

## CHARACTERIZATION OF SOIL ADDITIVE DERIVED FROM SEWAGE SLUDGE

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**Abstract:** The aim of the present work is to characterize the soil additive derived from sewage sludge as potentially economically acceptable material for agricultural production as well as for soil and environment protection. The soil additive consisting of sewage sludge obtained from the wastewater treatment plant Pannon-Víz Zrt. (Győr, Hungary) and agricultural byproducts represented by wastes from grain mill industry and crushed corn cobs was prepared using the low-capacity granulator equipment constructed by Energy Agency Public Nonprofit Ltd. (Hungary). The characterization of sewage sludge as primary composite and prepared soil additive includes the determination of physico-chemical parameters such as pH determined in suspension with distilled water, 0.01 mol/dm<sup>3</sup> CaCl<sub>2</sub> or 1 mol/dm<sup>3</sup> KCl solutions, pH<sub>zpc</sub> predicted by potentiometric titration and ProtoFit software, water holding capacity (*WHC*), cation-exchange capacity (*CEC*) and total organic carbon (*TOC*). The elemental analysis by X-ray fluorescence spectrometry revealed that sewage sludge as well as prepared soil additive contain significant amount of Zn and Cu as important microelements in plant nutrition. Also, it was found that prepared soil additive represents the considerable source of a significant proportion, strong bound and in this way gradually released microelements. Obtained results suggest on the application potential of prepared soil additive in agricultural production as well as in remediation and reclamation of contaminated or degraded soil.

**Key words:** sewage sludge, waste, soil additive, agriculture, remediation, lysimeter

### 1. Introduction

In the 20<sup>th</sup> century, industrialization and ore mining led to the increasing of the number of sites contaminated with metals or organic xenobiotics. Nowadays, environmental issues also have been broadened in connection with concepts involving sustainable development, which implies not only ecological, but economical and social responsibilities as well. However, globally the intensification of production processes and relative human activities raise the production of gaseous, liquid and solid wastes. The European Community generates approximately two billion tons of waste per year (DÜRING and GÄTH, 2002). The handling of sewage sludge (SSL) represents one of the most significant challenges in wastewater management (FYTILI and ZABANIOTOU, 2008).

SSL is defined by the U.S. Environmental Protection Agency (EPA) as the “solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works” (NRC, 2002). Within wastewater treatment plant the SSL represents the residue generated during the primary (physical and/or chemical), the secondary (biological) and the tertiary (additional to secondary, often nutrient removal) treatment (FYTILI and ZABANIOTOU, 2008). The composition of SSL is

dependent on its origin in terms of the type of wastewater treatment, and therefore is variable and unpredictable as well. In this way, the public concern and definition of regulations or directives are primarily associated with toxic metals, organic xenobiotics or pathogen occurrence in this type of wastes. SSL treatment by a variety of processes including aerobic digestion, anaerobic digestion, composting, heat drying, air drying, lime stabilization, and chemical fixation is the possible key to minimizing the risks in terms of the quantitative occurrence or negative impacts of mentioned components (MATHNEY, 2011). Also, the proportion of macro- or microelements and pH levels, alkalinity or organic acid content are important parameters from the point of view of the SSL ultimate disposal as well as the process of anaerobic digestion (TCHOBANOGLIOUS *et al.*, 2003), respectively.

All these factors play an important role in decision with regard to the ultimate SSL disposal, which can involve: composting, landfilling, agricultural reuse as well as sea or surface waters disposal and incineration of SSL (DONATELLO and CHEESEMAN, 2013). During the last decades there has been a major change in the ways SSL is disposed (FYTILI and ZABANIOTOU, 2008). Prior to 1998, municipal SSL was primarily disposed at seawaters or was used in agriculture (ODEGAARD *et al.*, 2002). Additional solutions include incineration of SSL or landfilling. Since 1998 onwards, European legislation prohibits the sea disposal of SSL (FYTILI and ZABANIOTOU, 2008). Large differences between individual EU countries exist in current SSL disposal concerning on the character of disposal operations or their proportion on SSL disposal.

Some papers have been reported that SSL, except the conventional methods of disposal, can be disposed by pyrolysis or incineration for biochar (MÉNDEZ *et al.*, 2013) or ash production as building construction materials (CHEN and LIN, 2009) as well as can be used in remediation of soils contaminated with heavy metals (GARRIDO *et al.*, 2012).

Approximately 5.6 million tons of dry SSL are used or disposed of annually in the United States, of which 60 % is used for land application or public distribution (NRC, 2002). In Europe, dry weight per capita production of SSL resulting from primary, secondary and even tertiary treatment represents more than 90 g per person per day (DAVIS, 1996).

In conditions of Slovak Republic the production of SSL within the last decade is relative constant, e.g. in 2002 represent 51,270 tons per year and in 2012 58,706 tons per year. In mentioned year 2012, the SSL was predominantly used for compost production (62.7 %), reclamation (16.4 %), landfilling (13.5 %), incineration (5.5 %) and direct application into the soil (1.9 %) (according to data of MŽP SR, 2012).

Previous works deal with the possibility of application of the sludge originated from sewage treatment plants as potential sorbent for Co removing from contaminated solutions (FRIŠTÁK *et al.*, 2013) or application of simultaneous and sequential extraction protocols as tools for determination of zinc bioavailability in dried anaerobic sludge (FRIŠTÁK *et al.*, 2012). The aim of the present work is to characterize the soil additive derived from SSL as potentially economically acceptable material for agricultural production as well as for remediation and reclamation of contaminated or degraded soil.

## 2. Materials and methods

### 2.1 Sewage sludge and soil samples

Dried samples of sewage sludge (SSL) as primary composite for soil additive preparation were obtained from the wastewater treatment plant Pannon-Víz Zrt. (Győr, Hungary). The sample represented concentrated, anaerobically digested, dewatered and dried SSL.

Soil samples as a model of agricultural used soil were obtained from experimental fields of Plant Production Research Center Piešťany (PPRC Piešťany) in Borovce (spring period, 2013; altitude 160 m, north latitude 48°34', east longitude 17°44').

All obtained samples were kept under laboratory conditions without their special treatment. Dry weight of studied matrices was determined at 105 °C in drying chamber and the distribution of particles size of individual samples was evaluated by sieve analysis with standard sieves using.

### 2.2 Soil additive derived from sewage sludge

Dried samples of soil additive consisting of mentioned SSL and agricultural byproducts represented by wastes from grain mill industry and crushed corn cobs (Top Feed & Cargo Hungary Holding Zrt., Hungary) were prepared in volume ratio 1 : 1.5 using the low-capacity granulator equipment (Fig. 1) designed by Energy Agency Public Nonprofit Ltd. (Budapest, Hungary). The low-capacity granulator provided the mixing of both primary composites and thermal treatment (~ 75 °C) for inhibition of present microorganisms.

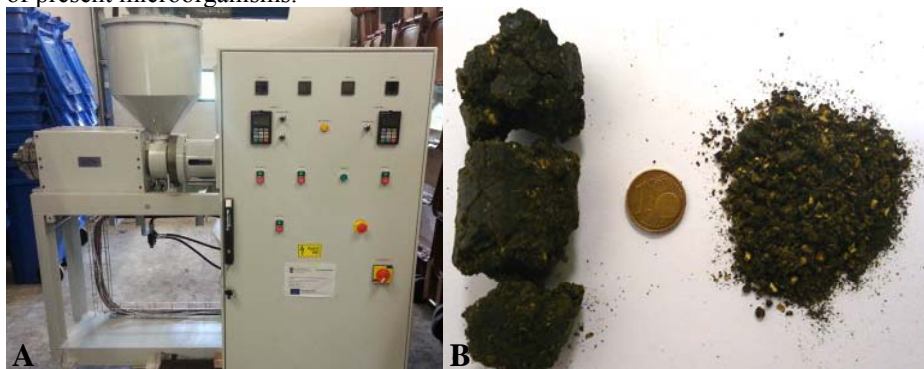


Fig. 1. Low-capacity granulator equipment designed by Energy Agency Public Nonprofit Ltd. (Hungary) (A) for production of designed soil additive (B) – primary pellets (left) and crushed material applied in experiments (right).

### 2.3 Determination of pH and cation-exchange capacity

The pH determination or cation-exchange capacity (CEC) of SSL, prepared soil additive and agricultural used soil were realized according to ISO standard method No. 10390 or No. 11260, respectively.

According to mentioned standard method soil suspensions with deionized water,  $1 \text{ mol/dm}^3$  KCl or  $0.01 \text{ mol/dm}^3$   $\text{CaCl}_2$  at volume ratio  $V(\text{matrix}) : V(\text{solution}) = 1 : 5$  were stirred on orbital incubator shaker ( $150 \text{ min}^{-1}$ ) within 1 h at  $25 \text{ }^\circ\text{C}$  and subsequently the pH value of these suspensions was measured using glass electrode.

In the case of CEC determination the studied matrix was suspended in  $\text{BaCl}_2$  solution for the reason Ba binding in matrix and removing of others present cations. Subsequently, the matrix saturated with Ba was suspended with  $\text{MgSO}_4$  solution and remaining, non-binding amount of  $\text{Mg}^{2+}$  cations was analyzed by chelatometric titration using EDTA- $\text{Na}_2$  on Eriochrome black T indicator.

#### 2.4 Elemental and total organic carbon analysis

The elemental analysis of SSL and prepared soil additive samples was performed by X-ray fluorescence spectrometry using the high performance X-ray fluorescence spectrometer X-LAB 2000, SPECTRO (Germany). The content of As, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Sb, Se and Zn was analyzed in samples treated to granularity  $< 0.063 \text{ mm}$ .

Total organic carbon (TOC) was determined using TOC analyzer TOC- $\text{V}_{\text{CPN}}$  SHIMADZU (Japan).

#### 2.5 Potentiometric titration

With the aim to prediction of protonation constants  $pK_a$  and binding sites concentration of functional group  $c_{An}$  on the surface of studied matrices the potentiometric titration according to modified procedure described by ZHANG *et al.* (2010) was carried out. The sample was transferred into Erlenmeyer flask containing a mixture of  $0.1 \text{ mol/dm}^3$  HCl and  $0.1 \text{ mol/dm}^3$  NaCl, stirred on orbital shaker and centrifuged. The studied matrix was suspended in  $0.1 \text{ mol/dm}^3$  NaCl solution and in this suspension the titration solution  $0.1 \text{ mol/dm}^3$  NaOH was gradually added with the parallel measuring pH. The obtained data describing the relationship between the volume of added titration solution and the measured pH values were analyzed by modelling program ProtoFit ver. 2.1.(TURNER and FEIN, 2006).

#### 2.6 Determination of water holding capacity

The determination of water holding capacity (WHC) value was realized in 30 cm length glass column with internal diameter 2.5 cm. The defined amount (in grams) of individual samples of SSL, soil additive and soil or the mixture soil additive : soil in weight ratios 1 : 9; 1 : 4; 1 : 1.5 or 1 : 1.25 was transferred into the column with the bottom cap. Subsequently, the defined amount of distilled water (in grams) equivalent with the amount of matrix sample was added into the mentioned system. After 30 min the bottom of the column was opened and the water eluate was collected into Erlenmeyer flask during the next 30 min. The WHC value was calculated

according to gravimetrically evaluation of water balance between added water into system and obtained amount of eluate.

### *2.7 Single extraction of Zn and Cu from studied matrices*

For the evaluation of available microelements Zn and Cu amount in studied matrices the Mehlich method was used. The suspension of matrix and Mehlich-III solution in weight ratio 1 : 10 was stirred on orbital shaker during 10 min. The Mehlich-III extraction solution consisted of 0.2 mol/dm<sup>3</sup> CH<sub>3</sub>COOH, 0.25 mol/dm<sup>3</sup> NH<sub>4</sub>NO<sub>3</sub>, 0.015 mol/dm<sup>3</sup> NH<sub>4</sub>F, 0.013 mol/dm<sup>3</sup> HNO<sub>3</sub> and 0.001 mol/dm<sup>3</sup> EDTA (MEHLICH, 1984). Subsequently, the suspension was filtered and in solution the concentrations of Zn and Cu were analyzed by atomic absorption spectrometer (AA-7000 Shimadzu, Japan) with electrothermal atomization (GFA-7000 Shimadzu, Japan). From the obtained concentration of Zn and Cu the available amount of Zn and Cu in milligrams per kilogram of matrix was calculated.

### *2.8 Laboratory lysimetric experiment*

A plastic laboratory lysimeter (EcoTech, Germany) with diameter 30 cm and height 50 cm was filled with 45 kg of dried agricultural used soil (content of water max. 2.1 %). Mentioned laboratory lysimeter was equipped with: sprinkling head for soil watering, temperature sensors and tensiometers located in soil column within 10 cm, 20 cm or 30 cm from the surface, suction bottom with controlled vacuum pump for sampling of soil eluates, and datalogger for data acquisition with communication and evaluation software. The whole lysimeter system containing soil column with 0.28 m<sup>2</sup> of surface and 40 cm height was maintained under defined conditions of plant growth chamber (KBWF 720 Binder, Germany) and in the given time intervals weighted for water balancing in the system.

## **3. Results and discussion**

### *3.1 Physico-chemical characterization of studied matrices*

In the first step of sewage sludge (SSL), prepared soil additive and model of agricultural used soil characterization the analyses aimed to the determination of pH (pH<sub>H2O</sub>, pH<sub>CaCl2</sub> and pH<sub>KCl</sub>), cation-exchange capacity (CEC) and total organic carbon (TOC) values were carried out. Obtained results showed that studied matrices were significantly differed in all evaluated values (Table 1). The lowest pH value was determined for designed soil additive consisting of SSL as primary studied composite and agricultural byproducts represented by wastes from grain mill industry and crushed corn cobs. On the other side, the sample of soil additive showed higher values of cation-exchange capacity (CEC) and total organic carbon (TOC) in comparison with SSL and agricultural used soil. This fact suggests on the potential

positive effect of such soil additive, particularly in the case of basic soils, in terms of the increasing metals availability for plant production purposes as well as in remediation of soils contaminated with toxic metals using selected plant species applied in phytoremediation methods (CHIU *et al.*, 2006).

Table 1. Determined values of pH ( $\text{pH}_{\text{H}_2\text{O}}$ ,  $\text{pH}_{\text{CaCl}_2}$  and  $\text{pH}_{\text{KCl}}$ ), cation-exchange capacity (*CEC*) and total organic carbon (*TOC*) for studied matrices.

Matrix	$\text{pH}_{\text{H}_2\text{O}}$	$\text{pH}_{\text{CaCl}_2}$	$\text{pH}_{\text{KCl}}$	<i>CEC</i> (meq/100 g)	<i>TOC</i>
Sewage sludge*	6.73	6.66	6.57	28.2	28.6 %
Soil additive **	5.75	5.61	5.38	33.2	37.4 %
Soil ***	7.26	6.78	6.30	29.0	1.10 % ( $\text{C}_{\text{ox}}$ )

\* Sewage sludge obtained from the company Pannon-Viz Zrt. (Hungary) as primary composite of prepared soil additive;

\*\* Soil additive consisting of sewage sludge and agricultural byproducts represented by wastes from grain mill industry and crushed corn cobs was prepared using the low-capacity granulator equipment constructed by Energy Agency Public Nonprofit Ltd. (Hungary);

\*\*\* Soil obtained from the experimental fields of PPRC Piešťany as a model of agricultural used soil.

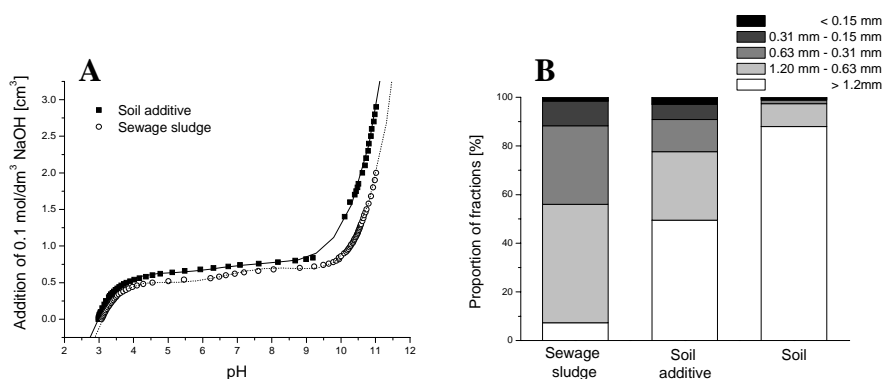


Fig. 2. A. Potentiometric titration curves for sewage sludge and designed soil additive ( $3.0 \text{ g/dm}^3$ ). The titration was performed with addition of  $0.1 \text{ mol/dm}^3 \text{ NaOH}$  and  $0.1 \text{ mol/dm}^3 \text{ NaCl}$  as background electrolyte and at  $25 \text{ }^\circ\text{C}$ .

B. Sieve analysis of studied matrices for determination of fraction proportion of individual particles on the basis of their size.

In the context with the *CEC* value, the potentiometric titration analysis of SSL and prepared soil additive was realized (Fig. 2A). This analysis confirmed that prepared soil additive containing except the evaluated SSL also agricultural byproducts represented by wastes from grain mill industry and crushed corn cobs showed higher proportion of important functional groups from the point of view of metal cations binding such as carboxyl ( $-\text{COOH}$ ), hydroxyl ( $-\text{OH}$ ), phosphate ( $-\text{PO}_3\text{H}_2$ ) or amino ( $-\text{NH}_2$ ) groups. ProtoFit software predicted that in prepared soil additive the concentrations of mentioned functional groups were minimally 4-times higher in comparison with the primary composite – sewage sludge, particularly

in the case of basic functional groups ( $-\text{NH}_2$  and  $-\text{OH}$ ). From the potentiometric titration data fitted by the program ProtoFit the values of  $\text{pH}_{\text{zpc}}$  were also predicted, whereby the  $\text{pH}_{\text{zpc}}$  value (pH of zero point charge) represents the pH at which the matrix has a net zero surface charge. The matrix surface has a net positive charge at  $\text{pH} < \text{pH}_{\text{zpc}}$ , while at  $\text{pH} > \text{pH}_{\text{zpc}}$ , the surface has a net negative charge (SUN *et al.*, 2011). SSL showed practically neutral value of  $\text{pH}_{\text{zpc}} = 7.8$  in contrast to the prepared soil additive, when the  $\text{pH}_{\text{zpc}}$  reached the value 9.4.

In cation binding the specific surface of matrix particles plays also a decisive role. Fig. 2B depicts the fraction proportion of individual particles on the basis of their size for studied matrices determined by sieve analysis.

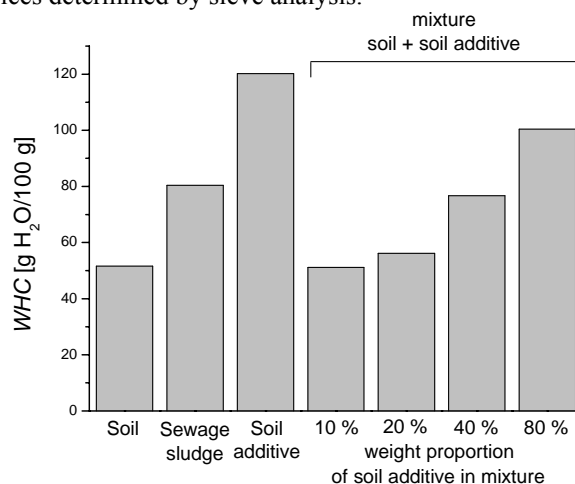


Fig. 3. Water holding capacity (*WHC*) determined for individual studied matrices or for mixture of model agricultural used soil and prepared soil additive with different weight proportion of soil additive.

In the last decades, the climatic changes in terms of floods and dry season rotation play an important role in agricultural production. Therefore, the soil additive of this type and its characteristics should take into account the mentioned negative effects of climatic changes on the soil quality. In experiments evaluating the values of water holding capacity (*WHC*), we found that soil additive prepared from SSL and agricultural by-products represented by wastes from grain mill industry and crushed corn cobs showed the highest values of *WHC* in comparison with SSL and model of agricultural used soil. Also, the addition of prepared soil additive had the positive effect on the increasing of *WHC* values of mixture soil additive : soil (Fig. 3).

From the point of view of SSL application into the soil is very important to know the presence and concentration of toxic substances as well as microbial contamination. These factors are reflected in the relevant EU legislative directions. As we mentioned, the SSL added as composite into the designed soil additive was thermally treated with the aim of microorganisms inhibition. In the context of toxic substances presence in SSL, we focused on toxic metals as well as important macro- and microelements content (Table 2).

United States Environmental Pollution Agency (US EPA) developed parameters the effects range low (ERL) and the effects range median (ERM) as predictive tools for contamination characterizing in sediments. The ERL represents the tenth percentile of the effects database, below which harmful effects on aquatic biota are rarely observed. The ERM represents the fiftieth percentile of the effects data and is indicative of concentrations above which harmful effects are often observed (US EPA, 2002). Also, these parameters can be applied for SSL as water sediments. From the elemental analysis by X-ray fluorescence spectrometry, we found that studied SSL showed overload of the ERL parameter in the case of Cr and Ni and overload of the ERM parameter for Cu and Zn. Despite this fact, it can be concluded that the concentrations of Cr and Ni do not represent a serious risk of soil contamination with heavy metals after designed soil additive application into the soil in the case of observance of rules defined by legislation of the Slovak Republic (Act No. 188/2003) determining the maximal amount of applied SSL into the soil 15 tons (dry weight; d.w.) per ha and per 5 years. Also, this Act No. 188/2003 determines the limits of maximal concentrations for mentioned metals Cr and Ni in SSL applied into soil, which represent the values 1,000 and 300 mg/kg (d.w.), respectively. On the other hand, in the case of soils deficient in Zn or Cu as important microelements in plant nutrition, the prepared soil additive containing Zn and Cu in this level can represent a valuable source of these nutrients.

Table 2. Elemental analysis of studied matrices by X-ray fluorescence spectrometry.

Element	Sewage sludge*	Soil additive**
As	8.0 ppm	6.5 ppm
Ca	4.74 %	3.21 %
Cd	< 2 ppm	< 2 ppm
Cr	<b>84.7 ppm<sup>a</sup></b>	67.5 ppm
Cu	<b>654 ppm<sup>b</sup></b>	<b>583 ppm<sup>b</sup></b>
Fe	3.92 %	3.13 %
Mg	0.61 %	0.21 %
Mn	0.03 %	0.03 %
Ni	<b>42 ppm<sup>a</sup></b>	<b>44 ppm<sup>a</sup></b>
Pb	36 ppm	26 ppm
Sb	4.67 ppm	< 2 ppm
Se	2.67 ppm	< 1 ppm
Zn	<b>1,940 ppm<sup>b</sup></b>	<b>1,510 ppm<sup>b</sup></b>

a Overload of the effects range low (ERL);

b Overload of the effects range median (ERM).

### 3.2 Single extraction of Zn and Cu from studied matrices

In the context with previous results indicating the fact that SSL as well as prepared soil additive showed high content of Zn and Cu as important microelements in plant



nutrition, the experiment evaluating availability of these metals for plants were carried out. For these purposes, the method according to Mehlich (MEHLICH, 1984) was applied. From the Fig. 4A, it is evident that more than 2-times higher amount of Zn was extracted by Mehlich-III solution from prepared soil additive in comparison with SSL (130 mg/kg; d.w.) as primary composite. In the case of Cu up to 6-times higher extractable amount for soil additive (10 mg/kg; d.w.) was found. For comparison, the extractable amount of Zn and Cu for sample of agricultural used soil is also mentioned in Fig. 4A. Within these results, the fact of higher total content of Zn and Cu in the case of SSL as well as 3-times higher total amount of Zn in comparison with Cu in studied matrices should be taken into account (Table 2). In this way, the proportion of available Zn and Cu for soil additive represents more than 19 % and 11 %, respectively (Fig. 4B). It can be concluded that the addition of agricultural by-products represented by wastes from grain mill industry and crushed corn cobs and the treatment of SSL at production of designed soil additive using the low-capacity granulator equipment caused the changes responsible for increasing of available Zn and Cu proportion in this matrix. Also, it can be supposed that the proportion of Zn and Cu will be lower in the case of agricultural by-products represented by wastes from grain mill industry and crushed corn cobs in comparison with SSL. Therefore the mentioned changes probably take place significantly within the SSL.

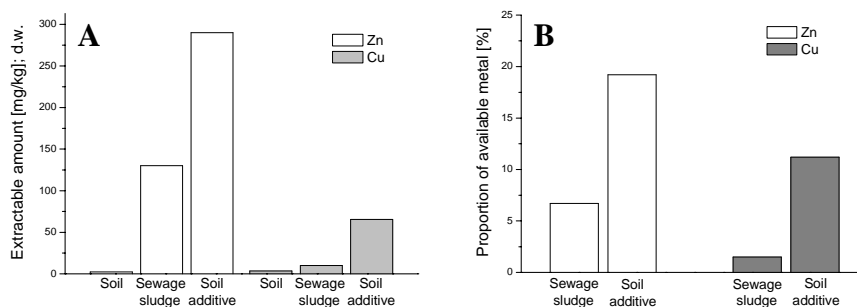


Fig. 4. The single step extraction of Zn and Cu from agricultural used soil, sewage sludge and designed soil additive by Mehlich-III solution expressed as the total extractable amount of metal (in mg/kg) (A) or the ratio of extracted amount of metal to the total amount of metal in matrix (B).

YU *et al.* (2004) found that between the total amount of Cu in soil and extractable amount of Cu by Mehlich-III solution the linear dependence exists. Also, these authors observed the proportion of extractable amount of Cu in comparison with the total amount of Cu in degraded soil more than 50 %. It is generally known that the availability of heavy metal such as Zn and Cu is also strongly determined by factors e.g. pH, organic matter, clay minerals, oxyhydroxides, and others (KABATA-PENDIAS, 2011).

Obtained results showed that the availability of Zn and Cu in soil additive is relatively low. This fact suggests that prepared soil additive represents the source of a significant proportion, strong bound and in this way gradually released

microelements. These characteristics correspond with suitable parameters for agricultural production. Strong binding of metals or relative high *CEC* values can be also utilized in remediation and reclamation of contaminated or degraded soil.

### 3.3 Laboratory lysimetric experiment

In this part the potential of laboratory lysimetric system application in further study of positive or negative characteristics of soil additive derived from SSL for agricultural production or remediation and reclamation of contaminated or degraded soil is demonstrated. The following preliminary experiment under laboratory conditions was focused on evaluating the possibility to imitate the behaviour of mentioned soil additive in conditions of agricultural used, contaminated or degraded soils. In this term, the possibility to control the soil column watering, the obtaining of soil eluate and vertical distribution of soil moisture, as well as the effect of temperature, relative humidity or illumination on these processes were studied.

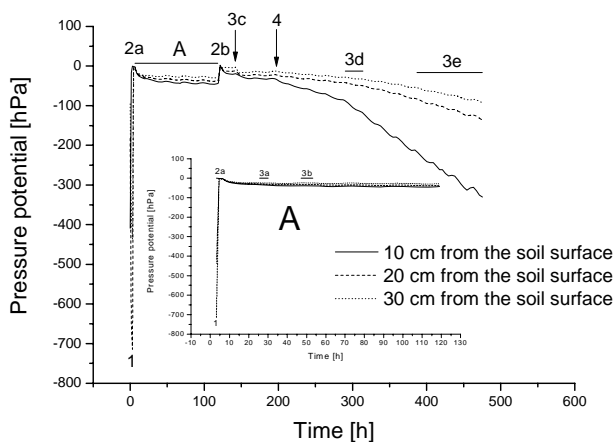


Fig. 5. The changes in the soil moisture within the soil column (diameter 30 cm; height 40 cm) located in the laboratory lysimeter caused by watering, suction of soil eluate, evapotranspiration of water under given conditions in plant growth chamber (temperature, relative humidity or illumination). 1. Start of the experiment with column of dried soil (content of water max. 2.1 %); 2. Watering of soil with distilled water using lysimeter sprinkling head: a – during 6 h with the watering rate  $0.66 \text{ dm}^3/\text{h}$ , b – during 3 h with the watering rate  $0.66 \text{ dm}^3/\text{h}$ ; 3. Suction of soil eluate by controlled vacuum pump: a – during 4 h under pressure 20 – 40 hPa, b – during 6 h under pressure 20 – 40 hPa, c – during 1 h under pressure 50 – 100 hPa, d – during 24 h under pressure 20 – 40 hPa, e – during 72 h under pressure 20 – 40 hPa; 4. Activation of illumination 16 h day / 8 h night with 11 450 lx intensity up to end of experiment.

The Fig. 5 depicts the tensiometric data of water pressure potential defining the changes in the soil moisture within the soil column (diameter 30 cm; height 40 cm) installed in the laboratory lysimeter caused by watering, suction of soil eluate or evapotranspiration of water under given conditions in plant growth chamber (temperature, relative humidity or illumination). At the start of experiment the sample

of agricultural used soil in individual 10 cm layers from the soil surface showed the values of water pressure potential up to 700 hPa, which correspond with the water content approx. 2 %. The values of water pressure potential near to 0 hPa represent the water saturated soil. It can be seen that the application of 4 dm<sup>3</sup> distilled water in the amount and rate typical for natural rain conditions caused significant increasing of water content in soil column (45 kg; d.w.) near to soil saturation with water, but without soil eluate obtaining. Within the next 6 days the gradually decreasing of soil moisture in all analyzed vertical soil layers supported by 2 suction under pressure was observed. Subsequently, the repeated soil watering with 2 dm<sup>3</sup> distilled water was carried out. The next decreasing of soil moisture was sequentially supported by suction of soil eluate in different time duration as well as illumination (16 h day / 8 h night with 11 450 lx intensity) provided by plant growth chamber. It was found that under mentioned conditions, it is possible to significantly change the soil moisture within short time correlating with the real natural conditions. Moreover, the different quantitative distribution of soil moisture within the vertical location of analyzed soil layers was obtained. In the Fig. 6, the conditions related with temperature and relative humidity within lysimetric experiment are described.

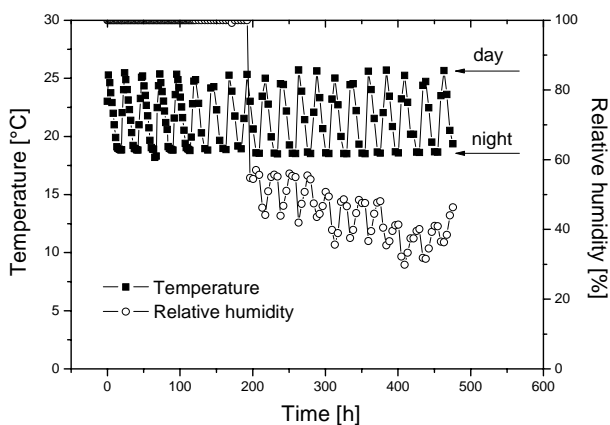


Fig. 6. The changes in the values of temperature and relative humidity within the lysimetric experiment described in the Fig. 5.

#### 4. Conclusions

The soil additive consisting of sewage sludge and agricultural by-products represented by wastes from grain mill industry and crushed corn cobs, and prepared by designed low-capacity granulator equipment was characterized on the basis of physico-chemical parameters such as pH,  $pH_{zpc}$ , cation-exchange capacity (*CEC*), water holding capacity (*WHC*), total organic carbon (*TOC*) and the content of toxic metals or microelements. The elemental analysis revealed that applied sewage sludge as well as prepared soil additive contain significant amount of Zn and Cu as important microelements in plant nutrition. In this context, it was found that prepared soil

additive represents the considerable source of a significant proportion, strong bound and in this way gradually released microelements. These characteristics correspond with suitable parameters for agricultural production as well as for remediation and reclamation of contaminated or degraded soil. In a separate part of the work the potential of laboratory lysimetric system application in further study of positive or negative characteristics of soil additive derived from sewage sludge for mentioned purposes was evaluated.

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