Response of Prairie cordgrass (*Spartina pectinata* Link) to a residual effect of municipal sewage sludge application

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Abstract: The objective of our study was to assess the residual effect of sewage sludge on the growth and yield of Prairie cordgrass and the content of crude ash, macroelements and heavy metals in the plant biomass. Field trials conducted in the years 2011 to 2013 focused on the assessment of the impact of municipal sewage sludge applied from 2008 to 2010 on the growth and yield of Prairie cordgrass. The experiments followed the split-plot design with two variables: the rate of sewage sludge (DM-dry matter) at 0, 1.4, 2.8 and 4.2 t ha⁻¹, corresponding to nitrogen fertilization with: 0, 50, 100, 150 kg ha⁻¹, and the harvest time - fall and winter. The total dose of sewage sludge applied in 2008–2010 was 0, 4.2, 8.4 and 12.6 t DM ha⁻¹, which corresponded to the total dose of nitrogen fertilization: 0, 150, 300 and 450 kg ha⁻¹, respectively. The municipal sewage sludge at a rate of 8.4 t DM ha⁻¹, compared to the Control, significantly increased the number of leaves per plant, the leaf and culm matter, the number of shoots per 1 m², the dry matter yield, crude ash deposition and uptake of macroelements and heavy metals.

Keywords: Prairie cordgrass, municipal sewage sludge, harvest period, crude ash, macroelements

1 Introduction

Prairie cordgrass is a perennial C₄ grass characterized by high adaptability to different habitats [1]. It is a plant that utilizes the C₄ carbon fixation pathway in which the CO₂ is first bound to a phosphoenolpyruvate in mesophyll cell resulting in the formation of four-carbon compound (oxaloacetate) that is shuttled to the bundle sheath cell where it is decarboxylated to liberate the CO₂ to be utilized in the C₃ pathway. In the first year of cultivation, the Prairie cordgrass had modest nutritional requirements. The mineral fertilization was recommended to begin in the second year of cultivation, because that is when fertilization showed a favorable effect on the quality of the plant. The optimum dose of mineral fertilization is as follows: nitrogen (N) 60–110 kg ha⁻¹, potassium (K₂O) 50 kg ha⁻¹, phosphorus (P₂O₅) 100 kg ha⁻¹. P and K fertilization should be applied after a prior analysis of the chemical composition of soil samples [2,3]. Sewage sludge is a source of organic matter, which in the process of mineralization releases mainly N and P, and therefore it may be recognized as an organic fertilizer with a high impact on the improvement of the organic matter balance in the soil [4-6]. Types of sewage sludge differ in terms of fertilization values since their effect may be similar to that of mineral fertilizers, and sometimes close to the manure [7]. The presence of heavy metals in sewage sludge runs a risk of soil contamination and a risk of metal uptake by plants [8]. Therefore, sewage sludge may be a source of nutrients for the crops not intended for human consumption and animal feed [9]. An application of 280 t ha⁻¹ of sewage sludge to the alkaline soil elevates the content of available Cu, Zn and Mn [10]. However, it poses no threat to the environment, but only improves the nutrition of the plants. Fertilization with a high dose of sewage sludge has a long-lasting effect on a microbial activity in the soil accumulation layer [11]. During year four after the sewage sludge application, a distinct stimulation of protease activity and nitrification process, and slight inhibition of ammonification are observed [11]. Irrespective of the plantation age, the fertilization of sugar miscanthus with 30 t ha⁻¹ of sewage sludge, compared to the control, significantly increases the content of heavy metals in the plant biomass, and its uptake can...
be arranged in the following series of decreasing values: 
Zn > Cd > Ni > Cu > Pb > Cr > Co [12].

The ash and sulfur content in the biomass of Prairie cordgrass is influenced by nitrogen fertilization and the number of cuts [13]. Plants harvested once during the winter season contain less ash and sulfur compared to those harvested twice. Silica prevalence and smaller amounts of Ca, K, S, P and Mg oxides can be observed in the ash of Prairie cordgrass [14]. A high content of heavy metals, in particular Pb, in the above-ground parts of Prairie cordgrass, demonstrated by some authors [15], speaks for its use in the restoration of degraded areas.

Our study evaluated the residual effect of fertilization with municipal sewage sludge on the growth and yield of Prairie cordgrass and determined the amounts of crude ash, macroelements and heavy metals in the plant biomass.

2 Experimental procedure

The studies conducted from 2011 to 2013 focused on the residual effect of sewage sludge applied from 2008 to 2010 on the growth and yield of Prairie cordgrass. The field experiment followed the split-plot design with two variables. The first factor studied was the rate of sewage sludge: 0, 1.4, 2.8 and 4.2 t DM ha⁻¹, corresponding to nitrogen fertilization with: 0, 50, 100, 150 kg ha⁻¹, and the second factor was the harvest time: fall and winter. The total dose of sewage sludge applied in 2008–2010 was: 0, 4.2, 8.4 and 12.6 t DM ha⁻¹, corresponding to the total dose of nitrogen fertilization: 0, 150, 300 and 450 kg ha⁻¹, respectively. The area of each plot was 3.5 m².

The experiment was established on the very light alluvial soil, on loose sand and sandy gravel, classified as a 5th soil valuation class. The content of available macroelements in the soil (mg kg⁻¹) was as follows: P (61–97) – medium to very high; K (60–88) – low; Mg (14–37) – very low to low. The soil pH in 1 M KCl was from slightly acidic to neutral (6.0–6.7) [16].

The experiment was set up in June 2008, and the planting of Prairie cordgrass followed the spacing of 0.35 × 0.35 m (82 thousand seedlings per 1 ha). Spartina pectinata was planted on the site where white mustard had been previously grown for seeds. During the growing season, the height of the crop was measured at two-week intervals. Prior to the harvest, the number of fully developed shoots (culms) per 1 m² was counted. Major morphological features, such as a shoot diameter at 0.10 m above the ground, the height of the plants before harvest and the number of leaves on the culm, were recorded on 10 shoots selected at random. In addition, the content of water in the leaves, culm and the whole plant was measured using the oven-drying method, and the yield structure of the above-ground parts of the plant and the yield of fresh and dry matter were determined.

The chemical analysis performed in the laboratories of the Crop Production Department and Plant Nutrition Department at the Wrocław University of Environmental and Life Sciences focused on dry matter – oven-drying method; drying shredded plants for 4 hours at the temperature of 105°C, crude ash – burning plants in an electric furnace at the temperature of 600°C, general nitrogen – Kjeldahl’s method, P an Mg – colorimetric method, K and Ca – flame photometry, S – Barclay’s method, Mn, Fe, Cu, Cd, Pb, Ni and Zn – flame atomic absorption spectroscopy (Varian 220 FS AA Spectrometer). The above methods are standard in laboratory analyses when assessing the content of minerals in plant materials [17].

The chemical composition of the sewage sludge was typical for sewage sludge from municipal sewage treatment plants (Table 1). The sewage sludge was applied on the following dates: start of June 2008, end of March 2009, and end of March 2010. Apart from the dose of nitrogen introduced to the soil according to the methodology, the sewage sludge contributed macro- and microelements, toxic to the plants elements, the weight of which was proportional to the dose of sewage sludge (Table 2).

The data collected were statistically analyzed using the variance analysis, and the experiment was designed as ‘split-plot’ with two variables. Their significance was assessed at α = 0.05. The Polish AWA programme [18] was used for data computation.

3 Results and discussion

The results obtained confirmed the residual effect of sewage sludge applied in the years 2008 to 2010 on the availability of P and Mg in the soil (Fig. 1). An application of the total dose of sewage sludge from 4.2 to 12.6 t DM ha⁻¹ resulted in a gradual increase in available P and Mg (Fig. 1) compared to the Control. Experiments carried out by other authors also demonstrate an increase in available P and Mg due to sewage sludge applications [19,6,20].

The weather conditions during our experiment varied, in particular with regard to the total precipitation. In the first year of the experiment, the precipitation was similar to the long-term average. In years two and three,
the precipitation was increased by 125 and 236 mm, respectively. The onset of the growing season in 2010 and 2011 took place in the second week of March (days 11th to 20th of March) and in 2013 it started one month later. The inhibition of the growing period was observed during the first week of November 2010; however in other years the inhibition of the growing period occurred by the end of November. The start of flowering was recorded during the third week in July for all of the relevant years. 

*Spartina pectinata* began to lodge during the first week in July during all the years of the experiment (Figs. 2-4) irrespective of the sewage sludge dose. The experimental factors did affect the number of leaves per shoot and the percentage of flowering culms (Table 5). As compared to the Control, the dose of 8.4 and 12.6 t ha\(^{-1}\) of DM of sewage sludge increased the number of leaves per plant by 6%, and shifting the harvest time to winter weakened this feature by 4% due to plant breaking, compared to the fall harvest. The weather conditions during the years of the experiment had a significant impact on the culm diameter, number of leaves per plant and percentage of flowering culms. The latter two features showed the lowest values in the third year of the experiment. The lowest values of morphological features of *Spartina pectinata* were found in 2013 (Table 5) since the plants' growth began in the second week of April, which in turn shortened the entire growth period. The findings of some studies [21] indicated a strong correlation of the height of Prairie cordgrass to the soil compactness in the fifth year of cultivation. The plants grown on clay and sandy soils were shorter than those grown on the loamy ones. Other findings reported the height of 230 cm in the fourth year of cultivation [22]. The number of leaves on

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**Table 1:** Sewage sludge chemical composition. Wrocław Sewage Treatment Plant, Janówek.

| Unit (g DM kg\(^{-1}\)) | N   | P   | K   | Ca   | Mg  | Cu  | Fe  | Mn  | Zn  | Ni  | Pb  | Cd  |
|------------------------|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Cont.                  | 200 | 35.7| 12.9| 1.8  | 19.5| 7.0 | 412 | 2385| 464 | 1260| 47.6| 36.4|

**Table 2:** Macro and microelements and heavy metals in a sewage sludge dose.

| DM sewage sludge (kg ha\(^{-1}\)) dose (t ha\(^{-1}\)) \* | N | P | K | Ca | Mg | Mn | Cu | Zn | Ni | Fe | Pb | Cd |
|--------------------------------------------------------|---|---|---|----|----|----|----|----|----|----|----|----|
| 4.2                                                    | 150| 54 | 7.6| 81.9| 29.4| 1.95| 1.73| 5.29| 0.20| 10.02| 0.15| 0.01|
| 8.4                                                    | 300| 108| 15.1|163.8| 58.8| 3.90| 3.46|10.58| 0.40| 20.03| 0.31| 0.02|
| 12.6                                                   | 450| 163| 22.7|245.7| 88.2| 5.85| 5.19|15.88| 0.60| 30.05| 0.46| 0.03|

\* - total sewage sludge dry matter in 2008-2010

**Table 3:** Soil macroelements (mg kg\(^{-1}\)) and pH.

| DM sewage sludge dose (t ha\(^{-1}\)) \* | Years | pH in 1 M KCl | P | K | Mg |
|----------------------------------------|-------|---------------|---|---|----|
| 4.2                                    | 2011  | 6.3           | 61| 60| 16 |
| 8.4                                    | 2012  | 6.0           | 72| 68| 19 |
| 12.6                                   | 2013  | 6.1           | 65| 69| 14 |

\* - total sewage sludge dry matter in 2008-2010

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**Figure 1:** The effect of a growing dose of communal sewage sludge on available phosphorous and magnesium in soil.
a shoot, as recorded by others [23], may have been from 4.4 to 4.8; this value was higher than that in those plants reproduced generatively.

Sewage sludge at a rate of 8.4 t DM ha⁻¹, as compared to the Control, increased the weight of shoot leaves by 18%, that of culms by 44% and that of leafy culms by 29%, which resulted in a significant increase in the contribution of a shoot to the yield structure (Table 6). Sewage sludge applications affected the water content in culms and leafy culms. The highest amount of water was recorded

| Month | Temperature (°C) | Precipitation (mm) |
|-------|------------------|--------------------|
|       | 2011  | 2012  | 2013  | Average 1981–2010 | 2011  | 2012  | 2013  | Average 1981–2010 |
| Jan.  | 0.6   | 1.5   | -1.6  | -0.8  | 35.6  | 57.1  | 51.3  | 31.9  |
| Feb.  | -1.6  | -4.0  | 0.05  | 0.3   | 10.5  | 38.7  | 29.5  | 26.7  |
| March | 4.4   | 6.1   | -0.9  | 3.8   | 45.2  | 13.7  | 43.0  | 31.7  |
| April | 11.9  | 9.8   | 9.2   | 8.9   | 27.0  | 27.6  | 42.7  | 30.5  |
| May   | 14.8  | 15.8  | 14.6  | 14.4  | 49.4  | 63.7  | 136   | 51.3  |
| June  | 19.1  | 17.3  | 17.7  | 17.1  | 95.7  | 94.7  | 171.7 | 59.5  |
| July  | 18.2  | 20.0  | 20.5  | 19.3  | 17.9  | 108.0 | 36.3  | 78.9  |
| Aug.  | 19.3  | 19.3  | 19.0  | 18.3  | 83.1  | 72.2  | 181.1 | 61.7  |
| Sept. | 15.5  | 14.6  | 12.9  | 13.6  | 30.4  | 52.6  | 105.8 | 45.3  |
| Oct.  | 9.3   | 8.6   | 10.0  | 13.6  | 42.6  | 35.4  | 7.8   | 32.3  |
| Nov.  | 3.8   | 5.9   | 5.6   | 3.9   | 0.0   | 31.8  | 25.8  | 36.6  |
| Dec.  | 3.9   | -0.8  | 3.0   | 0.2   | 48.7  | 24.9  | 13.0  | 9.0   |
| Average temperature or total precipitation | 9.9 | 9.5 | 9.2 | 9.0 | 481.9 | 621.4 | 731.1 | 495.4 |

Table 5: Morphological features of Prairie cordgrass shoots (means by factors and years).

| DM sewage sludge dose (t ha⁻¹)* | Harvest time | Years | Diameter (mm) | Height before harvesting (cm) | Number of leaves per shoot | Plant part with florets (%) |
|---------------------------------|--------------|-------|---------------|-----------------------------|---------------------------|---------------------------|
| 0                               | Autumn       | 2011  | 4.48          | 146                         | 6.8                       | 29.2                      |
| 4.2                             | Autumn       | 2012  | 4.40          | 148                         | 6.9                       | 26.4                      |
| 8.4                             | Autumn       | 2013  | 4.44          | 150                         | 7.2                       | 23.9                      |
| 12.6                            | Autumn       |        | 4.48          | 150                         | 7.2                       | 24.7                      |
| LSD (α = 0.05)                  | Winter       | 2011  | 4.42          | 148                         | 7.2                       | 27.7                      |
| LSD (α = 0.05)                  | Winter       | 2012  | 4.48          | 149                         | 6.9                       | 24.4                      |
| LSD (α = 0.05)                  | Winter       | 2013  | 4.48          | 148                         | 6.7                       | 22.0                      |
| LSD (α = 0.05)                  |              |       | 0.14          | NS                         | 0.3                       | 3.0                       |

*– total sewage sludge dry matter in 2008–2010
LSD = Least Significant Difference
NS = No Significance
for leafless culms, followed by less leafy culms with the lowest values for leaves losing water most quickly. A delay in harvesting led to a lower moistening of the leaves and leafy culms. However, it was the varied weather pattern that determined the shoot morphology and structure and the content of water in shoot parts during the years of the experiment. The shortening of the growth period in 2013, due to a delayed onset of the development of spring crops, resulted in a less efficient process of photosynthesis and reduced the dry matter accumulation of leaves and stems. At the same time, a shortened growth period brought about higher water content in the harvested leaves and shoots (Table 6).

The municipal sewage sludge also affected the number of shoots per 1 m², which continually grew in the subsequent years of cultivation (Table 7). Moreover, we found a significant increase in the number of shoots per 1 m² and in the amount of fresh and dry matter when a high dose of sewage sludge was applied, as compared to the Control. A similar number of shoots (197–397) under changeable soil conditions was reported by other authors [21]. The density of Prairie cordgrass stands during the first

Table 6: Prairie cordgrass dry matter structure and shoot moistening (means by factors and years).

| DM sewage sludge dose (t ha⁻¹)* | Harvest time | Years | 1 shoot dry matter (g) | Percentage in shoot mass (%) | Water content (g kg⁻¹) |
|----------------------------------|-------------|-------|------------------------|------------------------------|------------------------|
|                                  |             | Leaves | Culms | Total                | Leaves | Culms | Leaves | Culms | Above-ground matter |
| 0                                |             | 2.53   | 1.76  | 4.29                 | 59.0   | 41.0  | 576    | 682   | 633              |
| 4.2                              |             | 2.81   | 1.83  | 4.64                 | 60.6   | 39.4  | 586    | 668   | 627              |
| 8.4                              |             | 2.99   | 2.54  | 5.53                 | 54.1   | 45.9  | 562    | 541   | 556              |
| 12.6                             |             | 3.15   | 2.28  | 5.43                 | 58.0   | 42.0  | 576    | 587   | 585              |
| LSD (α = 0.05)                   |             | 0.32   | 0.23  | 0.42                 | 2.7    | 2.8   | NS     | 45    | 34               |
| Autumn                           |             | 2.84   | 2.13  | 4.97                 | 57.1   | 42.9  | 590    | 627   | 615              |
| Winter                           |             | 2.89   | 2.08  | 4.97                 | 58.1   | 41.9  | 560    | 612   | 585              |
| LSD (α = 0.05)                   |             | NS     | NS    | NS                  | NS     | NS    | 25     | 29    |                  |
| 2011                             |             | 3.07   | 2.53  | 5.60                 | 54.8   | 45.2  | 513    | 574   | 548              |
| 2012                             |             | 3.46   | 2.55  | 6.01                 | 57.6   | 42.4  | 590    | 555   | 582              |
| 2013                             |             | 2.07   | 1.23  | 3.30                 | 62.7   | 37.3  | 622    | 729   | 671              |
| LSD (α = 0.05)                   |             | 0.27   | 0.20  | 0.37                 | 2.4    | 2.4   | 47    | 39    | 30               |

* − total sewage sludge dry matter in 2008–2010
LSD = Least Significant Difference
NS = No Significance

Figure 2: Prairie cordgrass growth dynamics – 2011.

Figure 3: Prairie cordgrass growth dynamics – 2012.
years of cultivation was primarily correlated to the number of seedlings per 1 m², which were most often planted with a 1.80–3.00 m inter-row and a 0.50–0.75 m intra-row spacing. The plant population per hectare ranged from 4 444 to 11 111 using the spacing above. However, the higher planting density was possible, even with a 0.25 × 0.25 m spacing [24] or 0.90 × 0.35 m [25], or 1.00 × 0.50 m [26]. In our study, the plant spacing was 0.35 × 0.35 m, which corresponded to 82 thousand plants per hectare. A large number of plants caused a high density of the plant stand already in the second year of the experiment and no presence of weeds, which in the absence of registered chemical plant protection products became an important issue for those plantations holding only a small number of plants. In natural conditions of East England, the number of shoots of Prairie cordgrass per 1 m² steadily increased for four consecutive years, but dropped significantly in years five and six [24].

The municipal sewage sludge in the amount of 8.4 t DM ha⁻¹ increased the dry matter yield of Prairie cordgrass by 30% (Table 7) compared to the Control. The harvest time had no impact on the dry matter yield. As the other authors demonstrated [21], the yield of Prairie cordgrass in the fifth year of cultivation may have depended on the soil type and range from 10 to 16 t ha⁻¹. Other studies reported [26] that the dry matter yield of one-year-old Prairie cordgrass did not exceed 1 t ha⁻¹, and that in the third year could be 11 t ha⁻¹, with 180 shoots per m². The experiments conducted in South Dakota [23] showed that the biomass yield of Spartina pectinata could be related to the type of propagation. In those experiments, the yield of the plants grown from seeds was 11.7 t ha⁻¹ and the yield of vegetatively propagated plants reached 14.6 t ha⁻¹. It should be noted that the rhizome mass and that of underground shoots to a depth of 0.25 m in the generatively reproduced plants was 20.6 t ha⁻¹ and that in vegetatively propagated plants was 21.8 t ha⁻¹. A wide variability in the Prairie cordgrass yield in the years of observations and a low correlation between the number of shoots and the dry matter yield are reported under East England [24].

A few-years of sewage sludge application increased the content of phosphorous and magnesium in the biomass of Prairie cordgrass (Table 8) compared to the Control. It was also shown [13] that the crude ash content in the Prairie cordgrass biomass could be on average 48 g kg⁻¹ and that of sulfur 1.1 g kg⁻¹. In our studies, the content of these elements was 37.7 and 1.84 g kg⁻¹, respectively. The winter harvest of Prairie cordgrass, due to leaching of the said elements, brought about a decrease of the crude ash content by 8%, N by 7%, P by 5%, K by 50%, Ca by 31%, Mg by 10% and S by 21%. Similar results were obtained for Miscanthus giganteus [27], as the winter harvest caused the lower values of the dry matter yield by 9.5%, water content by 16.8% and crude ash by 26%.

The accumulation of crude ash and macronutrients in the biomass of Prairie cordgrass is a function of yields and content of all macronutrients. With little differentiation of the content of crude ash and macronutrients, their uptake from an area unit was proportional to the dry matter yield. Compared to the Control, a significant

Table 7: Number of shoots per 1 m² and biomass yield (means by factors and years).

| DM sewage sludge dose (t ha⁻¹)* | Harvest time | Years | Number of shoots per 1 m² before harvesting (pcs) | Yield (t ha⁻¹) |
|--------------------------------|--------------|-------|-----------------------------------------------|---------------|
|                                |              |       | Fresh matter                                   | Dry matter    |
| 0                              |              |       | 246                                           | 24.1          |
| 4.2                            |              |       | 266                                           | 25.5          |
| 8.4                            |              |       | 277                                           | 27.2          |
| 12.6                           |              |       | 280                                           | 31.5          |
| LSD (α = 0.05)                 |              |       | 20                                            | 2.7           |
| Autumn                         |              |       | 268                                           | 27.4          |
| Winter                         |              |       | 267                                           | 26.7          |
| LSD (α = 0.05)                 |              |       | NS                                            | NS            |
| 2011                           |              |       | 188                                           | 21.4          |
| 2012                           |              |       | 224                                           | 27.0          |
| 2013                           |              |       | 389                                           | 32.8          |
| LSD (α = 0.05)                 |              |       | 17                                            | 2.3           |

* − total sewage sludge dry matter in 2008–2010
LSD = Least Significant Difference
NS = No Significance
residual impact of the sewage sludge fertilization was demonstrated for the rates of 8.4 and 12.6 t DM ha⁻¹, which led to the higher accumulation of crude ash (by 33.3% and 43.9%, respectively) and the uptake of all macroelements studied: N (by 37.8% and 54.3%, respectively), P (by 50.3% and 64.3%, respectively), K (by 46.6% and 57.8%, respectively), Ca (by 33.3% and 46.9%, respectively), Mg (by 65.9% and 76.0%, respectively) and S (by 43.8% and 57.3%, respectively) (Table 9).

The biomass of Prairie cordgrass harvested in winter accumulated fewer macroelements: K by 50%, Ca by 23%, and S by 11%, compared to the fall harvest, which was due to leaching of the biogenic elements.

| DM sewage sludge dose (t ha⁻¹)* | Harvest time | Years | Crude ash | N | P | K | Ca | Mg | S |
|----------------------------------|--------------|-------|-----------|---|---|---|----|----|---|
| 0                               | Autumn       | 2011  | 39.8      | 2.00 | 0.79 | 6.07 | 2.80 | 0.47 | 0.61 |
| 4.2                             | Winter       | 2011  | 36.5      | 1.83 | 0.75 | 3.02 | 1.92 | 0.42 | 0.48 |
| 8.4                             |              |       |           |     |     |     |     |     |     |
| 12.6                            |              |       |           |     |     |     |     |     |     |
| LSD (α = 0.05)                  |              |       |           |     |     |     |     |     |     |
| * − total sewage sludge dry matter in 2008–2010
LSD = Least Significant Difference
NS = No Significance
Among heavy metals, five elements (Mn, Fe, Cu, Ni and Zn) constitute microelements that were necessary for the growth and development of the plants, and two (Cd and Pb) were toxic elements. The sewage sludge amounts had no significant effect on the heavy metal content in the dry matter of Prairie cordgrass (Table 10), which was confirmed by other reports [28]. The harvest postponement (from fall to winter) resulted in an increase in the content of Fe and Pb, and a decrease in Mn in the biomass.

Plants grown on the soil contaminated with Ni, e.g. Dactylis glomerata, limed and fertilized with sewage sludge, contained more Fe, Cu and Ni in the first year than in the third year [29]. Fertilization of sugar miscanthus with sewage sludge resulted in more heavy metals in the third year biomass than in the fourth year [12].

The uptake of heavy metals by *Spartina pectinata* can be presented in the following order of decreasing values: Mn > Fe > Zn > Pb > Cu > Ni > Cd (Table 11). As compared
to the Control, on the plots fertilized with sewage sludge at a rate of 12.6 t DM ha⁻¹, we recorded an increase in the uptake of Mn by 30%, Fe by 59%, Cu by 55%, Cd by 58%, Pb by 44%, Ni by 60% Ni and Zn by 67%. The plants harvested in winter, compared to those collected in fall, accumulated the lower amounts of Fe, Cu, Pb, Ni and Zn.

4 Conclusions

1. Morphological characteristics, yields and chemical composition of Prairie cordgrass are differentiated firstly by changeable weather conditions during the field trials and secondly by the residual effect of the municipal sewage sludge application and the harvest time.
2. Our studies show that *Spartina pectinata* can be used to remediate soils contaminated with sewage sludge and heavy metals.
3. Winter harvest causes the lowered content of crude ash, macroelements, manganese and cadmium, and the lowered uptake of K, Ca and S, which is to the advantage of the biomass use for energy purposes.

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