J. Elem. s. 519–532

DOI: 10.5601/jelem.2014.19.2.653

INTERACTION OF ORGANIC FERTILISATION WITH MULTI-COMPONENT MINERAL FERTILISERS AND THEIR EFFECT ON THE CONTENT OF MICROELEMENTS IN PERENNIAL RYEGRASS*

Piotr Styrczula[1], Ewa Możdżer[2]

[1]Factory of Mineral Fertilizers "Fosfan" SA, Szczecin
[2]Western Pomeranian University of Technology in Szczecin

Abstract

In 2007-2008, a plant growing pot experiment was carried out, in which the content of microelements, including heavy metals, in soil material and in compost produced by the GWDA method was found equal or less than the threshold values set by the Regulation of the Ministry of the Environment. Thus, the aim of this study was to determine the interaction between organic fertilisation and selected multi-component mineral fertilisers (SuproFoska 20, Suprofos 25 and Inmarc 4 with added urea) as well as their influence on the development of some qualitative traits of perennial rye-grass. The results showed that double doses of multi-component mineral fertilisers with urea contributed to a higher increase in the content of microelements in biomass of perennial ryegrass *Lolium perenne* than their single doses. The highest concentrations of cadmium, copper and lead were contained by ryegrass biomass after the application of a double dose of Inmarc 4, i.e. 9.37%, 11.0% and 2.81% more, respectively, than after the application of a single dose of SuproFoska 20 or Suprofos 25. The experiment demonstrated the highest content of cadmium, copper, manganese and lead in perennial ryegrass biomass in the treatments with combined organic (compost) and mineral (SuproFoska 20 with urea) fertilisation. However, the nickel and zinc content in biomass were the highest in the variant with combined organic (compost) and mineral (Inmarc 4 with urea) fertilisation. Multi-component mineral fertilisers and urea applied in combination with compost made of municipal sewage sludge increased the content of microelements in the biomass of cv. Stadion perennial rye-grass *Lolium perenne* when compared to the fertilisation objects with organic fertilisation alone.

Keywords: *Lolium perenne Stadion* cultivar, compost, multiple mineral fertilizers, content of heavy metal.

dr inż. Piotr Styrczula, Factory of Mineral Fertilizers "Fosfan" SA, Szczecin, ul. Nad Odrą 44/65, Szczecin, Poland, phone: 0694454879, e:mail: p.styrczula@fosfan.pl

* This study was conducted under the research and development project No N N305 359239.

WSPÓŁDZIAŁANIE NAWOŻENIA ORGANICZNEGO Z WIELOSKŁADNIKOWYMI NAWOZAMI MINERALNYMI NA ZAWARTOŚĆ MIKROSKŁADNIKÓW W ŻYCICY TRWAŁEJ

Abstrakt

W latach 2007-2008 przeprowadzono doświadczenie wegetacyjno-wazonowe. Zawartość mikroskładników, a wśród nich metali ciężkich, w materiale glebowym oraz użytym do badań kompoście wyprodukowanym metodą GWDA nie przekraczała wartości dopuszczalnych określonych w przepisach ministerialnych. Celem badań było określenie współdziałania nawożenia organicznego z wybranymi wieloskładnikowymi nawozami mineralnymi (SuproFoska 20, Suprofos 25 i Inmarc 4 z dodatkiem mocznika) w kształtowaniu niektórych cech jakościowych życicy trwałej. Wykazano, że podwojone dawki wieloskładnikowych nawozów mineralnych z dodatkiem mocznika przyczyniły się do zwiększenia zawartości mikroskładników w biomasie życicy trwałej *Lolium perenne* w porównaniu z dawkami pojedynczymi. Najwięcej kadmu, miedzi i ołowiu zawierała biomasa rośliny testowej po zastosowaniu podwojonej dawki Inmarc 4, odpowiednio o 9,37%, 11,0% i 2,81% więcej w porównaniu z wprowadzoną pojedynczą dawką SuproFoski 20 i Suprofosu 25. Stwierdzono, że najwięcej kadmu, miedzi, manganu i ołowiu w biomasie życicy trwałej było na obiektach z łącznym nawożeniem organicznym (kompost) i mineralnym (SuproFoska 20 z mocznikiem). Natomiast zawartość niklu i cynku w biomasie rośliny testowej była także największa na obiektach z łącznym nawożeniem organicznym i Inmarc 4 z mocznikiem w porównaniu z pozostałymi obiektami nawozowymi. Wieloskładnikowe nawozy mineralne i mocznik stosowane łącznie z kompostem wpływały na zwiększenie zawartości analizowanych mikroskładników w biomasie życicy trwałej *Lolium perenne* odmiany *Stadion* w porównaniu z obiektami, w których stosowano wyłącznie nawożenie organiczne.

Słowa kluczowe: życica trwała odmiana *Stadion*, kompost, wieloskładnikowe nawozy mineralne, zawartość metali ciężkich.

INTRODUCTION

The livestock of sheep, cattle and horses kept on farms has decreased considerably over the last several years. On the other hand, natural fertiliser prices have increased, while farmland liming has been neglected. These are the causes of growing acidification of over 50% of arable land. Changes have also taken place in the crop structure in favour of cereals and industrial crops. This leads to the imbalance of organic matter and nutrients in soils. Therefore, multidirectional research has been initiated with the aim to acquire new, cheap and environmentally safe sources of organic matter and nutrients for plants. Many authors claim that municipal sewage sludge may be used for fertilisation purposes (Aggelides, Londra 2000, Jakubus 2006, Selivanovskaya, Latypova 2006, Jasiewicz et al. 2007, Singh, Agrawal 2008, Hargreaves et al. 2008, Czekała 2008, Torri, Lavado 2008, Chiba et al. 2009) because it is rich in organic substances and some macro- and microelements (Walter et al. 2006, Haroun et al 2007, Ngole 2007, He et al. 2009). However, municipal sewage sludge may contain excessive amounts of heavy metals or be contaminated with pathogenic microorganisms, parasites and their live eggs. For this reason, municipal sewage sludge should meet the standards defined in the *Regulation of the Ministry of the Environment* (Official Journal of Law No. 137, item 934 of 2010) before being introduced into soil.

Saha et al. (2007) and Zhao et al. (2009) conclude that tests should be run on the presence of heavy metals as well as organic pollutants in sewage sludge. Organic pollutants are persistent organic compounds comprising carbon. The research carried out by Venkatesan and Senturpandian (2006) implies a very important role played by organic fertilisation, which determines the carbon content in soil and in general is positively correlated with soil activity. Dinesh et al. (2004) and Cai et al. (2007) claim that organic fertilisers are beneficial for the relationships between the soil tilth and its physical and chemical properties.

According to Kabata-Pendias and Pendias (1999), the main sources of cadmium and lead in arable soils unexposed to industrial emissions are mineral fertilisers. Gorlach and Gambuś (1997) believe that the degree of pollution, including heavy metals, caused by application of mineral fertilisers is most strongly affected by the raw material from which fertilisers are made, and by the technological processes through which they are manufactured. The fertilisers most heavily polluted with heavy metals include phosphate, lime, potassium and nitrogen formulas. Phosphate fertilisers may constitute a considerable source of soil pollution with heavy metals, particularly with cadmium. The average content of heavy metals in these fertilisers is arranged in the following order: Cd < Cu < Pb < Ni < Zn, with the level of their content being largely dependent on the form of fertiliser.

The aim of this study was to determine the interaction of organic fertilisation (compost produced from municipal sewage sludge) and selected multi-component mineral fertilisers (SuproFoska 20, Suprofos 25 and Inmarc 4 with added urea) as well as their impact on the development of some qualitative traits of perennial ryegrass.

MATERIAL AND METHODS

In spring 2007, a pot experiment was set in a greenhouse of the Western Pomeranian University of Technology in Szczecin. The soil material used in the experiment had the texture of heavy loamy sand and was classified as very good rye complex, soil quality class IVa.

The soil was characterised by reaction close to neutral (6.50). The content of plant-assimilable phosphorus, potassium and magnesium forms (64.5, 123.0 and 8.4 mg kg^{-1}, respectively) was average. The soil application of municipal sewage sludge composts necessitated determinations of the total content of heavy metals in the soil material (Table 1). The data in Table 1 show that the content of microelements, including heavy metals, did not exceed the acceptable levels specified in the *Regulation of the Ministry of the Environment* (Official Journal of Laws No. 137, item 934 of 2010) for the use of municipal sewage sludge.

Table 1

The content of microelements, including heavy metals, in the soil material used in the study

Cadmium	Copper	Manganese	Nickiel	Lead	Zinc
0.50	5.50	2.71	7.55	8.00	46.8

The compost used in the study was produced by the GWDA method and came from the Municipal Sewage Treatment Plant in Stargard Szczeciński. It contained more nitrogen and phosphorus (28.0 and 12.5 g kg^{-1} d.m., respectively) than potassium (6.00 g·kg^{-1} d.m.). The cadmium, copper, chromium, manganese, nickel, lead and zinc content (0.90, 67.0, 26.7, 259.0, 8.61, 56.0 and 143.0 mg kg^{-1} d.m.) in this compost was within the standards set by the *Regulation of the Ministry of Agriculture and Rural Development* (Official Journal of Laws No. 119, item 765 of 2008). Microbiological analyses received from the Municipal Sewage Treatment Plant in Stargard Szczeciński show that the compost made of municipal sewage sludge met the sanitary and hygienic requirements specified in ministerial regulations.

Table 2

The content of microelements in multi-component mineral fertilisers

Type of fertiliser	Microelement (mg kg^{-1} d.m)					
	Cd	Cu	Mn	Ni	Pb	Zn
SuproFoska 20	16.8	16.0	50.3	6.80	6.60	26.0
Suprofos 25	16.4	16.2	50.8	6.80	6.70	26.2
Inmarc 4	17.8	16.4	55.2	6.25	6.45	26.5

Based on the data comprised in Table 2, it is possible to conclude that the content of microelements, including heavy metals (such as cadmium, copper, manganese, nickel, lead and zinc), was within the standards set for mineral fertilisers (Official Journal of Laws No. 119, item 765 of 2008).

The study design included three factors (Table 3). The first factor was a series with and without municipal sewage sludge compost; the second factor was the type of multi-component mineral fertiliser (SuproFoska 20, Suprofos 25, Inmarc 4 with added urea), while the third one was the dose of multi-component mineral fertilisers. The test plant was perennial ryegrass (*Lolium perenne*) cultivar *Stadion.* Each of the experimental variants was run in four replications.

The soil material collected for analyses was sieved through a 5 mm mesh to remove larger impurities. Next, batches of 9 kg of the soil were put into pots. The dose of compost was determined at a level of 100 kg N ha^{-1}; this corresponded to 16.92 Mg fresh compost mass per 1 ha. When converted per pot, the compost dose was 50.8 g of fresh mass. In the treatments with planned application of municipal sewage sludge compost, the fertiliser was

Table 3

The design of pot vegetation experiment

Fertilisation objects and doses of mineral fertiliser	Without compost	With municipal sewage sludge compost at a dose corresponding to 100 kg N ha^{-1}
Control	+	+
SuproFoska 20 + urea – dose I	+	+
SuproFoska 20 + urea – dose II	+	+
Suprofos 25 + urea – dose I	+	+
Suprofos 25 + urea – dose II	+	+
Inmarc 4 + urea – dose I	+	+

spread on the soil surface and then mixed with the soil to the depth of 8-10 cm. After 7 days, mineral fertilisers were introduced into the soil material.

The dose of mineral fertilisers (SuproFoska 20, Suprofos 25 and Inmarc 4) was determined at a level of 200 kg ha^{-1} (dose I) and 400 kg ha^{-1} (dose II). When converted per pot, the fertilisers were applied in the amount of 0.6 g (dose I) and 1.2 g (dose II). Due to the low nitrogen content in the above multi-component mineral fertilisers, any possible nitrogen deficiency was prevented by the application of urea.

The multi-component mineral fertilisers and a 1/3 of the dose of urea in the form of aqueous solution were introduced into the soil material in spring 2007, prior to sowing ryegrass. The fertilisers were mixed with the soil material to the depth of 5-7 cm. After 5 days, perennial ryegrass was sown on the soil surface in pots, 50 seeds per each pot. The seeds were covered with 1 cm layer of quartz sand. Afterwards, the pots were placed under a foil roof. In order to maintain the moisture of soil material at 60% of full water capacity, the soil material and the plants in pots were sprinkled with redistilled water. The remaining 2/3 of the nitrogen dose in the form of urea were divided into 2 parts and applied in the form of aqueous solution after the first and the second cut of perennial rye-grass.

Each year, three cuts of the grass were harvested. In 2007, perennial ryegrass was sown on 19 April, the first cut harvested on 2 June, the second one was carried out 15 July and the third one took place on 26 August. After the last cut, the pots with grass were wintered in a greenhouse.

In spring 2008, the pots with grass were placed again under a foil roof. According to the design, doses of multi-component mineral fertilisers and 1/3 of the total dose of aqueous urea solution were introduced into the pots. The remaining doses of urea were introduced into soil after the first and the second cut of perennial ryegrass. The mineral fertiliser doses and plant care measures were the same as in 2007.

In 2008, three cuts of perennial ryegrass biomass were harvested, with the first cut made on 31 May, the second one – on 13 July and the third one – on 30 August. During the experiment, the yield of perennial ryegrass dry matter from each replication of every fertilisation treatment was determined in 2007 and 2008. The grass plants from the four replications of a given fertilisation object were mixed and ground. This way, averaged samples of the ryegrass biomass was obtained for all fertilisation variants. The total cadmium, copper, manganese, nickel, lead and zinc content was determined in the dry matter of collected perennial ryegrass samples after their previous wet mineralisation according to the Polish standards PN–ISO 11466 and PN-ISO 11047. The determinations were carried out with the method of atomic absorption spectrometry on a Perkin Elmer AAS 300 spectrometer.

The experiment was performed in a randomised complete block design with four replications and a control group. Statistical calculations on the significance of differences in the content of microelements, including some heavy metals, were conducted using a three factorial analysis of variance and FR-ANALWAR computer software. Confidence half-intervals were calculated at the significance level $p = 0.05$, using the Tukey's test.

RESULTS AND DISCUSSION

The average content of microelements in perennial ryegrass, including some heavy metals, obtained in the pot experiment is presented in Tables 4 and 5.

The data comprised in Tables 4 and 5 prove that the content of microelements in perennial ryegrass biomass was within the average values given by Kabata-Pendias and Pendias (1999). Whenever the multi-component mineral fertilisers SuproFoska 20, Suprofos 25 and Inmarc 4, used in the current experiment, are mentioned while describing the experimental results, it must be remembered that they were applied with urea due to their low nitrogen content.

The highest average content of cadmium in ryegrass biomass was determined in the variant with the application of the multi-component mineral fertiliser Inmarc 4 (0.34 mg Cd kg^{-1} d.m.). The cadmium concentrations in perennial ryegrass in the fertilisation treatments with SuproFoska 20 and Suprofos 25 were similar and 3.03% lower than in the variant with Inmarc 4. The type of multi-component mineral fertiliser with the urea supplementation did not have any significant effect on the differences in the cadmium content in the analysed ryegrass biomass. In the series without municipal sewage sludge compost, most cadmium was in perennial ryegrass biomass from the fertilisation object with Inmarc 4 (0.31 mg Cd kg^{-1} d.m.). Less cadmium was determined in plants fertilised with Suprofos 25 and SuproFoska 20 (6.89% and 10.7% less, respectively). The cadmium content in perennial ryegrass biomass in the fertilisation treatments with Suprofos 25 and Inmarc 4 was the same (0.36 mg Cd kg^{-1} d.m). Double doses of multi-compo-

Table 4

The effect of multi-component mineral fertilisers and urea applied with and without municipal sewage sludge compost on the average content of cadmium, copper and manganese in perennial ryegrass biomass. Mean values from two years (2007-2008) in mg kg^{-1} d.m. grass

Specification		Fertilisation variants											
		cadmmium				copper				manganese			
		fertilisers types (T)											
		Supro-Foska 20	Suprofos 25	Inmarc 4	mean	Supro-Foska 20	Suprofos 25	Inmarc 4	mean	Supro-Foska 20	Suprofos 25	Inmarc 4	mean
		+ urea				+ urea				+ urea			
Without compost	(C)	0.28	0.29	0.31	0.29	6.56	6.61	6.75	6.64	67.1	68.7	67.8	67.8
With compost		0.37	0.36	0.36	0.36	7.59	7.62	7.53	7.58	74.6	76.1	73.6	74.8
Dose I	(D)	0.32	0.32	0.33	0.32	6.91	7.01	7.00	6.97	69.7	71.0	69.1	69.9
Dose II		0.33	0.33	0.35	0.34	7.24	7.22	7.28	7.24	71.9	73.8	72.3	72.7
Mean		0.33	0.33	0.34		7.07	7.11	7.14		70.8	72.4	70.7	
Control without compost		0.25				5.59				62.7			
Control with compost		0.34				6.73				67.2			
LSD $_{0.05}$:													
Fertilisers types (T)		n.s.				n.s.				n.s.			
Fertilisation doses (D)		n.s.				n.s.				1.481			
Without and with addition of compost (C)		0.022				0.307				1.481			
Interaction TxC		n.s.				n.s.				n.s.			

Table 5

The effect of multi-component mineral fertilisers and urea applied with and without municipal sewage sludge compost on the average content of nickel, lead and zinc in perennial ryegrass biomass. Mean values from two years (2007-2008) in mg kg^{-1} d.m. grass

Specification		Fertilisation variants											
		nickiel				lead				zinc			
		fertilisers types (T)											
		Supro-Foska 20	Suprofos 25	Inmarc 4	mean	Supro-Foska 20	Suprofos 25	Inmarc 4	mean	Supro-Foska 20	Suprofos 25	Inmarc 4	mean
		+ urea				+ urea				+ urea			
Without compost	(C)	0.93	0.93	0.91	0.92	1.39	1.39	1.40	1.39	24.6	25.3	23.8	24.5
With compost		1.01	0.98	0.90	0.96	1.46	1.48	1.49	1.48	27.8	27.4	27.0	27.4
Dose I	(D)	0.97	0.95	0.93	0.95	1.42	1.42	1.43	1.42	25.5	25.6	25.0	25.4
Dose II		0.97	0.97	0.88	0.94	1.44	1.45	1.46	1.45	26.9	27.0	25.9	26.6
Mean		0.97	0.96	0.90		1.43	1.43	1.44		26.2	26.3	25.4	
Control without compost		0.87				1.32				21.4			
Control with compost		0.95				1.43				23.7			
LSD $_{0.05}$:													
Fertiliser types (T)		n.s.				n.s.				n.s.			
Fertilisation doses (D)		n.s.				0.022				0.691			
Without and with addition of compost (C)		n.s.				0.022				0.691			
Interaction TxC		n.s.				n.s.				n.s.			
Interaction TxD													
Interaction TxDxC													

nent mineral fertilisers and urea did not have any significant effect on the increase in the cadmium content in the examined biomass when compared to their single doses (Table 4). The largest increase in the cadmium content, by 9.37%, was found between the fertilisation variants with a single dose of SuproFoska 20 and Suprofos 25 versus the one with a double dose of Inmar 4. As reported by CZUBA (1996), in order to achieve high and good quality plant yields while preserving a high level of soil fertility, attention should be paid to the close interaction between organic and mineral fertilisers. This interaction grows stronger when optimal doses, terms and forms of applied mineral, natural and organic fertilisers are selected and the plant rotation system is likewise optimal.

The average content of copper in perennial ryegrass biomass ranged from 7.07 to 7.14 mg Cu kg^{-1} d.m. The highest copper concentration was found in ryegrass biomass in the fertilisation treatment with Inmarc 4, while the lowest one appeared in the pots fertilised with SuproFoska 20. Differences in the effect between the multi-component mineral fertilisers with urea on the copper content in perennial ryegrass biomass were not significant.

In the fertilisation objects with and without municipal sewage sludge compost introduced to soil, most copper was detected in perennial ryegrass biomass from pots with the multi-component mineral fertiliser Inmarc4 (6.75 and 7.53 mg Cu kg^{-1} d.m.). Less copper was obtained in the fertilisation objects with SuproFoska 20 and Suprofos 25, namely 2.1 and 2.89% less, respectively, than in pots with Inmarc 4 had. The doubling of the doses of multi-component mineral fertilisers and urea did not have any significant effect on the increase in the copper content in perennial ryegrass biomass when compared to their single doses (Table 4). Nevertheless, an increase was observed in the copper content, on average by 29.5%, when compared to the control object.

The average content of manganese in perennial ryegrass biomass in fertilisation treatments with multi-component mineral fertilisers and urea ranged from 70.7 to 72.4 mg Mn kg^{-1} d.m. The type of multi-component mineral fertilisers did not have any significant effect on the manganese content in the biomass but an average increase of 13.7% was found in its content when compared to the control object. Doubled doses of the mineral fertilisers added to soil significantly increased the manganese content in perennial ryegrass biomass when compared to their single doses.

The highest content of manganese in the experimental series without municipal sewage sludge compost was in perennial ryegrass biomass from the fertilisation variant with Suprofos 25 (68.7 mg Mn kg^{-1} d.m.), while the least manganese was in ryegrass biomass harvested from the pots with SuproFoska 20 (67.1 mg Mn kg^{-1} d.m.). After the application of the organic fertiliser, most manganese in biomass was obtained after the application of Suprofos 25, while the least was determined in the fertilisation variant with Inmarc 4.

Regarding single doses of the mineral fertilisers, most manganese was found in perennial ryegrass biomass from the fertilisation variant with Suprofos 25 (71.0 mg Mn kg^{-1} d.m.), while the least was in biomass harvested from the pots with Inmarc 4 (69.1 mg Mn kg^{-1} d.m). Double doses of mineral fertilisers induced the highest accumulation of manganese in perennial ryegrass biomass in the fertilisation treatment with Suprofos 25, while the lowest one was in the variant with SuproFoska 20. An increase in the manganese content in ryegrass biomass between these fertilisation objects reached 13.4%. An increase in the manganese content following the application of mineral fertilisation between dose I and dose II was 3.15, 3.94 and 4.63%, respectively. The highest increase in the manganese content in ryegrass biomass was obtained in the fertilisation treatments where organic fertilisation and a double dose of mineral fertilisers had been applied, reaching 19.3% and 15.9% respectively, when compared to the control (Table 4). Similar results were obtained by Antonkiewicz et al. (2003), Antoniewicz and Jasińska (2009) and Kasperczyk et al. (2001), who reported that organic fertilisers interact with mineral ones because they are rich in organic matter and some microelements which mineral fertilisers do not contain.

The nickel content in perennial ryegrass biomass did not undergo significant changes in response to the application of multi-component mineral fertilisers in the experimental series without municipal sewage sludge compost. Double doses of mineral fertilisers did not have any significant effect on the increase in the nickel content in biomass compared to their single doses. Nevertheless, an average increase was observed in the nickel content, by 8.33%, between the fertilisation objects and the control. Municipal sewage sludge compost introduced to soil did not have any significant effect on changes in the nickel content in perennial ryegrass biomass compared to exclusive organic fertilisation. The mineral fertilisers and their doses applied in conjunction with municipal sewage sludge compost did not have any significant effect on changes in the nickel content in ryegrass biomass (Table 5).

The average content of lead in perennial ryegrass biomass in the fertilisation variants with SuproFoska 20 and Suprofos 25 reached the same values (1.43 mg Pb kg^{-1} d.m.) and was slightly smaller (by 0.70%) than that in the fertilisation treatment with Inmarc 4. The doubling of doses of mineral fertilisers and urea significantly increased the lead content in biomass compared to single doses (Table 5). The highest average increase in the lead content in ryegrass biomass (by 12.1% versus the control) was obtained in the fertilisation variants with combined organic and mineral fertilisation.

In the experimental series without municipal sewage sludge compost, the highest zinc content in perennial ryegrass biomass was obtained after the introduction of Suprofos 25. This content was higher by 6.30 and 2.84% compared to the fertilisation variants with Inmarc 4 and SuproFoska 20. In the experimental series with municipal sewage sludge compost, the highest increase in the zinc content (by 2.96%) was obtained between the fertilisation treatments with SuproFoska 20 and Inmarc 4. When taking into account single and a double doses of the multi-component mineral fertilisers with urea, the highest increase in the zinc content (by 4.24%) occurred between the fertilisation variants with Suprofos 25 and Inmarc 4 (Table 6). The highest average increase in the zinc content in perennial ryegrass biomass appeared between the fertilisation objects without and with organic fertilisation as well as the one with mineral fertilisation (by 21.5% versus the control; Table 5). The multi-component mineral fertilisers used in the study did not have any significant effect on differences in the average content of zinc in perennial ryegrass biomass, whereas their doubling significantly increased its amount in biomass compared to their single doses. The applied organic fertilisation significantly affected the increase in the average cadmium, copper, manganese, lead and zinc content in perennial ryegrass biomass compared to the fertilisation treatments with municipal sewage sludge compost. In the opinion of Gorlach (1992), the risk of environmental loading with organic fertilisers is often larger than with mineral ones. The main reason is the inability to synchronise the release of nutrients from organic fertilisers with their demand by plants and with their large amounts of various organic compounds and heavy metals.

In brief, it is possible to state that most cadmium, copper and lead was accumulated in ryegrass biomass after the application of a double dose of Inmarc 4, more by 9.37%, 11.0% and 2.81% respectively, compared to single doses of SuproFoska 20 and Suprofos 25 introduced into soil. The results show that the highest cadmium, copper, manganese and lead content in perennial ryegrass biomass occurred in the fertilisation treatments with combined organic (municipal sewage sludge compost) and mineral (SuproFoska 20 with urea) fertilisation. However, the nickel and zinc content in ryegrass biomass was also the highest in the fertilisation variant with combined organic (compost) and mineral (Inmarc 4 with urea) fertilisation compared to the other fertilisation objects.

Similar results were obtained by Krzywy-Gawrońska and Gutowska (2007) and Krzywy-Gawrońska (2009), who showed that organic fertilisation contributes to some increase in the cadmium, copper, manganese, nickel and lead content in test plants. Iżewska (2007) reported that application of moderate doses of composts (5-20 Mg d.m. ha^{-1}) free from excessive amounts of heavy metals induced limited accumulation of the above metals in the biomass of energy crops, including grasses.

As reported by Kabata-Pendias and Pendias (1999), the abundance of cadmium, copper, manganese, nickel, lead and zinc in grasses is 0.05 to 0.8, 2.20 to 21.0, 20 to 665, 0.4 to 1.70, 0.30 to 3.50 and 3.70 to 29.8 mg kg^{-1} d.m., respectively. In our two-year experiment, the content of cadmium, copper, manganese, nickel, lead and zinc in perennial ryegrass biomass did not exceed the values given by Kabata-Pendias and Pendias (1999) in any of the tested fertilisation variants.

CONCLUSIONS

1. Municipal sewage sludge compost introduced into soil significantly affected the increase in the average content of cadmium, copper, manganese, lead and zinc in the biomass of perennial ryegrass *(Lolium perenne)* of the cultivar *Stadion* compared to the fertilisation variants without organic fertilisation.

2. Multi-component mineral fertilisers and urea applied with municipal sewage sludge compost increased the content of cadmium, copper, nickel, manganese, lead and zinc in perennial ryegrass biomass compared to the fertilisation variants with exclusive organic fertilisation.

3. As affected by single and double doses of multi-component mineral fertilisers and urea, the content of cadmium, copper, nickel, manganese, lead and zinc in perennial ryegrass biomass was higher than in the control.

4. Double doses of multi-component mineral fertilisers with urea contributed to the increase in the content of microelements in perennial ryegrass biomass when compared to their single doses.

5. The average content of cadmium, copper, manganese, nickel, lead and zinc in perennial ryegrass biomass did not exceed the standard values given in literature concerning the application of organic and mineral fertilisation during two-year experiments.

6. The results indicate that it is possible to combine the application of organic and mineral fertilisers when using their optimal doses and dates of fertilisation treatments.

REFERENCE

Aggelides S.M., Londra P.A. 2000. *Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil.* Biores. Techn., 71(3): 53-259. DOI:10.1016/S0960-8524(99)00074-7

Antonkiewicz J., Radkowski A., Jasiewicz C. 2003. *Effect of manure on the content and uptake of macroelements by meadow sward.* Zesz. Probl. Post. Nauk Rol. 494: 17-26. (in Polish)

Antonkiewicz J., Jasiewicz C. 2009. *Organic pollutants in sewage sludge*. Zesz. Probl. Post. Nauk Rol., 537: 15-23. (in Polish)

Cai Q.Y., Mo C.H., Wu Q.T., Zeng Q.Y. & Katsoyiannis A. 2007. *Concentration and speciation of heavy metals in six different sewage sludge-composts*. J. Hazard. Mat., 147: 1063-1072. DOI. 10.1016/j.jhazmet.2007.01.142.

Chiba M.K., Mattiazzo M.E., Oliveira F.C. 2009. *Sugarcane field in Untisol, Rusing sewage sludge as a phosphorus source.* Acta Sci-Agron., 31(3):495-501.

Czekała J. 2008. *Chemical properties of compost produced from municipal sewage sludge and various bio-waste.* J. Res. Appl. Agric. Engine., 53(3): 35-41. (in Polish)

Czuba R. 1996. *Mineral fertilization of crops*. Wyd. Zak. Chem. Police, ss 413. (in Polish)

Dinesh R., Chamdhuri S.G., Sheeja T.E., 2004. *Soil biochemical and microbial indices in wet tropical forests: Effect of deforestation and cultivation.* J. Plant Nutr. Soil Sci., 167:(1), 24-32. DOI:10.1002/jpln.200321254

Gorlach E. 1992. *Some ecological aspects of production and use of organic fertilizers.* Mat. Konf. Nauk. „Nawozy organiczne", Szczecin 8-9 września 1992, 5-13. (in Polish)

GORLACH E., GAMBUŚ F. 1997. *Phosphate and compound fertilizers as a source of soil contamination with heavy metals*. Zesz. Probl. Post. Nauk Rol., 448a:139-146. (in Polish)

HARGREAVES J.C., ADL M.S., WARMAN P.R. 2008. *A review of the use of composted municipal solid waste in agriculture*. Agric. Ecosys. Environ**.,** 123, 1-14. DOI. 10.1016/j.agee.2007.07.004

HAROUN, M., IDRIS, A., OMAR, S.R.S. 2007. *A study of heavy metals and their fate in the composting of tannery sludge.* Waste Manage., 27(11): 1541-1550. DOI:10.1016/j.wasman.2006.09.006

HE M., TLAN G., LIANG X. 2009. *Phytotoxicity and speciation of copper, zinc and lead during the aerobics composting of savage sludge*. J. Hazard. Mater., 163: 671-677. DOI.10.1016/j.jhazmat.2008.07.01

IŻEWSKA A. 2007. *Effect of fertilization with manure, sewage sludge and sludge compost on soil properties.* Zesz. Probl. Post. Nauk Rol., 518, 85-92. (in Polish)

JASIEWICZ CZ., ANTONIEWICZ J., MAZUR Z., KRAJEWSKI W. 2007. *Agrochemical properties of soil fertilized with sewage sludge from sewage treatment plant in Olecko*. Ecol. Chem. Eng., 14(5-6): 457-463. (in Polish)

JAKUBUS M. 2006. *Effect of long-term applications of sewage sludge on changes in selected soil chemical properties*. Zesz. Probl. Post. Nauk. Rol., 512: 209-219. (in Polish)

KABATA-PENDIAS A., PENDIAS H. 1999. *Biogeochemistry of trace elements.* Wyd. Nauk. PWN, Warszawa, ss 364. (in Polish)

KASPERCZYK M., RADKOWSKI A., KACORZYK P. 2001. *Force of fertilizer bovine manure.* Pam. Puł., 125: 37-42. (in Polish)

KRZYWY-GAWROŃSKA E. GUTOWSKA I. 2007. *The content of macro-and micronutrients in perennial ryegrass after application of compost from potato pulp and municipal sewage sludge.* Wyd. IMUZ Raszyn, Woda, Środowisko, Obszary Wiejskie, 7, 2a(20): 231-244. (in Polish)

KRZYWY-GAWROŃSKA E. 2009. *Investigations of the effect of compost from municipal sewage sludge and the active substance PRP Sol on soil fertility and productivity*. Monografia, Wyd. ZUT, Szczecin, 96. (in Polish)

NGOLE V.M., 2007. *Response of copper, lead and zinc mobility and bioavailability to sludge application on different soils*. Pol. J. Soil Sci., 40(2): 125-138.

Regulation of the Ministry of the Environment on municipal sewage sludge. Official Journal of Law No. 137, item 924 of 2010. (in Polish)

Regulation of the Ministry of Agriculture and Rural Development of 18 June 2008 on the execution of some provisions of the Act on fertilisers and fertilisation. Official Journal of Law No. 119, item 765 of 2 July 2008. (in Polish)

SAHA S., PRAKASH V., KUNDU S., KUMAR N., MINA B.L. 2008. *Soil enzymatic activity as affected by long-term application of farm yard manure and mineral fertilizer under a rainfed soybean wheat system in N-W Himalaya.* Europ. J. Soil Biol., 44: 309-315.

SELIVANOVSKAYA S.YU., LATYPOVA V.Z. 2006. *Effect of composted sewage sludge on microbial biomass, activity and pine seedlings in nursery forest.* Waste Manage., 26: 1253-1258. DOI: 10.1016/j.wasman.2005.09.018

SINGH R.P., AGROWAL M. 2007. *Potential benefits and risks of land application of sewage sludge*. Waste Manage., 28:347-358. DOI: 10.1016/j.wasman.2006.12.010

TORRI S.I., LAVADO R. 2008. *Zinc distribution in soils amended with different kinds of sewage sludge*. J. Environ. Manage., 88(4): 1571-1579. DOI: 10.1016/j.jenvman.2007.07.026

WALTER I., MARTINEZ F., CALA V. 2006. *Heavy metal speciation of phototoxic effects of three representative sewage sludges for agricultural uses*. Environ. Pollut, 139: 507-514. DOI.10.1016/j.envpol.2005.05.020

VENKATESAN S., SENTHURPANDIAN V.K. 2006. *Comparison of enzyme activity with depth under tea plantations and forested sites in south India.* Geoderma, 137: 212-216.

ZHAO Y., WANG P., LI J., CHEN Y., YING X., LIU S. 2009. *The effect of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat-maize cropping system.* Europ. J. Agron., 31(1): 36-42. DOI:10.10164/eja.2009.03.001