UNIVERSITY OF DEBRECEN
Centre of Agricultural Sciences
Faculty of Agronomy
Department of Environmental Management and Technology

DOCTORAL SCHOOL OF INTERDISCIPLINARY AGRICULTURAL AND NATURAL SCIENCES

Head of Doctoral School:
Prof. Dr. János Nagy
Doctor of Hungarian Academy of Sciences

Consultants:
Prof. Dr. Szilárd Thyll
professor emeritus, C.Sc. in agricultural sciences

Dr. habil. László Simon
C.Sc. in agricultural sciences

ABSTRACT OF Ph.D. THESIS

IMPACT OF MUNICIPAL SEWAGE SLUDGES ON CULTIVATED PLANTS AND SOIL

Written by:
Zsuzsanna Edit Uri
Ph.D. candidate

Debrecen
2007

1. PRELIMINARIES AND AIMS OF RESEARCH

Supply with water public utilities has been coming to the front after EU-accession of Hungary in the last few years (GAZDAG, 2003). From environmental aspect the development of sewage disposal and sewage treatment in Hungary is more and more important. As a result of the National Municipal Sewage Disposal and Treatment Realization Programme the present quantity of municipal sewage sludges (about 1 million t/yr with 25-30% dry matter content) may increase to more than twice (25/2002. (27. II.) governmental regulation). The harmless disposal and utilization of sewage sludges is absolutely necessary (THYLL, 1998). In the European Union the volume of utilization of sewage sludges in the agriculture for soil ameliorating and nutrient supply is increasing. Controlled agricultural utilization of sewage sludges – in accordance with EU directions – is prefferred in Hungary (JUHÁSZ, 2000).

The raw sewage sludge is a biologically active, infective, and smelly material. In this form utilization in the agriculture or for other purposes is not allowed. Properly treated municipal sewage sludge enhances the fertility of soil, and promotes the growth and development of plants. Fertilization effect of sewage sludge succeeds through natural organic substances, plant nutrients (nitrogen, phosphorus, trace elements), and water content present in this material. This was confirmed in numerous studied (SZLÁVIK et al., 1984; SOLERROVIRA et al., 1996; SIMON és SZENTE, 2000; HAIDEKKER, 2002; VERMES, 2003).

Since harmful, toxic and infective components may be present in sewage sludges, their utilization is more hazardous compared to other fertilizers. Between toxic components organic micropollutants and heavy metals (Cd, Hg, Pb, Zn, etc.) are the most dangerous, because of their direct toxicity to living organisms. Depending on their origin there is a great variation in heavy metal concentrations of municipal sewage sludges. Similarly to other countries of the world, heavy metal content limits the agricultural utilization of the Hungarian municipal sewage sludges, in spite of their relatively low heavy metal content (TAMÁS, 1995; SOLERROVIRA et al., 1996; SIMON et al., 2000; HAIDEKKER, 2002; VERMES, 2003; AMIR et al., 2005).

Uncontrolled amendment of arable soils with sewage sludges may result in excessive accumulation of heavy metals in soil, and through soil–plant system these dangerous materials can get into the food chain (KÁDÁR, 1995, 1999, SILVEIRA et al., 2003). During agricultural utilization of sewage sludges, therefore, their harmful effect on the surface and subsoil water, plants, animals, and human health have to be minimized or reduced. All these are possible in case of knowledge of chemical and biological processes in treated soils.

The research of sewage sludge – soil – plant – heavy metal interaction have started at the College of Nyíregyháza Technical and Agricultural Faculty (Nyíregyháza, Hungary) 10 years ago. Three variously pre-treated municipal sewage sludges were selected in present study to compare their effects on basic soil and cultivated plants. It can be supposed, that the used pre-treatments of sewage sludges (composting after digesting in Nyíregyháza, anaerobic digestion and dewatering in Debrecen, granulation and mixing with mineral materials in Miskolc) will be widely utilized in Hungarian practice for successful final disposal and utilization. When sewage sludges were selected for our study it was also considered that their composition is heterogenous and their heavy metal content differ from each other.

I have compared the effects of four times applied low doses of sewage sludges on fodder plants and soil with the effects and after-effects of higher doses which were applied in two parts into the soil.

Based on the issues mentioned above, the aims of my research were the following:

1. Chemical analysis of experimental soil and applied municipal sewage sludges:
   Quantity determination of „total” heavy metal content (Cd, Cr, Cu, Ni, Pb and Zn) in basic uncontaminated soil (which was utilized for the pot experiment), and sewage sludge from Nyíregyháza (which was composted after digestion), sewage sludge from Debrecen (which was anaerobically digested, and was dewatered), and sewage sludge from Miskolc (which was granulated, then mixed with rhyolite tuff and carbide lime and matured).

   Analysis of chemical forms of heavy metals in experimental soil and variously pre-treated municipal sewage sludges: examination of potentially „phytoavailable” and „exchangeable” (potentially leaching) element content of untreated soil and of applied sewage sludges, and analysis of chemical forms of heavy metals in sludges using sequential extraction technique.

2. Examination of heavy metals in soil–plant system in case of sewage sludge applications:
   Setting up of the sewage sludge loading pot experiments in the growth chamber of the College of Nyíregyháza, Department of Land and Environmental Management between 2001 and 2003.

   Evaluation the effects of applied sludges on the heavy metal content in basic soil: examination of differences of heavy metal concentration in sludge-treated soils, observation of heavy metal content changes, and analysis of „phytoavailable” element content of treated soil.

Evaluation of heavy metal accumulation in test plants (which were cultivated in the order of rye, sudangrass, winter rape, fodder pea) grown in sewage sludges treated soil, and analysis of relationship between „phytoavailable" element concentration of soil and plant uptake of heavy metals.

3. Examination of dry matter yield of fodder plants influenced by sewage sludge applications.
4. Evaluation of soil microbiological effects of applied municipal sewage sludges in pot experiment with fodder pea test plant: on the quantity of soil microorganisms (determination of total numbers of bacteria and microscopic fungi), and on several, from the agricultural application aspect important activity of enzymes (measurement of the activity of phosphatase, urease, dehydrogenase and cellulose enzymes).

2. MATERIALS AND METHODS

2.1. Materials

Untreated, uncontaminated basic soil utilized for the pot experiments was collected from the 0-30 cm soil level of the demonstration garden of the College of Nyíregyháza, Technical and Agricultural Faculty (Nyíregyháza, Hungary). The most important characteristics of this soil (Ramann's rusty brown forest soil) were the following: pH_{H2O} 7.66; pH_{KCl} 7.48; clay + silt content 24.9%; humus content 1.3%; total lime content $CaCO_3$ 5.9%; total water-soluble salt content 0.03%; bioavailable nutrient content: P_2O_5 1396±20 mg/kg, K_2O 725.11±55 mg/kg, Mg 295.2± 32 mg/kg, NO_3^- + NO_2^- 46.17±2 mg/kg.

Municipal sewage and sludge treatment technology and variously treated sewage sludges of three county towns (Nyíregyháza, Debrecen, Miskolc) were studied. Spatial average samples from sewage sludges were taken. Spatial average samples were taken from the various spots of a given place, which were carefully mixed. Sewage sludge from Nyíregyháza was digested in earth-basin, and was composted with wheat straw. The basic characteristics of this compost were the following: pH_{H2O} 6.35; total water-soluble salt content 3.21%; total organic matter content 21.9%; total (Kjeldahl) N 0.99±0.05 mg/kg; total P 6827±225 mg/kg; total K 2707±15 mg/kg. Sewage sludge from Debrecen was anaerobically digested, and was dewatered. The characteristics of this sewage sludge were the following: pH_{H2O} 6.51; total water-soluble salt content 7.40%; total organic matter content 55.23%; total (Kjeldahl) N

3.68±0.3 mg/kg; total P 20400±265 mg/kg; total K 1833±38 mg/kg. Granulated sewage sludge from Miskolc was matured with rhyolite tuff and carbide lime. The most important characteristics of this sludge were the following: pH_{H2O} 12.52; total water-soluble salt content 2.80%; total organic matter content 9.12%; total (Kjeldahl) N 0.34±0.02 mg/kg; total P 1307±175 mg/kg; total K 1427±110 mg/kg.

2.2. Pot experiments with fodder plants

Series of pot experiments were set up on Ramann's rusty brown forest soil. The sewage sludge loading experiments were performed in the growth chamber of the College of Nyíregyháza, Department of Land and Environmental Management between 2001 and 2003. Test plants were cultivated on uncontaminated soil (it meant the control treatment) and on soil–sludge mixtures. At the beginning of the experiment series the ratio of sewage sludges from Nyíregyháza, Debrecen and Miskolc was 2.5% or 10% (m/m), respectively, which corresponds to 75, and 300 t/ha sludge doses in case of field experiments. To continue this pot experiment the soil was further loaded with sewage sludges. The low dose of sludges was further enhanced by 2.5% (m/m) in soil–sludge mixture before starting the next 3 experiments. This corresponds to 75 t/ha annual sludge application rate in case of field experiments. In case of higher dose the rate of sludges in soil–sludge mixture was enhanced by 5% (m/m) (150 t/ha/yr) in second experiment. In following experiments no more sludge were mixed to the soil. Rye (*Secale cereale* L. cv. Kisvárdai legelő) was grown in soil-sewage sludge mixture in my first pot experiment. Shoots were sampled 40 days after sowing. At the termination of this experiment (65 days after sowing) shoot and root samples were taken. After soil–sludge mixtures incubating (the mixture were stored in plastic sack at room temperature for about 3 months) the rate of sewage sludges in soil–sludge mixtures was enhanced in case of low 2.5% dose of sludges to 5%, (m/m) while in case of higher 10% dose to 15% (m/m), respectively. Second pot experiment was set up with sudangrass (*Sorghum bicolor* (L.) Moench x *Sorghum sudanense* (Piper) Stapf. cv. Gardavan). After 65 days of sudangrass growth and soil–sludge mixture incubating the low 5% dose of sewage sludge from Nyíregyháza, Debrecen or Miskolc was raised to 7.5 % (m/m), while in case of higher 15 % dose this value remained unchanged in soil-sewage sludge mixture. Winter rape (fodder rape) (*Brassica napus* L. ssp. *oleifera* Metzg. Ap. Sinsk. cv. Emerald) test plant was grown in this pot experiment for 65 days. At the termination of the experiments the low 7.5% dose of sewage sludges was enhanced to 10% (m/m) while in case of higher dose the 15% remained also unchanged in soil cultures. This experiment was set up with fodder pea (*Pisum sativum*

L. (partim) cv. IP 5), which was harvested before flowering, when test plant was 60 days old. Roots and shoots samples were collected at the harvest of fodder plants in case of each and every experiment. Soil samples were taken two times during the experiments for the first time after sewage sludge dose rising, and then before sowing of test plants. The second soil sampling was done at the harvest of fodder plants. The treatments and percentual rations (m/m%) of municipal sewage sludges are summarized in Table 1.

Table 1: Treatments of sewage sludge loading pot experiments (Nyíregyháza, Hungary, 2001-2003)

Treatments	Percentage of sewage sludges (m/m%)			
	Experiment 1 with rye test plant	Experiment 2 with sudangrass test plant	Experiment 3 with fodder rape test plant	Experiment 4 with fodder pea test plant
Control	0	0	0	0
Low dose of SS from Nyíregyháza	2.5	5	7.5	10
High dose of SS from Nyíregyháza	10	15	15	15
Low dose of SS from Debrecen	2.5	5	7.5	10
High dose of SS from Debrecen	10	15	15	15
Low dose of SS from Miskolc	2.5	5	7.5	10
High dose of SS from Miskolc	10	15	15	15

Abbreviation: SS=sewage sludge

2.3. Extractions and analysis of elements

Before „total" element concentration determining the soil and sewage sludge samples were digested with cc. HNO_3 - cc. H_2O_2 using the method of KOVÁCS et al. (2000) and considering the Hungarian standard MSZ 21470-50:1998. The Lakanen-Erviö extraction (LAKANEN and ERVIÖ, 1971) was performed according to MSZ 21470-50:1998. The „exchangeable" (potentially leaching) ($CaCl_2$-soluble) heavy metal content was determined according to HOUBA et al. (1986). The chemical forms of heavy metals in variously pre-treated municipal sewage sludges were also determined using sequential extraction. A chemical fractionation procedure according to PETRUZZELLI et al. (1994) was used to estimate water-soluble (distilled water extract), exchangeable (KNO_3-extract), and organically bound ($CaCl_2$+EDTA extract) forms of heavy metals in sludges. The dry matter of plants was digested in cc. HNO_3 - cc. H_2O_2 (3:1 v/v, 3 M HNO_3 final concentration) mixture according to KOVÁCS et al. (1996) before determining the „total" element concentration.

Multielemental analysis of was done with inductively coupled plasma optical emission spectroscopy (ICP-OES) technique.

2.4. Soil microbiological effects of sewage sludges

The soil microbiological effects of three variously pre-treated municipal sewage sludges were studied in the fourth pot experiment. Fodder pea was cultivated in soil, which was untreated (control 0%) or amended with 10% or 15% sewage sludge. Soil samples were taken three times during the experiment; (1) for the first time at the harvest of the previous crop (this was fodder rape), (2) for the second time after soil–sewage sludge mixture incubating (and after two weeks of sewage sludge dose rising), and then at the sowing of the fodder pea. (3) The third soil sampling was done after 60 days of fodder pea growth, at the harvest of the plants.

The total numbers of bacteria and microscopic fungi in soil samples were determined using plate dilution method (SZEGI, 1979). The numbers of bacteria was determined on Bouillon agar, while in case of the microscopic fungi selecting pepton-glucose agar culture medium was used. The number of microorganisms was referred to 1 g dry soil.

The measurement of the activity of phosphatase was carried out according to KRÁMER és ERDEI (1959) at the original soil pH. Phenol forming from phenyl phosphate was measured with spectrophotometer, expressed in P_2O_5 mg/100g/24h. The activity of urease was determined using method of Kuprevics and Scherbakova modified by Kempers (FILEP, 1988). Ammonia (NH_4^+ mg/100g/24h) forming from carbamide was measured with spectrophotometer. The activity of dehydrogenase was measured according to MERSI and SCHINNER (1991), based on the determination of residual iodonitrotetrazolium formazan (INTF µg/1g/2h) with spectrophotometer. The activity of cellulase was evaluated according to MERSI and SCHINNER (1996), the glucose forming (glucose µg/g/24h) was measured with spectrophotometer.

2.5. Statistical analysis

We used the Microsoft Excel programme to filter and analyse experimental data, and to calculate Pearson's correlation coefficients. The statistical analysis of the results of the pot experiments were carried out with SPSS 12.0.1 software, using analysis of variance followed by Tukey's b-test.

3. RESULTS

3.1. Heavy metal concentrations in untreated experimental soil and in applied sewage sludges, and chemical forms of heavy metals

The basic characteristics of untreated experimental soil meets the requirements of the 50/2001. (3. IV.) Hungarian governmental regulation, and concentrations of toxic metals (Cd–0.99; Cr–15.6; Cu–15.1; Ni–8.77; Pb–43.6; Zn–71.3 mg/kg) are below the regulatory limits. Therefore, parameters of soil could be advantageous in case of agricultural utilization of municipal sewage sludges.

Table 2 shows „total" (cc. HNO_3+H_2O_2 soluble) metal concentrations in applied – variously pre-treated – municipal sewage sludges.

Table 2: „Total" heavy metal concentrations (mg/kg) in applied sewage sludges (2001), and regulatory limits of toxic element concentrations in municipal sewage sludges

Elements (mg/kg)	Sewage sludge from Nyíregyháza*	Sewage sludge from Debrecen*	Sewage sludge from Miskolc*	Regulatory limit**
Cd	2.54	2.42	1.29	10
Cr	29.3	166	14.7	1000
Cu	92.2	319	41.1	1000
Ni	11.8	22.3	3.38	200
Pb	93.1	84.4	25.5	750
Zn	792	1091	222	2500

* Data are means of 3 replications.
**Heavy metals concentration regulatory limits in sewage sludges in case of agricultural utilization (50/2001. (3. IV.) governmental regulation, Appendix 5)

The studied municipal sewage sludges proved to be relatively uncontaminated with heavy metals; their metal content was conciderably lower than the values of Hungarian regulatory limits. Of the studied six toxic elements in sludges, Zn was present in the highest amounts. Comparing heavy metal contents of sewage sludge from Nyíregyháza, Debrecen and Miskolc, Cr content of sludge from Debrecen was higher than average (Table 2).

„Phytoavailable" (Lakanen-Erviö soluble) and „exchangeable" ($CaCl_2$ soluble) heavy metal concentration in soil and in sewage sludges were determined. Comparing the heavy metal content in various extractants of untreated soil, Lakanen-Erviö soluble element contents were 47.5-42.3-29.6-28.6-18.8-1.73% of the „total" (cc. HNO_3+H_2O_2 soluble) Cd-Cu-Pb-Zn-Ni-Cr concentrations, respectively. This suggests that at the beginning of the experiments (before application of sludges) considerable amount of Cd and Cu occupied soil fraction that was potentially available for plant uptake. Of the studied six toxic elements in untreated soil, mostly Cr was present in soil fractions that were not plant available. In case of „exchangeable" (potentially leaching) heavy metal concentrations in soil Cd, Cu and Ni approached the limits, while Cr, Pb and Zn were below analytical detection limits for ICP-OES.

Comparing „available" (Lakanen-Erviö soluble) heavy metal concentrations to the „total" heavy metal concentrations of sewage sludge compost from Nyíregyháza, the following order was found: Zn (63%) > Cd (58%) > Cu (55%) > Pb (31%) > Ni (23%) > Cr (5%). In case of digested sewage sludge from Debrecen this order was found to be the following: Zn (52%) > Cd (48%) > Ni (33%) > Pb (23%) > Cu (20%) > Cr (2,5%). Relative element proportions in the Lakanen-Erviö fraction of sewage sludge from Miskolc were the following: Cu (47%) > Zn (36%) = Cd (36%) > Ni (31%) > Cr (8%) > Pb (6%). It means that considerable amount of „total" Zn, Cd and Cu content in studied sewage sludges was found in potentially phytoavailable form, and this rate was the highest in case of compost from Nyíregyháza.

Very low percentual ratios were calculated when „exchangeable" heavy metal concentrations in sludges were compared to „total" metal concentrations, and in many cases the measured values were below analytical detection limits for ICP-OES.

Chemical forms of heavy metals in applied sewage sludges were determined by sequential extraction technique, too. Figure 1-6 shows sequential extraction results in relative percentage („total" element content was considered 100%).

Sequential extraction results shows that heavy metals in the studied sewage sludges are in various chemical forms. In case of sewage sludge compost from Nyíregyháza considerable percentage of the total Cr was extracted from the first water soluble fraction, but Cd, Cu, Pb and Zn were found predominately in the third organically bound fraction, while Ni was prevalent in all three soil fractions. In case of sewage sludge from Debrecen Cr, Cu and Ni was present primarily in the first fraction, while the greatest concentrations of Cd, Pb and Zn occupied the third fraction, this latter means that these heavy metals are mainly in organic complex and carbonate bound forms. In case of sewage sludge from Miskolc the studied toxic elements were found to be present in the first (i.e. water soluble) fraction.

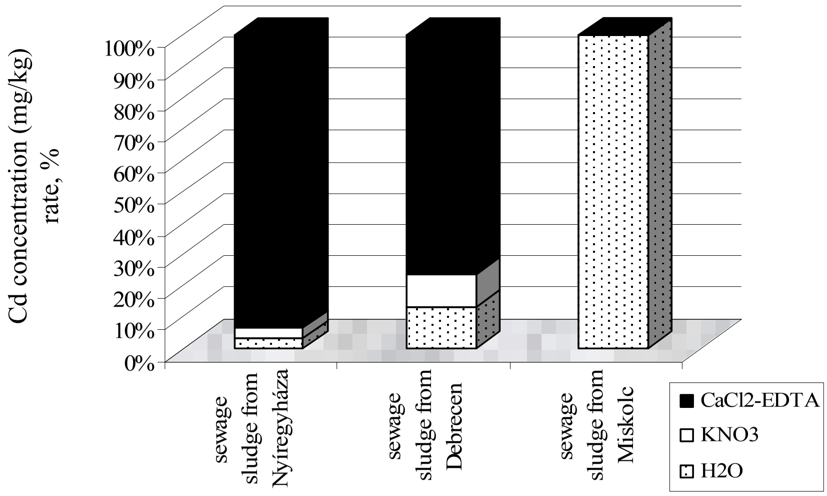


Figure 1: Relative Cd-distribution in sequential extraction fractions

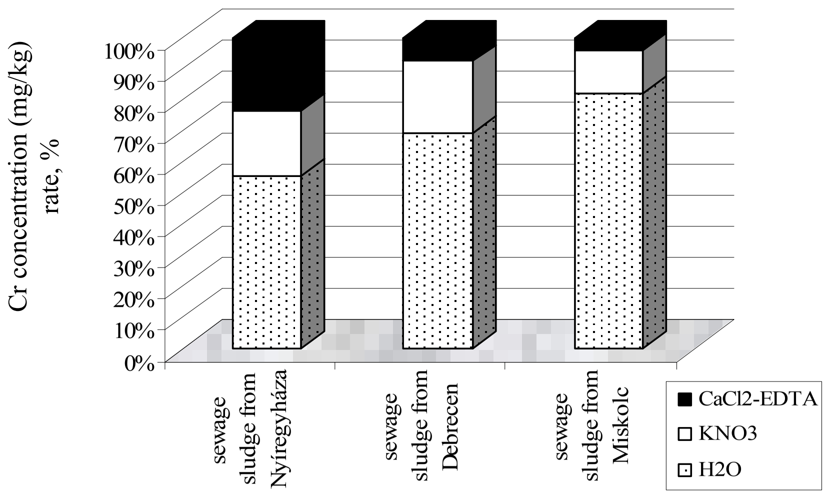


Figure 2: Relative Cr-distribution in sequential extraction fractions

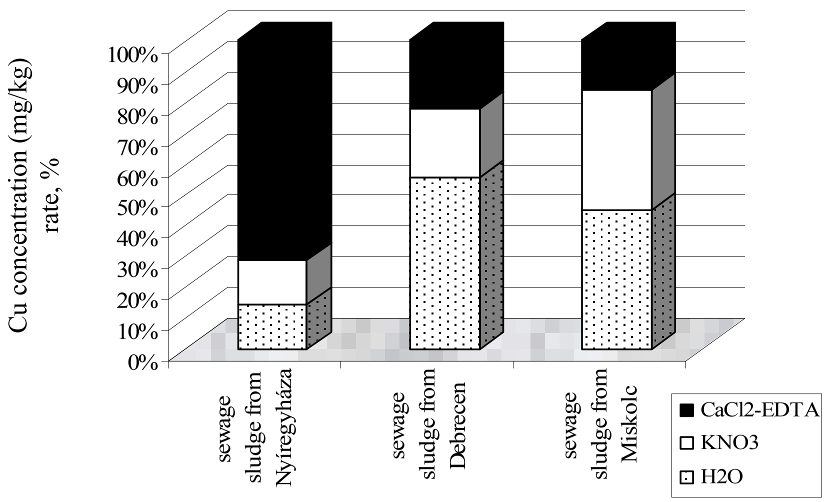


Figure 3: Relative Cu-distribution in sequential extraction fractions

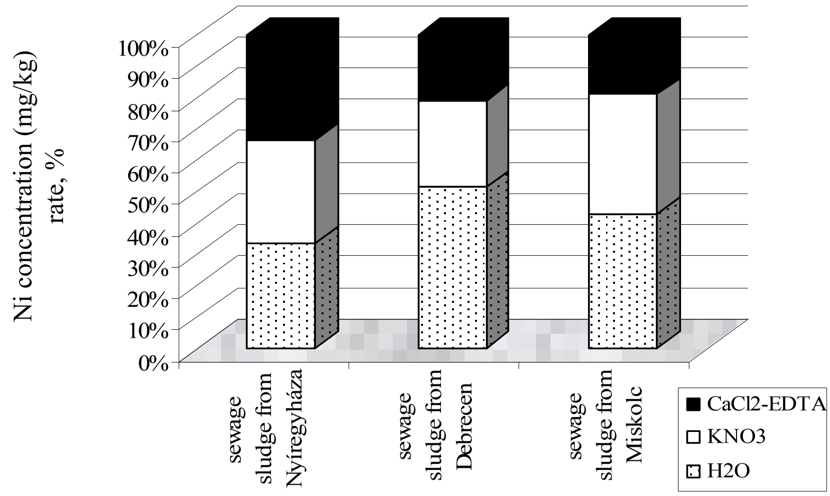


Figure 4: Relative Ni-distribution in sequential extraction fractions

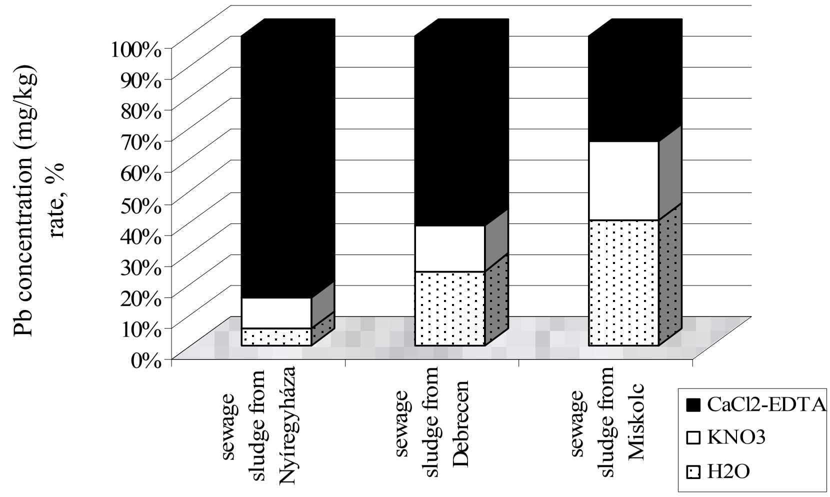


Figure 5: Relative Pb-distribution in sequential extraction fractions

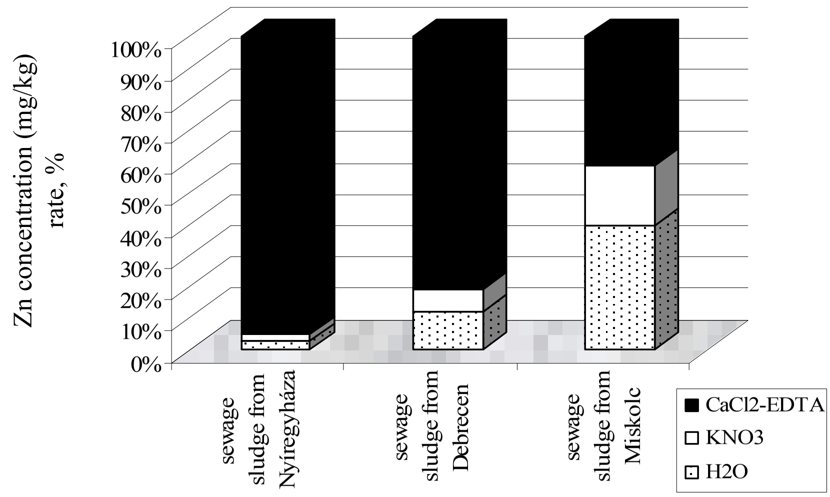


Figure 6: Relative Zn-distribution in sequential extraction fractions

3.2. Heavy metals in soil–plant system in case of sewage sludge applications

3.2.1. Effect of variously pre-treated municipal sewage sludges on the „total" and „phytoavailable" heavy metal concentration of soil

Impact of municipal sewage sludges on the heavy metal concentration of treated soil was studied in pot experiments. It was found, that both doses of the studied three sewage sludges have significantly enhanced the Cu and Zn concentration of soil as compared to the control (Table 3). The highest heavy metal content in soil was observed in case of high dose of sludge from Debrecen. Because of highest Cr content of sewage sludge from Debrecen the Cr content of treated soil was more enhanced that in case of other two sewage sludges.

Heavy metal concentrations in sludge-treated soil were compared to the toxic elements' concentration regulatory limits in soil valid for agricultural utilization of sewage sludges. In case of high dose of sewage sludge from Nyíregyháza and Debrecen the Zn concentration in soil was above the value of Hungarian regulatory limit in the experiments with sudangrass and fodder rape. When high dose of sludge from Debrecen was mixed to the soil in experiment with fodder pea the Zn content in soil also exceeded the regulatory limit (200 mg/kg), when high dose of sludge from Debrecen was mixed to the soil (Table 3). Zn accumulation in soil warns us for the suitable calibration of the doses of sewage sludge before agricultural utilization.

Repeated low doses of composted sewage sludge from Nyíregyháza and granulated sewage sludge from Miskolc enhanced significantly the "total" Pb and Zn concentrations in treated soil between 2001 and 2003. Low dose of sewage sludge from Debrecen significantly enhanced the Cr, Cu, Pb and Zn concentrationa in soil during the studied period. In case of all three sludges, which were applied in high dose and in two parts in the first half of the experiment series, a significant increase was found only in Pb concentration of soil at the end of the experiments. It can be supposed that because of soil buffering capacity heavy metals were strongly bound to soil colloids.

Effect of applied sludges on the „phytoavailable" element concentration of soil was also evaluated. It was found that the rate of „total" and „phytoavailable" element concentrations in soil samples was different in case of each element. The concentrations of Cr in the Lakanen-Erviö extract of sludge-treated soil remained below compared to the control, while the „available" Cu, Zn and Cd content increased at the beginning and at the end of experiments. It predicted that these elements will be accumulated in test plants.

Table 3: Effect of variously treated municipal sewage sludges on the copper and zinc concentration of soil (pot experiments, Nyíregyháza, Hungary, 2001-2003)

Treatments		Elements (mg/kg)			
		Rye	Sudangrass	Fodder rape	Fodder pea
		Cu			
Control	before sowing	16.4[a]	20.5[a]	19.2[a]	15.1[a]
	after harvest	17.3[ab]	18.9[a]	19.3[a]	14.0[a]
Low dose of SS from Nyíregyháza	before sowing	17.8[ab]	24.0[a]	24.1[c]	23.7[cd]
	after harvest	19.3[bc]	22.9[a]	25.5[c]	23.8[cd]
High dose of SS from Nyíregyháza	before sowing	24.0[d]	31.9[b]	31.5[d]	25.7[d]
	after harvest	26.0[d]	31.1[b]	31.1[d]	27.3[d]
Low dose of SS from Debrecen	before sowing	23.7[d]	33.7[b]	39.6[e]	44.7[e]
	after harvest	23.7[d]	32.7[b]	40.3[e]	42.2[e]
High dose of SS from Debrecen	before sowing	44.6[e]	62.8[c]	67.3[f]	59.1[f]
	after harvest	51.8[f]	61.4[c]	64.7[f]	58.3[f]
Low dose of SS from Miskolc	before sowing	17.5[ab]	21.1[a]	20.7[ab]	15.8[a]
	after harvest	18.0[ab]	21.0[a]	20.6[ab]	16.8[ab]
High dose of SS from Miskolc	before sowing	20.7[c]	23.1[a]	23.5[bc]	17.7[ab]
	after harvest	21.2[c]	24.0[a]	22.6[bc]	20.0[bc]
		Zn			
Control	before sowing	68.2[a]	87.7[a]	90.1[a]	107[c]
	after harvest	69.3[a]	82.4[a]	88.0[a]	86.1[ab]
Low dose of SS from Nyíregyháza	before sowing	85.8[b]	129[c]	148[d]	173[f]
	after harvest	88.2[b]	123[bc]	162[de]	140[d]
High dose of SS from Nyíregyháza	before sowing	143[c]	202[d]	222[f]	189[h]
	after harvest	156[d]	194[d]	216[f]	156[e]
Low dose of SS from Debrecen	before sowing	97.3[b]	138[c]	177[e]	182[gh]
	after harvest	96.3[b]	135[c]	175[e]	160[ef]
High dose of SS from Debrecen	before sowing	161[d]	225[e]	270[h]	207[i]
	after harvest	174[e]	218[e]	251[g]	161[ef]
Low dose of SS from Miskolc	before sowing	67.9[a]	91.3[a]	95.5[ab]	100[bc]
	after harvest	65.9[a]	86.7[a]	102[ab]	82.3[a]
High dose of SS from Miskolc	before sowing	86.0[b]	109[b]	122[c]	106[c]
	after harvest	87.7[b]	112[b]	111[bc]	88.4[ab]

Data are means of 4 replications. Tukey's b-test. Means within the columns followed by the same letter are not statistically significant at P=0.05. Abbreviation: SS=sewage sludge
Low dose: Rye=2.5%, Sudangrass=5%, Fodder rape=7.5%, Fodder pea=10%
High dose: Rye=10%, Sudangrass=15%, Fodder rape=15%, Fodder pea=15%

3.2.2. Impact of municipal sewage sludges on the heavy metal accumulation in fodder plants, and evaluation of relationship between phytoavailable element concentration of soil and plant uptake of heavy metal

Analysis of heavy metal concentration in test plants revealed that toxic elements were accumulated prevalently in the roots of plants. The studied metals were not transported to above ground parts of plants, with the exception of Cu and Zn. The Cu and Zn concentrations measured in the shoots of test plants were considerably lower than the critical values valid for fodders (50, 300 mg/kg, respectively). Therefore, the Cu and Zn accumulation can be evaluated as advantageous (Table 4).

Table 4: Effect of variously treated municipal sewage sludges on the copper and zinc accumulation in fodder plants (pot experiments, Nyíregyháza, Hungary, 2001-2003)

Treatments	Elements (µg/kg)				
	Rye		Sudangrass	Fodder rape	Fodder pea
	40-day-old	65-day-old			
	Cu				
	Root				
Control		20.0^{a}	11.6^{a}	25.9^{a}	27.3^{a}
Low dose of SS from Nyíregyháza		25.2^{abc}	13.8^{ab}	38.0^{a}	35.8^{ab}
High dose of SS from Nyíregyháza		30.5^{bc}	24.5^{c}	29.9^{a}	37.7^{ab}
Low dose of SS from Debrecen		33.2^{cd}	18.9^{bc}	38.6^{a}	69.4^{c}
High dose of SS from Debrecen		47.2^{e}	19.1^{bc}	35.0^{a}	46.0^{b}
Low dose of SS from Miskolc		22.5^{ab}	13.2^{ab}	35.3^{a}	35.1^{ab}
High dose of SS from Miskolc		41.2^{de}	15.2^{ab}	30.7^{a}	30.2^{a}
	Shoot				
Control	13.5^{ab}	11.2^{a}	4.26^{a}	3.26^{a}	4.17^{a}
Low dose of SS from Nyíregyháza	13.2^{a}	12.6^{ab}	8.14^{b}	3.73^{ab}	5.25^{abc}
High dose of SS from Nyíregyháza	13.3^{a}	13.6^{ab}	8.87^{b}	4.05^{ab}	4.74^{ab}
Low dose of SS from Debrecen	13.3^{a}	12.4^{a}	10.2^{b}	4.99^{b}	6.50^{c}
High dose of SS from Debrecen	15.3^{b}	14.9^{bc}	12.6^{b}	6.63^{c}	8.14^{d}
Low dose of SS from Miskolc	14.2^{ab}	11.4^{a}	8.61^{b}	3.32^{a}	5.54^{abc}
High dose of SS from Miskolc	14.2^{ab}	15.9^{c}	10.0^{b}	4.34^{ab}	6.21^{bc}
	Zn				
	Root				
Control		400^{a}	62.3^{a}	90.5^{a}	153^{ab}
Low dose of SS from Nyíregyháza		620^{a}	80.7^{ab}	156^{a}	193^{b}
High dose of SS from Nyíregyháza		540^{a}	113^{b}	153^{a}	156^{ab}
Low dose of SS from Debrecen		550^{a}	89.1^{ab}	134^{a}	220^{b}
High dose of SS from Debrecen		451^{a}	114^{b}	122^{a}	202^{b}
Low dose of SS from Miskolc		303^{a}	56.1^{a}	139^{a}	101^{a}
High dose of SS from Miskolc		477^{a}	72.0^{ab}	95.4^{a}	108^{a}
	Shoot				
Control	80.7^{b}	107^{bc}	40.9^{a}	30.2^{a}	24.0^{a}
Low dose of SS from Nyíregyháza	88.6^{b}	87.8^{abc}	60.1^{ab}	42.4^{ab}	43.2^{c}
High dose of SS from Nyíregyháza	88.3^{b}	123^{c}	93.7^{bc}	54.9^{bc}	44.3^{c}
Low dose of SS from Debrecen	85.0^{b}	72.1^{ab}	78.9^{abc}	58.7^{c}	50.6^{c}
High dose of SS from Debrecen	85.9^{b}	87.0^{abc}	110^{c}	83.4^{d}	63.8^{d}
Low dose of SS from Miskolc	62.1^{ab}	58.3^{a}	57.4^{ab}	28.0^{a}	33.9^{b}
High dose of SS from Miskolc	53.6^{a}	80.2^{ab}	60.7^{ab}	37.9^{a}	43.9^{c}

Data are means of 4 replications. Tukey's b-test. Means within the columns followed by the same letter are not statistically significant at P=0.05. Abbreviation: SS=sewage sludge
Low dose: Rye=2.5%, Sudangrass=5%, Fodder rape=7.5%, Fodder pea=10%
High dose: Rye=10%, Sudangrass=15%, Fodder rape=15%, Fodder pea=15%

The Cr concentration in sewage sludge from Debrecen was found to be higher than average, which was also manifested in treated soil. In spite of this, test plants accumulated only low amounts of Cr from the soil, and translocation of Cr within the plants was negligible. Based on the element concentrations of test plants grown in treated soil, the applied sludges the studied trace elements were taken as a basis, made the crop fit for animal consumption.

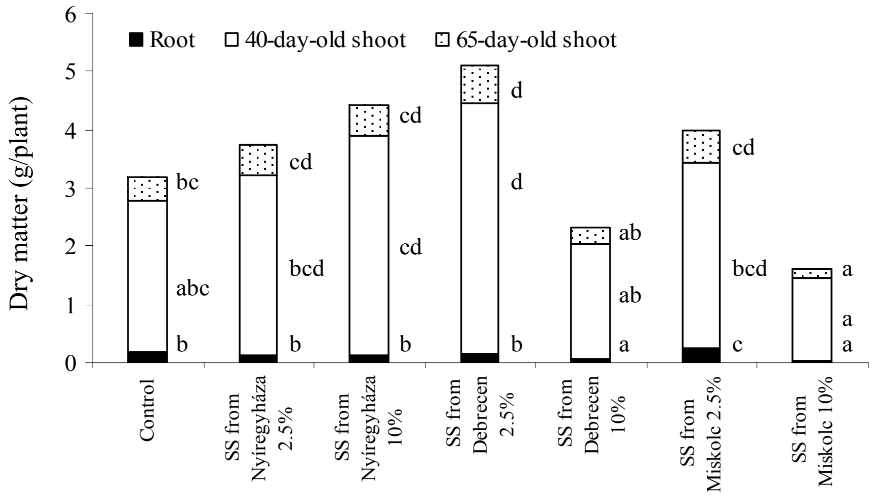
The „available" element concentration in the NH_4-acetate+EDTA extract of soil does not correlate in every case with the plant uptake of elements, it was different for each element and every plant. The only exception was copper, in this case a close, positive correlation (Pearson's correlation; r_{Cu}= 0,84-0,99) was found between Cu content in the Lakanen-Erviö extract and plant uptake of Cu.

3.3. Dry matter yield of fodder plants grown in sewage sludge-treated soil.

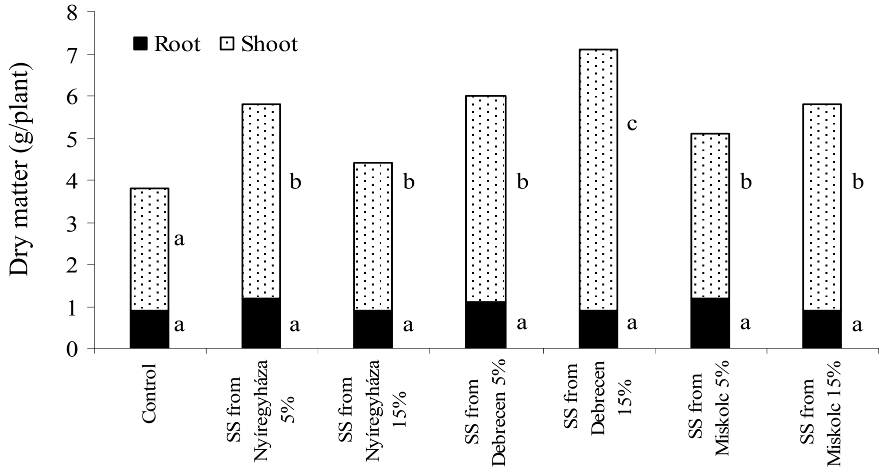
Low doses of all three of sewage sludges had influenced positively the dry matter yield of test plants. The most beneficial effect was observed in case of anaerobically digested and dewatered sewage sludge from Debrecen, when sludge was applied repeatedly in low doses. This positive effect on dry matter yield can be attributed to considerable amount of nitrogen present in sludge from Debrecen. The higher dose of sewage sludge from Debrecen, however, reduced dry matter accumulation of rye and fodder pea. The higher dose of sewage sludge from Miskolc depressed dry matter yield of rye. The high Zn accumulation in plants may explain this negative effect.

Figure 7 shows dry matter yield of test plants grown in sewage sludge–soil mixture.

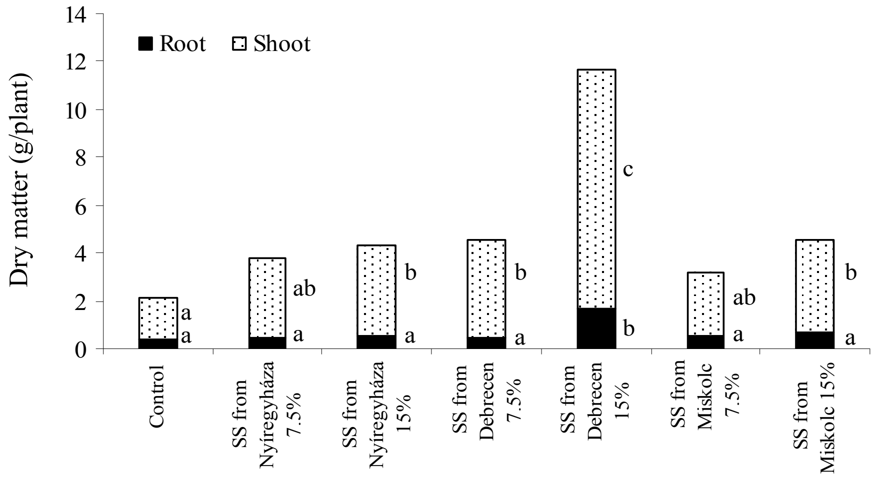
a) Rye



b) Sudangrass



c) Fodder rape



d) Fodder pea

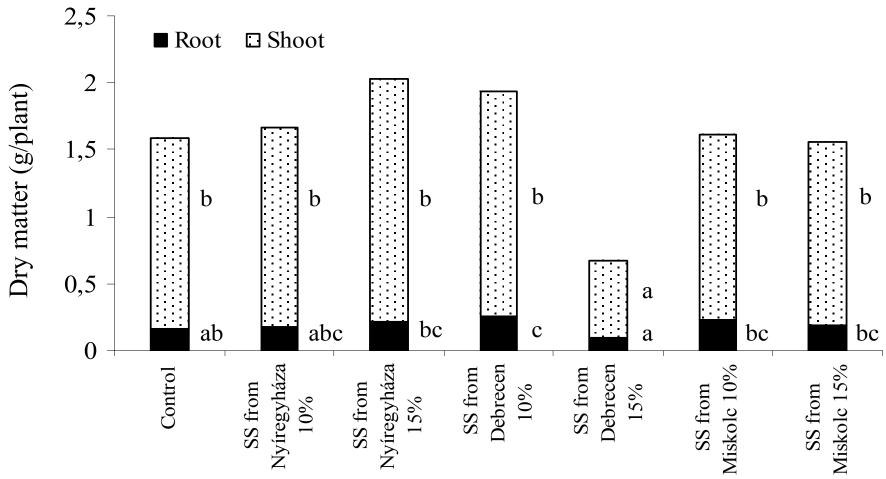


Figure 7: Effect of municipal sewage sludges on the dry matter yield of test plants (pot experiments, Nyíregyháza, Hungary, 2001-2003)

Data are means of 4 replications. Tukey's b-test. Means within the columns followed by the same letter are not statistically significant at P=0.05. Abbreviation: SS=sewage sludge

3.4. Effect of variously pre-treated municipal sewage sludges on the microbe composition and enzyme activity of the soil

According to the results of soil microbiological examination in experiment with fodder pea, a close relationship was found between the sewage sludge treatments and the number and activity of soil microbes. All sewage sludges at all three sampling times enhanced significantly the total numbers of bacteria and microscopic fungi. Even high doses of sewage sludges have not reduced significantly these parameters.

The application of sewage sludge enhanced the activity of urease, dehydrogenase and cellulase, while the activity of phosphatase was not influenced (Table 5). This beneficial effect can presumably be attributed to materials present in sewage sludge that stimulate the proliferation of soil microbes and the activity of enzymes.

Table 5: Effect of municipal sewage sludges on the soil enzymatic activity (pot experiment, Nyíregyháza, Hungary, 2003)

Treatment (ratio of sewage sludge mixed with the soil, %)	Phosphatase activity, P_2O_5 mg/100g/2h	Urease activity, NH_4 –N mg/100g/24h	Dehydrogenase activity, INTF µg/g/2h	Cellulose activity, glucose µg/g/24h
(1) At the harvest of the previous crop				
Control (0%)	9.37^{ab}	118^{a}	136^{a}	14.4^{a}
SS from Nyíregyháza 7.5%	8.34^{ab}	123^{a}	209^{a}	44.0^{ab}
SS from Nyíregyháza 15%	5.20^{a}	130^{a}	230^{ab}	74.9^{ab}
SS from Debrecen 7.5%	13.4^{b}	198^{b}	383^{b}	105^{bc}
SS from Debrecen 15%	8.67^{ab}	317^{c}	377^{b}	166^{c}
SS from Miskolc 7.5%	9.37^{ab}	124^{a}	189^{a}	62.3^{ab}
SS from Miskolc 15%	8.15^{ab}	124^{a}	144^{a}	48.7^{ab}
(2) Two weeks after the application of sludges				
Control (0%)	13.05^{a}	107^{a}	92.7^{a}	32.8^{a}
SS from Nyíregyháza 7.5%	18.3^{a}	114^{ab}	174^{b}	36.4^{a}
SS from Nyíregyháza 15%	13.9^{a}	118^{ab}	182^{b}	48.9^{a}
SS from Debrecen 7.5%	9.23^{a}	175^{b}	422^{c}	135^{b}
SS from Debrecen 15%	12.1^{a}	327^{c}	406^{c}	173^{b}
SS from Miskolc 7.5%	15.6^{a}	128^{ab}	177^{b}	32.9^{a}
SS from Miskolc 15%	11.2^{a}	120^{ab}	172^{b}	12.5^{a}
(3) At the harvest of fodder pea				
Control (0%)	3.70^{a}	137^{a}	77.7^{a}	8.25^{a}
SS from Nyíregyháza 7.5%	2.39^{a}	135^{a}	131^{b}	11.6^{a}
SS from Nyíregyháza 15%	1.91^{a}	181^{a}	120^{b}	14.9^{a}
SS from Debrecen 7.5%	2.93^{a}	354^{b}	336^{d}	48.9^{b}
SS from Debrecen 15%	1.52^{a}	645^{c}	233^{c}	70.2^{c}
SS from Miskolc 7.5%	2.52^{a}	184^{a}	103^{b}	13.3^{a}
SS from Miskolc 15%	4.30^{a}	147^{a}	108^{b}	7.43^{a}

Data are means of 4 replications. Tukey's b-test. Values followed by the same letters are not statistically significant at $P<0.05$. Abbreviations: SS=sewage sludge

All municipal sewage sludges had a positive influence on the total number of microbes and on the activity of enzymes in the soil, but their effects differed slightly from each other. The most beneficial effect was exhibited by the digested, dehydrated sewage sludge from Debrecen. In case of this sludge it can be supposed that the organic matter was slightly biodegraded, therefore, more mineralizable organic matter was applied, which stimulated the biological processes in sludge-treated soil. The sewage sludge from Nyíregyháza (which was composted after digestion) and Miskolc (which was granulated and mixed with minerals and matured) had similar, but somewhat less beneficial effects on these parameters compared to the sludge from Debrecen.

Environment-friendly treatment of municipal sewage sludges in case of agricultural utilization has a primary importance. To get municipal sludge which is rich in nutrients and poor in harmful substances and which is not hazardous for environment an appropriate pre-treatment of sewage is needed. Our results show that all studied sludge treatments could contribute to successful final disposal of sewage sludges in agriculture.

4. NEW SCIENTIFIC RESULTS

1. The variously pre-treated municipal sewage sludges contain the studied toxic elements (Cd, Cr, Cu, Ni, Pb, Zn) in various chemical forms. Zn, Cd and Cu in sludges are present primarily in the Lakanen-Erviö fraction, indicating potential plant availability of these elements. The results of sequential chemical extraction confirmed also the potential bioavailability of Zn, Cd, Cu and Pb.
2. The applied sewage sludges enhanced the concentration of heavy metals (mostly Cu and Zn) in treated soil as compared to the control. The repeated low dose-applied sewage sludges more enhanced heavy metals' concentration in soil than higher doses applied in two parts.
3. The rate of „total" and „phytoavailable" heavy metal concentrations in sludge-treated soil was different in case of each element. Cu, Zn and Cd were present in soil fraction that was potentially available for plant uptake. The mobility

4. Generally heavy metals were accumulated prevalently in the roots of test plants, which could be advantageous in case of animal feeding of biomass. Enhanced levels of essential Cu and Zn were measured in aboveground tissues of test plants. This, however does not decrease directly the fodder value of the test plants.

5. PRACTICAL APPLICATION OF THE RESULTS

1. Application of municipal sewage sludges enhanced the dry matter yield of fodder plants, After a suitable dose calibration, therefore, municipal sewage sludges can be used successfully for increasing biomass productivity of fodder plants.
2. When appropriately used in agriculture, studied sewage sludges may have a positive influence on the biological activity of the soil, having a beneficial effect on the dynamics of the nutrient cycles and enhancing soil fertility.
3. According to dry matter yields and soil microbiology examinations anaerobically digestion was the most advantegeous pre-treatment of sewage sludges. Regarding the toxic element concentration in sludge-treated soil and heavy metal accumulation in test plants, however, granulation and maturation with mineral substances such as rhyolite tuff and carbid lime is the most adequate treatment of sludges.

REFERENCES

AMIR, S., M. HAFIDI, G. MERLINA, J. C. REVEL, 2005. Sequential extraction of heavy metals during composting of sewage sludge. Chemosphere. 59. 801-810.

EPSTEIN, E., 2002. Land Application of Sewage Sludge and Biosolids. Lewis Publishers. Boca Raton FL. USA.

FILEP GY., 1988. Talajvizsgálat. Egyetemi jegyzet. DATE. Debrecen. 105-107.

GAZDAG I., 2003. Elvárások a víziközmű-ellátás és -szolgáltatás területén az EU-csatlakozási szerződés teljesítése érdekében. Vízellátás, csatornázás. Info-Prod Kiadó és Kereskedő Kft., Budapest. (VI.) 6-13.

HAIDEKKER B., 2002. A szennyvíziszap-felhasználás előnyei és veszélyei. Környezetvédelmi Füzetek. BME OMIKK, Budapest.

HOUBA, V. J. G., I. NOVOZAMSKY, A. M. HUYBREGTS, J. J. VAN DER LEE, 1986. Comparison of soil extractions by 0.01 M $CaCl_2$ by EUF and some conventional extraction procedures. Plant and Soil. 96. 433-437.

JUHÁSZ E., 2000. A szennyvíziszap kezelése. In: Környezettechnika. (Szerk.: BARÓTFI I.) Mezőgazda Kiadó. Budapest.

KÁDÁR I., 1995. A talaj–növény–állat–ember tápláléklánc szennyeződése kémiai elemekkel Magyarországon. Akaprint. KTM, MTA TAKI, Budapest.

KÁDÁR I., 1999. A tápláléklánc szennyeződése nehézfémekkel. Agrokémia és Talajtan. 48. 561-581.

KOVÁCS, B., Z. GYŐRI, J. PROKISCH, J. LOCH, P. DÁNIEL, 1996. A study of plant sample preparation and inductively coupled plasma emission spectrometry parameters. Communications in Soil Science and Plant Analysis. 27. 1177-1198.

KOVÁCS, B., J. PROKISCH, A. BALLA KOVÁCS, A. J. PALENCSÁR, 2000. Studies on soil sample preparation for inductively coupled plasma atomic emission spectrometry analysis. Communications in Soil Science and Plant Analysis. 31. 1949-1963.

KRÁMER, M., ERDEI, G., 1959. Application of the method of phosphatase activity determination in agricultural chemistry. Soviet Soil Sci. 9. 1100-1103.

LAKANEN, E., R. ERVIÖ, 1971. A comparison of eight extractants for determination of plant available micronutrients in soil. Acta Agronomica Fennica. 123. 223-232.

MERSI, W., F. SCHINNER, 1991. An improved and accurate method for determining the dehydrogenase activity of soils with iodonitrotetrazolium-chloride. Biol. Fertil. Soils. 11. 216-220.

MERSI, W., F. SCHINNER, 1996. CM-Cellulose Activity. In: Methods in Soil Biology. (Ed.: SCHINNER, F. et al.) 190-193. Springer-Verlag Berlin Heidelberg.

PETRUZZELLI, G., M. OTTAVIANI, L. LUBRANO, E. VESCHETTI, 1994. Characterization of heavy metal mobile species in sewage sludge for agricultural utilization. Agrochimica. 38. 277-284.

SILVEIRA, M. L. A., L. R. F. ALLEONI, L. R. G. GUILHERME, 2003. Biosolids and heavy metals in soils. Scientia Agricola, 60. 793-806.

SIMON L., PROKISCH J., GYŐRI Z., 2000. Szennyvíziszap komposzt hatása a kukorica nehézfém-akkumulációjára. Agrokémia és Talajtan. 49. 247-255.

SIMON L., SZENTE K., 2000. Szennyvíziszap komposzt hatása a kukorica nitrogéntartalmára, néhány élettani jellemzőjére és hozamára. Agrokémia és Talajtan. 49. 231-246.

SOLERROVIRA, P., J. SOLERSOLER, J. SOLERROVIRA, A. POLO, 1996. Agricultural use of sewage sludge and its regulation. Fertilizer Research. Kluwer Academic Publ., Dordrecht. 43. 173-177.

SZEGI J., 1979. Talajmikrobiológiai vizsgálati módszerek. Mezőgazdasági Kiadó. Budapest.

SZLÁVIK I., OLÁH J., SZŐNYI I., 1984. Települési szennyvíziszapok mezőgazdasági elhelyezése és hasznosítása. VIZDOK. VMGT-148. Budapest.

TAMÁS J., 1995. Szennyvíziszapokkal terhelt talajok nehézfém forgalma. Debreceni Agrártudományi Egyetem Tudományos Közleményei. Debrecen. 31. 101-112.

THYLL SZ., 1998. Vízszennyezés, vízminőségvédelem. Debreceni Agrártudományi Egyetem. Debrecen. (egyetemi jegyzet).

VERMES L., 2003. Szakirodalmi áttekintés a szennyvíziszapok elhelyezésével és hasznosításával foglalkozó publikációkról. BKÁE Kertészettudományi Kar Talajtan és Vízgazdálkodás Tanszék, Budapest.

50/2001. (IV. 3.) KORM. RENDELET a szennyvizek és szennyvíziszapok mezőgazdasági felhasználásának és kezelésének szabályairól. Magyar Közlöny. 39. 2532-2543.

25/2002. (II. 27.) KORM. RENDELET a Nemzeti Települési Szennyvíz-elvezetési és -tisztítási Megvalósítási Programról. Magyar Közlöny. 27. 1596-1640.

MSZ-21470-50, 1998. Környezetvédelmi talajvizsgálatok. Az összes és az oldható toxikuselem-, a nehézfém- és a króm(VI)tartalom meghatározása. Magyar Szabványügyi Testület, Budapest.

PUBLICATION LIST REFFERING TO THE SUBJECT OF THE THESIS

Book chapter in Hungarian (domestic publisher)

Uri Zs., Simon L., Kovács B., 2003. Szudánifű nehézfém akkumulációjának vizsgálata szennyvíziszapokkal kezelt talajból. In: Simon L.**,** Szilágyi M. (szerk.), 2003. Mikroelemek a tápláléki láncban. Bessenyei György Könyvkiadó, Nyíregyháza. 290-300. old. ISBN:963 9385 81 6

Lectured publications in periodicals (in Hungarian)

Uri Zs., Simon L., 2005. Települési szennyvíziszapok hatása a takarmánynövények réz és cink akkumulációjára. Acta Agronomica Óváriensis 47. (1): 61-66.

Uri Zs., Lukácsné Veres E., Kátai J., Simon L., 2006. Különböző módon előkezelt települési szennyvíziszapok hatása a talaj mikroorganizmusaira és enzimaktivitására. Agrokémia és Talajtan. 54. (3-4): 439-450.

Lectured conference proceeding in English (international)

Uri Zs., L. Simon, P. Keresztúri, 2003. Accumulation of heavy metals in rye (*Secale cereale* L.) from municipal sewage sludges. Proceedings of the 5th International Multidisciplinary Conference, Serie C, Volume XVII, Baia Mare, Romania, May 23-24, 2003. pp. 529-532.

Keresztúri, P., G. Lakatos, **Zs. Uri**, L. Simon, 2003. Evaluation of possibility of phytostabilization of heavy metals by plants. Proceedings of the 5th International Multidisciplinary Conference, Serie C, Volume XVII, Baia Mare, Romania, May 23-24, 2003. pp. 243-246.

Uri Zs., L. Simon, B. Kovács, 2003. Heavy metal concentration in rye grown in soil treated with three different municipal sewage sludges from Eastern Hungary. Proceedings of the 7th International Conference on the Biogeochemistry of Trace Elements, Uppsala, Sweden, June 15-19, 2003. pp. 300-301.

Varga, Cs., **Zs, Uri**, 2005. Effect of municipal sewage sludges on CO_2 production of soil. Proceedings of the 6th International Multidisciplinary Conference, Serie C, Volume XIX, Baia Mare, Romania, May 27-28, 2005. pp. 769-774.

Lectured conference proceeding in English (domestic publisher)

Uri, Zs., L. Simon, 2003. Heavy metals in municipal sewage sludges from Eastern Hungary. In: Pais, I. (ed.), Proceedings of the 10th International Trace Element Symposium, July 2002, Budapest, Hungary. pp. 334-341. ISBN 963 9256 951

Uri, Zs., Z. Győri, L. Simon, 2005. Accumulation of cadmium, chromium, copper, nickel, lead and zinc from sewage sludges in soil and rye. In: Simon, L. (ed.), Proceedings of the International Scientific Conference „Innovation and Utility in the Visegrad Fours". Volume 1. Environmental Management and Environmental Protection. October 13-15, 2005. Nyíregyháza, Hungary. Continent-Ph. Nyíregyháza. pp. 49-54. ISBN:963 86918 0 8 Ö, ISBN:963 86918 2 4

Uri, Zs., Sz. Thyll, L. Simon, 2005. Impact of municipal sewage sludges on heavy metal accumulation in soil and fodder rape. In: Simon, L. (ed.), Proceedings of the International Scientific Conference „Innovation and Utility in the Visegrad Fours”. Volume 1. Environmental Management and Environmental Protection. October 13-15, 2005. Nyíregyháza, Hungary. Continent-Ph. Nyíregyháza. pp. 55-60. ISBN:963 86918 0 8 Ö, ISBN:963 86918 2 4

Uri, Zs., L. Simon, 2006. Investigation of the accumulation of heavy metals from sewage sludges in fodder pea. In: Szilágyi, M., K. Szentmihályi (eds.), Proceedings of the International Symposium on Trace Elements in the Food Chain. May 25-27, 2006. Budapest, Hungary. pp. 210-214.

Reviewed conference abstract in Hungarian (domestic)

Uri Zs., Varga Cs., 2005. A szennyvíziszapok mezőgazdasági felhasználásának és kezelésének aktuális kérdései. „Tudásalapú gazdaság és életminőség” a „Magyar Tudomány Napja 2004“ alkalmából rendezett Szabolcs-Szatmár-Bereg Megyei Tudományos Konferencia kiadványa, Szabolcs-Szatmár-Bereg megyei Tudományos Közalapítvány Füzetei 21. Nyíregyháza, 2004. nov. 9., p. 466-469.

Non-reviewed conference abstracts in Hungarian (domestic)

Simon L., **Uri Zs**. 1999. Talajtisztítás növényekkel. „Regionalitás és tudományos minőség”, a „Magyar Tudomány Napja 1998“ alkalmából rendezett Szabolcs-Szatmár-Bereg Megyei Tudományos Konferencia előadás-összefoglalói, Szabolcs-Szatmár-Bereg megyei Tudományos Közalapítvány Füzetei 11. Nyíregyháza, 1998. nov. 5. p. 107.

Simon L., **Uri Zs**., 2000. Nyíregyházi települési szennyvíziszap komposzt hatása a kukorica tesztnövényre. „Életesélyek az ezredfordulón”, a „Magyar Tudomány Napja 1999“ alkalmából rendezett Szabolcs-Szatmár-Bereg Megyei Tudományos Konferencia előadás-összefoglalói, Szabolcs-Szatmár-Bereg megyei Tudományos Közalapítvány Füzetei 13. Nyíregyháza, 1999. nov. 3. p. 139.

Uri Zs., 2000. A szennyvíz- és szennyvíziszap kezelés, illetve elhelyezés lehetőségei Szabolcs-Szatmár-Bereg megyében. „A vidékfejlesztés szellemi erőforrásainak hasznosítása”, a „Magyar Tudomány Napja 2000“ alkalmából rendezett Szabolcs-Szatmár-Bereg Megyei Tudományos Konferencia előadás-összefoglalói, Szabolcs-Szatmár-Bereg megyei Tudományos Közalapítvány Füzetei 14. Nyíregyháza, 2000. nov. 7. p. 219.

Uri Zs., 2001. Szennyvíziszap elhelyezés és hasznosítás lehetőségei Szabolcs-Szatmár-Bereg megyében. MTA-AMB Kutatási és Fejlesztési Tanácskozás Nr.25. Előadások tartalmi összefoglalói, Gödöllő, 2001. jan. 23-24. p. 45.

Uri Zs., Simon L., 2001. Települési szennyvíziszapok nehézfém szennyezettségének vizsgálata szekvens extrakcióval. „A nyelv szerepe Európa kultúrájában”, a „Magyar Tudomány Napja 2001“ alkalmából rendezett Szabolcs-Szatmár-Bereg Megyei Tudományos Konferencia előadás-összefoglalói, Szabolcs-Szatmár-Bereg megyei Tudományos Közalapítvány Füzetei 15. Nyíregyháza, 2001. okt. 29. p. 205-206.

Uri Zs., Simon L., 2002. Különbözőképpen kezelt szennyvíziszapok nehézfém szennyezettségének vizsgálata. Heavy metals in fractions of diffrerent municipal sewage sludges. „JUTEKO 2002” „Tessedik Sámuel Jubileumi Mezőgazdasági Víz- és Környezetgazdálkodási Tudományos Napok” előadás-összefoglalói, Szarvas, 2002. aug. 29-30. p. 40-42.

Uri Zs., Simon L., 2002. Települési szennyvíziszap kezelések hatása a rozs (*Secale cereale* L.) nehézfém akkumulációjára. „Régiók szerepe, versenyképessége az Európai Unióban” a „Magyar Tudomány Napja 2002“ alkalmából rendezett Szabolcs-Szatmár-Bereg Megyei Tudományos Konferencia előadás-összefoglalói, Szabolcs-Szatmár-Bereg megyei Tudományos Közalapítvány Füzetei 18. Nyíregyháza, 2002. nov. 11. p. 208-209.