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CONTENT OF SELECTED ELEMENTS IN *Miscanthus sacchariflorus* (Maxim.) Hack BIOMASS UNDER THE INFLUENCE OF SEWAGE SLUDGE FERTILIZATION

ZAWARTOŚĆ WYBRANYCH PIERWIASTKÓW W TRAWIE *Miscanthus sacchariflorus* (Maxim.) Hack POD WPŁYWEM NAWOŻENIA OSADEM ŚCIEKOWYM

Abstract: The field experiment consisted in the examination of the sewage sludge and mineral fertilization application on contents of some elements: Fe, Mn, Mo, Li, Ti, Ba and Sr in stalks and leaves of *Miscanthus sacchariflorus* grass cultivated in the first year as well as in the whole biomass harvested in the second year. Total elements concentrations were analyzed by means of ICP-AES technique after combustion in a muffle furnance at 450 ^{o}C. Much higher concentrations of analyzed elements in leaves of amur silvergrass than in its stalks was found. More molybdenum, and less iron and titanium was recorded in the second year than in the first year of the experiment. Contents of other elements determinated in biomass were at similar levels in both years of cultivation.

Uptake and accumulation of selected elements in yields of amur silvergrass was higher in the first as compared with the second experimental year. Leaves showed higher uptake of Fe, Mn, Li, and Ti due to sewage sludge fertilization, while stalks uptake more Mo and Sr.

Keywords: *Miscanthus sacchariflorus,* iron, manganese, molybdenum, lithium, titanium, barium, strontium, waste activated sludge

Introduction

Some of several tens of grass species of *Miscanthus* genus are among perennial plants cultivated for energetic purposes [1–5]. Grass of *Miscanthus* genus is one of the few ones with C_4 photosynthesis mechanisms, and under European conditions, it is very resistant towards majority of plant diseases and pests [4]. Due to its properties, it is characterized by high industrial and energetic values, which are comparable with those for firewood, therefore it is considered as a valuable source of renewable energy [6].

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Searching for new ways to achieve energy carriers is more often focused on an agriculture [7–9]. These plants distinctly react towards fertilization, namely organic one, and among other in a form of sewage sludge. Own studies involving many amur silvergrass species as well as other authors [10–15] reveal that fertilization using sewage sludge had positive influence on yielding of *Miscanthus sacchariflorus*. To produce large biomass, the plant needs great amounts of nutrients that can be supplied in a form of fresh sewage sludge instead of mineral fertilization. Fertilizing with that organic material is one of more efficient methods for sewage sludge utilization, which ensures the safety for an environment and restoring nutrients to further turnover. Cultivation of amur silvergrass cultivation on a wide scale in Poland would make possible to reduce the amounts of stored sludge, although many authors warn against its strong expansion, particularly in field cultivation [16–18]. Higher costs for fossil fuels output and allocation of deposits – namely of crude oil and natural gas – has to lead to the stress within whole worldwide economics. At increasing deficiency of the firewood, growing the energetic plant species, including silvergrass (*Miscanthus*), may in part satisfy the expectations on energy markets. Cultivating the fast-growing plants makes a challenge for farmers by promising the higher income and maintaining the employment. According to data in European Directive 2003/30/EC, energy from biological sources would be 5.75 % of the total amount of energy from fossil fuels in 2010. Moreover, producing the biomass of energetic plant species contributes to greenhouse effect reduction by means of CO_2 binding [19] and sequestration of carbon compounds in a soil [20].

The study was aimed at evaluating the influence of different rates of sewage sludge on contents of selected elements in biomass of *Miscanthus sacchariflorus* grass in the first and second years of field cultivation.

Material and methods

The experiment was laid out in spring 2005 on light soil of loamy sand granulometric composition (according to PN-R-04033) that was characterized by the following properties: pH_{KCl} = 6.60, organic carbon content 30.5 g · kg^{-1}, total content of nitrogen 1.85 g · kg^{-1}, total contents of some selected elements [mg · kg^{-1} soil]: Fe – 5186; Mn – 146; Mo – 0.231; Li – 1.70; Ti – 49.42; Ba – 82.18; Sr – 29.06, total amounts of those elements were determined by means of ICP-AES technique after soil dry digestion in muffle furnace at 450 ^{o}C. Plots of 2 m^2 area in three replications were separated in completely randomized pattern. Amur silvergrass (*Miscanthus sacchariflorus*) was the tested plant.

The experiment included following fertilization objects:

– control (with no fertilization);

– mineral NPK (mineral nitrogen was applicated in a form of urea according to the amount of nitrogen contained in 20 Mg · ha^{-1} d.m. of sludge);

– waste activated sludge at 10 Mg · ha^{-1} d.m.;

– waste activated sludge at 20 Mg · ha^{-1} d.m.;

– waste activated sludge at 30 Mg · ha^{-1} d.m.

The experimental objects were fertilized with phosphorus (triple superphosphate) and potassium fertilizer (potassium sulfate) maintaining the ratio N : P : K as 1 : 0.8 : 1.2. The chemical composition of sewage sludge indicated its usefulness for plant nutrition heavy metals and trace elements contents were at the levels acceptable (Table 1). Chemical composition of the sewage sludge indicated its usefulness for plant nutrition Decree of Environment Ministry [21]. Analyzed the sludge contained a limit (far from the critical value) of heavy metals [21, 22]. This sediment was characterized by, among others relatively high content of zinc (1453 mg $\cdot$ kg^{-1}), dominant over the other heavy metals. Czekala and Jakubus [23] found significantly higher amounts of this metal in sewage sludge, often exceeding the allowable amount.

Table 1

The content of selected elements in waste activated sludge

pH_{KCl}	Dry matter [%]	N	P	K	Ca	Mg	S	Na	Pb	Cd	Cr
		[g $\cdot$ kg^{-1} d.m.]							[mg $\cdot$ kg^{-1} d.m.]		
6.5	25	50.2	26.1	3.50	39.5	7.62	5.67	0.697	98.7	2.70	20.5
[mg $\cdot$ kg^{-1} d.m.]											
Fe	Mn	Mo	B	Li	Ti	Ba	Sr	Zn	Ni	Cu	Co
8991	607	3.64	8.12	6.31	32.7	91.0	83.1	1453	52.7	101	4.49

Prior to rhizomes planting, the sludge was mixed with soil up to 25 cm depth. The biomass harvest was performed in December 2005 and 2006 after the first and second cultivation years. In the first year, chemical compositions of stalks and leaves were analyzed separately, while all biomass (stalks plus leaves) in the second year. Plant samples in a from of 10 leafy steams were collected after each silver grass harvest. Plant material was ground to the particle size of 0.25 mm and 1 g was weighed out into the stoneware crucible, then organic substance was dry digested at 450 ^{o}C in muffle furnace to raw ash in crucible to dissolved the ash and decomposed hydrochloric acid (1:1) was added carbonate. Such prepared basic solution was subjected to determination of total contents of Fe, Mn, Mo, Li, Ti, Ba, and Sr by means of ICP-AES technique.

Harvested yields of biomass and contents of selected elements served to calculate their uptakes. Stalks and leaves yields in the first amur silvergrass cultivation year were published in the paper [24]. Results were statistically processed; differences between mean values for plant parts as well as fertilization were verified using Fisher-Snedecor's test, and in the case of their significance, the $LSD_{0.05}$ values were calculated according to Tukey's test.

Results and discussion

System of weather conditions during plant's vegetation, namely that of C_4 pathway, is one of the most important factors that affect the rate of their development and yield size [25]. Mean air temperatures and rainfall sums in 2005–2006 in middle-eastern Poland (data for Siedlce) are presented in Table 2. Average monthly temperatures in April, May, June, July, and August were higher than long-term average, which had positive effects on silvergrass growth. Low rainfall sum in April (by 31.2 mm lower than long-term average level) caused that most plants started their growth at the end of April and beginning of May. Irregular rainfall distribution since July till October, almost twice as high in some years as long-term average, made the shoots were bent due to leaves weight and in consequence their fall.

Table 2

Temperature [^{o}C] and rainfall [mm] during vegetation period of *Miscanthus sacchariflorus*

Year	Month							
	April	May	June	July	August	September	October	Sum / Mean
Temperature average in month [^{o}C]								
2005	8.60	13.0	15.9	20.2	17.5	15.0	8.51	16.5
2006	8.40	13.6	17.2	22.3	18.0	15.4	9.20	14.9
Mean	8.50	13.3	16.6	21.3	17.8	15.2	8.90	15.7
Mean for multiyears	7.70	10.0	16.1	19.3	18.0	13.0	7.50	
Rainfalls [mm]								
2005	12.3	64.7	44.1	86.5	45.4	15.8	0.0	269.0
2006	29.8	39.6	24.0	16.2	227.6	22.0	7.20	366.4
Mean	21.1	52.2	34.1	51.4	136.5	18.9	3.60	317.8
Mean for multiyears	52.3	50.0	68.2	45.7	66.8	60.7	68.3	

In the first of year experimental, much higher contents of analyzed selected elements were recorded in amur silvergrass leaves than stalks (Table 3).

Table 3

Total contents of selected elements [mg · kg^{-1} d.m.] in the biomass of *Miscanthus sacchariflorus* in the first year of the field experiment

Fertilization object	Yield [Mg · ha^{-1}]	Fe	Mn	Mo	Li	Ti	Ba	Sr
	Leaves							
Control object	1.12	293.2	17.93	1.06	1.47	3.44	7.67	23.27
NPK	1.57	276.2	16.41	0.880	1.41	3.54	8.91	27.61
10 Mg · ha^{-1}	1.56	334.8	15.48	1.12	2.50	4.86	8.45	23.16
20 Mg · ha^{-1}	1.60	322.4	19.13	0.924	1.85	3.95	8.55	25.81
30 Mg · ha^{-1}	1.53	360.4	22.92	0.846	2.27	4.67	8.83	26.53
Mean	1.48	317.4	18.37	0.966	1.90	4.09	8.48	25.28

Table 3 contd.

Fertilization object	Yield [$Mg \cdot ha^{-1}$]	Fe	Mn	Mo	Li	Ti	Ba	Sr
	Stalks							
Control object	0.690	61.72	6.07	0.093	2.16	0.537	2.36	8.44
NPK	1.10	60.08	5.28	0.090	3.51	0.491	2.14	7.47
10 $Mg \cdot ha^{-1}$	0.980	49.88	3.66	0.156	3.05	0.448	1.66	8.50
20 $Mg \cdot ha^{-1}$	1.15	55.63	7.14	0.271	2.50	0.429	2.48	10.11
30 $Mg \cdot ha^{-1}$	0.980	51.43	3.73	0.116	1.90	0.431	1.99	9.31
Mean	0.980	55.75	5.18	0.145	2.62	0.467	2.13	8.77
$LSD_{0.05}$ for:								
A – fertilization	0.018	9.18	0.575	0.056	0.564	0.117	0.309	1.03
B – plant's parts	0.008	20.83	1.30	0.126	n.s.	0.226	n.s.	2.35
A/B – interaction	0.026	29.46	1.84	0.178	n.s.	0.376	0.990	3.32
B/A – interaction	0.017	20.54	1.29	0.124	n.s.	0.262	0.690	2.31

n.s. – non significant difference; 10, 20, 30 $Mg \cdot ha^{-1}$ d.m. of waste activated sludge; yield of biomass published in the paper [14].

Mean concentrations in leaves can be lined up in following sequence: ($mg \cdot kg^{-1}$ d.m.): Fe (317.4) > Sr (25.28) > Mn (18.37) > Ba (8.48) > Ti (4.09) > Li (1.90) > Mo (0.966), while in stalks: Fe (55.75) > Sr (8.77) > Mn (5.18) > Li (2.62) > Ba (2.13) > Ti (0.467) > Mo (0.145).

Statistical analysis revealed significant influence of fertilization on contents of all tested elements in studied parts of amur silvergrass. More Fe, Mn, Mo, Ti, Ba, and Sr and much less Li was found in leaves than stalks. Sewage sludge fertilization differentiated contents of tested elements in leaves and stalks of amur silvergrass as compared with the control object. No univocal effect of sewage sludge rate on concentrations of selected microelements in studied parts of the grass was observed.

In the second cultivation year, analysis of chemical composition of the whole plant's biomass (leaves + stalks) harvested in December was made (Table 4). Mean contents of trace elements in question was lined up in the following sequence ($mg \cdot kg^{-1}$ d.m.): Fe (259.1) > Sr (20.36) > Mn (18.01) > Ba (8.55) > Li (2.47) > Ti (1.84) > Mo (1.64). It was found much more molybdenum, and less iron and titanium than in the first year of experiment; other elements were present at similar levels in both study terms. Fertilization considerably affected the iron and manganese contents in biomass of tested grass; in the case of other microelements, no significant influence of sludge fertilization was recorded. Kotecki [26] achieved similar iron content and highest manganese concentration in biomass of amur silvergrass. Own experiments revealed that sewage sludge fertilization did not cause the excessive accumulation of studied elements in analyzed grass [15]. Krzywy et al [27] obtained similar manganese content and significantly lower iron content in the biomass of *Miscanthus* fertilized with sewage sludge.

Table 4

Total contents of selected elements [mg · kg^{-1} d.m.] in the biomass of *Miscanthus sacchariflorus* in the second year of the field experiment

Fertilization object	Yield [Mg · ha^{-1}]	Fe	Mn	Mo	Li	Ti	Ba	Sr
Control object	1.65	291.6	13.36	2.12	3.03	2.01	8.06	22.10
NPK	1.95	238.1	17.52	1.53	1.58	1.60	7.59	19.64
10 Mg · ha^{-1}	1.67	230.6	13.09	1.50	3.11	1.64	7.89	19.84
20 Mg · ha^{-1}	1.71	241.7	18.29	1.56	2.31	2.01	9.21	20.42
30 Mg · ha^{-1}	1.58	293.6	27.76	1.50	2.33	1.95	10.02	19.80
Mean	1.71	259.1	18.01	1.64	2.47	1.84	8.55	20.36
$LSD_{0.05}$	0.999	60.96	4.65	n.s.	n.s.	n.s.	n.s.	n.s.

n.s. – non significant difference.

In the first cultivation season, plants uptake of Fe, Li, Ti, Ba, and Sr with sum of the yield was higher than in the second year, whereas uptake of Mn was 9 times lower and that of molybdenum and boron slightly lower (Tables 5 and 6).

Table 5

Uptake of selected elements [g · ha^{-1}] with yields of *Miscanthus sacchariflorus* leaves and stalks in the first year of the field experiment

Fertilization object	Fe	Mn	Mo	Li	Ti	Ba	Sr
	Leaves						
Control object	328.3	20.08	1.19	1.65	3.85	8.59	26.06
NPK	433.6	25.76	1.38	2.21	5.56	13.99	43.35
10 Mg · ha^{-1}	522.3	24.15	1.75	3.90	7.57	13.18	36.13
20 Mg · ha^{-1}	515.8	30.61	1.48	2.96	6.32	13.68	41.30
30 Mg · ha^{-1}	551.4	35.07	1.29	3.47	7.15	13.51	40.59
Mean	470.3	27.13	1.42	2.84	6.09	12.59	37.49
Stalks							
Control object	42.59	4.19	0.064	1.49	0.371	1.63	5.82
NPK	66.09	5.81	0.099	3.86	0.540	2.35	8.22
10 Mg · ha^{-1}	48.88	3.59	0.153	2.99	0.439	1.63	8.33
20 Mg · ha^{-1}	63.98	8.21	0.312	2.88	0.493	2.85	11.63
30 Mg · ha^{-1}	50.40	3.66	0.114	1.86	0.422	1.95	9.12
Mean	45.87	5.09	0.148	2.62	0.453	2.08	8.62
Sum							
Control object	370.9	24.27	1.25	3.14	4.22	10.22	31.88
NPK	499.7	31.57	1.48	6.07	6.10	16.34	51.57
10 Mg · ha^{-1}	571.2	27.74	1.90	6.89	8.01	14.81	44.46
20 Mg · ha^{-1}	579.8	38.82	1.79	5.84	6.81	16.53	52.93
30 Mg · ha^{-1}	601.8	38.73	1.40	5.33	7.57	15.46	49.71
Mean	524.7	32.22	1.56	5.45	6.54	14.67	46.11

Table 6

Uptake of selected elements [g · ha^{-1}] with yields of *Miscanthus sacchariflorus* leaves and stalks in the second year of the field experiment

Fertilization object	Fe	Mn	Mo	Li	Ti	Ba	Sr
Control object	481.1	22.04	3.50	4.99	3.32	13.30	36.47
NPK	464.3	34.16	2.98	3.08	3.12	14.80	38.30
10 Mg · ha^{-1}	385.1	21.86	2.51	5.19	2.74	13.18	33.13
20 Mg · ha^{-1}	241.7	31.28	2.67	3.95	3.44	15.75	34.92
30 Mg · ha^{-1}	463.9	43.86	2.37	3.68	3.08	15.83	31.28
Mean	407.3	30.64	2.81	4.18	2.59	14.57	34.82

More Fe, Mn, Li, and Ti was recorded in amur silvergrass leaves due to sewage sludge fertilization, while more Mo and Sr in stalks. Woloszyk [28] says that the grass may accumulate significant amounts of elements, especially at high fertilization with sewage sludge. Download and use of elements by plants from sewage sludge is dependent on many factors: water content, soil temperature, to microbiological activity [28, 29]. Each of these factors can stimulate, or inhibit mineral uptake by plants and affect their chemical composition [30]. Uptake of studied trace elements with amur silvergrass biomass yield can be lined up in the following sequence: the first year: Fe > Sr > Mn > Ba > Ti > Li > Mo; the second year: Fe > Mn > Sr > Ba > Li > Mo > Ti.

Kalembasa and Malinowska [31] found that *Miscanthus* of rhizomes and roots contain much more heavy metals and other elements than the stalks and leaves. *Miscanthus sacchariflorus* is therefore particularly suitable for the cultivation of the plant using sewage sludge. Accumulation of elements namely toxic, in roots is very positive phenomenon at energetic utilization of plants.

Conclusions

1. Leaves of *Miscanthus sacchariflorus*, in the first year of experiment, contained much higher levels of Fe, Mn, Mo, Ti, Ba, and Sr than stalks. No univocal influence of sewage sludge rate on concentrations of selected elements in studied grass parts was observed.
2. Much more Mo, and less Fe and Ti were found in the biomass of tested plant in the second vs. the first cultivation year. Contents of other analyzed elements were similar in both years.
3. Uptake and accumulation of selected elements in yields of amur silvergrass was higher in the first as compared with the second experimental year. Leaves showed higher uptake of Fe, Mn, Li, and Ti due to sewage sludge fertilization, while stalks Mo and Sr.

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ZAWARTOŚĆ WYBRANYCH PIERWIASTKÓW W TRAWIE *Miscanthus sacchariflorus* (Maxim.) Hack POD WPŁYWEM NAWOŻENIA OSADEM ŚCIEKOWYM

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Abstrakt: W doświadczeniu polowym badano wpływ nawożenia osadem ściekowym i nawozami mineralnymi (dla porównania) na zawartość wybranych pierwiastków: Fe, Mn, Mo, Li, Ti, Ba i Sr w łodygach i liściach trawy *Miscanthus sacchariflorus,* uprawianej w I roku oraz w całej biomasie, zebranej w II roku. Zawartość ogólną wymienionych pierwiastków oznaczono metodą ICP-AES, po mineralizacji na sucho w piecu muflowym, w temperaturze 450 ^{o}C. Stwierdzono kilkakrotnie większą zawartość analizowanych pierwiastków w liściach miskanta cukrowego niż w łodygach. W II roku zanotowano więcej molibdenu, mniej żelaza i tytanu niż w I roku eksperymentu. Zawartość pozostałych pierwiastków była na zbliżonym poziomie w obu terminach badań.

Pobranie i wyniesienie badanych pierwiastków z plonem miskanta cukrowego było większe w I roku uprawy, w stosunku do II roku. Liście pobierały więcej Fe, Mn, B, Li i Ti pod wpływem nawożenia osadem ściekowym, łodygi Mo i Sr.

Słowa kluczowe: *Miscanthus sacchariflorus*, żelazo, mangan, molibden, lit, tytan, bar, stront, osad ściekowy