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POSSIBLE USEFULNESS OF SHRIMP BIOWASTE AS A FERTILIZER IN THE CULTIVATION OF SELECTED SPECIES OF *Miscanthus* (ANDERSSON)

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ABSTRACT

Species of the *Miscanthus* genus are plants of considerable economic importance. During their vegetation, they produce a considerable amount of biomass, which makes them a useful source of bioenergy. They are also highly ornamental and, being highly tolerant of salt in the soil, they are useful both in city greeneries and in the reclamation of degraded areas. Several million tons of shrimps per year are fished and processed at present. This generates a huge amount of biowaste, contributing to the progressive degradation of natural environment. Proper utilization of this waste is, therefore, becoming a burning issue. The present study was carried out in the years 2020–2021. The plant material consisted of two species of the genus *Miscanthus*, i.e. *Miscanthus sinensis* and *Miscanthus* × *giganteus*. Dried and ground biowaste, a material of high nutritional value generated during shrimp cleaning, was used as an experimental component of the substrate. The shrimp biowaste was mixed with the soil at a dose of 5%, 10%, and 15% (v/v). The control was a mineral soil without the dried biowaste. No other fertilizer was used during the plant growth. The plant material was harvested at the end of the growing season in the first year, and at full bloom and at the end of the growing season in the second year. The following mineral components were assessed: N, P, K, Ca, Mg, Zn, Cu, Mn, Fe, Cd, Pb, and Ni. Regardless of the species, the plants growing in the substrates enriched with dried shrimps had a higher content of macro- and micronutrients in their leaves in comparison with the controls. In the next years of cultivation, the content of the assessed mineral components in the leaves seemed to drop. The biowaste generated during shrimp cleaning may successfully be used as fertilizer in the cultivation of *Miscanthus sinensis* and *Miscanthus* × *giganteus*.

Key words: grasses, crustaceans, biowaste disposal, shrimp biowaste dose, macro- and micronutrients

INTRODUCTION

Crustaceans, including shrimps [Mao et al. 2017], are an essential group of marine products processed in over 50 countries worldwide [Subasinghe 1999]. It is one of the most profitable and fast-growing processing industries [Nirmal et al. 2020, Zuorro et al. 2020]. Regarding shrimps alone, the volume fished in 2020 was 8.12 million tons, which is expected to be higher than in 2021–2026 [IMARC 2021]. In the shrimp cleaning process, their meat is separated from the inner part of the abdomen. Other parts of shrimps, namely, their chitin shell (carapace), exoskeleton, tail, and head, account for as much as 50–60% of post-production waste [Nirmal et al. 2020], depending on species [Sachindra et al. 2005]. Unfortunately, they are

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highly perishable [Sachindra et al. 2007]. Owing to the growing demand for shrimps, the processing industry is generating more and more solid waste [Mathew and Nair 2006, Zuorro et al. 2020], which is a severe threat to the environment [Prameela et al. 2012, Nirmal et al. 2020] because of its high protein content [Synowiecki and Al-Khateeb 2000].

New, environmentally friendly processing methods are sought everywhere in the world both for environmental and for economic reasons, to prevent decomposition and obtain valuable products from this particular kind of waste [Nirmal et al. 2020]. Typically, the shrimp biowaste is dried and used as animal fodder [Jugnia et al. 2012]. However, even the shrimp drying in the beach may contribute to environmental pollution [Prameela et al. 2010]. The problem can be solved by drying the biowaste on an impermeable substrate under a transparent roof [Begum et al. 2006]. The resulting biowaste may well be used for composting [Jugnia et al. 2012]. Another shrimp processing biowaste disposal method is their conversion and degradation by microorganisms [Prameela et al. 2010] for the production of enzymes [Mejía-Saulés et al. 2006, Sinha et al. 2012], antioxidants, peptides, and reducing sugar [Wang et al. 2010]. According to Świontek-Brzezińska et al. [2008] and Rojas et al. [2019], an environmentally-friendly alternative for using the shrimp processing biowaste is to use it as an organic fertilizer in agricultural and horticultural production.

New organic fertilizers are also needed because of the limited access to manure. However, the available literature provides no express information that the use of shrimp biowaste in the cultivation of horticultural and agricultural plants is justified and, therefore, it is the proper method to dispose of this environmentally noxious waste. Therefore, we deemed it desirable to verify the usefulness of dried shrimp biowaste as a source of nutrients and to determine its proper dosage in the cultivation of selected species of the genus *Miscanthus*, a plant of not only ornamental value but also one that generates a high amount of biomass for green energy.

MATERIALS AND METHODS

Experimental design. The study was carried out in 2020–2021 in the West Pomeranian University of Technology plant house in Szczecin (14°31' E and 53°26' N). It was a continuation of the previous experiments conducted a few years before (2015–2017), assessing the ornamental value of plants grown on substrates containing dried shrimp biowaste [Żurawik 2020]. We used two most frequently grown species of *Miscanthus*, i.e., *Miscanthus × giganteus* (J.M. Greef, Deuter ex Hodk., Renvoize) and *Miscanthus sinensis* (Andersson) [Erhardt et al. 2014].

Their rhizomes, reproduced at our unit, were planted into 60 × 40 × 20 cm openwork plastic containers after sealing the sides tightly with black foil and leaving the bottom openwork. In the middle part of each container, at a depth of 5 cm, we planted five rhizomes matched for size and number of developed buds, well-shaped, healthy, and without mechanical damage.

We used a soil with a loamy sand texture collected from the top layer of the field located in the experimental station of the Faculty of Environmental Management and Agriculture of the West-Pomeranian University of Technology in Szczecin, located in Lipnik on the Pyrzyce-Stargard Plain, at 25 m a.s.l., on the border of the Płonia and Ina basins. The soil was characterized by the following chemical properties: content of nutrients in $mg \cdot dm^{-3}$: N 72.3, P 38.5, K 108.3, Ca 4527.0, Mg 237.5, pH 7.18, salt content 0.9 g $NaCl \cdot dm^{-3}$.

The substrate was enriched with dried shrimp biowaste generated during shrimp processing for food purposes and consisting of heads, shells and tails, after drying and fragmenting them to obtain 2–3 mm long pieces. The dried shrimp biowaste was obtained from the IMPROJEKT production and service company in Resko and used in the experiments. The product, labeled “shrimp biowaste dose”, was characterized by the following chemical properties: content of nutrients per $mg \cdot dm^{-3}$: N 258.6, P 1472.0, K 3852.1, Ca 5223.0, Mg 886.4, pH 8.5, salt content 28.9 g $NaCl \cdot dm^{-3}$.

The substrates were prepared two weeks before the scheduled rhizome planting. The dried shrimp biowaste was mixed with the mineral soil in the ratio of 5%, 10%, and 15% (v/v). The control was a mineral soil containing no biowaste. The containers were filled with 45.0 dm^3 of the substrate. The rhizomes were planted on May 16, 2020 in open field containers, spaced every 80 cm. To prevent the roots from growing into the substrate, the soil was covered with a $110 g \cdot m^{-2}$ black mulch fabric.

The growing plants were properly taken care of, that is, the substrate was watered and scarified and the weeds were removed. Fertilization and top dressing were not applied in the first and second year of the cultivation. After the plant growing season in the first year of the study, on November 26, 2020, the containers were placed in a cold plastic tunnel and kept there till next spring. The containers were carried back to the open field on April 9, 2021.

Mineral content of the plant material. Plant material for chemical analyses was obtained, in accordance with generally accepted rules, from the one-year plants at the end of their growing season (October 20, 2020) and from the two-year plants both at full bloom (July 6, 2021) and at the end of the growing season (October 15, 2021). The plant material consisted of properly formed and fully grown healthy leaves from the middle section of the plants. The leaves were cut into 3 cm long pieces, dried in the SLN 115 ECO laboratory oven, and ground in the WŻ-1 laboratory mill. The material was analyzed to determine its content of macro- and micronutrients: N, P, K, Ca, Mg, Zn, Cu, Mn, Fe, Cd, Pb, and Ni. Total nitrogen was found by the Kieldahl method after mineralizing the samples in concentrated sulfuric acid with addition of selenium mixture. Phosphorus was determined using the colorimetric method of Egner-Riehm. Potassium was assessed using a flame photometer (Spekol 221). Magnesium and total calcium were found by atomic absorption spectrometry (ASA) using the Thermo scientific iCE 3000 series AA spectrometer, after mineralizing the samples in a 1 : 1 mixture of nitric and chloric acids. Copper, iron, manganese, zinc, cadmium, lead, and nickel were determined by ASA after mineralizing the samples in a 3 : 1 mixture of nitric and perchloric acids. The chemical analyses of the plant material were performed in the West Pomeranian University of Technology in Szczecin, Department of Agricultural Engineering.

Statistical analysis. This experiment evaluated eight variants formed by the shrimp biowaste dose (4) × species (2). Six repetitions, five plants each, were used for each variant.

The statistical analyses were carried out using the Statistica Professional 13.3 package (TIBCO StatSoft, Palo Alto, CA, USA). The data were subjected to the two-factor analysis of variance (ANOVA) in a complete randomization design. mean values were compared using the Tukey test, at the significance level $p < 0.05$.

RESULTS AND DISCUSSION

The content of macro- and micronutrients in the leaves of one-year plants. The available literature provides no information on the use of dried biowaste generated by shrimp cleaning as a fertilizer in growing horticultural and agricultural plants. In earlier experiments, Dufault and Korkmaz [2000] and Dufault et al. [2001] used the sea bottom deposit, formed during the production of these crustaceans, whereas Rojas et al. [2019] applied unprocessed shrimp biowaste, dried and hydrolyzed (42%) biowaste as an organic fertilizer in growing vegetables. The only known study on the topic reports the use of dried shrimp biowaste in growing freesia [Żurawik 2013]. The present study is the first one in which species of the genus *Miscanthus* were grown on substrates containing dried shrimp biowaste.

Shrimp processing biowaste can be used to enrich the soil in nutrients for growing legumes [Rojas et al. 2019]. Also Żurawik [2013] recommends the use of dried waste as a fertilizer in growing freesia except that their use is reported to depend on dosage. These reports were confirmed in our studies, which demonstrated, based on material collected from one-year plants at the end of the growing season, that the dried shrimp biowaste dose had a significant effect on the content of macronutrients in the leaves (Tab. 1). Significantly the highest content of N was found in the leaves of the plants growing in a substrate enriched with 15% of the dried biowaste, whereas the lowest was found in the controls. The differences were as high as 106%. These reports were not confirmed by Żurawik [2013], who reported that the highest biowaste dose (15%) was associated with the lowest content of N in freesia leaves. This may have resulted from the fact that freesia is highly sensitive to the content of salt in the substrate. Regardless of the biowaste dose, the leaves contained from 48.5 to 54.9% more P than the controls. Higher levels of K in the leaves were found in plants growing in the substrate enriched with 10% and 15% of the dried shrimp biowaste only in comparison with those grown in the substrate with no added

Table 1. Content of macronutrients in the leaves of one-year plants at the end of the growing season depending on the species and shrimp biowaste dose

Macronutrient ($g \cdot kg^{-1}$)	Species	Shrimp biowaste dose (%)				Mean
		0	5	10	15	
N	*Miscanthus sinensis*	18.2 e	22.8 d	25.4 cd	31.9 b	24.6 B
	Miscanthus × giganteus	18.2 e	26.0 c	25.1 cd	43.1 a	28.1 A
	mean	18.2 C	24.4 B	25.2 B	37.5 A	26.3
P	*Miscanthus sinensis*	2.79 c	3.74 b	4.09 a	3.65 b	3.57 A
	Miscanthus × giganteus	2.49 c	4.09 a	4.09 a	4.22 a	3.72 A
	mean	2.64 B	3.92 A	4.09 A	3.94 A	3.65
K	*Miscanthus sinensis*	10.11 d	10.44 d	12.21 b	10.97 c	10.93 A
	Miscanthus × giganteus	7.37 e	10.23 d	12.21 b	12.66 a	10.62 A
	mean	8.74 B	10.34 AB	12.21 A	11.82 A	10.78
Ca	*Miscanthus sinensis*	3.55 g	5.53 e	4.01 f	3.72 g	4.21 B
	Miscanthus × giganteus	5.89 d	10.06 a	7.10 b	6.13 c	7.30 A
	mean	4.72 B	7.79 A	5.56 B	4.93 B	5.75
Mg	*Miscanthus sinensis*	1.119 g	1.596 e	1.413 f	1.585 e	1.428 B
	Miscanthus × giganteus	2.777 c	3.150 a	2.470 d	2.923 b	2.830 A
	mean	1.948 B	2.373 A	1.942 B	2.254 A	2.129

Explanations: means marked with the same letters do not differ significantly at $\alpha = 0.05$

biowaste. A different relationship was found for the content of Ca. A higher content of this macronutrient was detected in plants grown in the substrate comprising only a low (5%) percentage of the dried shrimp biowaste in comparison with the other experimental variants. An identical relationship in growing freesia of the Beach group was demonstrated by Żurawik [2013]. On the other hand, higher levels of Mg were detected for the 5% and 15% doses of dried shrimp biowaste than for the 10% dose or for the control. The information reported by Himken et al. [1997], that in the above-ground parts of *Miscanthus* the content of K is much higher than that of P and Mg, was confirmed. The ornamental value of *Miscanthus* grown in substrates enriched with dried shrimp biowaste depends on the species [Żurawik 2020]. In our experiment, the content of macronutrients in the leaves also depended on the species. The one-year plants of *Miscanthus × giganteus* had an even higher content of N, Ca and Mg, respectively by 14.2%, 73.4%, and 98.2% in the leaves than the representatives of *Miscanthus sinensis*. Similar relationships were not observed for the content of P and K. For each analyzed macronutrient, a significant correlation was found between the species and the shrimp biowaste dose.

At the end of the growing season, among all analyzed micronutrients, Fe, Zn, Mn, and Cu were found in the leaves but the presence of Cd, Pb, and Ni was not detected (Tab. 2). Enriching the substrate with the dried shrimp biowaste, regardless of its dose, resulted in higher levels of Fe and Mn in the leaves. For Fe, the difference varied between 37.2% and 43.3%, while in the case of Mn, the differences were much more pronounced and they varied from 223.1% to 233.9%. According to Żurawik [2013], increasingly higher doses of shrimp biowaste resulted in lower levels of Fe and Mn in the leaves of freesia. Both for Zn and Cu, higher levels of these components were found in the substrate enriched with 5% of the dried shrimp biowaste than in the plants from other experimental variants. Also in freesia, the highest content of Cu was detected in plants grown in the substrate supplemented with 5% dried shrimp biowaste [Żurawik 2013]. Regardless of the shrimp biowaste dose, the leaves of *Miscanthus* × *giganteus* contained more Fe, Zn, and Cu than those of *Miscanthus sinensis*. According to Shoji et al. [1990] *Miscanthus sinensis* is one of the species using high amounts of minerals for generating its large biomass. The greatest difference (92%) was demonstrated for Cu. In the case of other micronutrients, the differences amounted to 15.5% for Fe and 45.4% for Zn. The analysis of variance indicated a significant interaction between the species and the dose of dried shrimp biowaste. Increasing the dose of minerals in the biomass of *Miscanthus* × *giganteus* is undesirable in plants intended to be used as energy sources [Gołąb-Bogacz et al. 2021]. In the opinion of Żurawik [2020], increasing the dose of the shrimp biowaste to 15% has a favorable effect on the ornamental value of *Miscanthus* × *giganteus.*

The content of macro- and micronutrients in the leaves of two-year plants. In the second year of the cultivation, at full bloom, we confirmed a significant effect of the investigated factors on the content of macronutrients in the leaves (Tab. 3). The same relationships regarding N content were observed as in the

Table 2. Content of micronutrients in the leaves of one-year plants at the end of the growing season depending on the species and shrimp biowaste dose

Micronutrient ($mg \cdot kg^{-1}$)	Species	Shrimp biowaste dose (%)				Mean
		0	5	10	15	
Fe	*Miscanthus sinensis*	45.3 f	48.7 e	55.2 d	57.7 cd	51.7 B
	Miscanthus × *giganteus*	40.8 g	74.5 a	63.2 b	60.2 bc	59.7 A
	mean	43.0 B	61.6 A	59.2 A	59.0 A	55.7
Zn	*Miscanthus sinensis*	15.5 f	18.2 c	13.0 h	14.1 g	15.2 B
	Miscanthus × *giganteus*	21.0 b	33.1 a	17.7 d	16.5 e	22.1 A
	mean	18.2 B	25.7 A	15.4 B	15.3 B	18.7
Mn	*Miscanthus sinensis*	25.9 e	87.9 a	67.0 c	61.0 d	60.4 B
	Miscanthus × *giganteus*	18.5 f	86.5 a	64.6 c	75.9 b	61.4 A
	mean	22.2 D	87.2 A	65.8 C	68.5 B	60.9
Cu	*Miscanthus sinensis*	1.739 e	3.117 bc	2.017 de	1.042 f	1.978 B
	Miscanthus × *giganteus*	2.343 d	6.237 a	3.588 b	3.020 c	3.797 A
	mean	2.041 B	4.677 A	2.802 B	2.031 B	2.888

Explanations as in the Table 1

one-year plants, except that the differences between the controls and the plants grown in the substrate with 15% dried shrimp dose were less obvious and reached 75.8%. The results confirmed what was reported by Żurawik [2020], that in comparison with the controls, the two-year plants had a higher nitrogen index and a higher leaf greenness index. In the opinion of Podsiadło and Jaroszewska [2013], this indicates a better nutritional status of the plants. Also in the case of P, its highest levels were detected in the plants grown in the substrate with 15% of the dried shrimp biowaste and the lowest levels were determined in the controls. In the substrate enriched with 5% of the biowaste, the detected level of Mg (67.2%) was higher only when compared with the control. At full bloom, no significant differences between the levels of K and Ca were found at any shrimp biowaste dose used. On the other hand, according to Roncucci et al. [2015], *Miscanthus* uptakes large amounts of K from the soil. At full bloom, the leaves of *Miscanthus sinensis* were found to contain 6.2%, 7.6%, and 82% more of N, P, and K than the leaves of *Miscanthus* × *giganteus*. A different response was demonstrated for the content of Ca and Mg in the leaves of the two species of *Miscanthus*: the differences were considerable, namely, 87.2% and 325.7%, respectively. These results corroborated

Table 3. Content of macronutrients in the leaves of two-year plants at full bloom depending on the species and shrimp biowaste dose

Macronutrient ($g \cdot kg^{-1}$)	Species	Shrimp biowaste dose (%)				Mean
		0	5	10	15	
N	*Miscanthus sinensis*	16.9 e	24.9 c	26.6 b	28.1 a	24.1 A
	Miscanthus × *giganteus*	15.3 f	23.2 d	23.7 d	28.6 a	22.7 B
	mean	16.1 C	24.1 B	25.1 B	28.3 A	23.4
P	*Miscanthus sinensis*	2.33 c	2.64 bc	3.06 ab	3.17 a	2.80 A
	Miscanthus × *giganteus*	2.33 c	2.64 bc	2.49 c	2.94 ab	2.60 B
	mean	2.33 C	2.64 BC	2.77 AB	3.05 A	2.70
K	*Miscanthus sinensis*	10.78 d	12.30 c	13.26 b	14.15 a	12.63 A
	Miscanthus × *giganteus*	7.98 e	5.50 g	6.37 f	7.90 e	6.94 B
	mean	9.38 A	8.90 A	9.82 A	11.03 A	9.78
Ca	*Miscanthus sinensis*	3.98 e	4.40 d	4.02 e	4.12 e	4.13 B
	Miscanthus × *giganteus*	6.80 c	7.45 b	8.30 a	8.38 a	7.73 A
	mean	5.39 A	5.92 A	6.16 A	6.25 A	5.93
Mg	*Miscanthus sinensis*	0.900 e	0.989 e	0.869 e	0.948 e	0.926 B
	Miscanthus × *giganteus*	2.586 d	4.842 a	4.508 b	3.833 c	3.942 A
	mean	1.743 B	2.915 A	2.688 AB	2.390 AB	2.434

Explanations as in the Table 1

the claim of Helios [2018] that the content of Ca in the plants depends on the species of *Miscanthus*. Our study demonstrated different effects of the investigated variables.

The most important factor affecting the uptake of nutrients by *Miscanthus* plants was the time of determination of a given nutrient [Roncucci et al. 2015]. At full bloom, a significant effect of the shrimp biowaste dose was found only for the content of Fe, Zn, and Mn. As in the first year of the plant growing, Cd, Pb, and Ni were not detected in the leaves (Tab. 4). The content of Fe was higher in the leaves of the plants growing in the substrate supplemented with 5% and 15% of dried shrimp biowaste only in comparison with the controls. The differences were 31.3% and 30.7%, respectively. Regardless of the shrimp biowaste dose, the plants grown in the substrate which comprised the component had a higher content of Zn in comparison with those grown in the control. Another interesting relationship was found for the content of Mn in the leaves, which grew considerably with increasing shrimp biowaste doses. The difference between the controls and the plants grown in the substrate with 15% dried shrimp biowaste was as high as 2324.4%. For all micronutrients, a significant correlation was found between the cultivated species and the dried shrimp biowaste dose. Only for the content of Zn in the leaves, there were significant differences between the species of *Miscanthus*. The content of Zn was by 50.3% higher in the leaves of *Miscanthus* × *giganteus* than in those of *Miscanthus sinensis*. As in the first year of the study, the species tended to respond in different ways to the shrimp biowaste doses.

During the growing season the leaf content of minerals fluctuates in both *Miscanthus* × *giganteus* and *Miscanthus sinensis* [Roncucci et al. 2015]. The content of N, P, and K in the summer is high for some

Table 4. Content of micronutrients in the leaves of two-year plants at full bloom depending on the species and shrimp biowaste dose

Micronutrient ($mg \cdot kg^{-1}$)	Species	Shrimp biowaste dose (%)				Mean
		0	5	10	15	
Fe	*Miscanthus sinensis*	35.5 e	40.1 d	45.0 c	47.8 b	42.1 A
	Miscanthus × *giganteus*	36.2 e	53.9 a	39.7 d	45.7 bc	43.9 A
	mean	35.8 B	47.0 A	42.3 AB	46.8 A	43.0
Zn	*Miscanthus sinensis*	10.6 g	15.8 e	16.2 d	18.4 c	15.3 B
	Miscanthus × *giganteus*	12.8 f	31.1 a	24.2 b	23.9 b	23.0 A
	mean	11.7 B	23.5 A	20.2 A	21.1 A	19.1
Mn	*Miscanthus sinensis*	4.5 g	15.9 f	52.1 c	86.8 b	39.8 A
	Miscanthus × *giganteus*	3.8 g	23.4 e	48.2 d	112.0 a	46.9 A
	mean	4.1 D	19.7 C	50.2 B	99.4 A	43.3
Cu	*Miscanthus sinensis*	1.801 d	2.178 cd	3.581 b	2.528 c	2.522 A
	Miscanthus × *giganteus*	4.479 a	2.424 c	2.517 c	3.410 b	3.207 A
	mean	3.140 A	2.301 A	3.049 A	2.969 A	2.864

Explanations as in the Table 1

time before slowly reaching lower values by the fall [Shoji et al. 1990]. At the end of the growing season, regardless of the species, the leaves of *Miscanthus* contained lower amounts of N, K, Ca, and Mg, and the level of P was similar to that at full bloom (Tab. 5). According to Gołąb-Bogacz et al. [2021], the content of Ca grows higher at the end of the growing season. Much higher levels of N, only when compared with the control, were found in the leaves of plants growing in the substrate with 10% and 15% of the dried shrimp biowaste. At the end of the growing season, the leaves were found to contain less N than at full bloom. Himken et al. [1997] speculated that this can be due to the plant aging. The content of K was higher in the leaves of the plants growing in the substrate with 10% of the dried shrimp biowaste only in comparison with the controls and plants growing in the substrate with the lowest percentage of the dried shrimp biowaste. The accumulation of this element was lower at the end of the growing season. According to Gołąb-Bogacz et al. [2021], a decrease in the level of K may be due to its leaching from the

Table 5. Content of macronutrients in the leaves of two-year plants at the end of the growing season depending on the species and shrimp biowaste dose

Macronutrient ($g \cdot kg^{-1}$)	Species	Shrimp biowaste dose (%)				Mean
		0	5	10	15	
N	*Miscanthus sinensis*	15.3 e	18.6 b	18.3 bc	17.4 c	17.4 A
	Miscanthus × *giganteus*	14.8 e	16.4 d	20.5 a	20.7 a	18.1 A
	mean	15.1 B	17.5 AB	19.4 A	19.0 A	17.7
P	*Miscanthus sinensis*	3.74 a	2.64 bc	2.93 b	2.93 b	3.06 A
	Miscanthus × *giganteus*	2.18 d	2.64 bc	2.49 cd	2.79 bc	2.52 B
	mean	2.96 A	2.64 A	2.71 A	2.86 A	2.79
K	*Miscanthus sinensis*	8.04 b	8.15 b	11.71 a	8.48 b	9.09 A
	Miscanthus × *giganteus*	3.74 e	5.31 d	6.19 c	6.51 c	5.44 B
	mean	5.89 B	6.73 B	8.95 A	7.50 AB	7.27
Ca	*Miscanthus sinensis*	4.64 c	3.93 e	2.92 f	2.33 g	3.45 B
	Miscanthus × *giganteus*	4.29 d	7.19 a	6.95 b	7.17 a	6.40 A
	mean	4.46 A	5.56 A	4.94 A	4.75 A	4.93
Mg	*Miscanthus sinensis*	1.20 f	1.35 e	1.32 e	1.34 e	1.30 B
	Miscanthus × *giganteus*	1.69 d	3.95 a	3.67 b	3.60 c	3.23 A
	mean	1.44 B	2.65 A	2.49 AB	2.47 AB	2.27

Explanations as in the Table 1

aging plant because this macronutrient is not metabolized organically. Mg was determined in the leaves of plants grown in the substrate with 5% of the biowaste only in comparison with the control, however, the difference was high and reached 84%. No significant effect of using dried shrimp biowaste as a component of the substrate was found on the content of P and Ca in the leaves of *Miscanthus*. At the end of the growing season for the two-year plants, regardless of the shrimp biowaste dose, higher levels of P and K were found in the leaves of *Miscanthus sinensis* than of *Miscanthus* × *giganteus*, and the differences were high, that is, 21.4% and 67.1%, respectively. A reverse relationship was observed for Ca and Mg, and the differences were even higher: 85.5% and 148.5%. We found a significant interaction between the plant species and the dried shrimp biowaste dose.

Himken et al. [1997] reported that the content of all nutrients in *Miscanthus* is the highest early in the growing season and decreases distinctly during the growing season. Kalembasa and Malinowska [2009], determined twice as low levels of Fe and Mn late in the growing season than in the summer. In our study, regardless of the species of *Miscanthus*, the content of Fe in the leaves of two-year plants late in the growing season was by 19.8% higher than at full bloom. On the other hand, the levels of Cu and Mn were by 51.8% and 182% lower (Tab. 6). At that time, only the levels of Mn and Cu depended on the shrimp biowaste dose. Higher levels of Mn were found in plants growing in the substrate with higher (10% and 15%) doses of dried shrimp biowaste than in the control and the substrate containing a 5% dose of the dried shrimp biowaste. The highest level of Cu was detected in the leaves of the plants grown in the substrate enriched with a 15% dose of the dried shrimp biowaste, and the lowest in those grown in the substrate with a 5% dose of the biowaste. The differences were significant and reached 226.9%. At the end of the growing season, *Miscanthus* × *giganteus*

Table 6. Content of micronutrients in the leaves of two-year plants at the end of the growing season depending on the species and shrimp biowaste dose

Micronutrient ($mg \cdot kg^{-1}$)	Species	Shrimp biowaste dose (%)				Mean
		0	5	10	15	
Fe	*Miscanthus sinensis*	59.4 b	45.3 de	43.7 e	57.1 c	51.4 A
	Miscanthus × *giganteus*	46.6 d	37.9 f	66.6 a	55.7 c	51.7 A
	mean	53.0 A	41.6 A	55.1 A	56.4 A	51,5
Zn	*Miscanthus sinensis*	17.5 e	20.2 c	16.3 f	15.6 g	17.4 B
	Miscanthus × *giganteus*	21.7 b	21.8 b	28.8 a	20.0 d	23.1 A
	mean	19.6 A	21.0 A	22.5 A	17.8 A	20.2
Mn	*Miscanthus sinensis*	5.82 e	10.97 d	26.50 a	26.21 a	17.37 A
	Miscanthus × *giganteus*	6.95 e	9.86 d	13.28 c	23.03 b	13.28 B
	mean	6.38 B	10.42 B	19.89 A	24.62 A	15.33
Cu	*Miscanthus sinensis*	2.019 b	1.061 cd	1.369 c	2.130 b	1.645 B
	Miscanthus × *giganteus*	2.441 b	0.646 d	1.972 b	3.453 a	2.128 A
	mean	2.230 AB	0.854 C	1.670 BC	2.792 A	1.886

Explanations as in the Table 1

accumulated by 28.9% and 32.8% more Cu and Zn than *Miscanthus sinensis*. A reverse relationship was found for Mn and the difference was 30.8%. For each of the analyzed micronutrients, a significant correlation between the plant species and the dried shrimp biowaste dose was observed.

CONCLUSIONS

The use of shrimp biowaste as a fertilizer in the cultivation of *Miscanthus sinensis* and *Miscanthus × giganteus* improves the plant's nutritional status. On the other hand, the content of minerals in their leaves depends on the species and on the biowaste dose. At the end of the growing season, higher levels of N, Ca, Mg, Fe, Zn, and Cu in one-year plants were found in *Miscanthus × giganteus* than *Miscanthus sinensis*. In the second year, higher levels were detected only for Ca, Mg, Zn and Cu. As the shrimp biowaste dose was increased, higher levels of N were found in the leaves regardless of the plant species. Higher levels of macro- and micronutrients were found in the leaves in the first year of the cultivation than in the second year, regardless of the plant species and of the shrimp biowaste dose. The differences for Fe, Zn, and Mn were more pronounced than those for N, P, and K. In the case of Ca and Mg, the differences were only minor.

The shrimp cleaning waste is useful as a fertilizer in the cultivation of *Miscanthus sinensis* and *Miscanthus × giganteus*. However, starting from the third year of the plant growing, when the plants produce increasingly larger biomass and the content of minerals is gradually depleted, another dose of the shrimp biowaste dose should be applied to replenish the nutrients after they had been used by the plants or lost into the soil. At present, as new, environmentally friendly ways of the disposal of harmful shrimp biowaste are being sought, the use of shrimp biowaste for fertilization in the cultivation of *Miscanthus sinensis* and *Miscanthus × giganteus* seems a safe and natural way to support the environment.

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