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SEWAGE SLUDGE AS SOURCE OF NITROGEN AND PHOSPHORUS FOR VIRGINIA FANPETALS

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Abstract

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By using sewage sludge for fertilization purposes it is possible to reduce amounts of mineral fertilizers used, to recycle biogenic substances in terrestrial ecosystems and to limit the costs of running plantations of energy crops. The objective of our study has been to assess the influence of sewage sludge on the content of macronutrients in Virginia fanpetals and the utilization of biogenic components from sewage sludge by the plants. Two forms of sewage sludge were tested: wet sludge dehydrated only by pressing and pelleted sludge. The content of dry matter, organic carbon, phosphorus, sodium, lead and nickel was higher in pelleted sludge. Wet sewage sludge had a more favourable effect on Virginia fanpetals' yield than sewage pellets. The form of sewage sludge had negligible impact on the content of crude ash, although wet sewage sludge increased the concentrations of nitrogen, calcium, magnesium and sodium in biomass of Virginia fanpetals. The highest amounts of crude ash and macronutrients (except phosphorus) were comprised in plants fertilized with the highest dose of sewage sludge. The accumulation of these components in plants increased parallel to the increase in doses of supplied sewage sludge. Plants utilized nitrogen and phosphorus more efficiently from wet sewage sludge than from its pelleted form.

Key words: wet sewage sludge, pelleted sewage sludge, macronutrients, Virginia fanpetals

Introduction

While the resource of fossil fuels are being depleted and the world fears climate change due to excessive carbon dioxide emission, a need arises to search for new sources of renewable energy. Biomass obtained from field plantations of perennial energy plants seems to be a possible solution (Stolarski et al., 2014; Kacprzak et al., 2012; Szczukowski et al., 2005). On the one hand, it helps to reduce the exploitation of non-renewable resources. On the other hand, it is an alternative to using forest biomass. According to Kabała et al. (2010), energy crop plantations, especially on marginal land or fertilized with sewage sludge, adhere to the principles of permanent and environmentally sustainable economic development.

In Poland, the total amount of municipal sewage sludge generated in 2013 was 540.3 mln t d.m., of which 19.5% (105.4 mln t d.m.) was used in agriculture, while another 11.7% was applied to land reclamation and cultivation of plants for compost (Environment, 2014). The domestic waste management plan of 2014 envisaged that less sewage sludge should be used directly in farming and for land reclamation. This document emphasizes the need to maximize the use of biogenic substances contained in sewage sludge, in which it resembles the conclusions drawn by some researchers, e.g. Ganchimeg Jambaldorj et al. (2007), Weigand et al. (2012). Numerous studies on the chemical composition of sewage sludge implicate that it could be a rich source of organic matter and plant nutrients (Arvas et al., 2011; Dusza et al., 2009; Fernandez et al., 2007; Flavel and Murphy, 2006; Kahiluoto

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et al., 2015, Mtshali et al., 2014; Sądej et al., 2007; Wang et al., 2005; Wei and Liu, 2005). However, prior to any application of sewagle sludge in the natural environment, the substance must be stablized and prepared through biological, chemical, thermal or other type of processing, so as to reduce its tendency towards putrefication and to eliminate any risk to the environment or to human health (Bień et al., 2011). The use of sewage sludge for fertilization limits the consumption of mineral fertilizers and returns biogenic elements to terrestrial ecosystems. Another advantage is the lower cost of running energy crops plantations (Stolarski et al., 2014; Petersen, 2003).

The objective of this study has been to determine the effect of sewage sludge on yields and content of macronutrients in aeraial biomass of Virginia fanpetals.

Materials and Methods

The research was based on two one-year, two-factor pot experiments with four replications (Table 1). Pots were filled with 10 kg of substrate of the texture of light loamy sand. The substrate had a slightly acid reaction (pH_{KCl}= 5.6), moderate abundance of available phosphprus (63.2 mg P/kg), high potassium (125.5 mg K/kg) and moderate magnesium (62.0 mg Mg/kg). Plants absorbed nitrogen and phosphorus from wet and pelleted sewage sludge produced at the Łyna Wastewater Treatment Plant, while being supplied potassium in the form of mineral fertilizer (potassium chloride). For comparison, Virgnia fanpetals plants grown without fertilization were taken.

Table 1
Design of experiment

Rate of sludge	Pelleted sewage sludge			Wet sewage sludge		
	N	P	K	N	P	K
	g per pot					
Control	0.00	0.00	0.00	0.00	0.00	0.00
N1	0.50	0.28	0.50	0.50	0.25	0.50
N2	1.00	0.56	1.00	1.00	0.50	1.00
N3	1.50	0.84	1.50	1.50	0.75	1.50

Two types of sewage sludge were tested in our experiments: wet sewage sludge passed through a press to remove extra moisture and pelleted sludge (Table 2). The content of dry matter, organic carbon, phosphorus, sodium, lead and nickel was higher in pelleted sludge, while the other analyzed elements were more abundant in wet sludge. The content of trace elements in both forms of sewage sludge was lower than the allowable amounts of heavy metals specified in the Regulation of the Minister for the Natural Enviornment of 13 July 2010, permitting use of municipal sewage sludge in agriculture.

Table 2
Chemical composition of sewage sludge

Specification	Units	Sewage sludge	
		pelleted	wet
Dry matter content	%	89.45	20.10
C org.	g/kg d.m.	31.42	25.82
N	g/kg d.m.	61.69	63.88
P	g/kg d.m.	34.70	31.84
Na	g/kg d.m.	0.644	0.291
Ca	g/kg d.m.	57.56	60.66
Mg	g/kg d.m.	22.56	26.65
Pb	mg/kg d.m.	36.60	34.35
Cd	mg/kg d.m.	1.26	1.25
Hg	mg/kg d.m.	1.37	2.04
Ni	mg/kg d.m.	45.14	37.40
Zn	mg/kg d.m.	1114.00	1491.17
Cu	mg/kg d.m.	223.04	331.33
Cr	mg/kg d.m..	89.10	99.37

The test plant was Virginia fanpetals, also known as Virgina mallow, grown from root cuttings. After harvest, the plants were weighed, dried and ground. The plant material was digested in concentrated sulphuric (VI) acid with hydrogen dioxide as an oxidant, and afterwards submitted to the following analyses: nitrogen – colorimetrically by the hypochlorite method, phosphorus – colorimetrically by the vanadium-molybdene method, potassium, calcium and sodium – by the atomic emission spectrometric method and magnesium – by the atomic absorption spectrophotometric method. The content of crude ash was assessed by the weight method, having ashed the plant material in a muffle furnace at the temperature of about 550°C.

The results were processed statistically by analysis of variance (supported by Statistica 10) and differences between means were compared by the Tukey's test at the significance level of $p = 0.01$.

Results and Discussion

Depending on the form of sewage sludge and level of fertilization, the yield of aerial biomass produced by Virginia fanpetals ranged from 20.15 to 53.95 g /pot d.m. (Figure. 1). More biomass was obtained from the pots fertilized with wet sludge (on average 37.62 g/pot d.m.) than with pelleted sludge (on average 32.79 g/pot d.m.). The yield of Virginia fanpetals nourished with wet sewage sludge increased as the

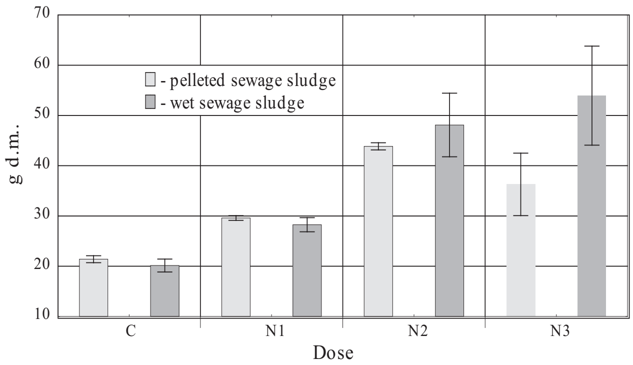

Fig. 1. Mass of Virginia fanpetals (means ± confidence interval)

sludge dose was raised, whereas among the treatments with pelleted sludge, the highest biomass was produced by Virginia fanpetals fertilized with the N2 dose.

Kalembasa and Wiśniewska (2006) report that mineral fertilization significantly differentiates the biomass yield of Virginia mallow. Sewage sludge applied in a dose equivalent to 100 kg N/ha increased the biomass yield of prairie cordgrass by 22% compared with the control (Helios et al., 2014). Chen et al. (2002) contend that composted sewage sludge is a valuable fertilizer to nourish grassland. Relative to the control, the yield of *Zoysia japonica* doubled after an applications of 45 t d.m./ha of compost produced from sewage sludge.

The content of crude ash in Virginia fanpetals ranged within 65.00–87.25 g/kg d.m. (Table 3). The form of sewage sludge did not affect it, but the medium and highest doses significantly increased the biomass content of crude ash. Among the macronutrients determined in biomass of Virginia fanpetals, the highest concentrations were achieved by potassium (19.94–30.48 g/kg d.m.), calcium (12.48–24.88 g/kg d.m.) and nitrogen (8.94–14.15 g/kg d.m.). Except for potassium, significantly higher quantities of macronutrients were determined in Virginia fanpetals fertilized with wet sewage sludge, but it was only the content of sodium and magnesium that was increased by a higher level of fertilization. Meanwhile, the highest concentration of phosphorus was found in control plants. Changes in the content of the other elements were less consistent.

Higher doses of sewage sludge did not affect the content of crude ash and macronutrients in aerial biomass of prairie cordgrass (Helios et al., 2014). In contrast, Ahmed et al. (2010) reported an increase in the yield and a higher concentration of nitrogen in barley as a result of fertilization with sewage sludge. According to Keskin et al. (2010), sewage sludge raised the content of nitrogen and potassium in awn-

Table 3
Content of crude ash and macronutrients in aerial biomass of Virginia fanpetals

Specification	Crude ash	N	P	K	Na	Ca	Mg
	g/kg d.m.						
Pelleted sewage sludge							
Control	69.50	9.12	2.99	29.25	0.223	19.55	2.63
N1	65.00	7.41	2.53	25.29	0.221	12.48	2.79
N2	85.50	9.17	2.06	19.94	0.232	12.48	2.87
N3	86.50	8.94	1.72	30.48	0.270	16.13	3.19
Mean	76.62	8.66	2.32	26.24	0.237	15.16	2.87
Wet sewage sludge							
Control	69.50	9.41	2.99	27.31	0.221	18.27	2.64
N1	69.50	10.58	2.54	23.75	0.298	18.61	3.53
N2	85.00	9.74	2.50	28.28	0.409	18.89	3.75
N3	87.25	14.15	2.84	28.59	0.479	24.88	4.42
Mean	77.81	10.97	2.72	26.98	0.352	20.16	3.58
Mean for dose							
Control	69.50	9.27	2.99	28.28	0.222	18.91	2.63
N1	67.25	9.00	2.53	24.52	0.259	15.54	3.16
N2	85.25	9.46	2.28	24.11	0.321	15.69	3.31
N3	86.87	11.55	2.28	29.53	0.375	20.51	3.81
$HSD_{0.01}$ F		0.74	0.14		0.034	2.32	0.52
D	11.17	1.28	0.24	3.63	0.058	4.02	0.89
FxD		2.08	0.40	5.90	0.095	6.54	

F – form of sewage sludge. D – dose of sewage sludge. FxD – interaction less brome (*Bromus inermis* Leyss.), but had no effect on the concentrations of phosphorus, calcium and magnesium in this crop. In a study conducted by Kalembasa (2006), the content of crude ash in aerial biomass of Virginia fanpetals was 59.5 g/kg, including 16.0 g/kg of true ash, while the dominant elements in the ash were calcium and potassium. The content of nitrogen increased under the influence of doses of nitrogen and the interaction with PK fertilization. Nitrogen doses caused a significant increase of the P and K content in the biomass of *Virginia mallow* (Kalembasa and Wiśniewska, 2006). Krzywy-Gawrońska (2012) demonstrated more P, Mg and S in biomass of Virginia fanpetals from treatments with municipal sewage sludge, with or without a supplement of brown coal ash, than from treatments fertilized with calcium carbonate or coal ash with high calcium content.

When analyzing the distribution of macronutrients in Virginia fanpetals, Szyszlak-Bargłowicz (2014) found the highest N, P, K, Ca, Mg content in leaves and the lowest – in roots. She also asserted that the applied fertilization had no significant effect on concentrations of most of the discussed elements in biomass of this plant. An exception was the content of calcium in leaves of Virginia fanpetals, which increased after a small dose of NPK had been applied. Finally, the cited researcher determined that nitrogen had not accumulated in leaves or stems of Virginia fanpetals, whereas the content of potassium and calcium in leaves was several-fold lower than recommended for trouble-free use of this energy crop.

Because of the higher yield and larger content of macronutrients in aerial parts, Virginia fanpetals fertilized with wet sewage sludge took up significantly more macronutrients (Table 4). The accumulation of these elements in plants was also significantly enhanced by the higher doses of sewage sludge. Most macronutrients were absorbed by Virginia fanpetals plants nourished with the highest dose of wet sewage sludge. Compared to the control, the plants in that treatment absorbed 4-fold more nitrogen and magnesium, 2- to 3-fold more phosphorus, potassium and calcium and over 6-fold more sodium.

Krzywy-Gawrońska (2012) suggested that the uptake of nutrients depended primarily on the yield of Virginia fanpetals and less so on its content of individual macronutrients. Rapid growth of plants entails their considerably larger demand for water and nutrients, as a result of which Virginia fanpetals can be useful in biological wastewater treatment. Amounts of biogenic components removed with stems of Virgina fanpetals can be as high as 270 kg N/ha and 74.3

Table 4
Accumulation of macronutrients in aerial biomass of Virginia fanpetals

Specification	N	P	K	Na	Ca	Mg
	mg/ pot					
Pelleted sewage sludge						
Control	187.2	67.0	616.6	5.0	377.7	54.2
N1	247.9	78.8	736.5	6.4	371.7	81.9
N2	394.3	95.7	926.8	9.9	552.1	140.2
N3	353.4	59.7	1034.4	13.4	537.2	132.5
Mean	295.7	75.3	828.6	8.7	459.7	102.2
Wet sewage sludge						
Control	173.0	64.2	589.4	4.5	369.4	50.5
N1	279.6	71.0	688.8	8.4	516.3	99.2
N2	528.0	109.4	1290.2	19.6	782.9	178.3
N3	708.9	162.9	1774.8	28.0	952.7	238.9
Mean	422.4	101.9	1085.8	15.1	655.3	141.7
Mean for dose						
Control	180.1	65.6	603.0	4.7	373.5	52.4
N1	263.8	74.9	712.6	7.4	444.0	90.5
N2	461.1	102.6	1108.5	14.8	667.5	159.2
N3	531.1	111.3	1404.6	20.7	745.0	185.7
$HSD_{0.01}$ F	37.52	8.25	60.50	2.19	2.19	63.22
D	64.94	14.27	104.70	3.79	3.79	109.41
FxD	105.66	23.22	170.35	6.16	6.16	178.03

F – form of sewage sludge. D – dose of sewage sludge. FxD – interaction kg P/ha annually. The quantity of nitrogen and phosphorus taken up by the yield of plants depends on the dose of these elements supplied with sewage and is higher as the age and yield of the plants increase. According to Kahiluoto et al. (2015), the assimilability of phosphorus contained in sewage sludge can be superior to that from mineral fertilizers. However, anaerobic fermentation and hygienization of sewage sludge with a high Ca content decrease the phytoavailability of this element. Ahmed et al. (2010) implicate that sewage sludge is a very poor source of phosphorus because of iron and aluminium which are used in the process of sewage treatment. Consequently, the microbiological mineralization of organic compounds of phosphorus has a very weak impact on the assimilability of this element by plants. It was concluded that changes in physicochemical conditions of wastewater treatment lead to alterations in the content of phosphorus forms in sewage sludge (Bezak-Mazur et al., 2014).

The form of sewage sludge tested in our experiment determined the degree to which major biogenic components were utilized by the aerial biomass produced by Virginia fanpetals (Figure 2). Plants were able to uptake nitrogen and phosphorus more efficiently from wet sludge (21.3–35.7% and 2.7–13.2%, respectively) than from pelleted sludge (12.1–20.7% and 0.9–5.1%). When wet sludge was used, the absorption of these elements increased under the influence of higher doses of sludge. Contrary to that, the highest utilization of the elements from pelleted sludge as well as the highest yield was obtained from the N2 treatment.

Strzelczyk (2013) determined that Virginia fanpetals watered with communal sewage from rural areas could utilize 2.9–13.4% of the nitrogen and 5.8–15.0% of the phosphorus it contained. The utilization of nutrients improved in the second year of the study, owing to a higher yield of aerial biomass. The relatively low utilization of biogenic component

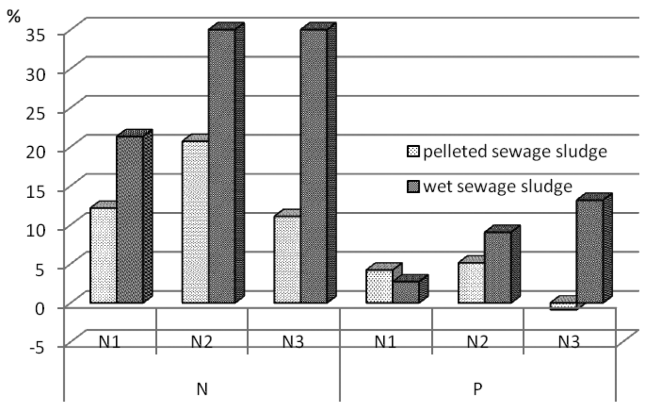

Fig. 2. Utilization of nitrogen and phosphorus from sewage sludge

was caused by the large doses of sewage applied and, on the other hand, by the fact that biomass of Virgina fanpetals harvested in late autumn consisted mainly of stems (leaves had shed before). Petersen (2003) claims that fertilizer value of sewage sludge, with respect to nitrogen, is similar to that of farmyard manure. Yoshida et al. (2015) state that stabilization of sewage sludge, prior to its incorporation into soil, largely reduced the mineralization process of organic matter it contains as well as the emission of greenhouse gases. It also shortens the period of immobilization of nitrogen compounds, which improves the fertilizer value of sewage sludge.

New legal regulations evidently restrict the possibility of sewage sludge depositing on municipal landfills. A possible solution, especially for small and medium size wastewater treatment plants, could be to recycle sewage sludge by composting. Gusiatin and Kulikowska (2012) found out that mature compost contained mineral nitrogen predominantly in the form of nitrate nitrogen, which is easily available to plants, and the $N\text{-}NH_4/N\text{-}NO_3$ ratio was determined to oscillate around 0.07. According to Chen et al. (2002), sewage sludge compost applied in an amount up to 45 t d.m./ha increased the soil content of organic matter, total phosphorus and the pool of phyto available nitrogen, while leaving underground waters unpolluted with $N\text{-}NO_3^-$.

Korboulewsky et al. (2002) believe that sewage sludge introduced to soil should be dosed according to the soil richness and plant demand for phosphorus because long-lasting application of unbalanced doses of this waste can lead to excessive accumulation of phosphorus in soil and increases the risk of its leaching. Contrary to that, the risk of nitrogen leaching is relatively small because of its substantial uptake by plants. Su et al. (2007) claim that soils are well capable of retaining phosphorus and that even repeated applications of standard doses of sewage sludge, for example to fertilize sandy forest soil, create a minimal risk of P losses due to leaching.

Conslusions

Wet sewage sludge had a more favourable effect on yields produced by Virginia fanpetals than pelleted sludge.

The form of sewage sludge did not affect the content of crude ash, but wet sewage sludge raised the concentrations of nitrogen, phosphorus, calcium, magnesium and sodium in biomass of Virginia fanpetals.

The highest levels of crude ash and macronutrients (except phosphorus) were determined in plants fertilized with the highest tested dose of sewage sludge.

The highest amounts of macronutrients were absorbed by Virginia fanpetals fertilized with wet sewage sludge. The accumulation of these elements in plants was also enhanced by the increasing doses of sewage sludge.

Plants could utilize nitrogen and phosphorus better from wet sewage sludge than from its pelleted form.

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