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# MODIFICATION OF SULFUR CONTENT IN *Miscanthus x giganteus* UNDER DIFFERENT NITROGEN AND POTASSIUM FERTILIZATION

## ZMIANY ZAWARTOŚCI SIARKI W MISKANCIE OLBRZYMIM POD WPŁYWEM ZRÓŻNICOWANEGO NAWOŻENIA AZOTEM I POTASEM

**Abstract:** The purpose of the presented work was to evaluate the changes in the sulfur content in the aboveground parts of *Miscanthus x giganteus* under the influence of applying incrementally increasing doses of nitrogen and potassium. Field experiments were conducted using the split-plot method on light, sandy soil. Varying doses of nitrogen-based fertilizers were used: 100 kg N; 150 kg N and 200 kg N $\cdot$ $ha^{-1}$, with potassium 83 kg K and 124 kg K (100 kg and 150 kg $K_2O$). Plant samples were taken from 2007 to 2009 during the months of June through October. Throughout the vegetation period the sulfur content in the studied Miscanthus was twice as high in the leaves as in the stems. The highest amount of sulfur was found in young plants. By the end of the vegetation period the sulfur content in the leaves fell by about 30 % and in the stems by 60 %. None of the studies found that fertilizing with nitrogen significantly modified the sulfur content in Miscanthus. However, it was determined that the sulfur content was significantly higher in the stems and leaves of the Miscanthus fertilized with higher doses of potassium. Throughout the three-year study period increasingly higher amounts of sulfur were observed in the aboveground parts of Miscanthus at all the field trial locations.

**Keywords:** *Miscanthus x giganteus*, nitrogen and potassium fertilizing, sulfur content, vegetation period

Despite its significant presence in the environment, sulfur is becoming an increasingly deficient ingredient in agrocenoses [1, 2]. A lack of sulfur makes it impossible to obtain high plant yields, because of the significant role sulfur plays in key physiological processes. More and more often prophylactic crop fertilization is being recommended for every kind of plant group, since even if there is a high content of sulfur in the soil, it does not usually have a toxic effect on plants. The purpose of growing energy plants is to obtain as much biomass as possible within a given set of quality parameters. In

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numerous studies the yields of different energy plants were compared, and their chemical content and the quality of the ash was analyzed [3–7]. The chemical content of energy plants depends to a high degree on the granulometric category of the soil [8, 9], fertilizing especially young plants, and soil fertility [10–12]. The chemical content of Miscanthus is dependent on the volume of the obtained yield, and above all, the timing of plant harvesting [13–15].

The sulfur content in the biomass of Miscanthus used for combustion should be as low as possible and stay below 0.08 % S because of the possibility of an adverse impact on energy-producing equipment [16, 17]. Miscanthus should not be fertilized with fertilizers containing sulfur, because in comparison with butterfly or cabbage plants, grasses show less need for sulfur, and its removal is connected to a much higher degree to the grain yield rather than the straw yield. Refraining from using sulfur during fertilization even with a sulfur deficiency in the soil does not mean there will be a low content of this element in plant tissues, since plants can absorb sulfur oxide from the atmosphere.

The purpose of the conducted study was to evaluate the changes in sulfur content in the aboveground parts of *Miscanthus x giganteus* throughout the vegetation period and evaluate the effect of applying fertilizers with the elements that most greatly modify the mass of vegetative parts – nitrogen and potassium.

## Materials and methods

A multiyear testing field was set up in 2004 in light soil, categorized as a weak rye complex, using the method of randomly drawn subblocks with two variables. In the study two levels of potassium fertilization (83 and 124 kg K $\cdot$ ha$^{-1}$) and three levels of nitrogen fertilization (100, 150 and 200 kg N $\cdot$ ha$^{-1}$) were tested. Potassium was in the form of a 60 % potassium salt, and nitrogen was used in the form of urea. At all testing plots phosphorus fertilization was applied in the amount of 26 kg P $\cdot$ ha$^{-1}$, in the form of granular triple superphosphate. An exact description of the experiment, sampling methodology, soil and atmosphere conditions, yields, and the chemical content of Miscanthus can be found in the monograph on Miscanthus [15].

The evaluation of the sulfur content dynamics was conducted in the years 2007–2009. Plant samples were taken five times during the vegetation period beginning in June through October in the first ten days of each month. Twenty plants were cut from the field plots, their mass was determined, and they were separated into leaves and stems. During the last sample taken in October the proportion of the leaf mass and the stem mass in the Miscanthus yield was determined. The sulfur content in the plant samples was determined by the nefelometric method of Butters-Chenery.

A statistical analysis with the application of variance analysis for the random subblock method was applied to the obtained results. Then, after determining the significance of the differences the results were evaluated with the help of the confidence interval (LSD = 0.05), based on multiple tests of the Duncan range.

## Results and discussion

During the studies the sulfur content in the Miscanthus leaves varied from 0.65 to 1.79 g S · kg$^{-1}$, while lower sulfur concentrations were found in the stems, which ranged from 0.19 to 1.40 g S · kg$^{-1}$ d.m. (Tables 1 and 2). The highest sulfur content was found in the leaves and stems in young plants intensively fertilized with nitrogen and potassium.

Table 1

Sulfur content [g · kg$^{-1}$] in the leaves of *Miscanthus x giganteus* during vegetation

| Month | Dose of K | Dose of N | Years | | | Mean 2007–2009 |
|---|---|---|---|---|---|---|
| | | | 2007 | 2008 | 2009 | |
| June | 83 | 100 | 1.36 | 1.19 | 1.58 | 1.38 |
| | | 150 | 1.30 | 1.22 | 1.40 | 1.31 |
| | | 200 | 1.47 | 1.85 | 1.48 | 1.60 |
| | 124 | 100 | 1.41 | 1.33 | 1.71 | 1.48 |
| | | 150 | 1.34 | 1.72 | 1.62 | 1.56 |
| | | 200 | 1.33 | 1.72 | 1.79 | 1.62 |
| July | 83 | 100 | 1.25 | 1.08 | 1.47 | 1.27 |
| | | 150 | 1.23 | 1.15 | 1.33 | 1.24 |
| | | 200 | 1.32 | 1.70 | 1.33 | 1.45 |
| | 124 | 100 | 1.32 | 1.24 | 1.62 | 1.39 |
| | | 150 | 1.22 | 1.61 | 1.50 | 1.44 |
| | | 200 | 1.20 | 1.59 | 1.66 | 1.48 |
| August | 83 | 100 | 1.05 | 1.09 | 1.29 | 1.14 |
| | | 150 | 0.96 | 1.24 | 1.18 | 1.12 |
| | | 200 | 0.76 | 1.04 | 1.05 | 0.95 |
| | 124 | 100 | 1.26 | 1.13 | 1.24 | 1.21 |
| | | 150 | 1.11 | 1.24 | 1.18 | 1.17 |
| | | 200 | 1.10 | 1.09 | 1.14 | 1.11 |
| September | 83 | 100 | 1.02 | 1.24 | 1.24 | 1.16 |
| | | 150 | 0.96 | 1.03 | 1.15 | 1.05 |
| | | 200 | 0.93 | 1.01 | 1.21 | 1.05 |
| | 124 | 100 | 1.13 | 1.31 | 1.25 | 1.23 |
| | | 150 | 1.06 | 1.19 | 1.52 | 1.26 |
| | | 200 | 1.04 | 1.04 | 1.19 | 1.09 |
| October | 83 | 100 | 0.65 | 0.91 | 1.23 | 0.93 |
| | | 150 | 0.91 | 0.90 | 1.27 | 1.03 |
| | | 200 | 0.97 | 0.92 | 1.09 | 0.99 |
| | 124 | 100 | 0.82 | 1.22 | 1.30 | 1.11 |
| | | 150 | 0.96 | 1.04 | 1.29 | 1.10 |
| | | 200 | 1.09 | 1.02 | 1.15 | 1.09 |

Table 1 contd.

| Month | Dose of K | Dose of N | Years | | | Mean 2007–2009 |
|---|---|---|---|---|---|---|
| | | | 2007 | 2008 | 2009 | |
| Mean values | | | | | | |
| June | | | 1.37 | 1.51 | 1.60 | 1.49 |
| July | | | 1.26 | 1.39 | 1.48 | 1.38 |
| August | | | 1.04 | 1.14 | 1.18 | 1.12 |
| September | | | 1.02 | 1.13 | 1.26 | 1.14 |
| October | | | 0.90 | 1.00 | 1.22 | 1.04 |
| **LSD $\alpha_{0.05}$** | | | **0.08** | **0.15** | **0.11** | **0.06** |
| | 83 | | 1.07 | 1.17 | 1.29 | 1.18 |
| | 124 | | 1.16 | 1.30 | 1.41 | 1.29 |
| **LSD $\alpha_{0.05}$** | | | **0.05** | **0.10** | **0.07** | **0.04** |
| | | 100 | 1.12 | 1.17 | 1.39 | 1.23 |
| | | 150 | 1.10 | 1.23 | 1.34 | 1.23 |
| | | 200 | 1.12 | 1.30 | 1.31 | 1.24 |
| **LSD $\alpha_{0.05}$** | | | **n.s.** | **n.s.** | **n.s.** | **n.s.** |
| Years | | | 1.12 | 1.23 | 1.35 | 1.23 |
| **LSD $\alpha_{0.05}$** | | | | **0.05** | | **—** |

n.s. – not significant difference.

During the beginning period of plant growth in June, the sulfur content in the stems was on average about 64 % of the sulfur content in the leaves. Towards the end of the vegetation period the sulfur content in the stems was about 37 % of the sulfur content in the Miscanthus leaves. In Malinowska's studies [11] during the first year of planting sugar Miscanthus it was determined that the amount of N, P, K was four times higher in the leaves and the amount of K and Mg was two times higher in the stems.

Over the period of vegetation and plant growth a decrease in the sulfur content in the plant tissues was observed. On the average the sulfur content in the Miscanthus leaves dropped during the study period by 0.45 g S $\cdot$ kg$^{-1}$, which was 30 % of the initial value. From June to October the drop in the sulfur content in the stems was even higher, 59 % (0.60 g S $\cdot$ kg$^{-1}$ d.m.). Similar dependencies – decreases in the sulfur content in the aboveground parts of Miscanthus throughout the vegetation period – were also determined in the studies with different Miscanthus clones done by Kalembasa et al [18]. However, in their studies the sulfur content in Miscanthus annuals decreased from the beginning of June through September, but later in October increased.

The determined sulfur content in the Miscanthus leaves was higher than in the stems of this plant. They also absorb much more moisture. For this reason it does not seem appropriate to use them for making into pellets [16]. At the end of the Miscanthus vegetation the leaves contained on average of 1.23 g S $\cdot$ kg$^{-1}$. This is a small amount compared with the organic waste materials such as manure – 4.9 g S $\cdot$ kg$^{-1}$, or a mushroom floor – 16.9 g S $\cdot$ kg$^{-1}$ [19]. However, because of limited access to organic waste materials, Miscanthus leaves can become a precious source of sulfur and other nutritional elements at farms which have an opportunity to obtain Miscanthus leaves and use them for fertilization in addition to organic waste.

The time of harvesting the Miscanthus also has a significant impact, not only on the sulfur content, but also on the dry mass content, moisture of the collected biomass, and the ash content [14]. In numerous studies it was determined that in the period from October through March the N, P, K and Mg content also dropped by almost half [13, 20].

In our experiment the decrease in the sulfur content in the aboveground parts of Miscanthus took place throughout the vegetation period, but it should be noted that both in the leaves and the stems an especially significant drop in the sulfur concentration took place in the first two months of vegetation – June and July. In each of the study years the decrease was statistically significant, and the average sulfur content in August was a 25 % decrease from the value found in the Miscanthus leaves at the beginning of the vegetation period and a 47 % decrease from the beginning value in the stems.

Despite the known interdependencies between sulfur and nitrogen, fertilizing the Miscanthus in the experiment with different doses of nitrogen did not significantly modify the sulfur content for any of the study years in either the leaves or stems (Tables 1 and 2). The mean sulfur content at all plots fertilized with nitrogen was similar. Increasing the nitrogen dose in the second year of studies from 100 to 200 kg N $\cdot$ ha$^{-1}$ only caused a slight difference in the sulfur content in the leaves from 1.17 to 1.30 g $\cdot$ S $\cdot$ kg$^{-1}$ and in the stems from 0.59 to 0.63 g $\cdot$ S $\cdot$ kg$^{-1}$; however, those tendencies were not confirmed statistically.

It should be added that fertilizing with nitrogen did not have any significant impact on the shooting mass created in this period [15].

A stronger factor impacting the sulfur content in the Miscanthus leaves and stems turned out to be potassium fertilizing (Tables 1 and 2). Increasing the dose of this element from 83 kg K to 124 kg K $\cdot$ ha$^{-1}$ caused a significant increase in the sulfur content of the Miscanthus biomass in each of the analyzed periods of plant growth.

In the Miscanthus leaves the average annual increase in the sulfur content was 0.12 g S $\cdot$ kg$^{-1}$, which corresponded to a 10 % increase in the concentration of this element. This was a uniform increase in the three consecutive years: 9 %, 12 % and 10 %, respectively. An increase in the sulfur content as the Miscanthus plantation aged was also observed in the stems of the plant (Table 2). The increase was pronounced, 0.25g $\cdot$ S (66 %) in the first year of studies and 0.24 g S $\cdot$ kg$^{-1}$ (49 %) in the second year. In the third year there were unfavorable atmospheric conditions. Despite a drop in the Miscanthus biomass, the observed increase of the sulfur content in the stems fertilized with potassium was smaller but still significant, measured at 0.1 g S $\cdot$ kg$^{-1}$ or 14 %.

Fertilizing with potassium modified the sulfur content in the Miscanthus stems even more than in the leaves (Table 2). On the average during the three years of studies an increase in the sulfur content in the stems from fertilizing with high doses of potassium was found to be over 35 %. An especially significant concentration of sulfur in the

Table 2

Sulfur content [$g \cdot kg^{-1}$] in the stems of *Miscanthus x giganteus* during vegetation

| Month | Dose of K | Dose of N | Years | | | Mean 2007–2009 |
|---|---|---|---|---|---|---|
| | | | 2007 | 2008 | 2009 | |
| June | 83 | 100 | 0.73 | 0.72 | 1.05 | 0.83 |
| | | 150 | 0.61 | 0.69 | 1.03 | 0.78 |
| | | 200 | 0.62 | 0.77 | 1.34 | 0.91 |
| | 124 | 100 | 0.87 | 0.86 | 1.40 | 1.04 |
| | | 150 | 0.85 | 1.12 | 1.27 | 1.08 |
| | | 200 | 0.92 | 1.09 | 1.29 | 1.10 |
| July | 83 | 100 | 0.60 | 0.59 | 0.92 | 0.70 |
| | | 150 | 0.48 | 0.57 | 0.91 | 0.65 |
| | | 200 | 0.47 | 0.62 | 1.19 | 0.76 |
| | 124 | 100 | 0.73 | 0.72 | 1.26 | 0.90 |
| | | 150 | 0.72 | 0.99 | 1.14 | 0.95 |
| | | 200 | 0.76 | 0.93 | 1.13 | 0.94 |
| August | 83 | 100 | 0.35 | 0.36 | 0.58 | 0.43 |
| | | 150 | 0.29 | 0.40 | 0.71 | 0.46 |
| | | 200 | 0.27 | 0.43 | 0.70 | 0.47 |
| | 124 | 100 | 0.50 | 0.71 | 0.57 | 0.59 |
| | | 150 | 0.61 | 0.61 | 0.55 | 0.59 |
| | | 200 | 0.54 | 0.61 | 0.53 | 0.56 |
| September | 83 | 100 | 0.22 | 0.47 | 0.42 | 0.37 |
| | | 150 | 0.26 | 0.35 | 0.42 | 0.34 |
| | | 200 | 0.24 | 0.39 | 0.40 | 0.34 |
| | 124 | 100 | 0.50 | 0.61 | 0.58 | 0.56 |
| | | 150 | 0.55 | 0.53 | 0.72 | 0.60 |
| | | 200 | 0.47 | 0.53 | 0.44 | 0.48 |
| October | 83 | 100 | 0.19 | 0.32 | 0.40 | 0.30 |
| | | 150 | 0.19 | 0.24 | 0.39 | 0.27 |
| | | 200 | 0.26 | 0.40 | 0.23 | 0.30 |
| | 124 | 100 | 0.42 | 0.54 | 0.51 | 0.49 |
| | | 150 | 0.55 | 0.62 | 0.47 | 0.54 |
| | | 200 | 0.52 | 0.51 | 0.34 | 0.45 |
| Mean values | | | | | | |
| June | | | 0.77 | 0.87 | 1.23 | 0.96 |
| July | | | 0.63 | 0.73 | 1.09 | 0.82 |
| August | | | 0.42 | 0.52 | 0.60 | 0.51 |
| September | | | 0.37 | 0.48 | 0.49 | 0.45 |
| October | | | 0.35 | 0.44 | 0.39 | 0.39 |
| **LSD $\alpha_{0.05}$** | | | **0.05** | **0.10** | **0.10** | **0.05** |

Table 2 contd.

| Month | Dose of K | Dose of N | Years | | | Mean 2007–2009 |
|---|---|---|---|---|---|---|
| | | | 2007 | 2008 | 2009 | |
| | 83 | | 0.38 | 0.49 | 0.71 | 0.53 |
| | 124 | | 0.63 | 0.73 | 0.81 | 0.72 |
| **LSD $\alpha_{0.05}$** | | | **0.03** | **0.06** | **0.06** | **0.04** |
| | | 100 | 0.51 | 0.59 | 0.77 | 0.62 |
| | | 150 | 0.51 | 0.61 | 0.76 | 0.63 |
| | | 200 | 0.50 | 0.63 | 0.76 | 0.63 |
| **LSD $\alpha_{0.05}$** | | | **n.s.** | **n.s.** | **n.s.** | **n.s.** |
| Years | | | 0.51 | 0.61 | 0.76 | 0.63 |
| **LSD $\alpha_{0.05}$** | | | | **0.04** | | — |

n.s. – not significant difference.

stems was observed during the first two years of studies in which higher yields of Miscanthus were obtained (Fig. 1).

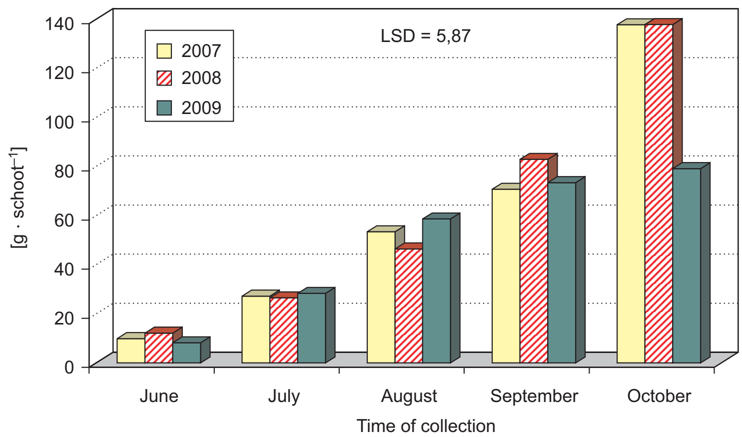


Fig. 1. Dynamics of the accumulation of dry mass in the Miscanthus shoots during the vegetation period

On the basis of the average proportion of the leaf mass and the stem mass in the final yield, the magnitude and the sulfur content of the yield was determined for the Miscanthus biomass collected in the fall in October (Fig. 2). The share of the leaves in the crop mass was an average of 26.6 % at the time of studies; however, the amount of accumulated sulfur in the leaves was over half of the total amount of sulfur in the biomass.

The concentration of sulfur in both the Miscanthus leaves and stems turned out to be significantly dependent on the year of planting (Table 1 and 2). This may be the result of stronger development and an increase in the range of the root system at the older

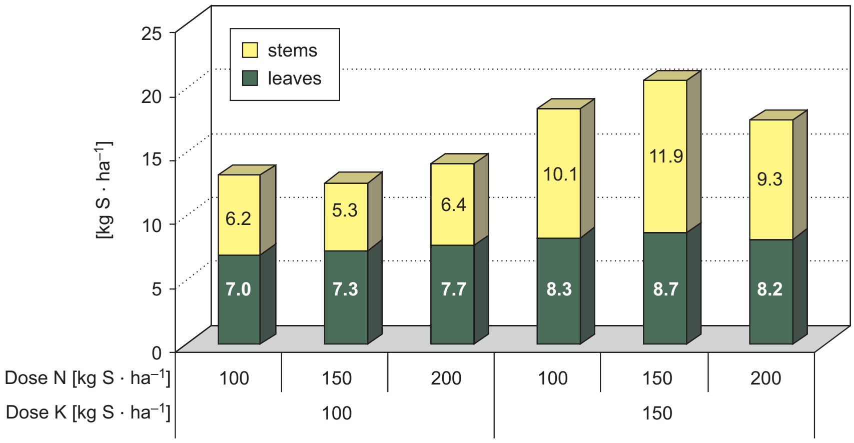


Fig. 2. Accumulation of sulfur in the Miscanthus leaves and stems towards the end of the vegetation period

plantations or varying weather conditions, since both of these could have impacted the access to nutritional elements and plant yields in the particular years of study (Fig. 1).

Other studies have found an increase in the sulfur content as well as other elements with the increasing age of an energy plant plantation [7]. This phenomenon is related to the withdrawal of elements from the aboveground parts to the rhizomes towards the end of the vegetation period and the successive reoccurrence in the spring in subsequent years. Because of this phenomenon an increase in the reserve base of nutritional elements is made possible and is available to be used by plants [13, 20].

In comparison with the amount of sulfur in mineral form transported with the transpiration current, the movement of this element from the leaves to the rhizomes is theoretically minimal, because movement in the phloem can only occur in the form of organic compounds. Thus, it seems that the increase in sulfur with the increased age of a plantation in the absence of sulfur fertilization is caused by the expansion of the rapidly growing root system and to a lesser extent to the withdrawal of sulfur from the aboveground parts to the rhizomes. The source of nutrition could also be fallen Miscanthus leaves; however, in the case of sulfur, the uptake of this element is connected with the earlier mineralization of the organic remains.

## Conclusions

1. The sulfur content in the aboveground parts of Miscanthus was mostly dependent on the vegetation period and decreased with the age of the plant.

2. At all times of taking samples more sulfur was found in the leaves than in the stems of Miscanthus. During the vegetation period the drop in the sulfur content in the stems was higher than in the sulfur content in the leaves.

3. Applying intensive nitrogen fertilizing did not modify the sulfur content in the aboveground parts of Miscanthus.

4. Fertilizing with high doses of potassium caused a significant increase in the sulfur content in the Miscanthus leaves and stems.

5. With the age of a plantation the sulfur content in Miscanthus increased.

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## ZMIANY ZAWARTOŚCI SIARKI W MISKANCIE OLBRZYMIM POD WPŁYWEM ZRÓŻNICOWANEGO NAWOŻENIA AZOTEM I POTASEM

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**Abstrakt:** Celem prezentowanej pracy była ocena zmian zawartości siarki w częściach nadziemnych miskanta olbrzymiego pod wpływem stosowania wzrastających dawek azotu oraz potasu. Ścisłe doświadczenie polowe założono metodą split-plot, na glebie piaszczystej lekkiej. Zróżnicowane dawki nawozów azotowych wynosiły: 100 kg N; 150 kg N oraz 200 kg N $\cdot$ ha$^{-1}$, natomiast potasu 83 kg K i 124 kg K (100 kg i 150 kg $K_2O$). Próbki roślinne pobierano w latach 2007–2009, w okresie od czerwca do października. Podczas całego okresu wegetacji miskanta stwierdzano prawie o połowę mniejsze zawartości siarki w łodygach niż w liściach. Najwięcej tego składnika zawierały rośliny młode. W miarę upływu okresu wegetacji zawartość siarki zmniejszała się w liściach o około 30 %, natomiast w łodygach o 60 %. W żadnym z lat badań nawożenie azotem nie modyfikowało istotnie zawartości S w miskancie. Stwierdzono natomiast istotny wzrost zawartości siarki w liściach i łodygach miskanta nawożonego większą dawką potasu. W kolejnych latach badań na wszystkich obiektach obserwowano w nadziemnych częściach miskanta coraz wyższą zawartość siarki.

**Słowa kluczowe:** miskant olbrzymi, nawożenie N i K, zawartość siarki, okres wegetacji