B humus content was at the same level.

Determining the quality of humus (Cox) is one of the important indicators of soil quality and health. A soil is considered to be of good quality if the proportion of humic acids (HA) is dominant over fulvic acids (FA) and therefore the HA/FA ratio is greater than one, as stated by Sotáková (1982). Unfortunately the humus quality (HA/FA) was lower than 1 in all variants, both in the surface layer and subsoil. This was due to weather during the vegetation period, when there was little rainfall and nitrogen was inaccessible, which also determines the quality of humus, i.e. higher humic acid content. As the mineralization of humus was slow, the release of nitrogen was also slow, and thus humus quality deteriorated. On average, the best humus quality was found in variants C and D.

In terms of humus quality according to colour quotient Q 4/6, according to the results of humic matter absorbance in the UV-VIS field of the spectrum, humus quality is moderate in all variants. Absorbance values are equal. Values of colour index were from 3.6 – 4.2 and indicate medium quality HL (Tab. 9).

Table 9: Humus contents and its quality (Litobratřice 2015)

Variant	Soil depth (m)	C_{OX} (%)	humus (%)	HK/FK	Q4/6
A	0 - 0.15	1.45	2.50	0.92	3.8
	0.15 - 0.30	1.47	2.53	0.87	3.9
	average	1.46	2.52	0.90	3.9
B	0 - 0.15	1.46	2.52	0.83	4.0
	0.15 - 0.30	1.49	2.57	0.92	3.8
	average	1.48	2.54	0.88	3.9
C	0 - 0.15	1.65	2.84	0.92	3.8
	0.15 - 0.30	1.65	2.84	0.92	3.8
	average	1.65	2.84	0.92	3.8
D	0 - 0.15	1.69	2.91	0.87	3.9
	0.15 - 0.30	1.49	2.57	0.98	3.7
	average	1.59	2.74	0.93	3.8

Biological characteristics of soil

Biological activity of soil is represented by various parameters of microorganism respiratory activity. Of these parameters it is basal respiration, potential respiration, and the ratio of these, which expresses the stability of organic material in soil – a higher value represents greater stability. It is an expression that indicates the level to which the potential capability of microorganisms to mineralise organic matter is used for actual mineralization.

Basal respiration is a “qualitative” parameter indicating the respiratory activity of microorganisms. This activity results from the actual state of microorganisms in the soil, and mainly depends on the amount of accessible substrate for respiration. It is also a result of the physiological state of microorganisms, their energy requirements, the influence of stress and inhibitory factors, etc.

Soil Biomass

Soil biomass is defined as the living part of organic matter. Its quantity is determined as the content of organic extractable carbon - C_{bio}, contained in cells.

The amount of microorganisms determined on the basis of the appraised level of carbon bound in microbial biomass (Tab. 10) varies significantly from the beginning of the vegetation period to the end. At the beginning of the vegetation period the amount of Cmic is higher. There was no conclusive difference between variants at the beginning of the vegetation period, but at the end the highest level of carbon was recorded in variant C. The accumulation of extractable extracellular carbon (µg CEX, Badalucco et al., 1992) in relation to 1mg soil microorganism biomass indicates the inability of soil microbial communities to trophically exploit their own extracellular metabolites. The reason for this is stress from various sources, which induces an increased proportion of dying or dead microbial cells. In the given case it was due to the negative influence of drought on the studied plots.

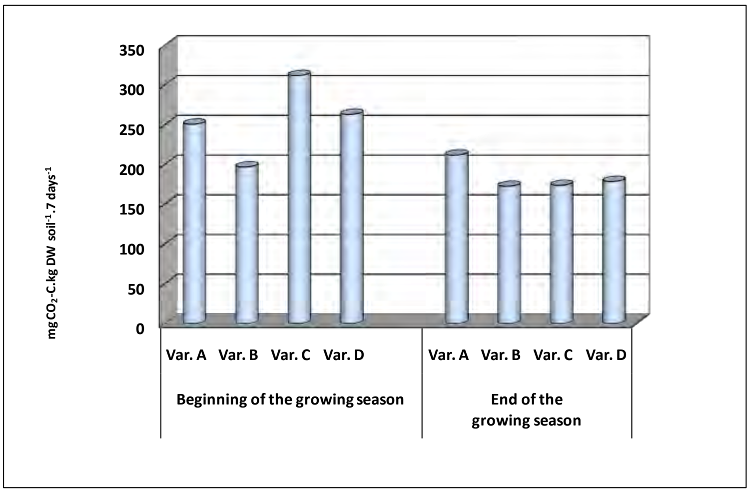
Table 10: Contents of carbon in microbial biomass (Litobratřice 2015)

Variant	Repetition	Sampling	
		Vegetation beginning	Vegetation ending
		Cbio /mg of DM pae kg-1 of soil matter)	
A	1	138.22	94.85
	2	158.27	108.08
	3	139.69	109.97
	average	145.39	104.30
B	1	119.56	92.29
	2	127.84	104.67
	3	108.37	108.48
	average	118.59	101.81
C	1	138.22	39.84
	2	101.20	71.25
	3	131.88	71.25
	average	123.77	60.78
D	1	135.78	85.38
	2	119.59	97.12
	3	110.26	83.03
	average	121.88	88.51

Basal respiration

Basal respiration (Graph 5) was conclusively higher in the spring period than at the end of the vegetation period when, due to less favourable conditions, there was a decline in microorganism activity and carbon matter was less accessible due to minimal soil moisture. Whereas at the beginning of the vegetation period a higher level of microorganism activity was recorded in the variant with application of PRP SOL, at the end of the vegetation period microorganism activity was equal in all variants.

Graph 5: Basal respiration of soil microorganisms (Litobratřice 2015)

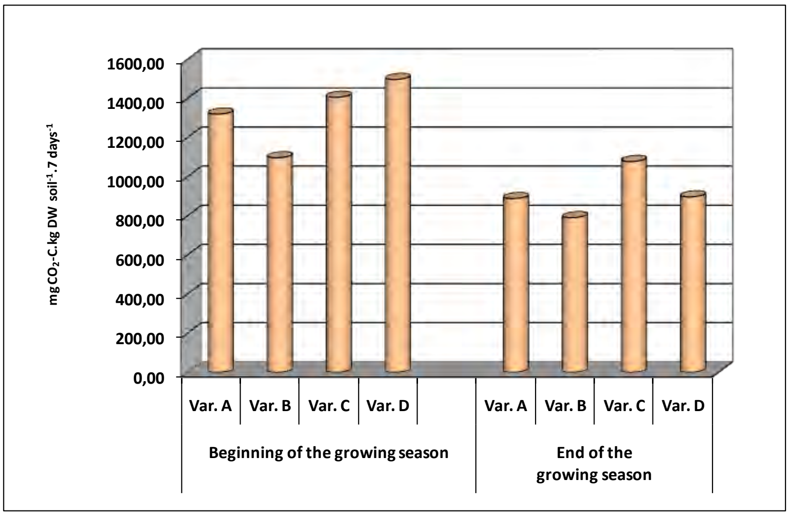


Potential respiration

By potential respiration we mean the maximum amount of microorganism respiration, unlimited by substrate, which best reflects the physiological state of microorganisms, their energy requirements and mineralization activity.

Graph 6 shows potential respiration at the beginning and at the end of the vegetation period. At the beginning of vegetation there was greater potential respiration (PR) compared to the measurement at the end of vegetation, probably due to lower availability of decomposable carbon-containing matter, which led to a reduction in the mineralization process in the soil due to drought. Unfavourable climatic conditions in the given period led to stressful conditions for microorganisms, resulting in reduced soil respiration. At the beginning and at the end there was greater PR in variants C and D, those with a higher dose of PRP SOL. In most soils microbial activity is limited by a lack of easily accessible carbon substrate (Fallih, Wainwright, 1996).

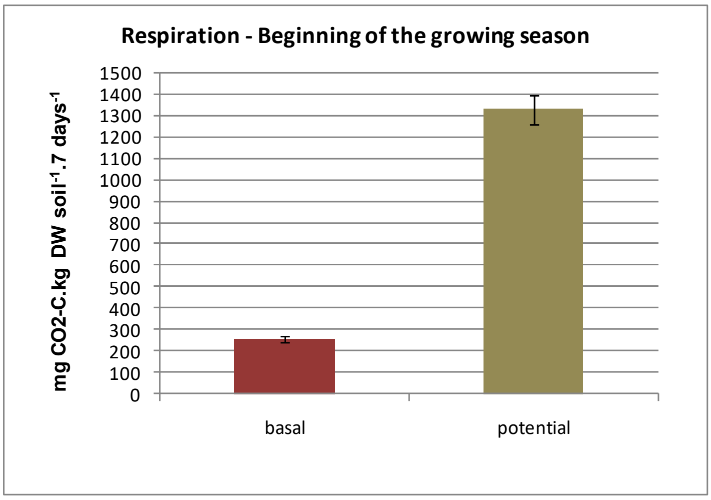
Graph 6: Potential respiration of soil microorganisms (Litobratřice 2015)



Graph 7 shows the high cogency between basal and potential respiration in soil at the beginning of vegetation. Potential respiration is higher at the beginning of vegetation than at the end of vegetation.

Graph 7: Standard deviation - basal and potential respiration (Litobratřice 2015)

Beginning of the growing season

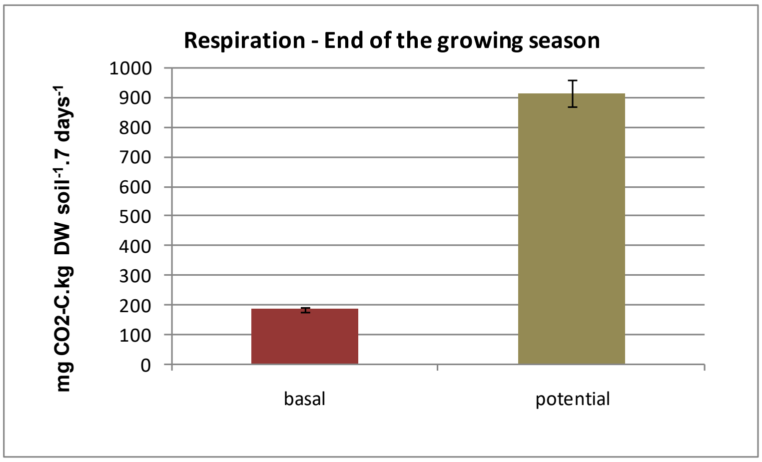


Graph 8 represents basal and potential respiration at the end of vegetation. Here too a significant difference is apparent between BR and PR. Potential respiration declined in comparison with the beginning of vegetation by 417 mg CO2, and by 72 mg in basal respiration. This was due to suppression of microbial activity as a result of the drought during the vegetation period.

The supply of carbon in the soil changes as a result of changes in carbon mineralization – soil respiration. Both an increase and a decrease in respiration was observed due to the C:N ratio. A greater amount of nitrogen generally accelerates the decomposition of plant tissue with a lower or higher content of lignin.

Graph 8: Standard deviation - basal and potential respiration (Litobratřice 2015)

End of the growing season



Evaluation of T20 preparation

Evaluation of T20 preparation is specified in the protocol according to the established methodology. In the year 2015, there is a table of yield of grain maize (Tab. 11) in the control and use of T20 preparation.

Table 11: Yields of grain maize after the application of T20 and control

(Litobratřice 2015)

Variant	Repetition	Yield of grain at harvest moisture $t.ha^{-1}$	Grain moisture content	Converted to standart moisture content 14% $t.ha^{-1}$	TKW g
T20	1	5.56	17.3	5.35	265.33
	2	4.85	17.7	4.64	269.98
	3	5.41	17.5	5.19	267.64
	Average	5.27	17.5	5.06	267.65
control	1	3.03	20.5	2.80	236.33
	2	2.75	20.3	2.55	237.23
	3	3.62	20.7	3.34	235.42
	Average	3.13	20.5	2.89	236.33

The table shows that the product T20 positively influenced the yield of grain maize. Yield at the standard 14% moisture was at T20 variations of 2.17 t ha^{-1} higher than the control, which in this unfavorable year due to drought highly beneficial.

CONCLUSION

In the final year of observation of the influence of the supportive soil preparation PRP SOL on soil environment, and spraying with growth stimulator PRP EBV on yield, it was found that:

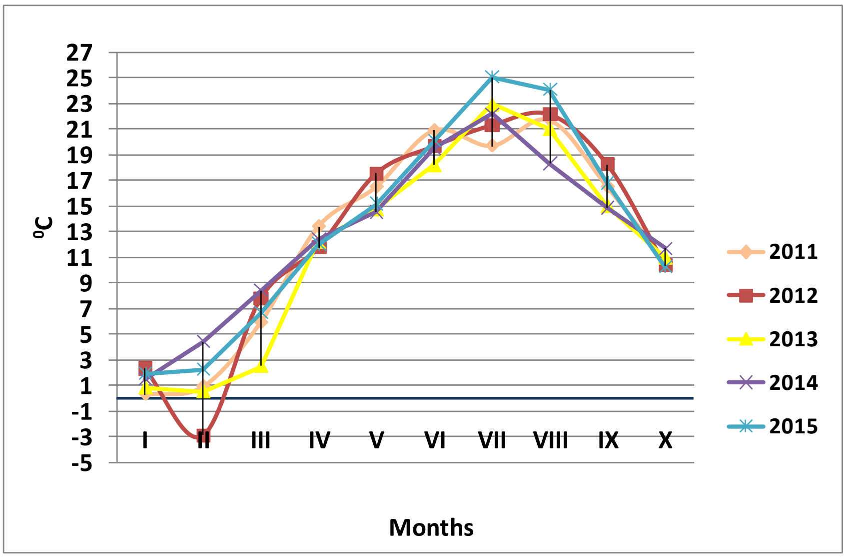
- Yield was greater in all variants with spray application of growth stimulator PRP EBV. The greatest yield was found in variants C and D in both experiments.

- Reduced bulk density was lower in all variants with PRP SOL, other physical soil characteristics correlated with this.
- Soil structure was found to be 50% worse in variants without PRP SOL. A better structural coefficient was always found in upper soil layers, in all variants.
- No significant differences between variants were found in values of water stability. Values varied around a moderate level. The best water stability of soil aggregates was found in variant D.
- Soil moisture was lower overall due to low rainfall during the vegetation period. In 2015 the average rainfall decreased by as much as 90 mm during the vegetation period compared with the long-term average. Soil moisture at the beginning and end of the vegetation period corresponded to this.
- Penetrometric resistance of soil also corresponded to rainfall conditions. In variant B the values exceeded the critical limit set for this soil, 3.7 MPa in the topsoil layer 0.10 – 0.15 m.
- No significant differences between variants were found in nutrient content during the observation period. Low phosphor content was found in all variants.
- The highest humus content was found where soil preparation had been applied, in variants C and D, where humus quality was also found to be highest. In all variants the humus quality was below 1, which means poor humus quality.
- Microbial biomass carbon was found to be highest in variant A, both at the beginning and end of the vegetation period. This was due to stress in soil conditions in the given plot.
- Basal soil respiration was much lower at the beginning and end of the vegetation period compared to potential respiration. Values were equal between variants. Microorganism respiratory activity was unfavourable due to dry conditions. In all variants the values for potential respiration were found to be one third higher at the beginning of the vegetation period than at the end. Mineralization activity of microorganisms was higher in variants C and D at the end of the vegetation period.
- T20 preparation positively influenced the yield of grain maize.

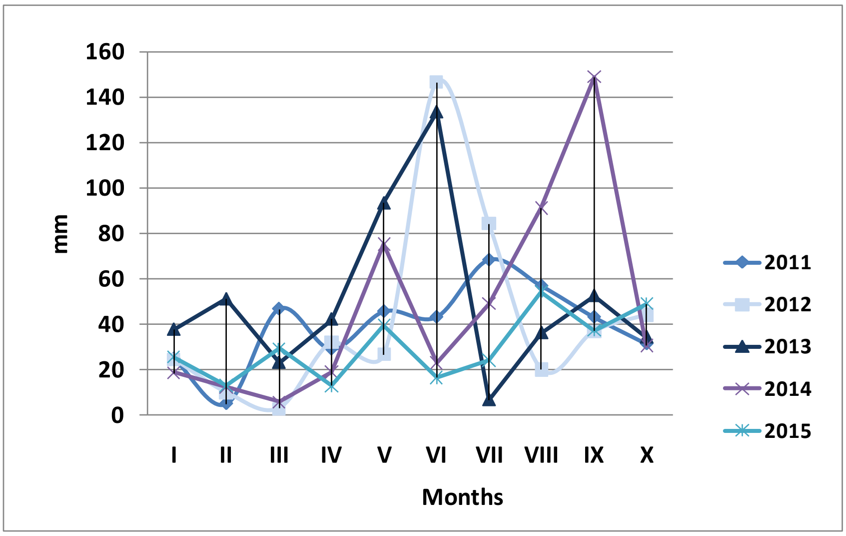
Final evaluation of the whole monitored period 2011 - 2015

The course of weather during 2011 – 2015 is shown in Graph 9 (monthly average temperatures) and Graph 10 (monthly rainfall).

Graph 9: Course of average monthly temperatures (2011 – 2015)



Graph 10: Sums of monthly precipitations (2011 – 2015)



The comparison of yield from 2011 in both experiments is evaluated in Tables 12 and 13, and in Graphs 11 and 12. Values in both the tables and graphs show a relationship between variants with PRP SOL and PRP SOL + EBV. In nearly all years the yield was higher in variants C and D. Yield was also positively affected by spraying EBV preparation at the time of the 4th leaf –growth phase of maize in the second part of the trial. There is also an evident significant influence of a particular year which is also proven statistically (Tabs 23, 24).

Table 12: The average value of yield (t ha^{-1}, at 14% moisture) in 2011 – 2015

Variant with the application of PRP SOL

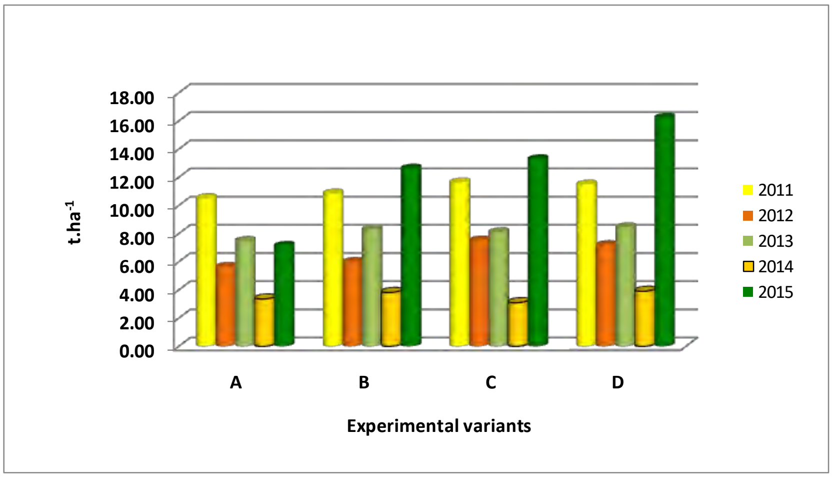
Variant	2011	2012	2013	2014	2015	Average
A	10.52	5.65	7.48	3.36	7.13	6.83
B	10.85	5.99	8.29	3.82	12.62	8.31
C	11.63	7.52	8.10	3.10	13.29	8.73
D	11.48	7.19	8.45	3.91	16.23	9.45

Table 13: The average value of yield (t ha^{-1}, at 14% moisture) in 2011 – 2015

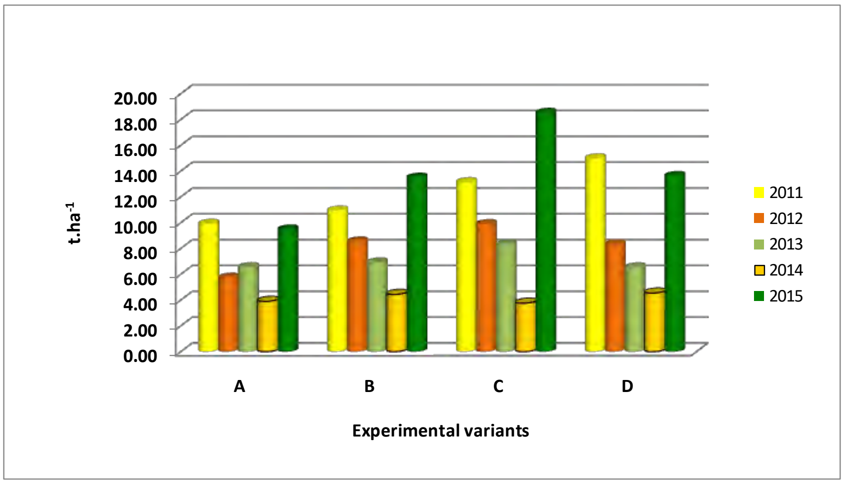
Variant with the application of PRP SOL+EBV

Variant	2011	2012	2013	2014	2015	Average
A	9.92	5.74	6.55	3.90	9.48	7.12
B	10.94	8.54	6.92	4.44	13.49	8.87
C	13.14	9.89	8.31	3.76	18.52	10.73
D	14.99	8.31	6.54	4.54	13.63	9.60

Graph 11: The average yield of grain maize for the years 2011 – 2015 with PRP SOL



Graph 11: The average yield of grain maize for the years 2011 – 2015 with PRP SOL+EBV



In an overall evaluation of average values obtained during the five years of the experiment, higher values of rBD (g.cm^{-3}) appeared in control variant A compared to other treated variants (Tab 14). The difference is statistically conclusive. Also variant D had a conclusively higher rBD level than variant B. rBD negatively correlates with porosity values (%) which showed in variant A – its porosity level was significantly lower than in the other variants. Variant B proved higher porosity compared to variant D (Tab 15). rBD and porosity also reflects the level of soil compaction which shows distinctively in the non-treated variant A where, in most years the limit values of the critical properties were exceeded at a depth of 0.1 – 0.3 m (Lhotský, 2000). The highest maximum capillary capacity (% vol.) was found in variant B; the difference was conclusive in comparison to variants A and D (Tab 16).

Table 14: Average values of bulk density (g.cm^{-3}) for the years 2011 – 2015

Variant	Soil depth (m)	2011	2012	2013	2014	2015	Average
A	0 - 0.1	1.37	1.29	1.58	1.23	1.28	1.35
	0.1 - 0.2	1.57	1.49	1.58	1.37	1.47	1.50
	0.2 - 0.3	1.54	1.57	1.57	1.26	1.59	1.51
	Average	1.50	1.45	1.58	1.29	1.45	1.45
B	0 - 0.1	1.33	1.20	1.27	1.19	1.13	1.22
	0.1 - 0.2	1.42	1.37	1.30	1.20	1.42	1.34
	0.2 - 0.3	1.36	1.48	1.51	1.33	1.44	1.42
	Average	1.37	1.35	1.36	1.24	1.33	1.33
C	0 - 0.1	1.27	1.19	1.28	1.18	1.26	1.23
	0.1 - 0.2	1.39	1.37	1.32	1.38	1.50	1.39
	0.2 - 0.3	1.39	1.47	1.40	1.41	1.43	1.42
	Average	1.35	1.34	1.33	1.33	1.40	1.35
D	0 - 0.1	1.20	1.32	1.37	1.46	1.14	1.30
	0.1 - 0.2	1.33	1.49	1.37	1.53	1.34	1.41
	0.2 - 0.3	1.43	1.43	1.41	1.44	1.39	1.42
	Average	1.32	1.42	1.39	1.48	1.29	1.38

Overall porosity of agricultural soils is usually within the range of 40 – 50% in topsoil and 30 – 40% in subsoil. It allows an objective assessment of soil aeration or compaction.

Table 15: Average values of total porosity (%) for the years 2011 – 2015

Variant	Soil depth (m)	2011	2012	2013	2014	2015	Average
A	0 - 0.1	48.70	51.67	40.48	53.75	51.21	49.16
	0.1 - 0.2	41.05	44.13	40.95	48.51	43.88	43.70
	0.2 - 0.3	42.89	40.93	41.07	52.53	39.15	43.31
	Average	44.21	45.58	40.83	51.60	44.75	45.39
B	0 - 0.1	49.98	55.08	52.74	55.62	56.77	54.04
	0.1 - 0.2	46.94	48.76	51.46	55.11	45.82	49.62
	0.2 - 0.3	48.70	45.12	44.15	50.72	45.06	46.75
	Average	48.54	49.65	49.45	53.82	49.22	50.14
C	0 - 0.1	52.40	55.26	52.05	55.64	51.99	53.47
	0.1 - 0.2	48.11	48.52	50.43	48.15	42.71	47.58
	0.2 - 0.3	47.71	44.92	47.27	46.86	45.51	46.45
	Average	49.41	49.57	49.92	50.22	46.74	49.17
D	0 - 0.1	54.93	50.24	48.37	45.17	56.45	51.03
	0.1 - 0.2	50.18	44.08	48.53	42.54	48.83	46.83
	0.2 - 0.3	46.26	46.07	46.95	45.70	46.81	46.36
	Average	50.46	46.79	47.95	44.47	50.70	48.08

Table 16: Average values of maximum capillary volume (% vol.) for the years 2011 – 2015

Variant	Soil depth (m)	2011	2012	2013	2014	2015	Average
A	0 - 0.1	33.97	36.98	25.69	38.52	39.22	34.88
	0.1 - 0.2	33.00	34.84	26.11	35.84	34.17	32.79
	0.2 - 0.3	32.47	34.65	26.85	33.51	30.70	31.64
	Average	33.15	35.49	26.22	35.96	34.70	33.10
B	0 - 0.1	36.87	42.23	29.46	37.29	39.41	37.05
	0.1 - 0.2	35.52	37.16	28.43	34.36	34.46	33.99
	0.2 - 0.3	34.96	35.40	23.04	34.56	32.76	32.14
	Average	35.79	38.26	26.98	35.40	35.54	34.39
C	0 - 0.1	39.41	40.55	28.64	38.40	38.11	37.02
	0.1 - 0.2	33.55	35.12	24.53	35.70	31.63	32.11
	0.2 - 0.3	35.10	33.88	26.62	34.36	33.05	32.60
	Average	36.02	36.52	26.60	36.15	34.26	33.91
D	0 - 0.1	39.34	39.34	28.80	31.80	39.72	35.80
	0.1 - 0.2	33.74	35.54	25.14	31.65	33.11	31.84
	0.2 - 0.3	33.85	36.60	25.32	33.36	33.61	32.55
	Average	35.65	37.16	26.42	32.27	35.48	33.40

The lowest structural coefficient was found in variant A – its average did not reach a value of 1 which indicates poor structure (Tab 17). The difference between A and other variants with a higher structural coefficient was statistically conclusive. Due to years of individual variants a distinct variability of values (measured in separate years) showed in terms of structural coefficient which is why no conclusive difference appeared in the other variants. Despite this, the highest level of structural capability was found in variants C and D.

Table 17: Average values of soil structure for the years 2011 – 2015

Variant	Soil depth (m)	2011	2012	2013	2014	2015	Average
A	0 - 0.15	1.18	1.32	0.63	0.75	0.44	0.86
	0.15 - 0.30	1.29	1.23	0.54	0.56	0.26	0.77
	Average	1.24	1.27	0.58	0.65	0.35	0.82
B	0 - 0.15	2.00	2.29	1.35	1.59	0.59	1.57
	0.15 - 0.30	2.14	1.95	1.24	0.51	0.61	1.29
	Average	2.07	2.12	1.30	1.05	0.60	1.43
C	0 - 0.15	2.65	2.76	2.10	1.45	0.75	1.94
	0.15 - 0.30	1.85	2.00	1.05	0.69	0.53	1.22
	Average	2.25	2.38	1.58	1.07	0.64	1.58
D	0 - 0.15	2.70	2.60	1.33	2.20	0.80	1.93
	0.15 - 0.30	2.19	2.08	0.80	1.03	0.54	1.33
	Average	2.44	2.34	1.07	1.62	0.67	1.63

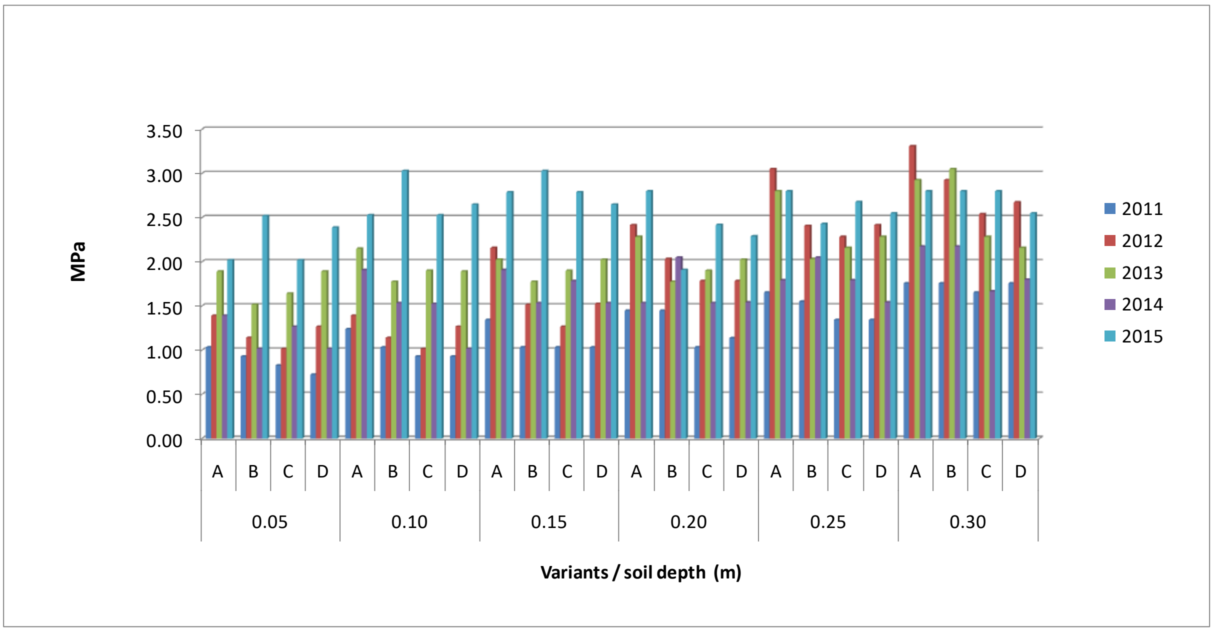
Quality of structure in terms of water stability of soil aggregates in this location, according to set table values, was low in all variants (Bartlová et al., 2015). The values fluctuated according to each particular year (Tab 18). The lowest water stability of soil aggregates (in %) was, on average, found in variant C, while the highest was that of variant D. This difference was statistically conclusive. In the last monitored year the level of water stability increased significantly mainly in variants treated with a bigger dose of PRP SOL which suggests a certain trend of soil structure improvement.

Table 18: Average values of water stability of soil aggregates (%) for the years 2011 – 2015

Variant	2011	2012	2013	2014	2015	Average
A	12.33	28.64	25.84	38.98	38.21	28.80
B	12.26	31.95	27.82	35.18	41.83	29.81
C	16.96	20.40	25.82	30.31	42.25	27.15
D	17.30	23.11	29.05	37.75	42.72	29.99

Graph 13 shows the course of penetrometric resistance (PRS) in the soil profile 0 – 0.3 m in individual years. The Graph shows how compaction intensifies with increasing depth. Variants with PRP SOL application (variants B and D) always have a lower PRS when compared to the control variant A. A positive effect of PRP SOL preparation is evident here. The values range from 0.72 MPa (variant D, at a depth of 5 cm, 2011) to 3.31 MPa (variant A, at a depth of 30 cm, 2012). The value of 3.9 MPa – critical for this soil type – was never exceeded.

Graph 13: Soil penetrometer resistance for the period 2011 – 2015



Total nitrogen (Tab 19) reached the lowest average level in variant C, the highest in variants A and B. This difference was statistically conclusive (Tabs 23, 24). A high level of nitrogen leads to a reduction in the physiological ratio C/N which indicates that microorganisms are better supplied with carbon than the missing nitrogen. This shows in the growing plants as visual symptoms of the lack of available nitrogen and additional fertilizing with nitrogen is used as a corrective measure. The lack of nitrogen for plant nutrition caused especially by biological processes can be called "positive biological feedback", due to which the efficiency of added nitrogen decreases (Pokorný et al., 2012).

Table 19: Average value Nt (%) in the years 2011-2015

Varianta	Hloubka (m)	2011	2012	2013	2014	2015	Průměr
A	0,0-0,15	0.16	0.22	0.19	0.22	0.18	0.19
	0,15-0,30	0.16	0.18	0.18	0.22	0.18	0.18
	průměr	0.16	0.20	0.19	0.22	0.18	0.19
B	0,0-0,15	0.19	0.22	0.21	0.21	0.18	0.20
	0,15-0,30	0.16	0.19	0.20	0.20	0.16	0.18
	průměr	0.18	0.21	0.21	0.21	0.17	0.19
C	0,0-0,15	0.16	0.19	0.18	0.19	0.18	0.18
	0,15-0,30	0.12	0.19	0.16	0.21	0.17	0.17
	průměr	0.14	0.19	0.17	0.20	0.18	0.18
D	0,0-0,15	0.20	0.18	0.19	0.20	0.16	0.19
	0,15-0,30	0.18	0.18	0.18	0.20	0.16	0.18
	průměr	0.19	0.18	0.19	0.20	0.16	0.18

No significant difference between individual variants was found in values of oxidised by carbon (%), (Tabs 23, 24). On average the values of Cox did not indicate any direct connection with the auxiliary soil preparation. The most distinct effect of PRP SOL was detected in 2014 and 2015, which suggests a certain positive trend in the preparation's influence (Tab 20).

Table 20: Average values of Cox (%) in the years 2011 – 2015

Variant	Soil depth (m)	2011	2012	2013	2014	2015	Average
A	0 - 0.15	1.69	1.67	1.68	1.55	1.79	1.68
	0.15 - 0.30	1.37	1.39	1.62	1.65	1.47	1.50
	Average	1.53	1.53	1.65	1.60	1.63	1.59
B	0 - 0.15	1.64	1.74	1.88	1.61	1.46	1.67
	0.15 - 0.30	1.45	1.51	1.59	1.64	1.49	1.54
	Average	1.55	1.63	1.74	1.63	1.48	1.60
C	0 - 0.15	1.38	1.88	1.76	1.83	1.65	1.70
	0.15 - 0.30	0.92	1.45	1.59	1.63	1.65	1.45
	Average	1.15	1.67	1.68	1.73	1.65	1.57
D	0 - 0.15	1.57	1.62	1.74	1.67	1.69	1.66
	0.15 - 0.30	1.38	1.55	1.61	1.74	1.49	1.55
	Average	1.48	1.59	1.68	1.71	1.59	1.61

Tab 21 shows the average levels of quality of humus within the monitored period. The differences between variants were not conclusive (Tabs 23, 24) and, apart from variants A and D in 2014, they never exceeded a value of 1, which means poor quality of humus. Fulvic acids prevailed over humic acids, thus lowering the quality of humus, assessed mainly according to the ratio of humic and fulvic acid content (HA / FA). The quality of humus increases with the increase of humic acids. The HA / FA ratio in top quality humus should be higher than 1.5. Such soils are more resistant to both compaction and acidification.

Table 21: Average values of humus quality in the year 2011 – 2015

Variant	Soil depth (m)	2011	2012	2013	2014	2015	Average
A	0 - 0.15	0.83	0.74	0.92	0.92	0.92	0.87
	0.15 - 0.30	0.71	0.71	0.98	1.04	0.87	0.86
	Average	0.77	0.73	0.95	0.98	0.90	0.86
B	0 - 0.15	0.95	0.71	0.92	1.04	0.83	0.89
	0.15 - 0.30	0.87	0.76	0.92	0.87	0.92	0.87
	Average	0.91	0.74	0.92	0.96	0.88	0.88
C	0 - 0.15	0.97	0.83	0.92	0.83	0.92	0.89
	0.15 - 0.30	0.83	0.76	0.98	0.74	0.92	0.85
	Average	0.90	0.80	0.95	0.79	0.92	0.87
D	0 - 0.15	0.94	0.71	0.92	0.92	0.87	0.87
	0.15 - 0.30	0.83	0.71	0.98	1.04	0.98	0.91
	Average	0.89	0.71	0.95	0.98	0.93	0.89

Tab 22 shows the average levels of microbial carbon biomass contained in soil. Biomass of plant roots, animal- and microorganism-based biomass is an important component for proper functioning of the ecosystem. Better availability of carbon should increase the chance for microorganisms to grow, thus increasing the amount of microbial carbon. Statistically conclusive values of carbon in soil biomass were found in variant A when compared to other variants. Conclusively highest values were detected in variant C (Tab. 23, 24).

Table 22: Average values of microbial carbon biomass in the year 2011 – 2015

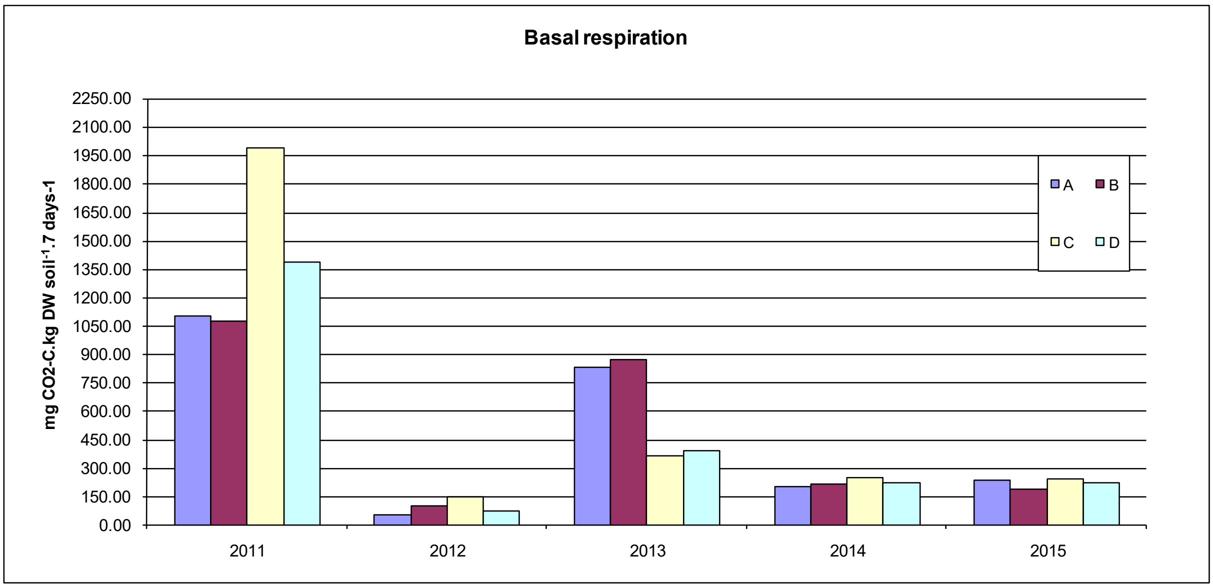
Variant	2011	2012	2013	2014	2015	Average
A	218.00	115.50	261.16	220.50	124.85	188.00
B	205.00	162.73	441.43	290.50	110.20	241.97
C	202.67	112.37	431.33	570.83	92.27	281.89
D	210.00	153.37	466.33	270.37	105.19	241.05

<u>Basal respiration</u> is a “qualitative” parameter indicating the respiratory activity of microorganisms with no added nutrition. Respiratory activity is determined by the actual state of microorganisms in the soil, and especially depends on the amount of accessible substrate for respiration. BR is also a result of the physiological state of microorganisms, their energy requirements, the influence of stress and inhibitory factors, etc.

Graph 14 shows the course of BR in the monitored years, i.e. BR decreased in all variants, which is due to a lower microbial activity in natural conditions. The high values of microbial activity in the initial monitored year were caused by a higher amount of easily decomposable organic matter in the soil, as the year's vegetation period was optimal in terms of climatic conditions – temperature and precipitation.

BR measured during incubation under suitable conditions for microbial growth is often perceived as an overall level of natural organic material decomposition. Soil respiration and microbial activity increase continuously on sites with a higher organic carbon content. Availability of organic carbon has a positive effect on soil respiration which is higher in soils with a higher proportion of organic residue and under suitable moisture and temperature conditions (see year 2011).

Graph 14: Basal respiration in the year 2011 – 2015



The extent of the difference between cumulative values of potential respiration after adding easily compostable organic material and those of basal respiration indicates the key role of this stimulation in microbial activity, together with increasing mineralization of the organic matter and improving the availability of nutrients for plants.

Graph 15 shows values of potential respiration in monitored years. Potential respiration is much higher than basal respiration as it is evaluated after adding nutrients and therefore the activity of microorganisms is much higher. Apart from the first year the values were quite balanced in all variants. In the last year potential respiration was higher in variants C and D. This indicates a higher amount of microorganisms in the soil accompanied by increased microbial activity after adding PRP SOL.

In statistic evaluation of the results analysis of variance was used, with subsequent testing of simple contrasts by the Tukey method. For statistical evaluation the Stagraphic system version 7.0 was used (Tabs 23, 24).

Graph 15: Potential respiration in the year 2011 – 2015

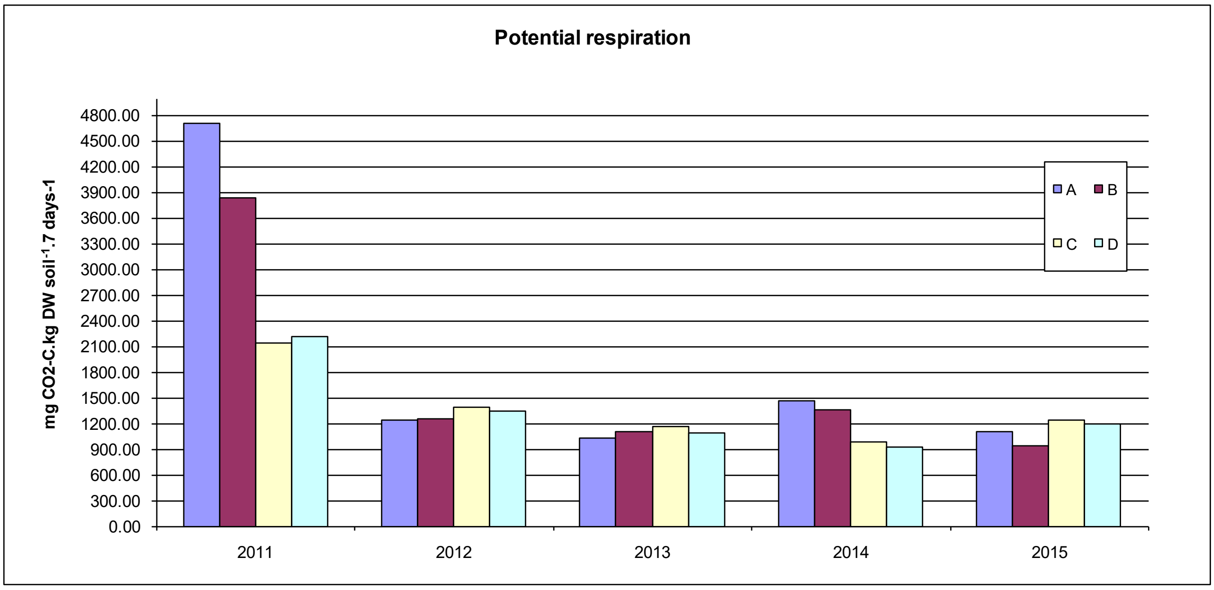


Table 23: Analysis of variance

	Source of variation	d.f.	Mean square
Bulk density	Variant	3	0.78 ***
	Error	264	0.01
Porosity	Variant	3	314.14 ***
	Error	264	8.64
Maximal capilar capacity	Variant	3	23.59 ***
	Error	264	3.47
Structure	Variant	3	1.39 ***
	Error	12	0.04
Water stable aggregates	Variant	3	25.37 *
	Error	40	8.21
Biomasa	Variant	3	23457.6 ***
	Error	40	184.2
Total nitrogen	Variant	3	0.0006 *
	Error	12	0.0001
Carbon oxidation state	Variant	3	0.01 n.s.
	Error	12	0.01
Yield	Variant	7	25.01 ***
	Error	80	2.37

**** P = 0,001; **P = 0,01; *P = 0,05; n.s. non-significant*

Table 24: Multiple range analysis - Tukey method

	Variant	Average
Bulk density	A	1.45 c
	B	1.33 a
	C	1.35 ab
	D	1.38 b
Porosity	A	45,40 a
	B	50.14 c
	C	49.17 bc
	D	48.08 b
Maximal capilar capacity	A	33.13 a
	B	34.39 b
	C	33.91 ab
	D	33.39 a
Structure	A	0.82 a
	B	1.42 b
	C	1.58 b
	D	1.63 b
Water stable aggregates	A	28.80 ab
	B	29.81 ab
	C	27.15 a
	D	29.99 b
Biomasa	A	193.01 a
	B	244.55 b
	C	289.69 c
	D	245.05 b
Total nitrogen	A	0.19 b
	B	0.19 b
	C	0.16 a
	D	0.18 ab
Carbon oxidation state	A	1.59 a
	B	1.62 a
	C	1.54 a
	D	1.61 a
Yield	A	6.83 a
	B	8.31 abc
	C	8.73bc
	D	9.45 cd
	A + EBV	7.11 ab
	B+ EBV	8.87 c
	C+ EBV	10.73 d
	D+ EBV	9.60 cd

Note: Average values indicated by various letters are statistically different (P = 0.05)

Reviews of of yields of grain maize by T20 preparation for the years 2011 to 2015

Results of yields of grain maize after the application of T20 for the following three years showed a definite positive effects on the increase of yields compared to the control variant. In year 2013, yield were higher by 0.57 t ha^{-1} in year 2014 by 1.51 t ha^{-1}, in year 2015 already on 2.17 t ha^{-1} at variant T20 compared to the control variant. It's more than three times the increase of yields and it is possible that this trend would continue.

Other observations - see protocols.

Table 25: Average values of yields of grain maize after the application of T20 and control

Variant	2013	2014	2015	Average
T20	6.45	4.13	5.06	5.21
Control	5.88	2.62	2.89	3.80

CONCLUSION

On the basis of results obtained during a five-year (2011 – 2015) study of physical, chemical and biological properties of soil, using various doses of PRP SOL preparation, we can state that the preparation has a positive effect on soil fertility and general condition of the soil. It improves physical properties of soil, reducing soil compaction, improving soil structure and, therefore, benefiting water retention and aeration of soil. This showed in statistically significant differences. One of the positive results was the increased yield, especially after application of PRP EBV in the 4th leaf stage of maize in one part of the experiment. A trend of increasing biological activity of soil microorganisms also appeared, as well as improvement in the quality of humus.

Over the course of a five-year project period we evaluated soil conditions with application of PRP SOL and reduced tillage. It became apparent that reduced tillage did not affect soil properties, while application of PRP SOL preparation improved the quality of soil fertility.

T20 product increased yields of grain maize in the three years up to three times compared to the control variant.

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REFERENCES

Bennet J. M., Greene R. S. B., Murphy B. W., Hocking P., Tongway D. (2014): Influence of lime and gypsum on long-term rehabilitation of a Red Sodosol, in a semi-arid environment of New South Wales. Soil Research, 52 (2): 120-128.

Birkás M.; 2002. Környezetkímélő és energiatakarékos talajművelés. (Ekologické a energeticky efektivní zpracování půdy). Gödöllő. Akaprint Nyomdaipari Kft., 25-97.

Brookes, P. C. The use of microbial parameters in monitoring soil pollution by heavy metals. Biology and Fertility of Soils. 1995, 19(4): 269-279. ISSN 0178-2762.

García-Gil, J.C, C Plaza, P Soler-Rovira A A Polo. Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biology and Biochemistry. 2000, 32(13): 1907-1913. ISSN 00380717.

Gregorich E.G., Carter M.R., Angers D. A., Montreal C. M., Ellert B. H. (1994): Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can. J. Soil Sci., 74, 367-385.

Lehmann J, Joseph S. 2009. Biochar for environmental management: an introduction. *In* Lehmann J, Joseph S (eds.) Biochar for Environmental Management: Science and Technology. Earthscan, London. pp. 1–12.

Li X. G., Li F. M., Zed R., Zhan Z.Y. (2007): Soil physical properties and their relations to organic carbon pools as affected by land use in an alpine pastureland. Geoderma, 139, 98-105.

Little K. R., Rose M. T., Jackson W. R., Cavagnaro T. R., Patti A. F. (2014): Do lignite-derived organic amendments improve early-stage pasture growth and key soil biological and physicochemical properties? Crop & Pasture Science, 65 (9): 899-910.

Lone A. H., Najar G. R., Ganie M. A., Sofi J. A., Ali T. (2015): Biochar for Sustainable Soil Health: A Review of Prospects. Pedosphere, 25 (5): 639-653.

Parab N., Sinha S., Mishra S. (2015): Coal fly ash amendment in acidic field: Effect on soil microbial activity and onion yield. Applied Soil Ecology, 96: 211-216.

Stefanovits P.; 1975. Talajpusztulás, talajszennyezés (Znečištění půdy). In: A környezetvédelem biológiai alapjai. (Biologické základy životní prostředí) (szerk. Kovács K.) Mezőgazdasági Kiadó. Budapest. 167-196.

Stefanovits P.; 1992. Talajtan. Mezőgazda Kiadó. Budapest.

Szűcs L., Zsembeli J.; 2014. Improvement of soil productivity by application of PRP-SOL in reduced tillage. Úroda 12/2014, vědecká příloha, roč. LXII, 119-126. ISSN 0139-6013

Taylor H.M.; 1987. Soil structure and plant performance. Trans. XIII. Congr. Hamburg, Vol.V. 301-309. Cit. in Várallyay. 1996.

Tejada, M., M. T. Hernandez A C. Garcia.; 2006. Application of Two Organic Amendments on Soil Restoration: Effects on the Soil Biological Properties. Journal of Environment Quality. 35(4): 1010-1015. ISSN 1537-2537

Impact of post-industrial landfills on the quality of the Wilga River in Krakow

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Abstract: The paper presents the impact of former chemical landfill on the quality of water on the example of the Wilga river in Krakow. The presence of former landfills clearly affects the surface water causing pollution. Water quality in the Wilga River did not allow its consumption by citizens. Studies have shown the necessity of taking care of drinking water resources due to the deepening decline in the possibilities of supplying large urban agglomerations in drinkable water.

Keywords: water, pollution, monitoring

INTRODUCTION

Pollution of surface waters is the primary problem of environmental protection. The most important sources of pollution include landfill sites for municipal and post-production waste, communication routes with heavy traffic and areas without sewerage system inhabited by people. In the era of widespread crisis in access to good quality drinking water, measures should be taken to limit the pollution of flowing waters from industrial and municipal installations [Gliniak, Sobczyk 2016; Poros, Sobczyk 2013; Pawul, Sobczyk 2011; Warzyniak, Sobczyk 2008].

The values of physicochemical parameters of flowing waters in Poland take varied values: ammonium nitrogen ($N\text{-}NH_3$) 0,05-10 $mg\cdot dm^{-3}$, nitrate nitrogen ($N\text{-}NO_3$) 0,15-10 $mg\cdot dm^{-3}$, phosphates (PO_4^{3-}) 0,02-1,0 $mg\cdot dm^{-3}$, chlorides (Cl^-) 3-250 $mg\cdot dm^{-3}$, sulphates (SO_4^{2-}) 0,9-400 $mg\cdot dm^{-3}$, solute 50-1000 $mg\cdot dm^{-3}$, total nitrogen (N_{tot}) 0,1-30 $mg\cdot dm^{-3}$, BOD_5 1-100 $mg\cdot dm^{-3}$, organic carbon (TOC) (TOC) 1-50 $mg\cdot dm^{-3}$ [Langmuir 1997; Dojlido 1987]. Exceeded concentrations of the above compounds indicate an anthropogenic pollution of waters. In post-industrial areas, the most common source of pollution are the leachates from post-production landfills, where there is no proper prevention from surface runoff and there is no isolation from the ground and the surrounding area. Such a situation applies to the landfills of chemical waste remaining after the former Krakow Soda Works SOLVAY, which ended their production activity in December 1990 [Gliniak et al. 2016 Małecki 1997; Ślęzak 1993]. Geological and engineering research carried out in the area of landfills showed that the contact of waste with the native substrate results in the formation of an impermeable layer of soil in between of them with a thickness of about 1 m and properties characteristic of lean concrete. During the research, the presence of filtration waters was found in the landfills as well as the presence of an unconsolidated material of the nature of lime putty and soft-plastic consistency [Gliniak, Sobczyk 2017; Gliniak, Sobczyk 2016; Sroczyński 2008].

The Wilga River is a right bank tributary of the Vistula, with its estuary located within the boundaries of the city of Krakow. The source of the river is located in the Pawlikowice village in the Wieliczka Foothills. The Wilga River drains the south-western part of the Foothills, the areas of Swoszowice, the Łagiewniki District and Borek Fałęcki in Krakow. Within the city of Krakow, the river was regulated and strengthened by backwater embankment on the section of the estuary to the Vistula [Kalisiewicz 2000]. The Wilga River on a two-kilometer-long section of its middle course flows through the area of the old Solvay factory and national road No. 7. Monitoring research carried out by the Regional Inspectorate for Environmental Protection in Krakow (WIOŚ – Wojewódzki Inspektorat Ochrony Środowiska w Krakowie) indicates the exceedance of numerous water quality indicators, including chlorides and sulphates [Report ... 2004]. The content of alkaline ions in the soil solution (water / solid phase ratio = 2.5) exceeds several times the limit of acceptable toxicity for plants [Gliniak, Sobczyk 2014; Gliniak, Sobczyk 2012; Zając et al. 2007].

The aim of the research was to determine the impact of landfills of former Krakow Soda Works on the physicochemical parameters of water in the river Wilga.

MATERIAL AND METHODS

Water tests were carried out in 2015-18 at six-month intervals (i.e. in March and October). Water samples were collected at 2 measurement and control points - below the landfill site (CP1) at Zakopiańska Street (3.6 km from the estuary) and in the spa resort (CP2) in Swoszowice (6.6 km from the estuary).

Water samples for in-situ and laboratory tests were collected in accordance with the guidelines contained in PN-EN ISO 5667: 2008 - Water quality. Sampling. The temperature, pH and electrolytic conductivity were measured during the sampling (in situ). In the taken water samples, following substances were determined by the photometric method: the solubility oxygen content, BOD_5, TOC, dissolved substances, sulphates, chlorides, nitrogen and phosphorus compounds. The Macherey-Nagel PF-12 photometer and NanoColor tube tests were used for these determinations.

RESULTS AND DISCUSSION

The water temperature in the Wilga River shows seasonal variability (Fig. 1), depending on the air temperature. The pH of the water varies within a small range, reaching a pH from 7.3 to 8.9. The highest pH values (8.7-8.9) were found at the measurement and control point below the landfill site (CP1).

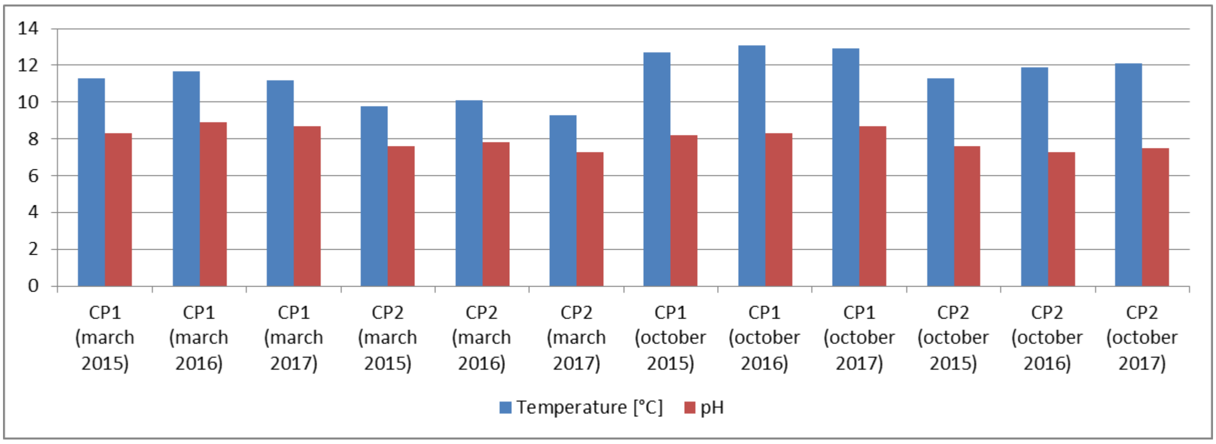

Fig. 1. Changes in temperature and pH in the water of the Wilga River

Concentrations of solubility oxygen and BOD_5 in the Wilga waters at all measurement and control points show similar values, reaching the maximum values of 8.7 $mg \cdot dm^{-3}$ and 2.6 $mg \cdot dm^{-3}$, respectively. The total organic carbon determined in the river's water varies to a small extent, and the highest values of this indicator (5.6 $mg \cdot dm^{-3}$) occur in the autumn (Fig. 2).

Seasonal variability was also observed in the concentrations of biogenic elements: ammonia nitrogen, nitrate nitrogen and total nitrogen (Fig. 3). This is due to the fact that the Wilga River flows in the upper course through agricultural areas. In the case of phosphates in total, no clear relationship between their concentration and the season was observed (Fig. 3).

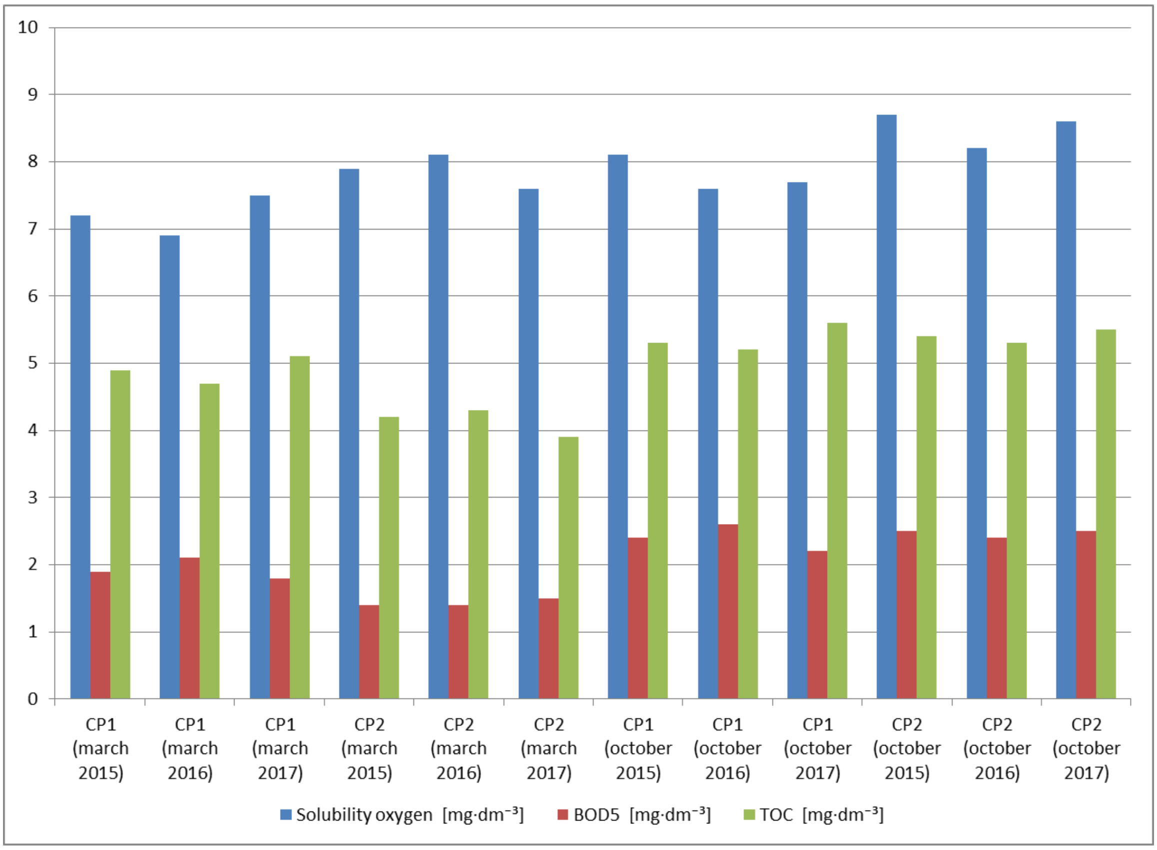

Fig. 2. Changes in the concentrations of solubility oxygen, BOD_5 and total organic carbon (TOC) in the Wilga River water

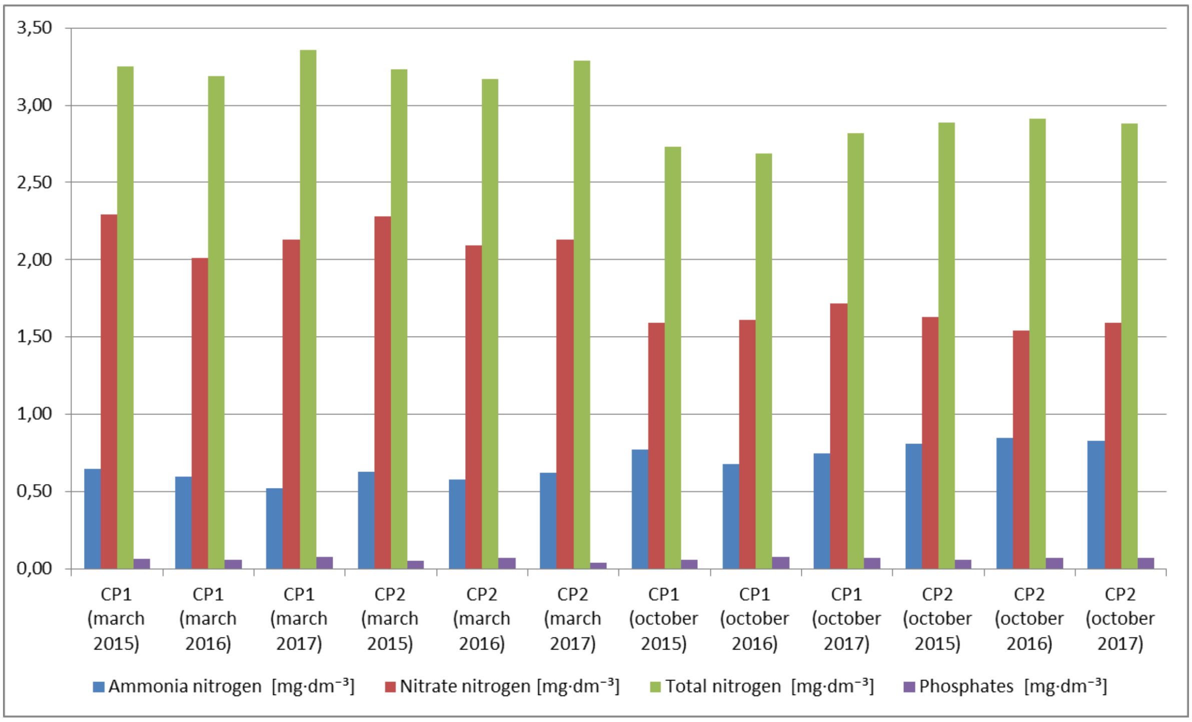

Fig. 3. Changes in concentrations of nitrogen and phosphate compounds in the water of the Wilga River

Figure 4 presents parameters characterized by the variability of the values reached depending on the placement of the measurement point. The electrolytic conductivity of water in the Wilga River shows very high variability. Its values range from 765 to 3461 μS·cm^{-1}, with the highest values also at the measurement and control point below the landfill site (CP1).

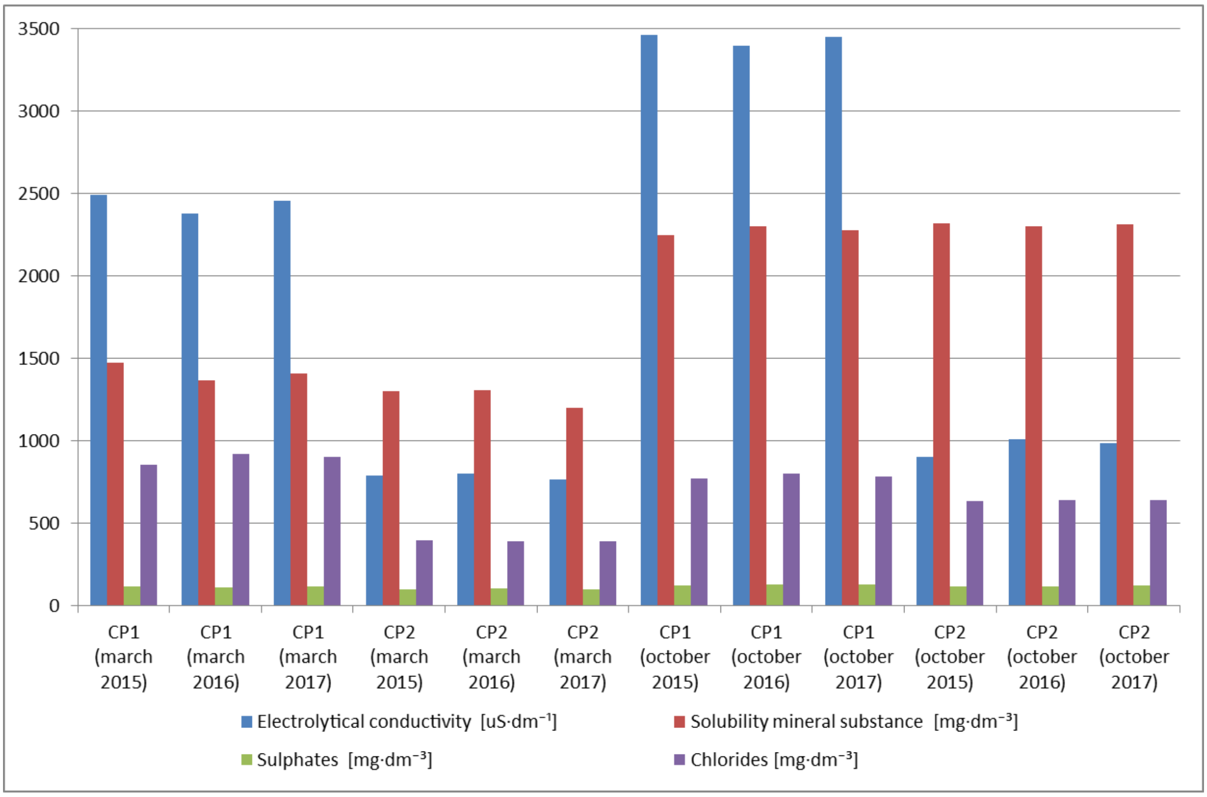

Fig. 4. Changes in indicators showing anthropogenic pollution in the water of the Wilga River

The greatest variability in the Wilga River waters characterizes the chloride ions. Their level varies from 389.8 to 921.5 mg·dm^{-3}. The lowest concentration of this indicator was noted at the measurement and control point in the spa resort in Swoszowice (CP2). Along with the flow of the river, the concentration of chlorides increased, reaching the highest values at the point below the landfills (CP1). At the same time, it can be noted that at all measurement and control points the lowest chloride concentrations were recorded in March, during very moderate water temperatures. During this period, the increase in chloride ions in the Wilga River waters between the point in the spa resort in Swoszowice and the point below the landfills amounted to 500 mg·dm^{-3} and it was the lowest increase in the concentration of these ions on a given section of the river throughout the study period. The highest increase in chloride ion concentration (1000 mg·dm^{-3}) between the above-mentioned points was noted in the summer. These observations indicate that the chloride ions from the area of chloride ions landfills are being washed out by infiltrating precipitation waters. Similar conclusions were also presented in the works of W. Sroczyński and in the spatial development plan for the area of "Białe Morza" ("White Sees" - Solvay Sodium Sediments) [Kupiec, Mleczko 2012].

The concentration of sulphate ions was characterized by the lowest variability, but also in this case, an increase in their concentration was observed in the water collected at the measurement point below the landfills (CP1) in relation to water from the spa resort in Swoszowice (CP2).

When analyzing the results of the carried out determinations, it can be noticed that some of the parameters examined are characterized by seasonal variability, while others are mainly dependent on the sampling area.

Comparison of the obtained results with the requirements specified for individual water quality classes shows that in the case of chloride ion concentration, class II limit values were exceeded in all collected samples. The high value of the electrolytic conductivity also classifies the Wilga River waters in points 1 and 2 to the III-V purity class [Dz. U. 2011 No. 257 item 1545]. At the measurement and control point in Swoszowice (CP2), the exceedance of the electrolytic conductivity defined as limit value for class II occurred only in September. In the remaining period, the values were at the level classifying the water as class I. The remaining examined parameters assumed characteristic values for class I or II.

CONCLUSION

Conducted research indicates seasonal and spatial variability of chemical composition of water in Wilga River. Due to the high concentration of chlorides and the accompanying high electrolytic conductivity of water, the Wilga River should be classified in the III-V purity class. The spatial distribution of chloride ions and electrolytic conductivity shows a clear impact of sodium sediments, remaining after the Krakow Soda Works SOLVAY, on the quality of water in the river. This is indicated both by the increased values of these indicators after the river flows through the sediments area, as well as their dependence on the amount of atmospheric precipitation occurring in the period preceding the measurements.

The impact of landfills on Wilga River waters is significant, but in recent years there has been a reduction in the infiltration of individual ions from sediments into the river with an infiltrating precipitation water [Kupiec, Mleczko 2012].

The carried out analyzes indicate that the use of water from Wilga River for human consumption is impossible in accordance with the requirements of the Ordinance of the Minister of Health [Dz.U. 2010 No. 72 Item 466]. Due to limitations in access to drinking water resulting from the location of Krakow, the care of flowing waters located in the city is a very important aspect. Due to the limited resources of drinking water, further monitoring research should be carried out to monitor on a regular basis water quality in the Wilga River and to detect seasonal changes in the water chemical composition that prevent its use for drinking.

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REFERENCES

Dojlido, J. 1987. *Chemia Wody*. Arkady, Warszawa.

Gliniak, M. 2014. *Kierunki rekultywacji obszarów zdegradowanych działalnością Krakowskich Zakładów Sodowych „Solvay"*. [in:] Kuczera M. (red.). Młodzi naukowcy dla Polskiej Nauki, Nauki Inżynieryjne, Wyd. Creativetime, Kraków.

Gliniak, M., Sobczyk, W. 2012. *Kierunki Rekultywacji Obszarów Zdegradowanych Działalnością Krakowskich Zakładów Sodowych Solvay*. Rocznik Ochrona Środowiska, Vol. 14, pp. 660-672.

Gliniak, M., Sobczyk, W. 2013. *Antropogeniczne Procesy Zasolenia Gleb*. Scientific Annual Education – Technology – Computer Science, Main Problems Of Technology And Professional Education, pp. 271-277.

Gliniak, M., Sobczyk, W. 2016. Proposal of brownfield land development on the example of the landfills of former Krakow Soda Works "Solvay". Journal of Ecological Engineering, Vol. 17, No. 5, pp. 96-100.

Gliniak, M., Sobczyk, W. 2017. *Zawartość metali toksycznych w glebach na terenach poprodukcyjnych*. Przemysł Chemiczny, vol. 96, nr 10, pp. 53-57.

Gliniak, M., Sobczyk, W., Wielewska, I. 2016. *Przestrzenna zmienność parametrów fizykochemicznych gruntów z terenów silnie zasolonych*. Rocznik Ochrona Środowiska, Vol. 18, pp. 372-386.

Kalisiewicz, D. (ed.). 2000. Encyklopedia Krakowa, PWN.

Kupiec, I., Mleczko, P. 2012. *Miejscowy Plan Zagospodarowania Przestrzennego Obszaru „Białe Morza" Prognoza Oddziaływania Na Środowisko*, Urząd Miasta Krakowa, Kraków.

Langmuir, D. 1997. *Aqueous Environmental Geochemistry*. Prentice Hall, New Jersey.

Małecki, Z. (ed.). 1997. *Restrukturyzacja – Likwidacja – Zagospodarowanie KZS „Solvay”*. Problemy Sozologiczne Aglomeracji Miejsko-Przemysłowych. Biuletyn Komitetu Inżynierii Środowiska Pan Nr 1/1997.

Pawul, M., Sobczyk, W. 2011. *Edukacja ekologiczna w zakresie gospodarki odpadami jako narzędzie realizacji zrównoważonego rozwoju*, Problems Of Sustainable Development, Vol. 6, No 1, pp. 147-156.

Poros, M., Sobczyk, W. 2013. *Rewitalizacja terenu pogórniczego po kopalni surowców skalnych na przykładzie kamieniołomu Wietrznia w Kielcach*. Rocznik Ochrona Środowiska, Vol. 15, pp. 2369-2380.

Raport o stanie środowiska naturalnego w województwie małopolskim w 2003 roku. Biblioteka Monitoringu Środowiska, Kraków 2004.

Rozporządzenie Ministra Środowiska z 9 listopada 2011 r. w sprawie sposobu klasyfikacji stanu jednolitych części wód powierzchniowych oraz środowiskowych norm jakości dla substancji priorytetowych. Dz. U. 2011 Nr 257 Poz.1545.

Rozporządzenie Ministra Zdrowia z dnia 20 kwietnia 2010 r. zmieniające rozporządzenie w sprawie jakości wody przeznaczonej do spożycia przez ludzi. Dz.U. 2010 Nr 72 Poz. 466.

Sroczyński, W. 2008. *Geologiczne uwarunkowania rewitalizacji i zagospodarowania tzw. „Białych Mórz” na terenach po byłych Krakowskich Zakładach Sodowych „Solvay”.* Geologia T. 34, Zeszyt 4, pp. 701-709.

Sybilski, D. 2009. Ekologiczne zagadnienia odwodnienia pasa drogowego. Praca wykonana na zlecenie Generalnej Dyrekcji Dróg Krajowych i Autostrad, Warszawa.

Slęzak, A. 1993. *Wpływ składowiska odpadów Krakowskich Zakładów Sodowych na wody powierzchniowe* [W]: Przewodnik III Konferencji Sozologicznej PTG. Sozologia na obszarze antropopresji – przykład Krakowa. AGH-UST, Kraków.

Wawrzyniak, S., Sobczyk, W. 2008. *Implementation procedures and principles of modern revitalization processes as exemplified by the community of Bierun*, Gospodarka Surowcami Mineralnymi - Mineral Resources Management, Vol. 24, pp. 263-270.

Zając, E., Klatka, S., Ryczek, M. 2007. *Wpływ nadkładu glebowego na zmiany odczynu i przewodnictwa elektrolitycznego odpadów posodowych w warunkach doświadczenia modelowego*. Zesz. Probl. Post. Nauk Roln. Vol. 520, pp. 213–219.

Selected elements of water management in facilities under cover with cultivation of plants on an inert substrate

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Abstract: The paper discusses issues related to water management of plants grown in an inert substrate. Requirements regarding the quality of water used for irrigation of plants and requirements for water intended for drip irrigation are presented. On the basis of experimental results, transpiration of plants was presented, the method of estimating water infiltration and global water demand was discussed. Discussed is the construction of a closed media system with devices used for its disinfection and dosing of concentrated medium for the process of fertigation of plants.

Key words: greenhouse, plants

INTRODUCTION

In crops under cover (greenhouses, plastic tunnels), optimization of production factors is an important issue. Not maintaining growth factors at the optimal level has a negative impact on both short and long-term processes in the plant. On the fig. 1 was illustrated graphically the influence of controllable growth factors on existing processes and the impact on cultivated plants [Bakker et all. 1995].

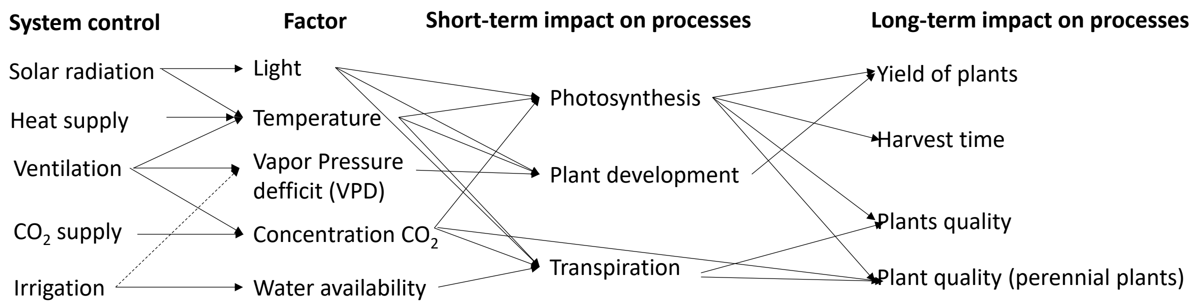

Fig. 1. The interaction between the growth factors in the greenhouse

As you can see, the irrigation system affects the availability of water and the course of processes affecting the growth and development of plants. Therefore, forecasting irrigation needs of plants and applying solutions that both minimize production costs and lead to the protection of the natural environment is of particular importance. This forecasting is valid in the era of today's production (mainly greenhouse), where the vast majority of commodity production is carried out on an inert substrate (including mineral wool, glass wool, gravel, sand, coconut fiber, cocoa shell). These substrates was dominated modern greenhouse crops, because of ease of maintaining optimal water-air relations, precise response to the nutritional needs of plants, ensuring microbiological purity of the substrates made these substrates effectively displaced the traditional horticultural substrate. The demand for water is variable and depends mainly on the parameters of the surrounding climate, the microclimate inside the plant, and the size and species of plants. Fig. 2 graphically illustrates the annual water demand of cultivated greenhouse tomatoes at a density of 2.5 plants / m^2 [Zwart 1996]. As you can see, the maximum demand can be as much as 3.5 kg / m^2 of growing area. Differences between individual months depend on climatic conditions, leaf areas and listability for gas exchange.

The key is therefore to provide water of adequate quality and quantity to cover the demand of the cultivated plants.

Water for irrigation of greenhouse crops

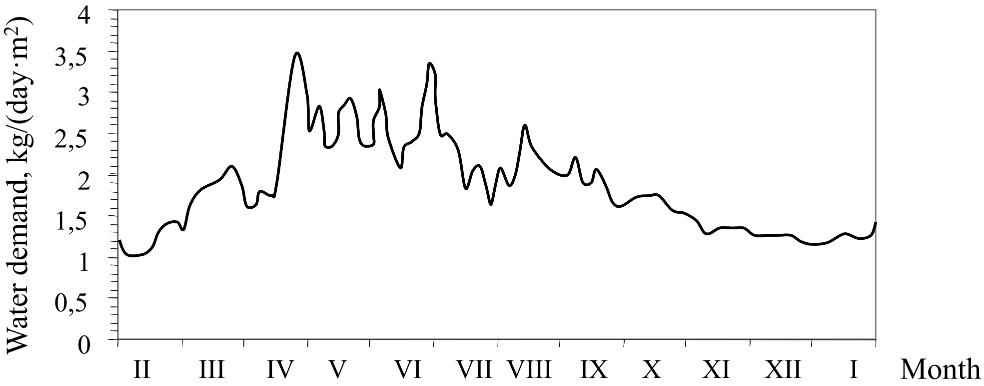

Fig. 2. Change in the demand for water by greenhouse tomatoes

The source of water used in the process of irrigation of plants in gardening facilities is groundwater, surface water and water stored in tanks located directly at the roof of the facility (rainwater). Table 1 shows the sources of water used for irrigating plants with the potential problems and ways to provide the recommended water properties.

Table 1. Sources and problems of quality water for irrigation [Kaniszewski 2005, Kloc- Szatniak 2004].

Water source		Substances that cause clogging	Type of filtering	Additional treatments
ground water	Well drilled	sand, calcium carbonates	mesh filter	using acid to eliminate calcium carbonate
	Wells dug	sand, calcium carbonates, iron (Fe^{2+})	mesh filter and with separator, hydrocyclone	installation of a water aeration tank
surface water	Rivers and streams	organic substances, algae, bacteria	sand filter, mesh filter with sand separator, hydrocyclone	using of chlorine or acid depending on the degree of emitter clogging
	Channels	organic substances, algae, bacteria	sand filter, mesh filter	
	Water tanks	organic substances, algae, bacteria	flow filter, sand filter, mesh filter	

While the composition of rainwater is known, the composition of groundwater depends on the type and construction of rocks, the degree of weathering and graining, the speed of underground water movement and the level of contact with surface and rainwater [Kowal, Świderska-Bróż 2009]. Groundwater is contaminated by gases and substances dissolved in water. The gases include: dissolved oxygen, carbon dioxide, hydrogen sulphide, nitrogen and others (methane, hydrogen, rhodium, noble gases). Substances dissolved in water such as: bicarbonates and carbonates, sulphates, chlorides (in the form of anions and cations), calcium, magnesium, sodium, potassium, iron, manganese, nitrogen compounds. In contrast to the groundwater in the formation of the chemical composition of surface waters play a significant role anthropogenic pollution (are related to the activities of man- example:

quarrying, clay, slag heaps, levees). Substances that cause surface water pollution are organic and inorganic compounds. Organic compounds such as: amino acids, phenols, fatty acids. In turn, the most important inorganic substances are: iron, calcium, sodium, magnesium, manganese, copper, molybdenum, others (selenium, lead, bromine). From the viewpoint of the parameters characterizing the water in terms of its suitability for watering characteristics of the water can be divided into physical properties and chemical composition. Among the physical parameters can be distinguished: color, turbidity, taste, smell and temperature. In turn, the chemical parameters are: pH of water, electrical conductivity (salinity of water), water hardness, content of toxic elements.

An indicator of the chemical composition is the concentration of hydrogen ions in water expressed as the **pH of water**. In general, in surface waters, the pH varies between pH 6.5 to 8.5. The acidity of water is caused by: dissolved in water free CO_2, mineral and organic acids (eg humic acids) and products of hydrolysis of salts present in water. The reason for the decreased water pH (sometimes even up to pH 4) is acid atmospheric precipitation. Acidification caused by acid precipitation changes during the year, and the largest is in a period of intense snowmelt runoff. Sometimes, also the discharge of underground water containing iron sulphate ($FeSO_4$) to the surface water may cause the acidity of the water to increase, because the iron hydroxide precipitates in the reaction of the sulphate and water, and the ferric hydroxide released in the reaction causes acidification of water. Table 2 presents the effect of water pH on the soil environment of cultivated plants.

Table 2. Influence of water reaction on soil environment of plants

Range of pH	Impact on the soil environment
< 4,3	free CO_2, pH decreases, possible damage to plants by excess CO_2
4,4 – 6,4	There is still free CO_2, there is a lowering of the pH of the environment (recommended pH)
6,5 – 8,3	The optimal range of pH
>8,4	Water contains oxygen, the pH of the greenhouse substrate increases

Another important and easily measurable chemical parameter is the **electrical conductivity** of water. The size of the electrical conductivity of water is a parameter characterizing the content of dissolved in water salts in the form of cations (calcium, sodium, magnesium) and anions (sulphates, bicarbonates, chlorides). Electrical conductivity is a measure of the **salinity of water**. The salinity of water is the sum of the content of all mineral salts dissolved in it. Water available in water supply systems, ponds or wells always contains minerals dissolved in it. Their quantity and quality determine its suitability for horticultural purposes. Geological conditions influence the mineral salts that are dissolved in the water. There is a relationship between the measurable electrical conductivity of water and the amount of salt dissolved in it. Distilled water or rainwater contain not enough mineral salts - they are characterized by low conductivity. Conversely - water containing a lot of dissolved mineral salts has a high conductivity. In practice, to determine the salinity of water we use electric conductivity units - conductivity, in short *EC* (electrical conductivity). The unit of electrical conductivity of solutions (in this case water, which is a natural solution of mineral salts) is Siemens (S). In horticultural practice, an EC 1 unit equal to 1 mS / cm (miliSiemens / cm) is used. The conductivity of water supplied to the greenhouse is usually in the range of 1 to several mS / m. For comparison, distilled water has an EC close to 0. **The hardness of water** is directly related to its salinity. Water hardness causes calcium, magnesium and multivalent salts dissolved in it. Calcium, magnesium and sodium salts (mainly carbonates and sulphates), dissolved in water, limit its suitability for watering. Calcium and magnesium carbonates and bicarbonates cause the hardness of so-called transient, it can be removed by acidifying or boiling water (deposits on the bottom and walls of the vessel). Calcium and magnesium sulphates cause the hardness, that is imperishable, not removable by boiling. If the hardness is higher and the plants are grown in small containers and under covers, then this water may need to be treated. Hard water has an alkaline reaction (pH> 7) and requires acidification. Long-lasting watering with alkaline water (at the same time the most often hard and often saline) causes an increase in the reaction of the root zone, which results in disturbances in the intake of nutrients (mainly microlights) and deterioration of the growth and appearance of plants. The following types of water hardness are distinguished:

carbonate hardness (transient); water contains calcium and magnesium bicarbonates,

solid hardness; it is caused by the content of chlorides, nitrates, sulphates, silicates and other soluble calcium and magnesium salts in water, general hardness - as the sum of transient and constant hardness.

Hardness is determined in degrees of German hardness (°n), in French degrees (°f), using milligram equivalents (mval / l), or in molecular weights (mmol / l). One degree of German hardness (°on) means the quantity of calcium and magnesium ions equivalent to: 10 mg CaO or 7,1 mg Ca_2 + or 7,19 mg MgO or 17,8 mg $CaCO_3$ contained in 1 dm^3 of water. Z kolei, jeden stopień twardości francuski (°f) odpowiada ilości jonów wapnia i magnezu równoważnej zawartości 10 mg $CaCO_3$ w 1 dm^3 wody. For determination of hardness by miligramo equivalents is the quantity miligramo equivalents of calcium and magnesium in the water volume unit: meq / dm^3 or val / m^3. Taking into account the basic chemical relationships (molecular weight CaO) between these units, there is a dependency:

1 mval/l=2,8°n, and 1 mmol/l= 5,6°n

Due to the hardness, the water is divided into: verry soft: from: from 0 to 5,6 °n; soft: from 5,6 to 11,2°n; medium hard: from 11,2 to 16,8°n , hard: from 16,8 to 22,4°n; very hard: on above 22,4°n.

The content of toxic elements in the water (mainly heavy metals) is harmful to fruit and vegetables grown in greenhouses, since these elements are easily accumulate in plants. Acceptable concentrations of certain elements in the water for watering is shown in Table 3.

Table 3. Acceptable levels of certain elements in irrigation water(PN – 84/C-04635)

Element	**Permissible concentration, mg/l**
Arsenic (As)	0,2
Bor (B)	0,5
Chlorides (Cl)	250
Sulphates (SO_4)	250
Zinc (Zn)	2,0
Cyanides (CN)	0,05
Fluorine (F)	1,5
Aluminium (Al)	5,0
Cadmium (Cd)	0,1
Manganese (Mn)	0,8
Copper (Cu)	0,2
Nickel (Ni)	1,0
Lead (Pb)	0,1
Mercury (Hg)	0,01
Selenium (Se)	0,05
Sulphides (S)	0,1

Element	Permissible concentration, mg/l
Sodium (Na)	140
Iron (Fe)	10
Sum of heavy metals (Ni, Co, Cu, Cr, As, Pb, Hg)	1,0
Substances dissolved	1000
Coli group bacteria (as a number in 100 ml of water)	10

The above features, mainly chemical, determine not only the usefulness of water for plants, as there are species more or less tolerant to salinity and water pH. In the table 4 lists the recommended value of salinity and hardness of the selected flowers.

Table 4. Water quality for some ornamental plants [Czekalski 2010].

A plant or group of plants	Water hardness, ^{o}n		Salt concentration, mg/l
	carbonate	Total	
Ferns, orchids	3 – 4	5 – 6	150 – 250
Azaleas, heaths, anuria, prisms	7 – 8	10 – 12	350 – 450
Cyclamen, begonias, roses, gerberas	12 – 15	18 – 20	600 – 650
Gildings, carnations	17 – 20	25 – 30	800 - 1000

The second addition to the reaction of plants on the quality of the water issue is the durability of the installation of irrigation. Irrigation installations (mainly droplet emitters) are exposed to failures due to the presence in the water of solid contaminants and elements and chemical compounds that in contact with oxygen contained in atmospheric air cause precipitation and, consequently, the danger of blocking emitters. In addition to chemical content, another important problem (especially in drip irrigation) is the total amount of bacteria in the water. Their excess affects the drop in the patency of droplets, and thus the possibility of blocking emitters dispensing water. In the table 5 lists the required water quality criteria, taking into account the risk of droplet emitter failure [Nakayama and Buck 1986].

Table 5. Criteria for the quality of water for drip irrigation

Type of pollution	Degree of danger of blocking emitters		
	low	medium	high
Physical, mg/l	50	50 - 100	>100
Chemical: pH	7	7– 8	>8

Soluble substances, mg/l	500	500 – 2000	>2000
Iron (Fe^{2+})	0,1	0,1 – 1,5	>1,5
Manganese (Mn)	0,1	0,1 – 1,5	>1,5
Calcium (Ca)	10	10 – 50	>50
Carbonates	100	100 – 200	>200
Biological (number of bacteria / ml)	10 000	10000 – 50 000	>50 000

An important problem is the removal of iron and manganese from the water. The following processes occur in their removal [Kowal, Świderska- Bróż 2009]:

aeration (removal of carbon dioxide, hydrogen sulphide, methane, divalent iron and manganese ions from water),

iron removal and demanganizing of water, used mainly in the use of groundwater, involves the oxidation of divalent iron ions to trivalent ions. In the case of manganese ions, the process removal of manganese is the oxidation of divalent manganese ions to tetravalent ions. Both in the case of iron removal and demanganation, the compounds resulting from these processes are removed from the water in the process of filtration or settling of particles (sedimentation).

The method of removing iron from water is determined by the form of its occurrence in raw water. If the iron is present as Fe $(HCO_2)_2$, then apply the simplest water treatment system according to the scheme:

Aeration → sedimentation (with substantial quantities $Fe(OH_3)$ → iron removal → disinfection.

In the case when the iron is contained in water in the form of $FeSO_4$, the alkalization process should be included in the above system. The quality of iron removal determined in the process of fulfillment of the following conditions:

ensuring the hydrolysis of iron compounds (decomposition of compounds under the influence of contact with water),

oxidation of divalent iron ions to trivalent iron,

formation, agglomeration and removal of colloidal ferric hydroxide (FeOH) 3 particles. This hydroxide, occurring in the form of flocks, is removed in the process of sedimentation and filtration.

The course of these processes depends on the chemical composition of the treated water and the type of technological processes used (water deacidification method, type of oxidizer, type of filter bed) and equipment.

The process of demanganation, is carried out using physical methods (aerating water) or by filtering water through a bed filled with grains covered with manganese dioxide.

Water disinfection is carried out mainly in drip irrigation and when the closed medium circulation is used in the greenhouse. Among the methods used, disinfection is carried out by the physical method in the form:

heating and pasteurization (heating up to effective temperature - maximum to 100°C,

use of ultrasound - water flows through piezoelectric quartz plates, which, when supplied with alternating current, produce ultrasound, which results in mechanical destruction of bacteria,

ozonizing water - ozone is produced in the place of dosing and is introduced into the water in the form of ozonated air. Ozone added to water reacts with water components and undergoes automatic decomposition.

slow filtration through a sand bed - low efficiency, the need for a frequent filter cartridge, medium flow through semipermeable membranes (membrane processes) - costs, frequent filter material replacement.

The mentioned methods are expensive (eg production of 1 g of ozone requires consumption of approx. 15 Wh energy, and the demand for ozone is from 0.2 to 6 g / m^3 of water), therefore the presented methods of disinfection are rarely used in the treatment of water intended for irrigation purposes . Currently, intensive research is underway to apply the so-called membrane processes in which the separation properties of membranes are used to separate the solution components [Zarzycki 2005]. It should be assumed that membrane techniques, due to their use in the broadly understood environmental engineering (including treatment and purification of liquid and gaseous industrial waste), will be used in medium disinfection. An additional argument for their widespread use is the high energy efficiency in separation processes.

However, nowadays, the most common method of disinfection is the use of ultraviolet rays. Based on numerous experiments, it can be concluded that ultraviolet rays effectively destroy microorganisms, and the maximum destruction efficiency occurs at a wavelength of 265 nm. The disadvantage of this method is the disinfecting action only during exposure of water with UV rays, so there is a risk of secondary bacterial growth in the irrigation installation. It follows that the disinfection device should be mounted directly in front of the water dispensing pump (medium) for the installation. The sources of UV radiation are high-pressure quartz mercury lamps. Such lamps are placed in conduits with flowing medium. The installed photocell indicates the degree of soiling of the lamp, and thus informs the operator about its current cleaning. In the Fig. 3. shows a diagram of a UV lamp dedicated to water disinfection is presented.

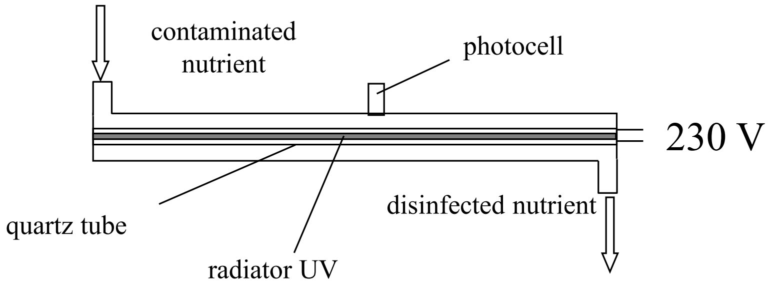

Fig. 3. Diagram of UV lamp for disinfecting nutrient solution

The production experience shows that the efficiency of work can be significantly improved by using a sand filter at the inlet, and on average after about 500 hours of work, the process of cleaning and disinfecting the lamp should be carried out.

Under the conditions of cultivation under inert substrate, the problem is to deliver the quantity and composition of the medium. The important issue is therefore to provide water with the appropriate quality parameters, only after obtaining the right water quality should be provided micro and macroelements. In cultivation carried out on a natural organic substrate, the irrigation process is usually carried out with clean water, while in the case of cultivation on inert media along with water, micro and macroelements are also supplied. Simultaneous irrigation with the supply of dissolved micro and macroelements to water is called the fertigation of plants. The group of micro and macroelements includes: nitrogen (N), phosphorus (P); potassium (K), calcium (Ca), sulfur (S), iron (Fe), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo), magnesium (Mg), zinc (Zn). In addition to the listed ingredients, an important parameter is the appropriate pH of the medium. Micro and macro elements are supplied to the nutrient solution by dissolving in the water fertilizers containing these elements, the reaction is regulated by the addition of nitric acid (HNO_3).

The procedure for determining the necessary mass of nutrients in the nutrient solution is as follows:

The first step is to determine the level of micro- and macro-elements in the water which will be used for the process of nutrient solution. Next, the nutritional requirements for the cultivated plants should be determined. In the next step, having a set of fertilizers (water-soluble fertilizers), you need to determine the necessary mass of fertilizers that you deposit in tanks. Depending on the type of fertilizers, there are 3 to 5 tanks in the installation where concentrated nutrient solution is stored. Their number depends on the type of fertilizers used, in such a way as to prevent the occurrence of chemical reactions while mixing individual micro and macro elements. Concentrated nitric acid (HNO_3) is stored in one of these tanks.

Plants cultivated on an inert substrate, depending on their size and type, have different concentration requirements [Breś et all. 2009].

MATERIAL AND METHOD

Estimation of irrigation requirements of plants

An integral issue, in addition to the preparation of water of appropriate quality in the irrigation economy, is the determination of its quantity, amount adapted to the current needs of plants. These needs result from two mechanisms: transpiration of plants and infiltration of water through drainage holes made of PE foil constituting the batten cover of the substrate.

Plant transpiration

In the literature there are a number of models describing the intensity of transpiration of plants as a function of ambient climate parameters, microclimate inside the greenhouse and the elements constituting the technical equipment of the object. The transpiration process itself plays an important role not only in determining the demand for water but also in the overall processes taking place under the covers, because it directly affects the physical parameters of the microclimate (temperature, concentration of water vapor). Consequently, this forces the need for ventilation and consequently for heat consumption. A detailed analysis of transpiration models is presented in the paper [Kurpaska, 1998]. The results of experimental studies were compared with the models: Jolieta et al. Kindelana, Nederchoff and Graf as well as a model developed by Stanghellini. In conclusion, it was found that the relative differences between measured and transpiration rate values from the models, depending on the intensity of solar radiation, range from 19 to 27%. The biggest differences were observed when using the Kindelan model, while the smallest ones were observed for the Stanghellini model.

In this paper, results of experimental research, which was conducted in a greenhouse, in which the surface of approx. 200 m^2 greenhouse grown tomatoes. During the tests, every 2 minutes the climate parameters were monitored inside (temperature, concentration of water vapor and carbon dioxide in the air), and outside the object (temperature and humidity of the air, wind speed and intensity of solar radiation). The mass of plants growing in the lysimeter was also monitored. In addition, during the experiments the total leaf area was determined. In the Fig. 3 presents the diagram of the measurement station. The diagram also shows 4 plants placed in a mineral wool bale. During cultivation, the whole bale was covered with PE foil, drainage holes were made at the side about 2 cm from the bottom. Transpiration of plants, after omitting systematic and accidental errors, was calculated from the following formula:

$$TR = \frac{dW}{d\tau} = \frac{W_{\tau 1} - W_{\tau 2}}{(\tau_1 - \tau_1)} \qquad (1)$$

where: $W_{\tau 1}, W_{\tau 2}$ reading mass, g

τ_1, τ_2- reading time, s

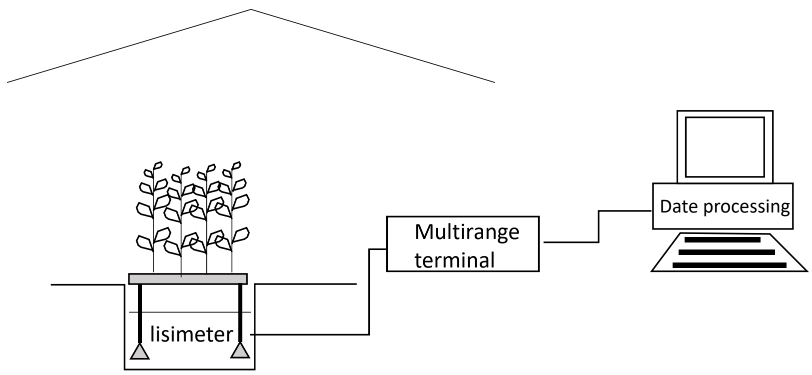

Fig. 4. Diagram of the measurement stand

During the experiments, based on the sum of solar radiation, the control system fed the nutrient solution to cultivated plants with a single mass set; additionally, performed periodically removing the medium from the container in which the bale of mineral wool provided. Fig. 5 depicts a diurnal change in the weight of cultivated plants for two days, sunny and cloudy. In addition, the detail of the change in plant mass was indicated due to: removal of medium from the measuring station (drainage), provision of nutrient solution and transpiration of plants. As you can see, on a cloudy day, two drainages were performed on that day, and the medium was delivered 11 times. In the case of a sunny day, only one-time drainage was carried out, and during the day it was delivered 16 times.

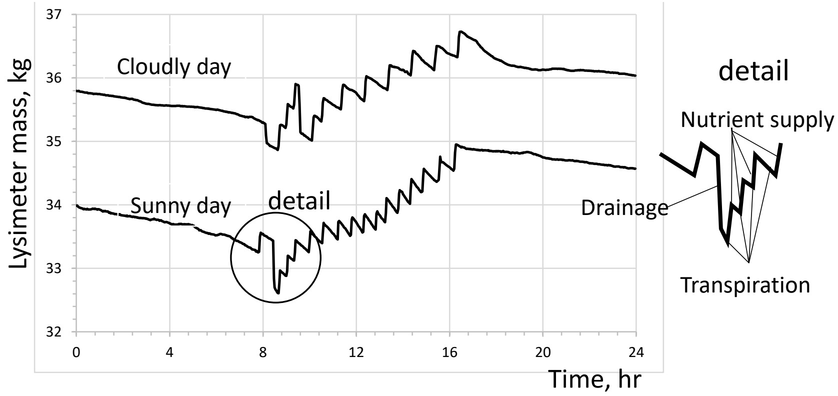

Fig.5. Diurnal change in the weight of cultivated plants

Detailed analysis showed that 4.247 kg of nutrient solution was delivered for the cloudy day, and 5.4 kg for the sunny day. During the experimental days presented, the total area of leaves was respectively: for a cloudy day 6.17 m^2, and for a solar day 5.58 m^2. At that time, the total transpiration of plants (calculated from equation 1) was: for a cloudy day 3.2 kg, and for a sunny day 4.45 kg.

Fig. 6 and 7 illustrate the course of measured parameters outside and inside the facility for a cloudy day; in turn, on figures 8 and 9 for the solar day. Charts are presented these days, which are shown in detail based on image presented in Fig. 5.

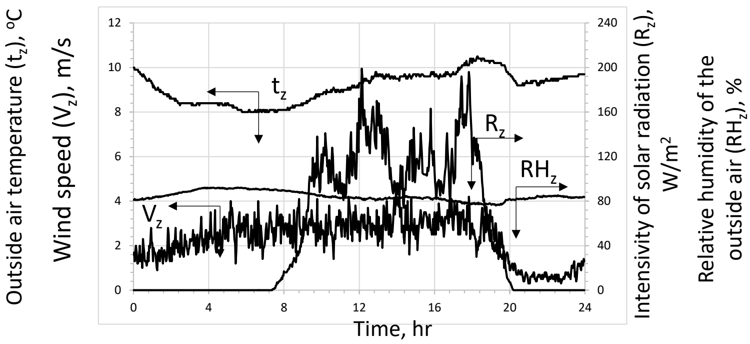

Fig. 6. The daily course of parameters of the surrounding climate for a cloudy day

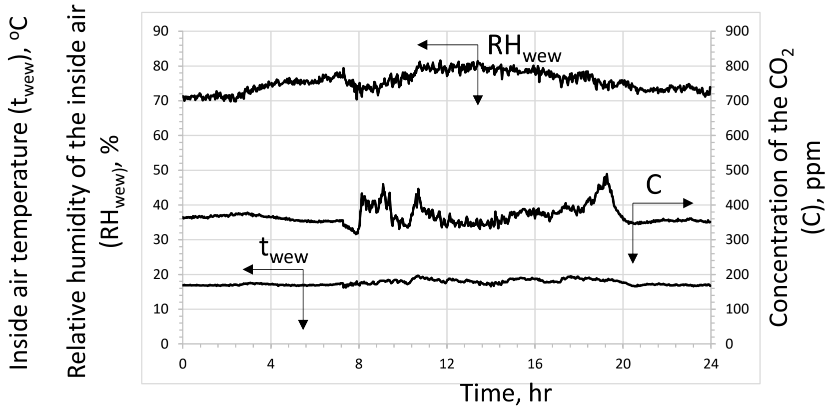

Fig. 7. The daily course of microclimate parameters inside the greenhouse for a cloudy day

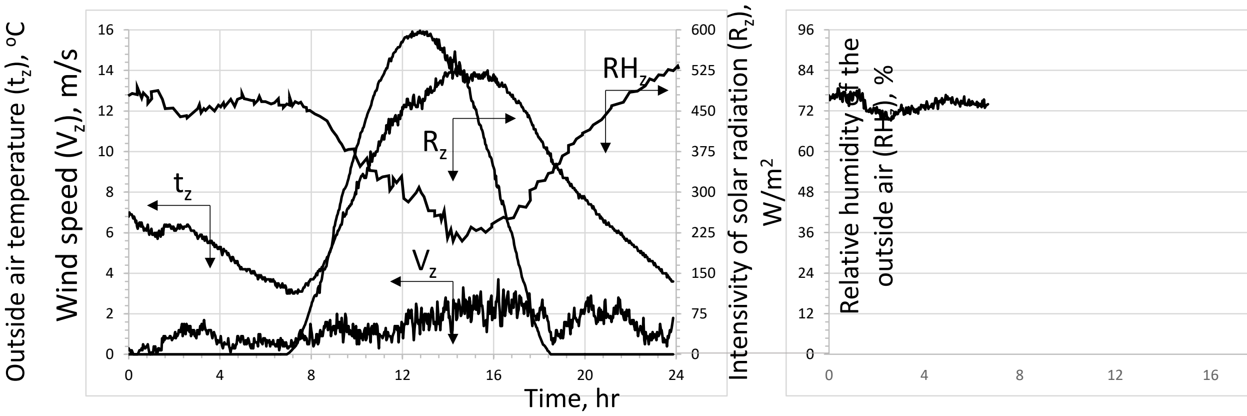

Fig. 8. The daily course of parameters of the surrounding climate for the sunny day

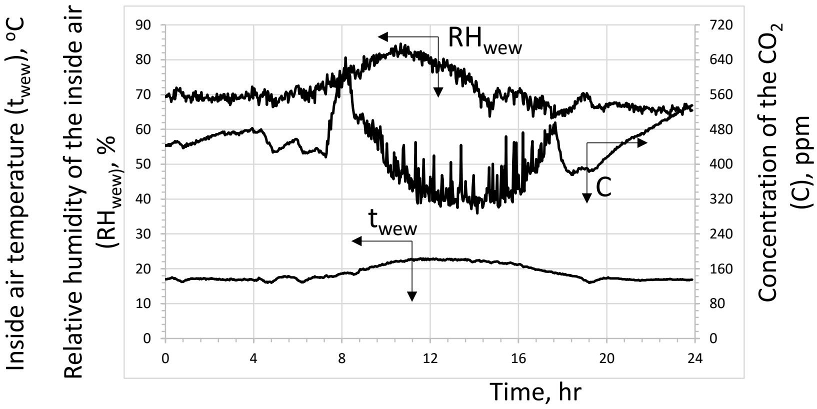

Fig. 9. The daily course of microclimate parameters inside the greenhouse for a sunny day

As we can see, the temperature inside the object, regardless of the intensity of solar radiation intensity (Fig. 5, 9) did not exceed the recommended values for cultivated plants. Also, in the case of relative air humidity, its value was within the range recommended for plants. Analyzing the value of carbon dioxide concentration, the dosing system was insufficient, because with intensive radiation (Figure 9), this concentration reached critical values (below the concentration of CO2 in the ambient air).

In the Fig. 10 and 11 depict the course of transpiration of cultivated plants along with daily variability of water vapor deficit. Transpiration is expressed in a unit of milligrams. This deficit was calculated using standard psychrometric relationships.

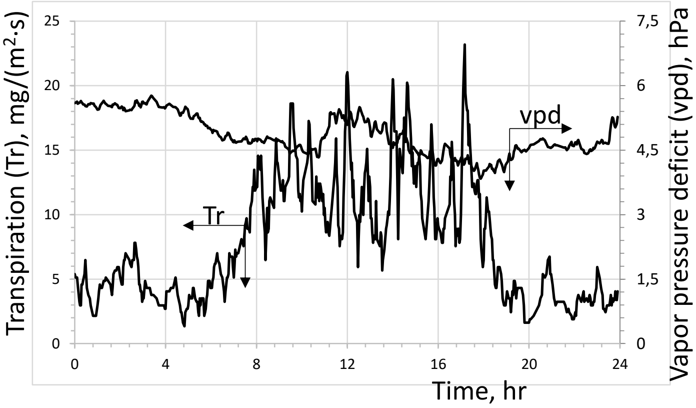

Fig. 10. The daily course of transpiration of plants for a cloudy day

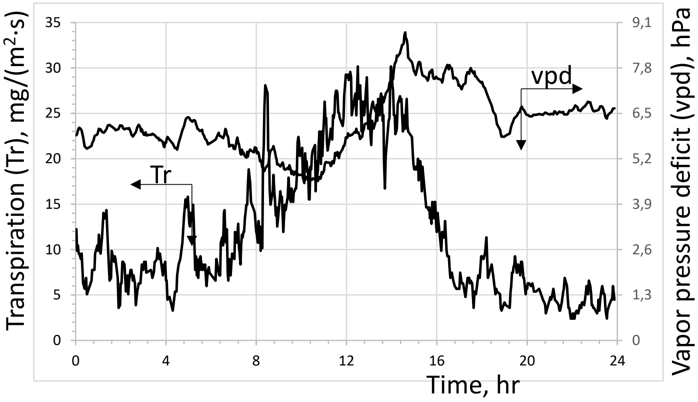

Fig. 11. The daily course of transpiration of plants for a cloudy day

Analyzing the obtained results it can be concluded that transpiration of plants (values calculated with reference to the unit area of leaves and unit time) is strongly dependent on the intensity of solar radiation. This conclusion can be formulated on the basis of the scope of other parameters (temperature water vapor pressure deficit).

For the calculated plant transpiration values, an equation was found that captures the relationship between this variable and independent variables (intensity of solar radiation - R_{zew}, the temperature inside the object - t_{wew}, water vapor pressure deficit - vpd). The procedure used took into account the time interval in which solar radiation occurred. Using the non-linear estimation procedure with the quasi-Newton method, the coefficient of concurrence 0.00001 was used to determine the form of the power model based on the largest value of the determination coefficient. The equation takes the form:

$$Tr = 0{,}013 \cdot R_{zew}^{1{,}195} + 489{,}2 \cdot t_{wew}^{-0{,}095} - 359{,}2 \cdot vpd^{0{,}008} \qquad R^2=0{,}72$$

In the range of application:

$$1<R_{zew}<600\ \mathrm{W/m^2};\ 16{,}8<t_{wew}<22{,}8\ \mathrm{^oC};\ 3{,}8<vpd<8{,}8\ \mathrm{hPa}$$

The comparison between the calculated value of the proposed equation transpiration measured and graphically illustrated in Fig. 12.

As you can see, the comparison is satisfactory because both the coefficient of determination (R^2) nd the mean square root error (σ) assume acceptable values.

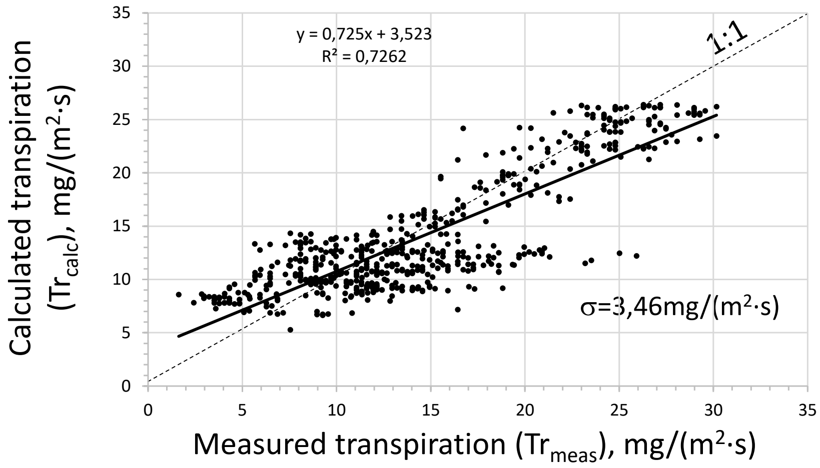

Fig. 12. A comparison between the calculated and measured transpiration

<u>Infiltration of medium in the mat</u>

The second important process that affects the nutrient needs is the infiltration of nutrient from the mineral wool mat. The intensity of infiltration describes Darcy's relationship in the form:

$$q_{\inf} = K\frac{dH}{dy}\cdot\tau \text{, [kg]} \tag{2}$$

where: *K*- coefficient of water conductivity of wool, mm/s; *H*- total potential, m; *y*- wool thickness, m, *τ*- time, s.

Fig. 13 shows the water conductivity and the potential as a function of mineral wool moisture [Sławiński et all. 1996].

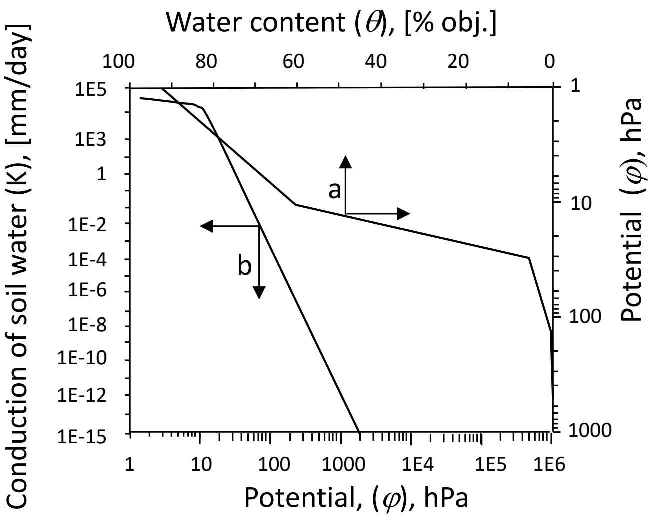

Fig. 13. Changing the soil water potential as a function of humidity (a) and wool conductivity depending on the water potential (b)

The procedure for determining the intensity of infiltration is as follows:

First, it must be assumed average humidity in wool and determine the potential of water in the mat at three different depths. It was assumed that the object of analysis is MASTER type wool, 10 cm thick, in which drainage holes were made at a distance of 2 cm from the bottom. The specified points are: depth 1; 4; 8 cm. It is planned to maintain an average humidity of 60% in wool. It follows that the standard size of wool (1 x 0.2 x 0.1 m) contains 12 kg of water. In these points (according to the available hydrophysical parameters) the following humidity occurs: 53% at a depth of 1 cm, 57% at a depth of 4 cm and 66% at a depth of 8 cm (weighted average humidity in the mat is 60%). Next, read the water potential (φ) for these humidities (rys. 13); for these data the potential value is: at a depth of 1cm -13; 4 cm -9.8 cm the potential is equal to -6 hPa. Then calculate the total potential. For this purpose, we place a vertical axis at a point at a depth of 8 cm and dependence on a point: $H = y + \varphi$ we calculate the total potential. In the case under consideration, this potential is: for a point at depth 8cm- H = 0-6 hPa = -0,06 m; for a point with depth 4 cm: H = 4-9= -5hPa= -0,05m; and for a point at a depth of 1 cm respectively: H = 7-13 = -6hPa= -0,06m. In the next step, the average potential in individual layers should be determined, and so in the layer between 1 and 4 cm depth it is equal to: H= -0,055 m; for the layer located between the points 4 i 8 cm H= -0,055 m. For such determined average values of the potential, the value of the soil water conductivity coefficient should be read from the graph. In the case analyzed for H=-0,055 m, K= 20000 mm/day (0,23mm/s). Hence, using Darcy's law mass flow between the layers will be:

depth between 1 and 4 cm: $0{,}23\dfrac{-0{,}07-(0{,}06)}{0{,}04-0{,}01}=0{,}076\ \text{mm/s},$

and for the layer in between 4 i 8 cm: $0{,}23\dfrac{-0{,}07-(-0{,}06)}{0{,}08-0{,}04}=0{,}08\ \text{mm/s}.$

The total flow of leaking mineral wool water is equal: 0,004 mm/s (0,08-0,076=0,004). It follows that in wool with an area of 0.2 m2, nearly 80 g of nutrient solution will leak in 100 seconds. It can therefore be concluded that after 100 seconds, there will be 11.92 kg of water in wool, which corresponds to 59.6% of humidity. In the next step, the entire procedure of calculating the water leakage from the mat should be calculated for the average moisture content in wool equal to 59.6%.

Fig. 14 presents the results of calculations of water leakage as a result of infiltration and the total demand for water including plant transpiration.

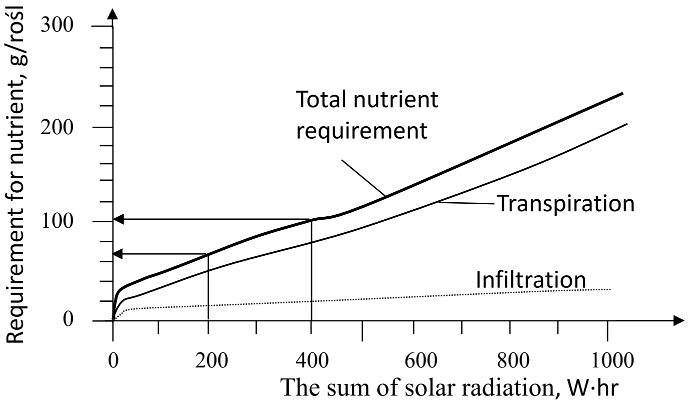

Fig. 14. Total nutrient requirement for tomatoes as a function of solar sum

When calculating the intensity of infiltration, it was considered that four tomatoes were grown in wool. As you can see, if in the control device the threshold of solar radiation is set equal to 200Wh of solar radiation energy, then for each plant the system must provide 65 g of medium, and if the threshold is set to 400 Wh of energy then provide 108 g of nutrient solution. After taking into account eg. 20% of a transfer dispenser, the medium must, therefore, for a single plant to provide 78 g of the medium (the threshold value of radiation equal to 200 Wh) or 126 g (from a predefined threshold level of radiation energy Wh 400). In our case (the daily sum of solar radiation was 4kWh), the irrigation system would provide for plants from 10 (with a threshold of 400Wh) to 20 times (at 200Wh). The developed nutrient control nomogram refers to plants with a total leaf area of 1.4 m^2. If the total area of leaves is, for example, 0.7 m^2, then we reduce the single dose of medium by 50%.

The irrigation frequency control system based on the measurement of solar radiation intensity is commonly used in controlling the irrigation process of cultivated plants.

Closed plant irrigation system

As mentioned, when controlling the mass of the nutrient solution supplied, due to the salinity of the mineral wool, an increased dose of nutrient solution for the cultivated plants is applied from 10 to 30%. Suppose that in a greenhouse on the area of 0.5 ha tomatoes are grown, and during the growing season, the need for nutrient will be 600 kg/m^2. As a last resort, approximately 3000 tons of nutrient solution should be delivered annually to the greenhouse area under consideration. Suppose, moreover, that a transfer will be made in the amount of 25% of the irrigation dose and, for example, the concentration of nitrogen will be 240 mg /l of medium; then 180 kg of pure nitrogen would be discharged from the crop to the waste water. If we take into account the remaining micro- and macroelements, this is an ecological and economic problem. Hence, the idea of using a closed circulation medium, i.e., mineral wool leaking, should be supplied back to the cultivated plants (eg in the Netherlands since 2000 there is an obligatory compulsion to use a closed circulation of nutrient solution). Macroelements accumulated in several independent tanks and micronutrients are mixed in a tank to which pure water is added. Nitric acid is added to the tank to regulate the recommended reaction of the medium.

The closed circulation system of the nutrient solution is realized due to the fact that the medium flowing from the mineral wool through the right profiling of the cultivation gutter (minimum slope towards the collecting gutter is 1%) is collected in the collecting tank, and thus through the buffer tank is directed to the further circulation. The direct use of the return medium for fertigation of plants, however, has two main problems:

changed concentration of elements in the leaking medium relative to the recommended concentration in fresh medium, danger of electric cultivated plants by pathogens present in the medium.

Therefore, in order to be able to use the return medium, it should be disinfected and the recommended composition should be restored. Based on the test results, it can be concluded that the return medium is diluted with pure water in a 5: 1 ratio (ie five units of pure water per one unit of medium) and should be subjected to a disinfection process (Figure 15). The disinfection of the medium is usually carried out by passing it through a lamp that produces ultraviolet rays. The parameters of the disinfection process (radiation intensity, stream of flowing medium) depend on the contamination of the nutrient solution. Fig. 15 shows a schematic diagram of the installation with closed medium circulation.

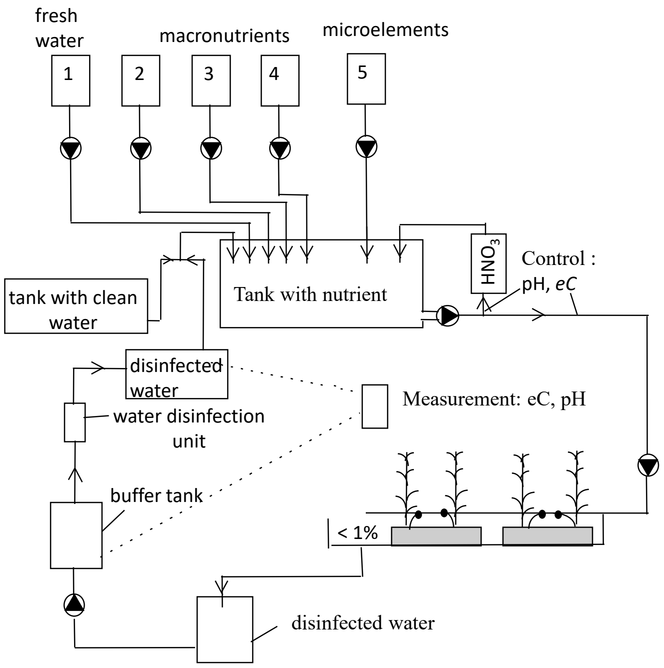

Fig. 15. Diagram of the closed medium circulation

During the process of fertigation (both open and closed loop medium) should follow the principles of which the most important are:

chemical analysis of water used as a diluent for the preparation of nutrient solution (content of micro and macro elements and determination of pH of water),

comprehensive calculations related to the amount of fertilizers delivered to prepare the recommended composition of the nutrient solution (including their content in clean water),

at least every 3 - 4 weeks monitoring: the composition of the medium in the inert medium (sampling at random from 10 different places in the greenhouse), the medium flowing out of the emitters and nutrient from the drainage.

the maximum differences between the recommended medium composition and the medium dispensed by the irrigation system should not exceed 20%.

In practice, the principle is applied that due to the so-called nutrient fatigue (development of phenolic compounds) on average every 2 weeks, complete emptying of the collecting container.

RESULTS AND DISCUSSION

Dosing concentrated medium to the irrigation system

The prepared medium is stored in tanks, and usually diluted in 100 times with water and dosed into the plant root system. Dilution of the nutrient solution is carried out using two solutions:

- proportional dispenser
- injector.

The proportional dispenser (fig. 16) is installed directly on the supply line, from where recirculating water reciprocates the main dosing piston (www.dozowniki.com.pl).

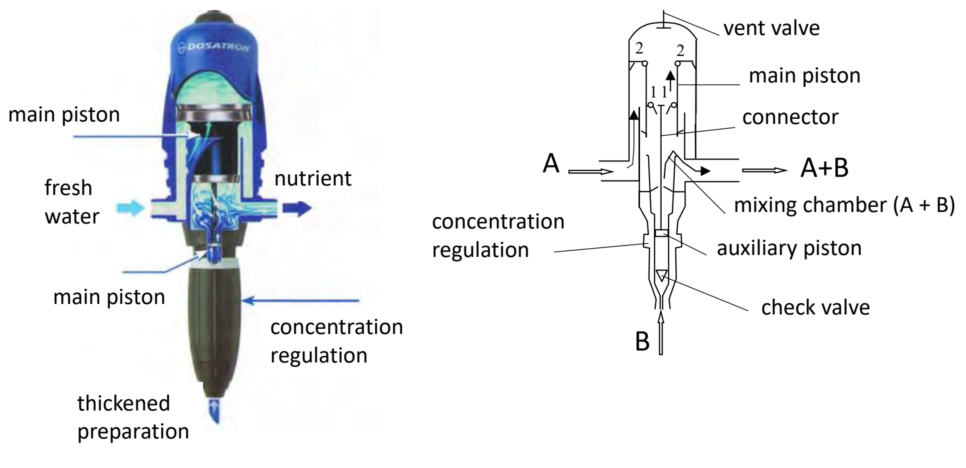

Fig. 16. Diagram of proportional dyspenser

The piston by a link connected to the auxiliary piston, which draws the prepared medium to the mixing chamber. The valves (1 and 2) installed in the dispenser and the non-return valve regulate the flow of clean water and medium into the mixing chamber, and the medium is supplied from the mixing chamber to the irrigation system. The concentration regulation (proportional to the amount of water flowing - scaled in percentage) is regulated by varying the active volume of the auxiliary piston supplying the medium to the stream of flowing clean water. Vent valve upon actuation of the dispenser, automatically removing the air.

The injector (Fig. 17) uses the phenomenon created in the Venturi orifice.

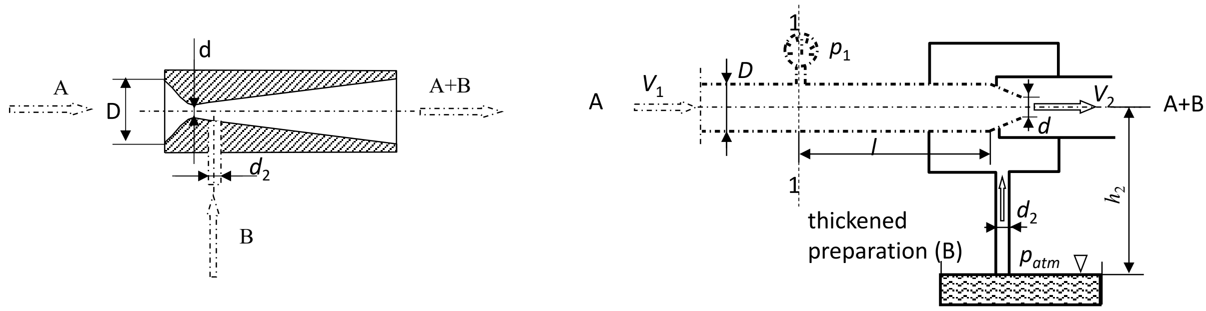

Fig. 17. Diagram of injector operation

In the place of fluid flow (gas, liquid) through a cross section with a much smaller diameter than the inlet diameter, a vacuum is created, whereby an independent fluid (B) is sucked in and mixed with the flowing fluid. The laws describing the flow of a real fluid indicate that the velocity square of the fluid in front of the Venturi orifice is proportional to the pressure difference before and after the Venturi orifice. The parameters influencing the change in fluid concentration are: the speed and pressure of the flowing fluid and the geometric suction height. Detailed calculations based on fluid mechanics [Orzechowski et.al 1997] showed that the input data accepted:V_1= 1m/s, l=2 m, p_1= 4kPa, D = 18 mm, d= 6mm, λ=0,03, d_2=10 mm, p_{atm}=100 kPa illustrated in table 6.

Table 6. Liquid calculation results when using a Venturi orifice

h, m	V_2, m/s	Q_2, l/min
0	6,9	32,5
0,5	4,62	21,7
2	2,18	10,27
3	1,23	5,8
3,81	0	0

As you can see, the amount at which the liquid is sucked depends on the amount of concentration (B); if the Venturi orifice is placed in the reservoir, then to the main liquid (in the case under consideration the flow of liquid flowing through the Venturi orifice is 15.3 l / min), the liquid stream (B) is delivered at 32.5 l / min. As soon as the height h reaches the critical height (h2), the liquid will not be sucked in (B).

CONCLUSSION

The paper discusses issues related to water management of plants grown in an inert substrate. Requirements regarding the quality of water used for irrigation of plants and requirements for water intended for drip irrigation are presented. On the basis of experimental results, transpiration of plants was presented, the method of estimating water infiltration and global water demand was discussed. Discussed is the construction of a closed media system with devices used for its disinfection and dosing of concentrated medium for the process of fertigation of plants.

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REFERENCES

Bakker J. C., Bot G. P. A., Challa H., Van de Braak N. J.: Greenhouse climate control -- An integrated approach : Edited by. Wageningen Pers, The Netherlands, 1995. 279 pp. ISBN 9074134173

Breś W., Golcz A., Komosa A., Kozik E., Tyksiński W. Żywienie roślin ogrodniczych. Wydawnictwo UP w Poznaniu, Poznań, 2009, pp. 191, ISBN 9788371605482

Czekalski M. Ogólna uprawa roślin ozdobnych. Wydawnictwo UP we Wrocławiu, Wrocław 2005, 242pp, ISBN 9788360574829

Kaniszewski S. Nawadnianie warzyw polowych. Wydawnictwo Plantpress, Kraków, 2005

Kloc- Szatniak A. Wpływ pH i stężenie wybranych metali ciężkich w glebie na ich zawartość w roślinach. Acta Agrophysica, 2004, 4(1), 177-183

Kowal A.L., Świderska-Bróż M. Oczyszczanie wody : podstawy teoretyczne i technologiczne, procesy i urządzenia. Wydawnictwo Naukowe PWN Warszawa, 2009, 802 pp. ISBN 9788301158712

Kurpaska S. Porównanie modeli opisujących transpirację pomidorów uprawianych w szklarni. Zeszyty Problemowe Postępów Nauk Rolniczych, Z. 461, 255- 265pp., 1998

Nakayama F.S., Bucks D.A. Trickle irrigation for Crop Production. Design, Operation and Management. Elsevier Science Publishers, Amsterdam, 1986.

Orzechowski Z., Prywer J., Zarzycki R. Mechanika płynów w inżynierii środowiska. Wydawnictwo WN-T, Warszawa, 1997.

PN-84/C-04635 Woda do nawadniania roślin na użytkach rolnych oraz do ich opryskiwania chemicznymi środkami ochrony roślin

Sławiński C., Sobczuk H., Walczak R.T. Hydrofizyczne charakterystyki podłozy ogrodniczych a dostępność wody dla roślin. Zeszyty Problemowe Postepów nauk Rolniczych, 429, 275-279, 1996

Zarzycki R. Wymiana ciepła i ruch masy w inżynierii środowiska. WN-T, Warszawa, 2005, 436 pp. ISBN 9788320436662

Zwart de H.F. Analyzing energy-saving options in greenhouse cultivation using simulation model. PhD, Wageningen University, 1996. 236 pp. ISBN 9054855339.

Internet webpage: www.dozowniki.com.pl

Designation of optimal location for the construction of an agricultural biogas plant using spatial information systems

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Abstract: The paper presents practical aspects related to the process of locating an agricultural biogas plant. Agricultural biogas plants producing "green energy" bring the so-called ecological effect that results from the reduction of emission of greenhouse gases to the atmosphere. Biogas plants make it possible to manage environmentally harmful waste products (waste and by-products), the utilization of which is difficult and expensive. And in the final stage of the process, a by-product is formed on the basis of post-fermentation substances, which can be used as an ecological natural fertilizer. The construction of a biogas plant gives the opportunity to cooperate with local producers of agricultural activities, in the field of supplying substrates and receiving the produced fertilizer in the form of digestate. Biogas production as well as the construction of a biogas plant is associated with certain hazards resulting from improperly connected installation or unwanted leakage. In the event of improper installation, leakage of the fermented substances may occur, which can have a very negative effect on surface and ground waters. Such hazard should therefore be taken into account in the process of locating such an installation. The article presents a case study of the location for the construction of an agricultural biogas plant using spatial information systems, including the risk of negative impact of the installation on the aquatic environment. Based on the conducted analysis, it appears that spatial information systems can be used to easily determine the location of the investment. The presented procedure for locating a biogas plant is of application nature and may be useful in practice.

Keywords: biogas plant, spatial information system, green energy.

INTRODUCTION

Limited resources of conventional energy resources, such as hard coal, oil or natural gas, force energy economies to use and search for alternative energy carriers, such as renewable energy that is environmentally friendly.

According to the "Poland's energy policy until 2030", adopted by the Council of Ministers on November 10, 2009, Poland must achieve at least a 15% share of energy from renewable sources in final gross energy consumption in 2020. The commitment to achieve the above objective results from Directive 2009/28 / EC referring to promotion of the use of energy from renewable sources (www.ieo.pl).

An opportunity for Poland in the implementation of 15% of the use of energy from renewable sources by 2020 is the use of energy generated in agricultural biogas plants. It is estimated that in 2012-2020 there will be a dynamic development in this sector (Tytko, 2013). According to the register of agricultural biogas producers from 06/04/2017, there are 85 agricultural biogas producers in Poland who use 112 biogas installations with a total installed capacity of approximately 101 MW_e (megawatt of electric power) (www.arr.gov.pl).

Agricultural biogas plants while producing "green energy" bring the so-called ecological effect which results from the reduction of emission of greenhouse gases to the atmosphere. Biogas plants make it possible to manage environmentally harmful waste products (excrement and by-products), the utilization of which is difficult and expensive. Reduces odors produced during the storage and utilization of slurry. Also in the final stage of the process, by-product on the base of digestate substances is created, this can be used as an ecological natural fertilizer (Podkówka, 2012).

An agricultural biogas plant, which has been properly designed, constructed and operated, is not a threat to the natural environment and is not burdensome for the local residents, pipes are tight and resistant to substances flowing through them, while the process itself is conducted in a hermetic manner - all that eliminates emission of gases to the atmosphere. A properly designed biogas plant should not create any onerous situation out of the operational area. And on the area of the plant, no unpleasant odors or excessive noise are felt. There is a probability of a failure, but the risk is similar like in case of other plants that deal with the processing of agricultural raw materials.

The construction of a biogas plant gives the opportunity to cooperate with local producers of agricultural goods, as well in the matter of substrates received as purchasing produced fertilizer in the form of digestate. It has a positive impact on the local community: an increase in revenues from the sale of intlet batch products, affects the protection of the environment and overlaps into the activities of renewable energy.

As a result of the construction of an agricultural biogas plant, new jobs position will be created, as well during the implementation of the investment as at the stage of its operation later on, for example opportunities for drivers collecting receiving raw materials from farmers, engineers, automation specialists, administrative workers, laboratory workers, technicians, manual workers, etc. (www.gmina.bio -gazownie.edu.pl)

Biogas production and the construction of a biogas plant are associated with certain risks resulting from improper connection of the installation, or its leaks. Improper installation and untight connections may cause leaks of the substance, resulting further in complex chemical compounds formation and excessive noise. The complex chemical compounds are formed as a result of improper biogas desulphurization and resemble the smell of cattle farm where the animals are fed with silage (www.gmina.bio-gazownie.edu.pl).

Storage of substrates in open tanks or lagoons causes gas emissions. There is also a risk of contamination of the environment, mainly soil and water as a result of improper use of digestate. A certain inconvenience to the local community is the increased traffic of vehicles that transport substrates (www.gmina.bio-gazownie.edu.pl).

The biggest difficulty in building a biogas plant may be a community disagreement, which is cause by incorrect connections between the local enviroment and the biogas plant side. Communities often protests against the implementation of investments, and if it is successfully implemented, there are long-lasting conflicts that bring losses to both parties (www.gmina.bio-gazownie.edu.pl).

The purpose of the conducted research was to find the optimal location for the construction of agricultural biogas for a farm located in the district called 'Powiat Kaizmierski' in Poland, with use of spatial information systems. In order to determine the eventual biogas plant locations, the area of the farm was taken into account, so that the obtained results would be within the range of fields belonging to the examined farm.

The scope of work included:

Obtaining data on the infrastructure of 'Powiat Kaizmierski' from the Marshal's Office of the Świętokrzyskie Voivodship (Urzędu Marszałkowskiego Województwa Świętokrzyskiego) in Kielce,

Performing in the AutoCAD system the thematic layers of the areas missing from the map and the location of the farm areas, further saving the completed fragments to .dwx format files,

Establishing optimal and exclusion criteria,

Analysis in ArcMap 10.2.1 based on the adopted thematic layers,

Designating and analyzing areas that meet all criteria,

Indication of the best area, based on investor preferences but also taking into account the recipient of the products

MATERIAL AND METHODS

Agricultural farms, which, as a result of its activity produce waste from crop and livestock production, can use them in installation used to producing biogas, which are called "agrobiogas plant" or "agricultural biogas plant". The biogas received from those system, also called "agricultural biogas" is used in cogeneration, to produce heat and electricity (Podkówka, 2012).

An agricultural biogas plant is an installation that is used to produce biogas from available plant biomass, organic waste (e.g. from the food industry), animal excrements, post-slaughter waste or biological sewage sludge (www.portalrolniczy.pl). This installation is included in renewable energy sources, because the organic substances necessary for the production of biogas come from renewable sources.

Biogas arising as a result of the biogas plant operation, pursuant to the Act on Renewable Energy Sources of 20 February 2015 (Ustawa o Odnawialnych Źródłach Energii z dnia 20 lutego 2015 roku), is defined as gas obtained in the process of methane fermentation of agricultural raw materials, agricultural byproducts, liquid or solid animal waste, by-products, waste or residues from processing of products of agricultural origin or forest biomass, or plant biomass collected from areas other than those recorded as agricultural or forestry, excluding biogas obtained from raw materials originating from sewage treatment plants and landfills.

The impact of agricultural biogas plants on the environment

Every major investment, including an agricultural biogas plant has a significant impact on the natural environment. Work of the installation brings many benefits, but also carries some risks. In this chapter, some of the most important aspects regarding the impact of biogas plants on the environment will be presented.

An agricultural biogas plant producing electricity and heat reduces emissions of, for example, greenhouse gases into the air. The operation of the installation does not generate technological wastewater and as a result of the process, gas and digestate are produced. Both of these products are used, for example, gas for energy production and post-fermentation substance as a valuable organic fertilizer (Report on the environmental impact of agricultural biogas plant in Topola, 2011).

Biogas plant construction brings many ecological benefits resulting from:

limiting the degradation of the natural environment by reducing the extraction of fossil fuels,

reduction of emissions of harmful substances into the atmosphere, including greenhouse gases. Reducing emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), which is responsible for the greenhouse effect, heavy metals and organic pollutants,

management of waste, manure and other by-products that are harmful to the environment, where other methods of their disposal are difficult and expensive,

reduction of odors that arise during the storage and use of slurry as fertilizer,

organic fertilizer production based on digestate, which can be used for growing crops (Podkówka, 2012).

Podkówka reports that when producing 1 MW of electricity in a conventional coal-fired CHP plant, significant amounts of gases and dusts enter the atmosphere: 937 kg of CO_2, 7,8 of kg SO_2, 3,2 kg of NO_x, 0,2 kg of CO and dust. However, when producing 1 MW of electricity from biogas (with 55% CH_4, 38% efficiency of the aggregate), about 562 kg of CO_2, 0,49 kg of NO_x, 0,015 kg of SO_2 are released into the atmosphere and no dust are present (Podkówka, 2012).

The fertilizer based on post-fermentation substance becomes an excellent solution for growing plants, because it contains ingredients easily absorbed by plants. The use of slurry and manure for anaerobic digestion prevents the entry of biogenic compounds into surface and groundwater, which reduces the risk of water eutrophication. Another advantage of using slurry is the continuity of its supply, because animal excrement are used in the biogas plant on a regular basis. The slurry storage period is about 7 days, and as a result of this, smaller amounts of methane goes into the atmosphere than when storing natural fertilizers in a conventional way.

Additionally, post-fermentation substance, unlike slurry, does not acidify the soil, and after application in the fields eliminates the risk of weeds, because during the fermentation the seeds die and are unable to sprout. Fermentation of slurry with other substances results in reducing odors by approx. 80% compared to raw slurry. The legal conditions regarding the use of digestate are similar to the conditions of using slurry, all that makes digestate a safe and more environmentally friendly substance (www.gmina.bio-gazownie.edu.pl).

The biogas plant also creates the possibility of developing and utilizing waste from non-agricultural areas, e.g. from the sugar and meat industry, etc., which would otherwise be required to be disposed of.

The installation, which has been correctly designed, built and operated, does not pose a threat to the environment outside the plant. Of course, there are failures and errors that are similar to hazards in plants processing agricultural products; however, in a properly operated biogas plant there is a low risk of emission of harmful compounds into the atmosphere. There is no excessive noise or odors on the site itself.

Rising the construction of an agricultural biogas plant activates the local community to cooperate, consisting in delivering inlet products or receiving post-fermentation substance.

Creates new jobs, for example during the construction of the installation itself, but also at the stage of its operation. It also has a positive impact on revenues from the sale of raw materials and environmental protection (www.gmina.bio-gazownie.edu.pl).

In addition to environmental benefits, raising the construction of a biogas plant brings economic benefits:

- limits the use of conventional fossil fuels,
- increases the energy security of the country,
- increases the domestic share of energy production from renewable sources and fulfills Poland's obligations regarding the reduction of harmful substances entering the atmosphere,
- biogas production reduces the costs of energy resources,
- use of biomass as energy potential (Report on the environmental impact of agricultural biogas plant in Topola, 2011).

The work of an agricultural biogas plant creates certain environmental risks. The process of methane fermentation is multi-stage, where each of these stages requires specially designed buildings, machines and devices. During operation, factors that adversely affect the environment arise at each stage (Podkówka, 2012).

It is very important to take special care during the construction and assembly works and pay a high attention to the quality of the work carried out (quality of connections made, tightness of tanks, etc.), which in the future may cause problems in operation. Also, during the operation, the correct 'culture' of running the fermentation process is extremely important, i.e. ensuring the cleanliness of the facilities, conducting regular inspections, maintenance, etc.

If the building standards are not adhered to, or downplayed at the assembly stage, the tanks may become un-tight and, as a consequence, an uncontrolled leak may appear, which in combination with the air will emits an unpleasant odor.

The first and the biggest problem could be appearing odors. Complex chemical compounds form due to improper biogas desulphurisation or errors made during the fermentation process, e.g. leakage of tanks or fermentation chambers. However, if the storages of substrates are properly secured, the risk of the release of odorous compounds is minimal. Although, it should be noted that it is not possible to eliminate them completely.

Even at the area of the properly designed biogas plant the smell is almost identical to that on larger cattle farms where animals are fed with silage. The largest epicenter of odors is located near the mixing chamber of substrates or slurry tank. The smell is barely noticeable at a dozen or so meters from the biogas plant.

Proper storage of substrates consists in providing closed or covered tanks with airtight membrane, and also by placing them on a suitably contoured and impermeable base, which has a sewage system.

Another source of unpleasant odors is the reservoir for post-fermentation substance. Most often when it is an open reservoir (lagoon), without a cover. Such tanks are most often used away from human settlements. And the smell of the fermented substance itself resembles the smell of moist soil or silage (www.gmina.bio-gazownie.edu.pl).

Another nuisance can be the excessive noise caused by the heavy traffic of vehicles transporting substrates. An important factor for the dispersed vehicle traffic is the distance of biogas plants from the substrate tanks. The number of transporters depends on the daily demand for fresh mass. That's why the right location is very important.

Next source of noise is the operation of machines and devices installed and necessary in technological process. There is a notable amount of them on different stages: separation of waste, their hygienization, fragmentation, mixing, transport to and from the mixing chamber, fermentation chamber. There are also some supporting devices. The number of all machinery applied depends on how post-fermentation wastes are managed (Podkówka, 2012). The largest source of noise is the cogeneration unit, which generates electricity used for ventilation system and fumes discharge (www.gmina.bio-gazownie.edu.pl).

The greatest threat to the environment is contamination of soils and waters, by leaks from un-tight chambers or poor management of post-fermentation substance. This mostly means an excessive fertilization with digestate, which may cause plants damages, infiltration of biogenic substances into ground and water (www.gmina.bio-gazownie.edu.pl).

There is a minimal risk of biogas explosion. Only under certain conditions, methane has explosive properties, including an appropriate concentration of methane with air. To initiate the combustion process, the following conditions must be met: a combustible substance, an ignition energy and oxygen which will sustain the combustion process. In order to eliminate the risks associated with the explosion, the entire installation should be equipped with a security system and devices that will ensure safe operation (www.gmina.bio-gazownie.edu.pl).

Due to the protests of the local community, it may turn out that the construction of an agricultural biogas plant will be postponed or even not implemented. However, if a biogas plant is built despite the opposition of community, it can cause a long-term conflict which should be taken into consideration (www.gmina.bio-gazownie.edu.pl).

Functioning of a biogas plant

The general principle of operation of an agricultural biogas plant is shown in Figure 2. The individual digits indicate substrates, reservoirs, and the possibilities of using biogas. In the following part, the individual stages of the biogas plant operation will be briefly described.

The proper functioning of an agricultural biogas plant is crucial for investors, as it prevents unforeseen failures, interruptions in biogas production or unforeseen expenses.

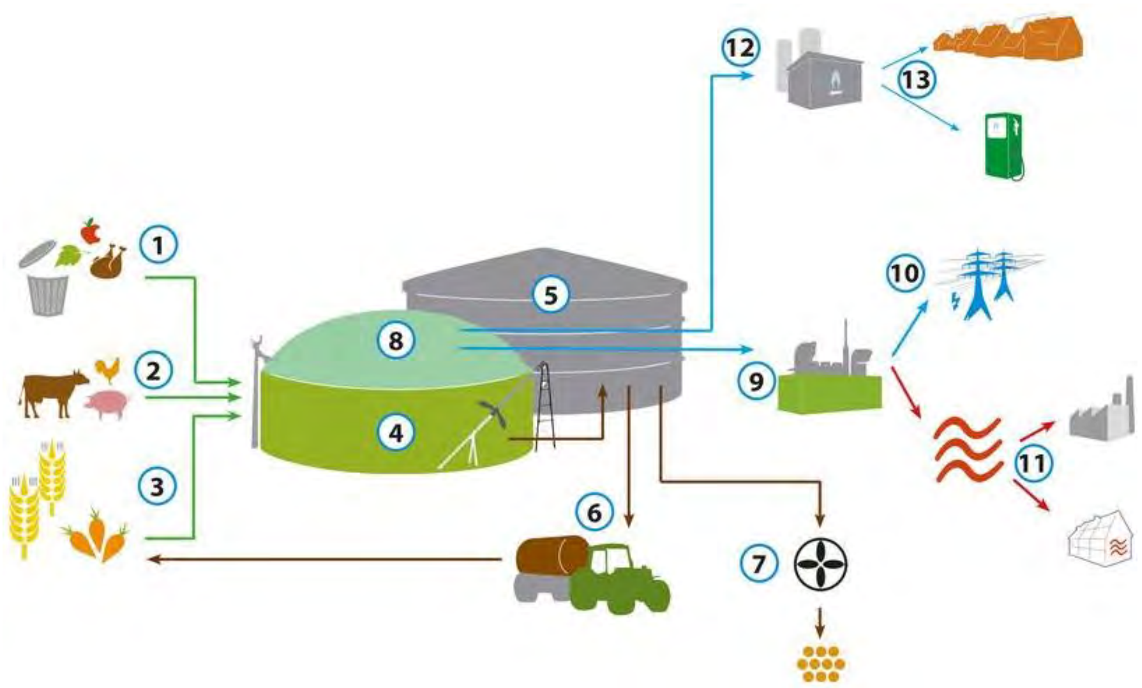


Figure 1. Functioning of a biogas plant

Source: Głaszczka, 2010

In biogas plants, as per the scheme shown in Figure 1, the main input substance is slurry (a substance consisting of faeces, urine and water) bovine or porcine (2). Another most commonly used substance is waste of plant origin or biomass from purpose plantations, e.g. corn, beetroots, grass (3), which can also be used as food for animals in order to obtain more slurry as well as microorganisms in the fermentation chamber. The last group, less frequently used are non-agricultural waste (1), e.g. urban waste (organic fraction, sewage sludge, food leftovers), industrial waste (sugar, meat, dairy, etc.).

The individual substrates differ among themselves with the rate of decomposition by microorganisms, dry matter content, organic solid content, or methane production capacity. Waste from animal production such as slurry, manure and chicken manure is characterized by very good composition. Waste of plant origin is less useful due to the high content of lignin, which slows down the fermentation process (Głaszczka, 2012).

At the design stage, it is very important to determine the number of substrates and their share in the whole inlet batch. It is important to ensure the required amount of material throughout the whole year of operation of the biogas plant. The lack of supply of a given substrate may cause that process will stop or the microorganisms will die. Raw materials should be stored in properly prepared silos, tanks or other warehouses. These tanks must contain a certain amount of material, must be tight, so there is no leak of any undesirable substance and also be placed close to devices mixing the batch.

Each biogas plant should have a substrate transport system or digester feed (4) - figure 1. In the fermentation chamber, if the required temperature, and the absence of light and oxygen are provided, all the phases of the process, biogas generation occur.

In the technological process, four stages of biogas production can be distinguished:

1. **Hydrolysis -** in which decomposes the insoluble organic compounds contained in the feed occur, using bacteria, mainly optional and obligatory anaerobic bacteria.
2. **Acidogenesis (acidification) -** the material dispersed in the hydrolysis stage is transported inside the cells of acidogenic bacteria. As a result, short chain organic acids with low molecular weight are formed.
3. **Acetogenesis -** formation of acetic acid, carbon dioxide and hydrogen with the help of bacteria processing volatile fatty acids and ethanol.

4. **Methanogenesis -** methane production via methanogenic bacteria: autotrophic and heterotrophic (Podkówka, 2012; Jędrczak, 2007).

There are one-, two- or multi-stage installations, depending on the number of tanks used (fermentation chambers). In the case when all the phases of the process occur in one chamber, we deal with a one-stage process, i.e. the lack of physically separated phases of the process (Podkówka, 2012). The number of tanks used affects the size of the investment, i.e. its location and economic aspects.

Fermentation chambers, also called fermenters, should be well thermally insulated to ensure a constant temperature inside the tank, and also for economic reasons. Each tank should have a mixing system, a heating installation and a system for removing the digested substrate from the tank. There are fermenters that have an additional function and are used as a biogas tank (8), those tanks have to be covered with a flexible and gas-tight covers. These tanks are built in collective concrete technology or as steel tanks (Podkówka, 2012).

In order to ensure the proper fermentation process, the temperature inside the tank must be constant. Because, any change in temperature can cause the process to stop. There are three temperature ranges: psychrophilic (4-30ºC), mesophilic (31-40ºC), thermophilic (41-60ºC) (Podkówka, 2012).

Another important factor is the level of mixing the batch. Continuous mixing of substrates brings many positive effects, ensures equal distribution of nutrients and heat in the entire mass of the feed, provides better connection of fresh substrate with fermented, prevents the formation of surface foam and sediments, helps to release the biogas from the substrate (Podkówka, 2012).

There are many ways to mix substrates, the simplest of which is the constant adding of fresh substrate. Mechanical, pneumatic and hydraulic pumps are changeably mounted (Podkówka, 2012).

Fermentation waste produced in the fermentation process contains biomass containing methane bacteria, unfermented organic compounds and other mineral components. It is removed from the chamber by a drain through the overflow or pulled out by a pump. Then it is transported to the post-fermentation waste tank, so-called lagoon (5), where it is cooled and stored until export (Podkówka, 2012).

The post-fermentation substance is most often used for fertilizing purposes (6) to fertilize crop fields as well as grassland. Compared to conventional fertilizers, for example slurry, digestate has many advantages:

- a lower level of odor substances compared to slurry. Wilkie reports that the smell level is reduced by 97%, while Kowalczyk - Juśko says that it is around 80% (Wilkie, 2000, Kowalczyk - Juśko, 2005),
- easier absorption of ingredients by plants,
- elimination of pathogens
- reducing the risk of contamination surface and ground waters with nitrogen and phosphorus compounds as well as with germs found in animal excrement,
- reduces the amount of weed seeds in the fertilizer and by that reduces the amount of products used for plant protection,
- reducing the probability of water eutrophication (Podkówka, 2012).

An important disadvantage of post-fermentation substance is the water content, ranging from 90 to 94%, the upper limit results from the use of the slurry itself for the production of biogas. The high water content influences the transport costs of the digestate from the lagoon to the cultivated field (Podkówka, 2012).

It is possible to reduce the water content by drying, centrifuging or separation. As a result, two fractions are obtained:

- liquid fraction: with a dry matter content 2-2.5%, which contains about 20% phosphorus and 80% nitrogen. It can be used to prepare the substrate before putting into the fermentation chamber.
- solid fraction: containing approx. 80-85% of phosphorus and 20-25% of nitrogen. This fraction can be used as a fertilizer for fertilization or as an addition to compost. In

case of further compaction, a loose material is obtained, which can be used, e.g. in gardening (Dennis, 2001, Podkówka, 2012).

Factors influencing the location of an agricultural biogas plant

The first stage in determining the location for the construction of an agricultural biogas plant is to determine the type of feed, its quantity, quality and availability of substrates. The most commonly used raw material is slurry, the long-distance transport of which is unprofitable, therefore it is recommended to build a biogas plant in the neighborhood of the farm, from which the slurry would be provided by a pipe system.

When planning and selecting a location, the below should consider:

- buildings and infrastructure existing on a given area,
- distance from animal farms from which liquid manure or other waste substrates would be collected,
- distance between biogas plant and crop fields and grassland from which the substrates of agricultural origin will be provided,
- the possibility of using and selling electricity and heat,
- the possibility of managing the produced digestate,
- requirements of the local development plan (Podkówka, 2012).

The development of renewable energy in Poland is regulated by the Energy Law Act (ustawa "Prawo energetyczne") of 10 April 1997 and the relevant implementing regulations. The Act suggests the inclusion of renewable energy sources in land use plans and in the plans to supply the district with electricity, heat and gas. In addition, it indicates that expenditures incurred on the development of energy from renewable sources can be included in energy prices and also make these prices more realistic (Romaniuk et al., 2008).

In accordance with the amendment of the Act of 8 January 2010 amending the Energy Law Act and some other acts (Dz. U. z 2010 r. Nr 21, poz. 104), there were changes that came live on January 1, 2011:

According to art. 9o:

The confirmation of the production and introduction of agricultural biogas into the gas distribution network is the certificate of origin, called the "biogas origin certificate". This certificate contains:

- the name and address of the energy company,
- location and rated installation performance,
- data on the amount of agricultural biogas produced covered by the biogas certificate of origin,
- data on the equivalent amount of electricity generated in RES (calculated in accordance with the regulations issued in line with the article 9a ust..11),
- the period in which agricultural biogas was produced.
- The biogas certificate of origin is issued by the President of the Energy Regulatory Office (Prezes Urzędu Regulacji Energetyki), based on the application of an energy company (involved in the production of biogas) (Dz. U. z 2012, poz. 1059 j.t.).

According to art. 9p section 1

Economic activity in the field of agricultural biogas production or generation of electricity from agricultural biogas is an activity regulated within the Act of 2 July 2004 due to the freedom of economic activity (Dz. U. z 2007 r. Nr 155, poz. 1095, z późn. zm.), hereinafter referred to as "the Act on the freedom of economic activity", and requires to be entered into the register of energy enterprises involved in the production of agricultural biogas.

The governing body of the register is the President of the Agricultural Market Agency (Dz. U. z 2012, poz. 1059 j.t.).

Pursuant to the law, the renewable energy producers are guaranteed the receipt and sale of the energy they produce. Other important provisions are:

• Act of 10 July 2007 on fertilizers and fertilization, which regulates the use of animal manure as fertilizer,

• Acts and regulations regarding permissible limits of emission of gases to the atmosphere and emission fees, including: integrated permits, technical supervision regulations and regulations regarding the use of waste in biogas production.

In the case of installations that may significantly affect the environment, it is required to prepare report on the company's environmental impact. In which the environmental impact assessment will be issued, carried out with the participation of the community (Romaniuk and others. 2008).

There are two basic legal documents that contain requirements for the construction of agricultural biogas plants. The first document is the regulation of the Minister of Agriculture and Food Economy of October 7, 1997 on technical conditions that should be met by agricultural buildings and their location. The second document is the Act of 7 July 1994 - "Construction Law" ("Prawo budowlane").

According to paragraph 3 of the ordinance of 7 October 1997, agricultural buildings are buildings for the purposes of agriculture and storage of agricultural products, in particular such as: tanks for liquid animal manure, manure storage panels, silage silos, grain and feed silos, chambers fermentation and biogas tanks (Dz.U. 1997 nr 132, poz. 877, with later amendeds).

All plans for the development of the plot and the location of agricultural buildings should be in accordance with the decision on land development and development conditions (Głaszczka, 2010).

Minimum distances are shown in the tables below in accordance with applicable law.

Table 1. Minimum distances from closed and open (with a capacity of 200 m3) tanks and panels for liquid animal excrement (measured from the cover and ventilation outlets)

Lp.	Specification	Minimum distances	
		From closed tanks	From open tanks
1	From the window and door openings, rooms intended for the stay of people on neighboring plots	15 m	30 m
2	From warehouses of foodstuffs, as well as construction facilities for agri-food processing	15 m	50 m
3	From the border of the neighboring plot	4 m	4 m
4	From general warehouse buildings	5 m	10 m
5	From silos for grain and feed	5 m	5 m
6	From silage silos	5 m	10 m

Source: Dz.U. 1997 nr 132, poz. 877 with later amendeds

Biogas tanks or fermentation chambers where biogas is produced should be protected by a fence of min. 1.8 m at a distance of at least 0.58 m from the tank's shell. In addition, these tanks should be designed and constructed to minimize the risk of:

- a fire or explosion,
- freezing of biogas inlet and outlet pipes,
- gas condensation,
- corrosion caused by substances contained in biogas (in particular by hydrogen sulphide and ammonia).

Table 2. Distance of fermentation chambers and biogas tanks with a capacity of up to 100 m^3

Lp.	Specification	Minimum distances
1	From the window and door openings, rooms intended for the stay of people and livestock buildings	15 m
2	From other buildings	8 m
3	From the border of the neighboring plot	5 m

4	From the composition of coal	15 m
5	From other fermentation chambers and biogas tanks	15 m
6	From silos for grain and fodder with a capacity of more than 100 Mg	15 m
7	From other building object	5 m

Source: Dz.U. 1997 nr 132, poz. 877 with later amendeds

Table 3. The distance of silos to grain and fodder with a capacity greater than 100 Mg

Lp.	Specification	Minimum distances
1	From the window and door openings, rooms intended for the stay of people and livestock buildings	15 m
2	From other buildings	8 m
3	From biogas plants	15 m
4	From the composition of coal	15 m
5	From the border of the neighboring plot	5 m

Source: Dz.U. 1997 nr 132, poz. 877 with later amendeds

In the case of tanks and digesters with a capacity greater than 100 m3, they should be located only on plots intended for biogas plants. And the minimum distances from other objects should be at least twice as large as in table 3.

Table 4. Required cross-section of ventilation openings in rooms with biogas tanks

Lp.	Tank capacity	Sectional area
1	Do 50 m^3	400 cm^3
2	Od 50 m^3 do 100 m^3	700 cm^3
3	Od 100 m^3 do 200 m^3	1000 cm^3
4	Powyżej 200 m^3	1500 cm^3

Source: Dz.U. 1997 nr 132, poz. 877 with later amendeds

Due to the possibility of a fire or explosion of biogas, agricultural buildings such as a digester or biogas tank should have a safety zone as a kind of security. Minimum distances from tank walls are shown in Table 5. The safety zone should be fenced (fencing at least 1.5 m high) and marked with an appropriate warning sign about the possibility of explosion.

Table 5 .The size of safety zones from biogas plants

Lp.	Tank capacity	Safety zone
1	Do 50 m^3	3 m
2	Od 50 m^3 do 100 m^3	5 m
3	Od 100 m^3	8 m

Source: Dz.U. 1997 nr 132, poz. 877 with later amendeds

In addition, the regulation can find the dimensions of explosion hazard zones for biogas plants (Table 6).

Table 6. Dimensions of hazardous areas

Lp.	Explosive areas	Safety zone	Distance / description
1	Digester chambers	Z0	The whole chamber

2	Around the manholes (not providing gas tightness)	Z1	3 m
3	Around the connections of wheeled, threaded and compressed gas pipelines, valve seats and glands (at pressure over 2 bar)	Z2	0,5 m
4	Control and measuring apparatus, indoor filters	Z2	The whole room
5	Filters in rooms equipped with explorators and mechanical ventilation (emergency)	-	It is not designated
6	Around safety valves	Z1	5 m
7	Around venting and blowing ducts	Z1	With a radius of 5 m (with 1 m down, 10 m up)
8	Room for biogas compressors	Z1	The whole room
9	The premises of biogas compressors, which are equipped with explorators and emergency vaporization	Z1	0.5 m (around possible sources of excretion)

Source: Dz.U. 1997 nr 132, poz. 877 with later amendeds

In Fig. 2, a plan of agricultural buildings (biogas plant) comply with the regulation is presented.

Source: Romulak, Biskupska, 2014

Figure 2. An overview of the distribution of biogas plants and tanks with a capacity of up to 100 m^3 from other structures

In Chapter 6, § 31 of the Ordinance of the Minister of Infrastructure of 12 April 2002 on technical conditions to be met by buildings and their location (Dz.U.2002 r. nr 75, poz.690), minimum distance requirements have been defined from a well that supplies drinking water (table 7).

Table 7. Minimum distances from the well

Lp.	Specification	The minimum distance
1	From the border of the plot	5 m
2	From the axis of the roadside ditch	7,5 m
3	From livestock buildings (silos, tanks for collecting livestock manure, compost or other sealed equipment)	15 m
4	From the individual sewerage pipe	30 m
5	From unprotected catwalks for farm animals	70 m

Source: Dz.U.2002 r. nr 75, poz.690

When choosing a plot for the construction of an agricultural biogas plant, the following distances should also be taken into consideration:

- from paved road: 70 - 200 m,
- from surface and groundwater - 50 m,
- from connection to overhead power network - 300 m,
- access to external media, including water, sewage, etc. - 500 m,
- from the recipient of thermal energy: 2000 - 3000 m,
- from the electricity recipient: 500 - 1000 m,
- from agri-food factory: up to 50,000 m.

Spatial analysis using GIS

There are many different definitions of spatial information systems in Poland, and there is no, one general definition. This is probably due to the short period of system operation on the Polish market and the lack of good translations to Polish.

The definition of a spatial information system is understood as a system that acquires, processes and makes available data that contains spatial information and accompanying descriptive information about objects highlighted in space (Gaździcki, 1990).

Depending on the accuracy and detail of data stored in spatial information systems, two subsystems are extracted (Fig. 4):

- Land Information System - cooperates with primary information (according to direct field measurements or aerial photographs, based on large-scale maps (scale 1: 5000 or more),
- Geographical Information Systems (GIS) - cooperates with secondary (processed) information based on small- and medium-scale maps (scale 1:10 000 and larger).

The terminology of spatial information management is used in a general sense, which includes the use of computer systems for creating maps and processing of spatial information. GIS belongs to the group of computer systems dealing with spatial information management.

GIS consists of five interrelated elements, the absence of any of them excludes the smooth functioning of the entire system, due to the concept the elements are: computer hardware, software, data, people and tasks (methods) (Kwiecień, 2004).

The analysis process is aimed at finding hidden information in the data set and usually takes place in two stages. First, choose the data and then perform the appropriate mathematical activities. The analysis concerns attributes of the object and their geometrical features.

The most commonly used operations in spatial analysis include:

- arithmetic - these operations are used to determine e.g. length, area, volume etc. and to process attributes. Geographic information systems use the following operators:
    - (+) adding,
    - (-) subtraction,
    - (·) multiplication,
    - (/) sharing,
    - (^) exponentiation,
    - other
- logical - logical operators are used in the relationship between attributes, often used in
  a certain range:
    - (>) bigger than,
    - (<) smaller than,
    - (> =) greater or equal,
    - (<=) less or equal,
- static
- geometric,

The most useful operations in spatial analysis, performed on two or more thematic maps is Boolean algebra. As a result, from a given set of attributes we can receive a part which is interesting for us (Kwiecień, 2004).

The research was conducted on a farm, located in 'Powiat Kazimierski' in 'Województwo Świętokrzyskie'. The farm's headquarters are located in the village 'Donosy', while the farm's production facilities and machines are located in the village 'Plechówka' (Figure 3).

Source: www.google.pl

Figure 3. Location of the farm

Due to the terrain and the very large fragmentation of agricultural land, the farm in 2017 has about 476 plots with a total area of about 350 ha. The average area of individual plots is 0.74 ha, while the largest area is about 4.5 ha and the smallest area is about 0.03 ha. In order to improve the functioning of the farm, the owner strives to connect adjacent plots in order to obtain one larger piece.

As mentioned above, the farm has about 350 ha, of which about 70 ha of arable land belongs to the owner, while the remaining part is used under a lease contract. In addition, the farm has about 10 hectares of meadows that are not used for production purposes. All outbuildings are located approx. 5 km from the owner's house, while the farthest areas are located at a distance of approx. 15 km from the farm's headquarters.

At present, the farm is focused on plant production. The following crops are grown: wheat, rape, maize and sugar beets. Figure 7 shows the share of individual crops in 2017. The largest share of crops is about 135 ha of wheat, followed by rape and sugar beet about 70 ha, while maize is approx. 60 ha of crops. One of the ideas for the development of the farm is the construction of a multi-stables cowshed for beef cattle. From the initial estimates, the number of animals would amount to approx. 60 LU (livestock unit).

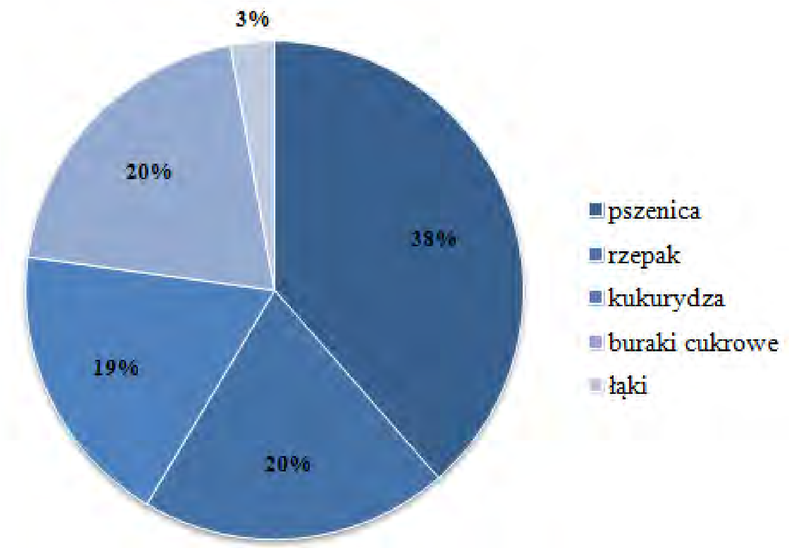


Figure 4. The crop structure of the surveyed holding for 2017 (wheat, rape, maize, sugar beet, meadows)

In order to limit the area on which a biogas plant could be located, data obtained from the farm was used. They concerned locations of plots belonging to the owner and leased plots. In Figure 5, their distribution is shown in light green.

The area for which research has been carried out includes the following towns and villages: Stojanowice, Chruszczyna Wielka, Chruszczyna Mała, Cło, Donosy, Gabułtów, Hołdowiec, Jakuszowice, Kazimierza Wielka, Kazimierza Mała, Odonów, Plechów, Plechowka, Podolany, Stradlice, Wojciechów, and Zagórzyce. .

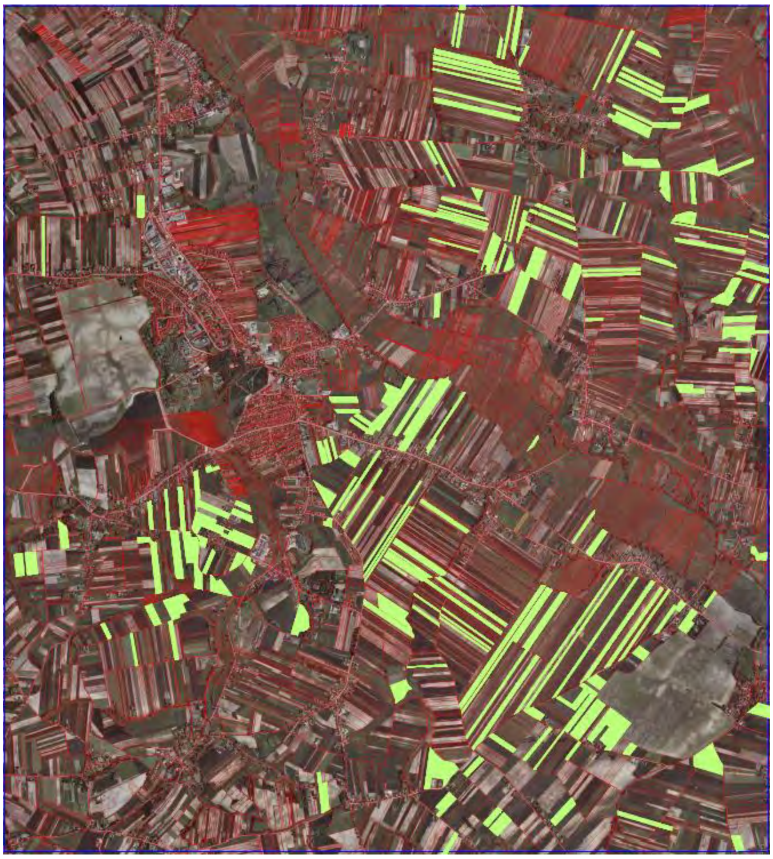
The study did not take into consideration the plots located the farthest from the farm's headquarters. Those areas are located in Dobiesławice, Mikołajów, Wymysłów, and some parts in Zagórzyce, Zięblice, Krzczonów and Topola, with a total area of approximately 62 ha.

Table 8. Division of farmland

Lp.	District	Village	Number of plots	Surface
1	Bejsce	Dobiesławice	1	2,11
2		Stojanowice	4	5,52
3	Czarnocin	Mikołajów	3	2,62
4		Stropieszyn	1	1,08
5		Broniszów	4	3,43
6	Kazimierza Wielka	Chruszczyna Mała	1	0,33
7		Chruszczyna Wielka	15	8,13
8		Cło	3	0,51
9		Cudzynowice	2	1
10		Donosy	34	24,15
11		Gabułtów	53	37,58
12		Gorzków	1	1,47
13		Hołdowiec	5	2,41
14		Jakuszowice	26	10,05
15		Kazimierza Wielka	22	9,35
16		Kazimierza Mała	21	14,97
17		Odonów	19	12,36
18		Paśmiechy	1	1,12
19		Plechów	6	5,12
20		Plechówka	9	10,01
21		Podolany	12	16,19
22		Stojanowice	1	1,97
23		Stradlice	60	53
24		Wojciechów	77	48,49
25		Wymysłów	28	19,5
26		Zagorzyce	38	27,83
27		Zięblice	5	4,1
28	Opatowiec	Krzczonów	12	17,56
29		Topola	12	8,93
		Suma	476	350,89

Source: own study

The area shown in Figure 5 has an area equal to approximately 53.4 km2 (5341 ha). The whole area infrastructure will be examined, i.e. the distribution of farm buildings, roads, electricity grids, lakes, rivers, forests and green areas (trees, shrubs, borders).



Source: Own study

Figure 5. The distribution of agricultural parcels in the examined farm at the period of research

In order to determine the location for the construction of an agricultural biogas plant, in the 'Powiat Kazimierski', the ArcMap 10.2.1 computer program was used. All research and analyzes were carried out at the University of Agriculture in Krakow, at the Institute of Agricultural Engineering and Computer Science.

The methodology for selecting the location for the construction of a biogas plant has been developed to include standards related to the location of agricultural biogas plants. These rules result directly from the Regulation of the Minister of Agriculture and Food Economy of October 7, 1997 on technical conditions to be met by agricultural buildings and their location as well as the Act of 7 July 1994.

They concern the minimum distance of all installations and buildings necessary for the functioning of a biogas plant:

• from other residential and useful buildings,
• from public roads (provincial and national),
• from the power transmission grid,
• from stagnant and flowing waters,
• from forests,
• from the well.

The process of determining the optimal location requires a comprehensive assessment, as well as the identification of areas which may be taken into consideration while thinking of the installation of an agricultural biogas plant. Due to the complexity of the structure of the areas, some analytical difficulty arises, because these areas must meet formal and legal requirements, they must minimize economic, technical, social and environmental costs (Wota, Woźniak, 2008).

Prior to the start of the research, data according areas locations, plots sizes and distributions were obtained. Then, the following steps were taken to create a map with selected plots belonging to the farm:

Using the MapoTeo_v3.0.0.4 program from the website www.geoportal.gov.pl a cadastral map of the 'Powiat Kaimierski' was downloaded in scale 1: 1000 in * .jpg format (Figure 6).

Source: www.geoportal.gov.pl

Figure 6. Cadastral map of the studied area

In order to make a vector map of the farm land layout, the downloaded cadastral map was "added" to the AutoCAD program.

The criteria determined were based on the basis of two documents. The first is the Regulation of the Minister of Agriculture and Food Economy of October 7, 1997 on the technical conditions that should be met by agricultural buildings and their location. The second document is the Act of July 7, 1994 - Construction Law.

Preferred criteria

Criteria have been set according to the preferences indicated by the owner and in terms of the minimum distances, so by providing both ensure the maximum profit from the operation of the biogas plant:

- Distance of the location from the road and electrical infrastructure:
  - maximum distance from roads - 200 m,
  - maximum distance from the power grid - 300 m.
- Distances from available biomass:
  - the maximum distance from the head office - 10,000 m
- Storage area for raw materials:
  - a minimum plot area - 0.5 ha. The area of the plot was determined on the basis of approximate calculations regarding the minimum area needed for the placement of all biogas plant buildings (including silos for substrates, digester chambers, reservoirs e.g. for fermented mass, etc.).

Exclusion criteria

- distance of biogas plant facilities from populated areas, public facilities, running waters, stagnant water, wells, etc.
    - According to the Regulation of the Minister of Agriculture, the minimum distance of tanks for liquid animal excrements with a capacity of up to 200 m^3 from agri-food and food processing buildings is 50 m. Minimum distance of the digester and biogas tanks with a capacity of up to 100 m^3 from other structures including from buildings is 15 m. For volumes above 100 m^3, this distance is 30 m (Głaszczka et al., 2010). According to the above, a minimum distance from the buildings of 50 m was adopted,
- a minimum distance from roads and pavements - 70 m,
- a minimum distance from running and standing waters - 50 m,
- a minimum distance from a well in a given area - 15 m.

RESULTS AND DISCUSSION

All results were carried out with the assumption that the capacity of the biogas plant will be 350 kW, and the demand for fresh mass of substrates is entirely covered by the surveyed farm. Additionally, based on the research "Determination of biogas energy potential in a selected agricultural holding", the assumptions and results regarding the determination of biogas plant power and the required volume of tanks were borrowed (Sikora, Tomal, 2016).

Assumptions

- Yield of individual substrates:
    - maize - 40 ha: including silage from maize 40 $t \cdot ha^{-1}$,
    - sugar beets - 40 ha: including sugar beet root 70 $t \cdot ha^{-1}$, sugar beet leaves 45 t $t \cdot ha^{-1}$,
    - liquid manure - 60 LU (large unit): daily yield 0,125 $m^{-3} \cdot d^{-1}$.

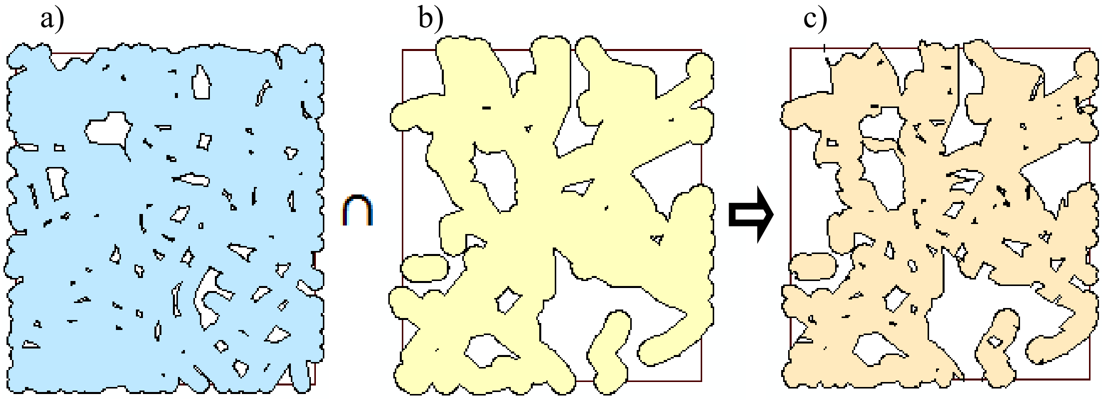
Findings

- nominal power of a generator in a cogeneration system: 336.78 KW,
- volume of the slurry tank: 103,13 $m^{-3} \cdot d^{-1}$,
- volume of tanks for individual batch weights:
    - maize silage: 2285,71 $m^{-3} \cdot year^{-1}$,
    - sugar beet root: 4000 $m^{-3} \cdot year^{-1}$,
    - sugar beet leaves: 2571.43 $m^{-3} \cdot year^{-1}$,
- volume of the fermentation chamber: 1111.23 $m^{-3} \cdot year^{-1}$,
- volume of the biogas tank: 595.61 m^3,
- volume of the tank for post-fermentation mass: 2424.14 m^3.

Spatial analysis been carried out with ArcMap 10.2.1 to determine the optimal location for the construction of an agricultural biogas plant, including plots belonging to the selected farm.

Based on the buffers created for each thematic layer, layers of preferred and excluded criteria were created:

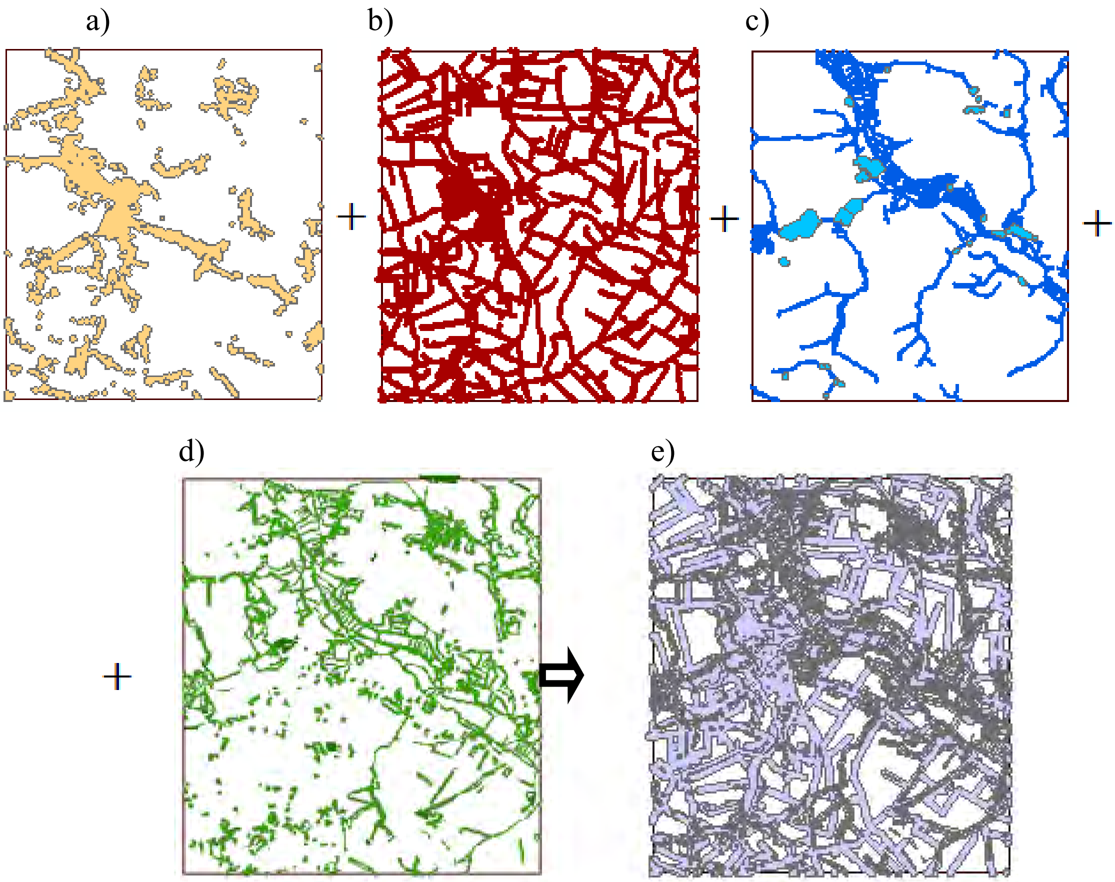
- the process of creating a layer of preferred criteria using the tool '*Inselct*'



Source: Own study

Figure 7. The process of creating the preferred criteria layer: a) buffer - distance from roads (200 m), b) buffer - power lines (300 m), c) resultant layer - preferred kritéria

- the process of creating an exclusion criteria layer with the '*Marge*' tool



Source: Own study

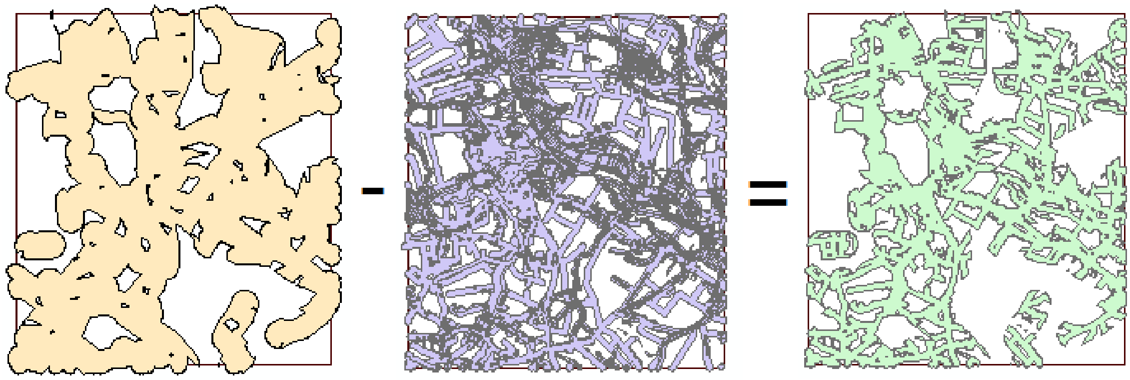
Figure 8. The process of creating the negative criteria layer: a) buffer - buildings (50 m), b) buffer - roads (70 m), c) buffer - standing and flowing waters (50 m), d) buffer - green areas (10 m), e) resultant layer - exclusion criteria

In the next stage of the research, areas for the construction of biogas plants were designated throughout the studied area:

- the process of creating a layer of areas possible to build a biogas plant:

Stage 1: create a layer using the '*Clip'* tool

a) b) c)



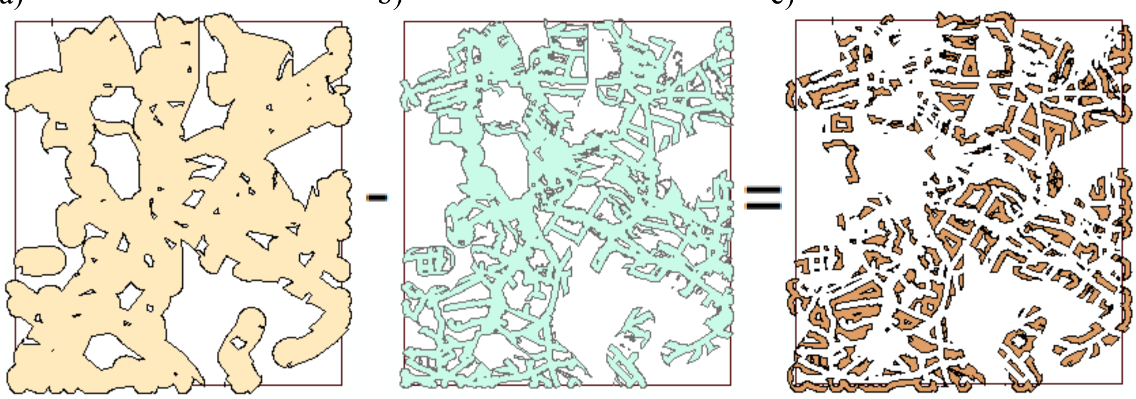
Source: Own study

Figure 9. The process of cutting the exclusion layer from the preferred layer:
a) the preferred layer, b) the exclusion layer c) the cut-out layer.

It should be noted, that this is not a layer that will be further analyzed, because the exclusion layer can be seen further on the resulting layer. This is due to the fact that the Clip tool only cuts off objects that intersect the input layer and does not cut off the objects in it.

Stage 2: creating a layer of possible areas for the construction of a biogas plant using the '*Symmetrical Difference'* tool

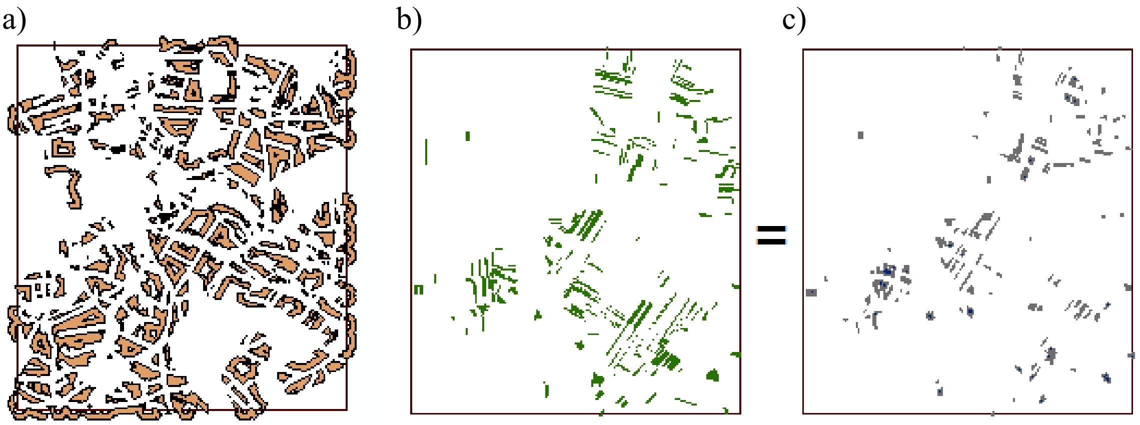
a) b) c)



Source: Own study

Figure 10. The process of creating a layer of areas suitable for the construction of a biogas plant: a) a layer of preferred criteria, b) a cut-out layer, c) theoretical areas for the construction of a biogas plant.

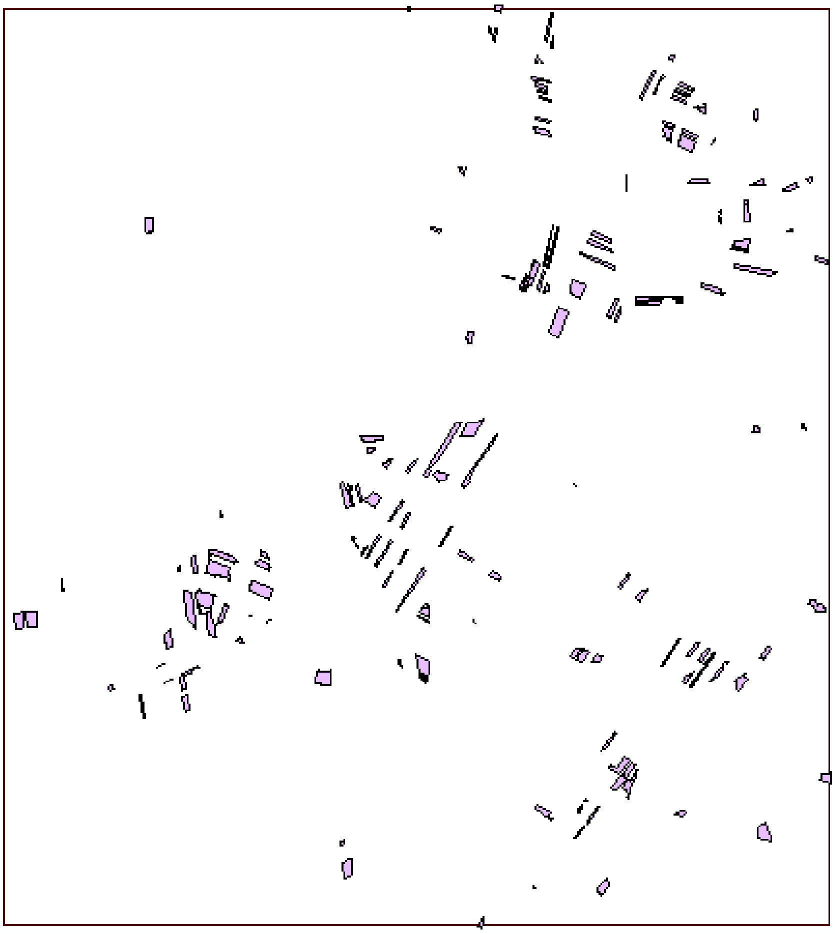
In Figure 10, the fragments marked in orange indicate the areas suitable for the construction of a biogas plant. However, to determine the final location, and make sure that biogas plant will be located on the property belonging to the farm an additional layer was made using the '*Intersect'* tool.



Source: own study

Figure 11. The process of creating a layer of areas for biogas plant construction: a) theoretical areas for the construction of a biogas plant, b) plots of a farm, c) areas for biogas plant construction

As a result, an imaging layer was obtained, and it shows on which plots a biogas plant could be created:



Source: own study

Figure 12. Layer illustrating the plot for the construction of a biogas plant

In Figure 12, 238 plots have been designated (this number is determined on the basis of their numbering on the website www.geoportal.gov), the total area of the designated area is approx. 72.3 ha. The area of the smallest plot is about $5 \cdot 10^{-5}$ ha, and the biggest about 1.92 ha. As you can see, the area of $5 \cdot 10^{-5}$ ha is too small for the construction of a biogas plant.

After analysis, the number of potential locations was reduced, by increasing the minimum plot area to about 1 ha. In addition, several areas not belonging to the farm are included, due to other factors, they are suitable for the construction of an agricultural biogas plant. Table 10 shows the areas in question, broken down by factors.

Table 9. Locations for the construction of an agricultural biogas plant

Lp.	Place	Number of plots	Surface [Ha]	distance from the farm's headquarters [Km]	Farmer's property
Plots belonging to the farm					
2	Donosy	3	0,99	4,18	Yes
11	Odonów	1	1,30	1,91	Yes
32	Gabułtów	4	1,72	6,27	Yes
Plots not belonging to the farm					
10	Odonów	1	1,78	2,81	No
44	Podolany	2	1,33	2,54	No
Plots ensuring the receipt of electricity and heat					
0	Plechówka	1	2,70	0,00	Yes
16	Kazimierza Wielka	1	0,73	3,62	Yes
45	Plechów - koło trans	1	0,74	1,21	No

Source: own study

Eight areas were selected, which according to the subjective assessment are the best for the construction of a biogas plant. A local inspection of each plot was carried out below to check whether the designated areas did indeed meet all the requirements. An area matching all criteria is marked in purple. On the other hand, an additional green color has been selected to mark areas that that meets the exclusion criteria but does not meet the preferred criteria. This means that a biogas plant can be built on it, but the investment and operating costs will be much higher.

CONCLUSIONS

Geographical Information Systems (GIS) are used to easily and quickly determine the location of the investment. With the help of systems, you can conduct the analysis and make a subjective assessment of the results obtained.

The area for which research was carried out was selected on the basis of plots used by the given farm. As a result, plots with a small area were shown, or those located far away from large urban agglomerations. In the case of an analysis where the locationn of farm plots would not be taken into account, other, probably larger and better plots for the construction of an agricultural biogas plant would have been designated.

1. On the basis of the analysis, 238 plots used by the surveyed farm were designated, with a total area of 72.3 ha, those chosen areas meet the preferred and exclusion criteria based on which an agricultural biogas plant could be established.
2. Assuming a minimum plot area (0.5 ha), 46 areas have been designated, with a total area of 47.3 ha. From the designated areas only 12 belong to the owner of the farm. The rest of the plots are used on the basis of a lease contract and in the

case of selecting a given plot for purpose of a biogas plant, the farmer would need to buy the area, what would bring the additional costs

3. According to the subjective assessment, the best location for the construction of an agricultural biogas plant is an area with the number 0. It is located directly behind the farm, it has the largest area for biogas plant construction (2.7 ha), which only meets the exclusion criteria. An additional advantage of a given location is the fact that the farm is planning to build a multi-station cowshed for beef cattle from which the slurry would be directly transported to the biogas plant. That would significantly reduce the costs associated with the transport of raw materials. Location no. 0 does not have a surface that meets the preferred criteria, because the distance from the overhead power line is greater than the assumed 300 m (about 370 m). However, this is a small distance, and the costs associated with connecting the generator to the network will be much smaller compared to the daily transport of raw materials to another plot.
4. The SWOT analysis carried out in a simple and comprehensive way shows the future investor whether building an agricultural biogas plant is profitable for him and which difficulties he may face.

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REFERENCES

Dennis A., Burke P.E. (2001). *Dairy waste anaerobic digestion handbook*, Env. Energy Company, Olympia, USA.

Gaździecki J. (1990). *Systemy informacji przestrzennej*. PPWK, Warszawa

Głaszczka A., Wardal W. J., Romaniuk W., Domasiewicz T. (2010) *Biogazownie rolnicze, monografia,* MULTICO Oficyna Wydawnicza, Warszawa.

Jędrczak A. (2007). *Biologiczne przetwarzanie odpadów*. Wyd. Naukowe PWN, Warszawa.

Kowalczyk - Juśko A. (2005). *Produkcja energii elektrycznej i cieplnej w biogazowni rolniczej. Materiały Konferencji - Ogólnopolskie Forum Odnawialnych Źródeł Energii*, Warszawa.

Kwiecień J. (2004). *Systemy informacji geograficznej - podstawy*. Bydgoszcz.

Podkówka W. (2012). *Biogaz rolniczy odnawialne źródło energii,* Powszechne Wydawnictwo Leśne, Warszawa.

Romaniuk W., Karbowy A., Łukaszuk M. (2008). *Wymagania formalno - prawne projektowania i budowy biogazowni rolniczych*, "Problemy Inżynierii Rolniczej" nr 3/2008

Romaniuk W., Biskupska K. (2014). *Biogazownia rolnicza krok po kroku*, Wyd. Hortpress Sp. z o. o., Warszawa.

Tytko R. (2013). *Urządzenia i systemy energetyki odnawialnej*, Wydawnictwo i Drukarnia Towarzystwa Słowaków w Polsce, Kraków.

Wilkie A. (200). *Anaerobic digestion: holistic bioprocessing of animal manures, In. Proceedings of the animal residuals management, conference*, Water Environment Federation, Alexandria, Virginia.

Wota A., Woźniak A. (2008). *Metodyka wyboru lokalizacji składowisk odpadów komunalnych*. Infrastruktura i Ekologia Terenów Wiejskich. Nr 2008/ 08.

Ustawa z dnia 7 lipca 1994 r. - Prawo budowlane (Dz.U. 1994 nr 89 poz. 414).

Ustawa z dnia 20 lutego 2015 r. o odnawialnych źródłach energii (Dz.U. 2015 poz. 478).

Ustawa z dnia 17 maja 1989 r. Prawo geodezyjne i kartograficzne (Dz.U. 1989 nr 30 poz. 163).

Rozporządzenia Ministra Rolnictwa i Gospodarki Żywnościowej z dnia 7 października 1997 r. w sprawie warunków technicznych, jakim powinny odpowiadać budowle rolnicze i ich usytuowanie. (Dz.U. 1997 nr 132 poz. 877).

Rozporządzenia Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz.U.2002 r. nr 75, poz.690).

Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 15 czerwca 2012 r. w sprawie ogłoszenia jednolitego tekstu ustawy – Prawo energetyczne (Dz. U. z 2012, poz. 1059 j.t.).

http://ieo.pl/dokumenty/ustawaoze/dokument51292_uzasadnienie_do_projektu_ustawy.pdf (access 08.04.2017).

http://www.arr.gov.pl/data/02004/rejestr_wytworcow_biogazu_rolniczego_07042017.pdf (access 08.04.2017).

http://www.gmina.bio-gazownie.edu.pl/korzysci (access 08.04.2017).

http://portalrolniczy.info/slownik-rolniczy/1201221-biogazownia (access 08.04.2017).