J. Elementol. 2010, 15(1): 65–79

ASSESSMENT OF THE INFLUENCE OF SEWAGE SLUDGE FERTILIZATION ON YIELD AND CONTENT OF NITROGEN AND SULPHUR IN MAIZE (*ZEA MAYS* L.)

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Abstract

The effect of sewage sludge fertilization on nitrogen and sulphur content in maize was assessed in a pot experiment conducted in 2003-2005. The experimental design comprised the following treatments in four replications on three soils: treatment without fertilizer – (0); mineral fertilization – (NPK); farmyard manure – (FYM); sewage sludge A – (SSA); a mixture of sewage sludge A with peat – (MSSA); sewage sludge B – (SSB) and a mixture of sewage sludge B with peat – (MSSB). The tests were conducted on weakly loamy sand (SI), sandy silt loam (SII) and medium silt loam (SIII), which were collected from the arable layer (0-20 cm) of ploughed land in the vicinity of Krakow. Sewage sludge which originated from two municipal mechanical and biological wastewater treatment plants, and their mixtures with peat (the materials were mixed in a 1:1 weight ratio in conversion to dry mass of organic matter) were used in the experiment. After wet mineralization of maize biomass in concentrated sulphuric acid, nitrogen was determined using Kjeldahl method in a Kjeltec II Plus apparatus. Sulphur was assessed after material mineralization in a concentrated nitric acid using the ICP–AES method in a JY 238 Ultrace apparatus. Fertilization with sewage sludge and sludge mixture with peat acted significantly better (as noted during the three-year experimental period) on maize yields than fertilization with mineral salts. In comparison with organic material and farmyard manure applied to soil, fertilization with mineral salts significantly increased nitrogen content in maize biomass. Sulphur content grew markedly in maize biomass fertilized with sewage sludge in comparison with the concentration of this element assessed in plants treated with farmyard manure. Values of the N:S ratio in aerial parts of maize from organic material treatments was within the optimal value range. The widest N:S ratio was assessed in the aerial parts and roots of maize receiving mineral fertilizers (NPK).

Key words: sewage sludge, maize, yielding, nitrogen, sulphur.

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OCENA ODDZIAŁYWANIA NAWOŻENIA OSADAMI ŚCIEKOWYMI NA PLONOWANIE ORAZ ZAWARTOŚĆ AZOTU I SIARKI W KUKURYDZY (*ZEA MAYS* L.)

Abstrakt

Ocenę wpływu nawożenia osadami ściekowymi na zawartość azotu i siarki w kukurydzy przeprowadzono w doświadczeniu wazonowym w latach 2003-2005. Schemat doświadczenia, w czterech powtórzeniach, obejmował następujące obiekty na trzech glebach: obiekt bez nawożenia – (0); nawożenie mineralne – (NPK); obornik – (FYM); osad ściekowy A (SSA); mieszanina osadu ściekowego A z torfem – (MSSA); osad ściekowy B – (SSB) oraz mieszanina osadu ściekowego B z torfem – (MSSB). Do badań użyto piasek słabo gliniasty (SI), glinę piaszczystą pylastą (SII) i glinę średnią pylastą (SIII), które pobrano z warstwy ornej (0-20 cm) pól uprawnych z okolic Krakowa. W badaniach zastosowano osady ściekowe pochodzące z dwóch różnych komunalnych oczyszczalni mechaniczno-biologicznych oraz ich mieszaniny z torfem (materiały zmieszano w stosunku wagowym 1:1 w przeliczeniu na suchą masę materiałów organicznych). W biomasie kukurydzy – po mineralizacji na mokro w stężonym kwasie siarkowym – azot oznaczono metodą Kjeldahla na aparacie Kjeltec II Plus. Siarkę – po mineralizacji materiału w stężonym kwasie azotowym – oznaczono metodą ICP-AES na aparacie JY 238 Ultrace. Nawożenie osadami ściekowymi i mieszaninami osadów z torfem działało istotnie lepiej (w trzyletnim okresie badań) na plony kukurydzy niż nawożenie solami mineralnymi. W porównaniu z zastosowanymi doglebowo materiałami organicznymi i obornikiem, nawożenie solami mineralnymi istotnie zwiększyło zawartość azotu w biomasie kukurydzy. Istotnie zwiększyła się zawartość siarki w biomasie kukurydzy nawożonej osadami ściekowymi, w porównaniu z zawartością tego pierwiastka oznaczonego w roślinach nawożonych obornikiem. Wartości stosunku N : S w częściach nadziemnych kukurydzy z obiektów nawożonych materiałami organicznymi mieściły się w zakresie wartości optymalnych. Najszerszy stosunek N:S stwierdzono w częściach nadziemnych i korzeniach kukurydzy nawożonej mineralnie (NPK).

Słowa kluczowe: osady ściekowe, kukurydza, plonowanie, azot, siarka.

INTRODUCTION

Biomass production leads to soil depletion of available forms of nutrients. Fertilization is a basic method applied to maintain their optimal content in soil.

Many research projects have revealed considerable fertilizer value of sewage sludge (Mazur 1996, Petersen 2003, Akdeniz et al. 2006, Lavado 2006, Togay et al. 2008). Suitability of sewage sludge for soil and plant fertilization results from its considerable concentration of organic substance and nutrients (Jarausch-Wehrheim et al. 2001, Baran et al. 2002). When adhering to all the rules of safe application, sewage sludge can supplement or replace farmyard manure.

Among biogenic substances, sewage sludge contains the highest amounts of nitrogen and phosphorus (Mazur 1996, Kalembasa et al. 1999). Czekała (2002) and Dewil et al. (2008) demonstrated that considerable quantities of sulphur are additionally accumulated in sewage sludge. Most plant nutrients, including nitrogen and sulphur in sewage sludge, occur as organic compounds. Having been introduced to soil, sewage sludge undergoes complex transformations, which do not determine its bioavailability.

Under the soil and climatic conditions occurring in Poland, nitrogen is the main factor affecting the amount and quality of plant yields. Nitrogen concentrations in plants do not pose any major hazard if balanced fertilizer doses are used (KOPEĆ et al. 1996). The need to fertilize plants with sulphur is mainly due to the role of this element in nitrogen metabolism, which may markedly improve yield biological value (MARSKA, WRÓBEL 2000, SCHERER 2001).

The use of sewage sludge causes changes in physical, chemical and biological soil properties, which, depending on grain size distribution of soil, can differently influence nitrogen and sulphur bioavailability and may affect biological value of crop yield. The aim of the research was to assess how fertilization with sewage sludge and its mixtures with peat affect yield of maize, cultivated on soils different in grain size distribution, and its content of nitrogen and sulphur.

MATERIAL AND METHODS

The effect of sewage sludge fertilization on nitrogen and sulphur content in maize was assessed in a pot experiment conducted in 2003-2005. The experimental design comprised the following treatments in four replications on three soils: treatment without fertilizers – (0); mineral fertilization – (NPK); farmyard manure – (FYM); sewage sludge A – (SSA); a mixture of sewage sludge A with peat – (MSSA); sewage sludge N – (SSB) and a mixture of sewage sludge B with peat – (MSSB). The term “fertilizer treatments” used in the paper refers to all treatments except the object without fertilizers (0). The following soil material was used in the experiment: weakly loamy sand – (SI), sandy silt loam – (SII) and medium silt loam – (SIII), which were collected from the arable layer (0–20 cm) of ploughed land in the vicinity of Krakow. The sewage sludge, obtained from two municipal mechanical and biological wastewater treatment plants, and its mixtures with peat (the materials were mixed in a 1:1 weight ratio in conversion to dry mass of organic matter) were used in the experiment. Peat, which had 408 $g \cdot kg^{-1}$ dry mass content, contained 88 $g \cdot kg^{-1}$ ash, 34.4 g $g \cdot kg^{-1}$ N, 0.91 g P, 1.14 g K and 2.48 g $S \cdot kg^{-1}$ d.m. The chemical composition of the other organic materials and soil (values converted into dry mass determined at 105°C) is specified in Tables 1 and 2.

PCV pots used for the experiment contained 5.50 kg of air-dried soil material. Before the experiment, the soils were gradually moistened to 30%

Table 1

Chemical composition of materials used in experiment

<table>
<tr><th colspan="2">Determination</th><th>FYM</th><th>Sewage sludge (SSA)</th><th>Sewage sludge + peat (MSSA)</th><th>Sewage sludge (SSB)</th><th>Sewage sludge + peat (MSSB)</th></tr>
<tr><td colspan="2">Dry matter, $g \cdot kg^{-1}$</td><td>189</td><td>310</td><td>343</td><td>418</td><td>372</td></tr>
<tr><td colspan="2">pH (H_2O)</td><td>6.22</td><td>6.12</td><td>5.57</td><td>5.73</td><td>5.20</td></tr>
<tr><td colspan="2">Organic matter, $g \cdot kg^{-1}$ d.m.</td><td>679</td><td>353</td><td>652</td><td>552</td><td>771</td></tr>
<tr><td colspan="7">Total forms</td></tr>
<tr><td>N</td><td rowspan="4">$g \cdot kg^{-1}$ d.m.</td><td>25.1</td><td>17.2</td><td>25.5</td><td>42.4</td><td>38.4</td></tr>
<tr><td>S</td><td>7.24</td><td>8.81</td><td>6.23</td><td>14.62</td><td>7.85</td></tr>
<tr><td>P</td><td>22.60</td><td>5.48</td><td>3.00</td><td>19.32</td><td>0.76</td></tr>
<tr><td>K</td><td>26.69</td><td>2.71</td><td>1.88</td><td>2.81</td><td>1.64</td></tr>
<tr><td>Cr</td><td rowspan="7">$mg \cdot kg^{-1}$ d.m.</td><td>6.07</td><td>19.74</td><td>10.25</td><td>37.88</td><td>17.47</td></tr>
<tr><td>Zn</td><td>531</td><td>899</td><td>488</td><td>1684</td><td>821</td></tr>
<tr><td>Pb</td><td>3.99</td><td>65.9</td><td>38.2</td><td>29.4</td><td>17.5</td></tr>
<tr><td>Cu</td><td>338.0</td><td>78.3</td><td>40.6</td><td>119.4</td><td>51.8</td></tr>
<tr><td>Cd</td><td>1.28</td><td>2.71</td><td>1.45</td><td>2.25</td><td>1.03</td></tr>
<tr><td>Ni</td><td>11.74</td><td>13.32</td><td>7.14</td><td>25.36</td><td>12.07</td></tr>
<tr><td>Hg</td><td>trace</td><td>3.58</td><td>1.80</td><td>2.29</td><td>1.07</td></tr>
</table>

Table 2

Some properties of soils before the establishment of the experiment

<table>
<tr><th colspan="3" rowspan="2">Determination</th><th colspan="3">Soil</th></tr>
<tr><th>(SI)</th><th>(SII)</th><th>(SIII)</th></tr>
<tr><td rowspan="3">Granulometric composition Ø</td><td>1.0 - 0.1 mm</td><td rowspan="3">%</td><td>78</td><td>42</td><td>28</td></tr>
<tr><td>0.1 - 0.02 mm</td><td>13</td><td>33</td><td>29</td></tr>
<tr><td>< 0.02 mm</td><td>9</td><td>25</td><td>43</td></tr>
<tr><td colspan="2">pH KCl</td><td></td><td>6.21</td><td>5.69</td><td>5.30</td></tr>
<tr><td colspan="2">Hydrolitic acidity</td><td rowspan="2">$mmol(+) \cdot kg^{-1}$ d.m.</td><td>11.2</td><td>23.4</td><td>33.2</td></tr>
<tr><td colspan="2">Sum of alkaline cation</td><td>39.9</td><td>86.8</td><td>128.4</td></tr>
<tr><td colspan="2">Total N</td><td rowspan="3">$g \cdot kg^{-1}$ d.m.</td><td>0.36</td><td>1.25</td><td>1.72</td></tr>
<tr><td colspan="2">Organic C</td><td>9.37</td><td>13.36</td><td>17.68</td></tr>
<tr><td colspan="2">Total S</td><td>0.16</td><td>0.28</td><td>0.32</td></tr>
</table>

of maximum water capacity. After moistening, sandy silt loam and medium silt loam were limed to fulfill the conditions stated in the Regulation of the Minister of the Natural Environment on municipal sewage sludge (*Regulation...* 2002). The dose of sludge was applied separately in each pot. Chemically pure CaO was used and its dose was calculated on the basis of soil hydrolytic acidity. Afterwards, all soils were left for 4 weeks and water loss was occasionally supplemented. After that, organic materials were introduced in the amount corresponding to a dose of 1.20 g $N \cdot pot^{-1}$. Phosphorus and potassium were supplemented in all treatments (except the control) to a level equal the one achieved with the organic materials. In the first year, 1.26 g $P \cdot pot^{-1}$ was used as an aqueous solution of $Ca(H_2PO_4)_2 \cdot H_2O$ and 1.48 g $K \cdot pot^{-1}$ as an aqueous KCl solution. An identical nitrogen dose was applied to the mineral (NPK) treatment as an aqueous solution of NH_4NO_3, and equal P and K doses, respectively in form of $Ca(H_2PO_4)_2 \cdot H_2O$ and KC, were added. Equal fertilizer component amounts, i.e. 0.80 g N; 0.20 g P and 1.40 g $K \cdot pot^{-1} \cdot year^{-1}$ as chemically pure salts, were used in the second and third year of the experiment.

Each year of the experiment, cv. San maize (FAO 240) was cultivated as a test plant and 5 plants per pot were left. Maize was harvested at the 7–9 leaves stage. The plant vegetation periods were respectively: 47 days in the first year, 66 days in the second and 54 days in the third. Throughout the experiment, the plants were watered with distilled water to 50% of maximum water capacity.

After the harvest, the plants were dried (at 70°C) to constant weight and the yield of dry mass of shoots and roots was determined. The plant material was comminuted in a laboratory mill and wet mineralized in concentrated sulphuric acid. Afterwards, nitrogen was determined using Kjeldahl method (OSTROWSKA et al. 1991) in a Kjeltec II Plus apparatus (Tecator). For sulphur determination, the plant material was wet mineralized in concentrated nitric acid and after evaporation mixed with magnesium nitrate and evaporated again. The samples thus prepared were mineralized in a muffle furnace, initially at 300°C (for 2 hours) and then at 450°C (for 3 hours). The remains were dissolved in diluted nitric acid (25%) (OSTROWSKA et al. 1991). Sulphur was determined in solutions prepared in the above way using the ICP–AES method in an Ultrace JY 238 apparatus.

The results were verified statistically according to a fixed model, in which the factor was soil fertilization or soil. One–way ANOVA was used for the computations and the significance of differences was estimated using LSD Fisher test at significance level α<0.05 (STANISZ 1998).

RESULT AND DISCUSSION

Organic materials used for the experiments differed in chemical composition, including nitrogen and sulphur content (Table 1). Peat supplement to sewage sludge diminished the content of most elements in the mixture in comparison with the content of elements in sludge, except the nitrogen content in A (MSSA) sludge mixture, which was a result of a higher level of this nutrient in peat.

The soil material used for the analyses belonged to different groups according to the grain size distribution, but it also significantly differed in chemical properties, including total nitrogen and total sulphur content (Table 2).

The three-year average of maize biomass yields (both aerial parts and roots) from the treatments obtained on weakly loamy sand (SI) were notably (over 20%) lower than yields produced on the other soils: sandy silt loam (SII) and medium silt loam (SIII) (Figure 1). The difference in the biomass yield obtained on sandy silt loam (SII) and medium silt loam (SIII) was not significant.

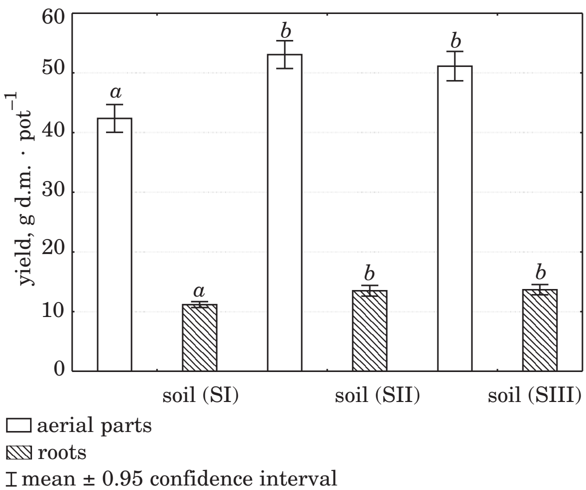

Fig. 1. Mean yields of aerial parts and of roots of maize from fertilization objects for a three-year period.
Means followed by the same letters did not differ significantly at $\alpha < 0.05$ according to Fisher's test

Fertilization with sewage sludge or the mixtures with peat and the treatment with farmyard manure produced markedly greater yields than the treatment where only mineral compounds were used (Table 3). Higher yields from the mineral salt treatment were recorded in the first year of the experiment (Figure 2). In the subsequent years, maize's response to fertiliza-

Table 3

Average (for 3 years) yields of maize aerial parts and roots, dry mass, total nitrogen and sulphur content in maize

Object	Yield of biomass		Nitrogen in the plant		Sulphur in the plant	
	g d.m.·pot^{-1}		g N·kg^{-1} d.m.		g S·kg^{-1} d.m.	
	PAG*	R**	PAG*	R**	PAG*	R**
No fertilisation (0)	22.1 *a*	7.4 *a*	8.1 *a*	6.95 *a*	0.98 *cd*	1.69 *b*
NPK	42.5 *b*	10.1 *b*	19.2 *d*	15.68 *b*	0.65 *a*	0.69 *a*
Farmyard manure (FYM)	48.0 *c*	13.1 *cd*	12.5 *bc*	7.81 *a*	0.92 *bc*	1.70 *b*
Sewage sludge A (SSA)	47.3 *bc*	11.8 *c*	13.1 *c*	7.83 *a*	1.06 *d*	2.99 *d*
Sewage sludge A + peat (MSSA)	49.3 *c*	11.8 *c*	12.7 *bc*	7.88 *a*	0.91 *bc*	1.86 *bc*
Sewage sludge B (SSB)	50.4 *c*	14.1 *d*	12.7 *bc*	7.21 *a*	1.00 *cd*	2.15 *c*
Sewage sludge B + peat (MSSB)	55.6 *d*	15.8 *e*	11.1 *b*	7.19 *a*	0.82 *b*	1.54 *b*

* aerial parts, ** roots
Means followed by the same letters in columns did not differ significantly at $\alpha < 0.05$ according to Fisher's test

tion with organic materials was positive despite the blurring differences in the harvest from soils of the granular structure of weakly loamy sand (SI) and sandy silt loam (SII). In both cases, higher biomass yields were obtained when sewage sludge and peat mixtures were used than when sludge alone was applied. The fertilizer value of municipal sewage sludge was confirmed in numerous studies (Christodoulakis, Margaris 1996, Stępień et al. 2000). Also in the authors' own investigations, fertilization with organic materials, including sewage sludge, produced better results expressed by the amount of maize biomass yields than the treatment with mineral salts. This effect cannot be attributed exclusively to the activity of the applied sewage sludge or its mixtures with peat. Beside the residual fertilizer effect of organic materials, the supplementary mineral fertilization conducted in the second and third year of the research proved to be an important factor affecting plant yielding. This conclusion was supported by the results obtained by Evanylo (1999), who demonstrated that about 30% of nitrogen is released from sewage sludge in the first year after application as a result of mineralization, in contrast to 15% in the second year and only 7% in the third year. It may be assumed that the factor that determined plant yielding in the treatments where organic substances were used may be the introduction of other components with organic materials, such as sulphur, magnesium or microelements to soil, whose amounts were not balanced. Wiater et al. (2004) observed inferior direct effect of sewage sludge granulate on maize yield than that achieved by mineral fertilization, but the residual effect of the granulate fertilizer was better. Chatha et al. (2002), Drab and Deren-

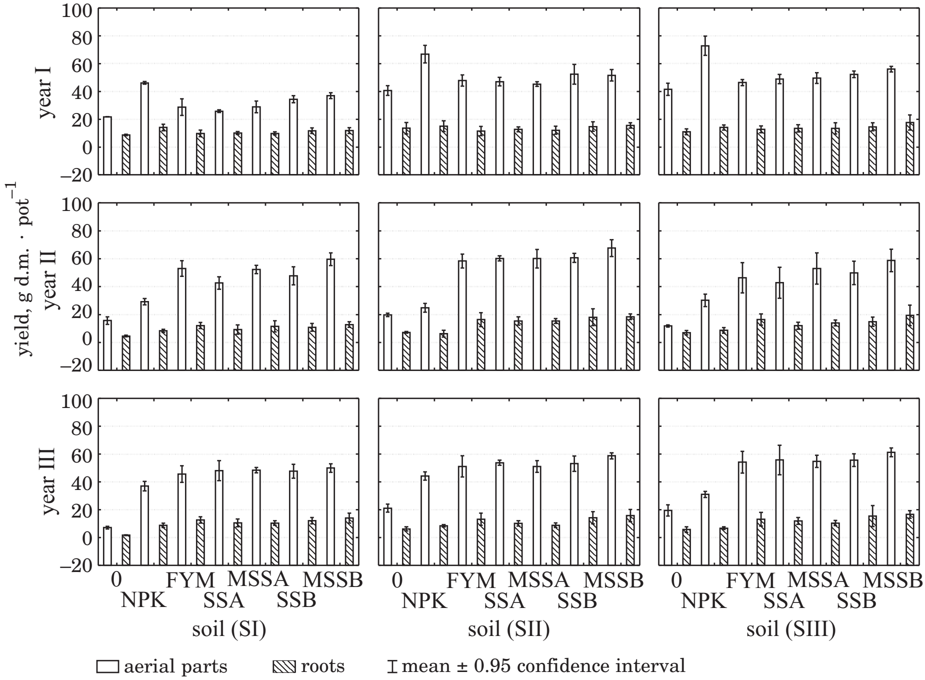

Fig. 2. Yield of aerial parts and roots of maize from the three- years experiment on each soil: 0 – soil without fertilization, NPK – soil with addition of mineral salts, FYM – soil with addition of farmyard manure, SSA – soil with addition of municipal sewage sludge A, MSSA – soil with addition of sewage sludge A mixture with peat, SSB – soil with addition of municipal sewage sludge B, MSSB – soil with addition of sewage sludge B mixture with peat

GOWSKA (2003) and LAVADO (2006) demonstrated an advantageous effect of fertilization with sewage sludge on crop yields. Moreover, VASSEUR et al. (1998) and AKRIVOS et al. (2000) revealed that crop yield, irrespective of the type of soil, was conditioned by the quantity of the applied sewage sludge.

The biomass of aerial parts and roots of plants from the mineral salt (NPK) treatment had the highest concentrations of nitrogen (Table 3). The three-year average nitrogen content in this treatment was 19.2 g $N \cdot kg^{-1}$ d.m., being from 46% to 73% higher than the concentration determined in the aerial parts of maize fertilized with organic materials. Contrary to mineral fertilization, more nitrogen contained in farmyard manure or sewage sludge occurs in organic compounds unavailable to plants. The rate of release of mineral nitrogen forms from organic material is conditioned by intensity of biological process, which may limit the effect of this fertilizer component, especially during the initial period (BARBARIKA et al. 1985, GONDEK and CHMIEL 2006). Bigger differences in nitrogen content were observed in roots, where it was from 99% to 118% lower in the organic treatments than in the treatment where mineral fertilization with this component was con-

Irrespective of the applied fertilization or soil, more total sulphur was found in maize roots, which resulted from the accumulation of this element in a much smaller yield of this maize part (Table 3, Figure 5). The applied fertilization with organic substances significantly raised sulphur content in maize biomass in comparison with the content found in biomass of plants fertilized with nitrogen, phosphorus and potassium as mineral salts (NPK). The average sulphur content in maize biomass, irrespectively of its part, in

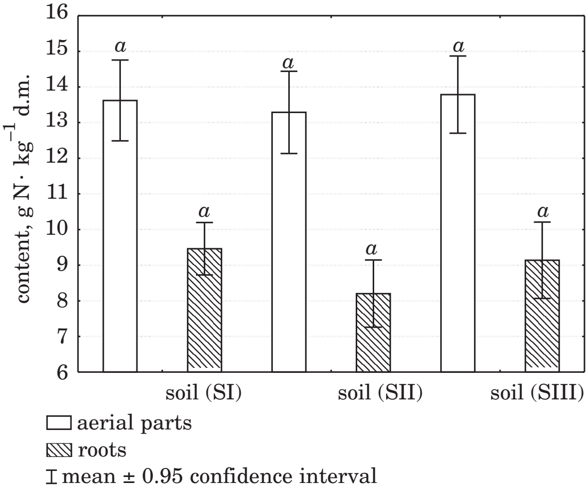

Fig. 3. Average (for 3 years) nitrogen content in maize aerial parts and roots from treatments

Means followed by the same letters did not differ significantly at $\alpha < 0.05$ according to Fisher's test

ducted. No significant differences in nitrogen content in maize biomass were found depending on soil (Figure 3), and the influence of sewage sludge fertilization on nitrogen concentrations in plant biomass was comparable with the effect of fertilization with sewage sludge mixtures and peat (Figure 4). Also in the previous research conducted by Gondek and Filipek-Mazur (2006), irrespective of the fertilization date or cultivated plant, or even its part, the highest nitrogen concentrations were found in plant biomass from mineral salt treatments. Moreover, farmyard manure and sewage sludge used on different dates did not differentiate largely the content of this nutrient in plants. In the authors' own investigations, an identical nitrogen dose was applied to all soils in treatments fertilized with organic materials and mineral salts. Considering the nitrogen amount which may be mobilised from the applied organic substances and its supplementation with the mineral form of this element or increased organic substance dose contributed to improved nitrogen uptake by plants. Jakubus (2006) points to a relatively weak effect of sewage sludge on chemical composition of plants, although the author demonstrated that it depended on the type of sewage sludge.

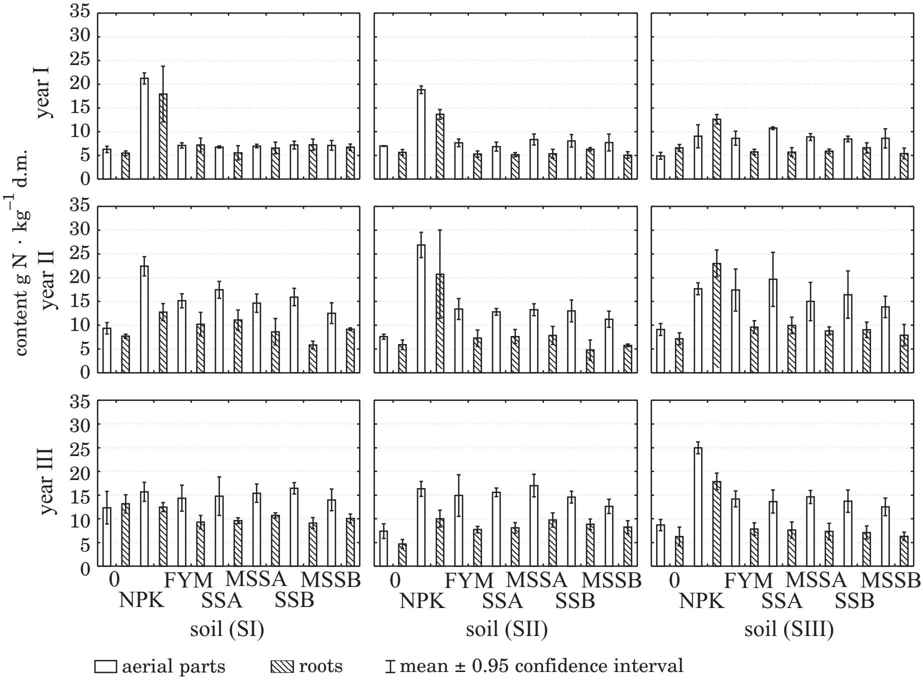

Fig. 4. Nitrogen content in maize aerial parts and roots from three soils in each year of the experiment; cf. Fig. 2 for the key

the treatment without fertilization (0) (at markedly smaller yield) did not differ significantly from its content determined in plant biomass from the treatments fertilized with farmyard manure (FYM) or mixtures of sewage sludge with peat (MSSA, MSSB) – Figure 5. Greater relative variation in sulphur content was detected in maize biomass depending on soil (Figure 6). In light soil (SI), the content was the highest, whereas the mean sulphur content in maize biomass from sandy silt loam (SII) and medium silt loam (SIII) soils did not differ markedly for fertilized treatments and years. These dependences clearly resulted from concentrations of this element in a lower yield of maize cultivated in weakly loamy sand (SI), but not from the content of bioavailable forms of this element in soils. According to KALEMBASA and KUZIEMSKA (2008), fertilization with sewage sludge markedly affects sulphur concentrations in plants, although, as demonstrated by CARDELLI et al. (2006), the rate of organic materials mineralization, including waste materials, may be different, which considerably conditions sulphur transfer into the soil solution and its uptake by plants. Also in the research conducted by WOŁOSZYK (2003), plant fertilization with composts manufactured from sewage sludge, both with and without industrial waste supplement, increased sulphur content in grass mixture. According to this author, fertilization with

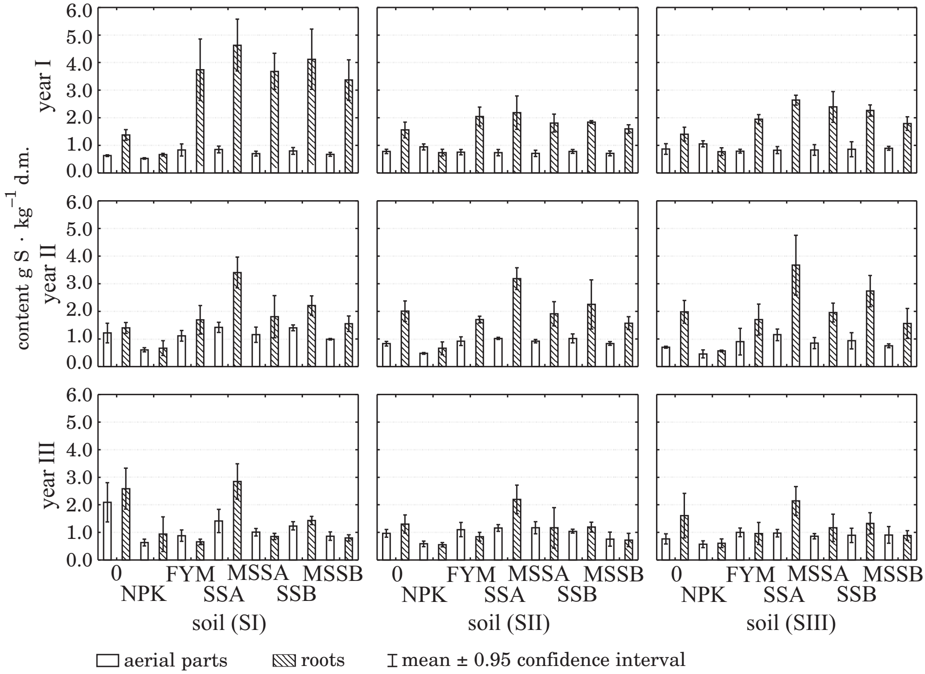

Fig. 5. Sulphur content in maize aerail parts and roots from three soils in each year of the experiment; cf. Fig. 2 for the key

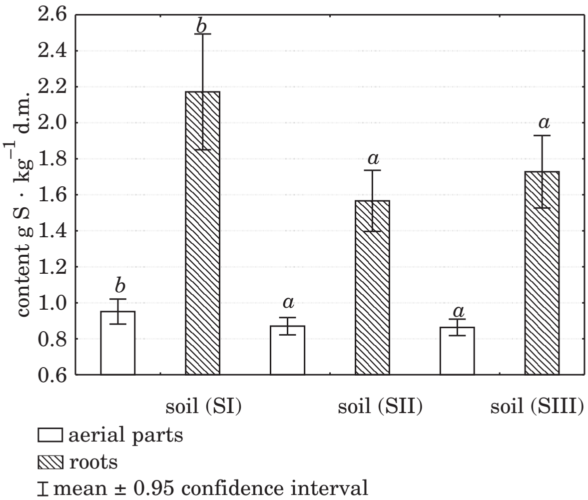

Fig. 6. Average (for 3 years) sulphur content in aerial parts and roots from fertilization objects for the three years of the experiment

Means followed by the same letters did not differ significantly at $\alpha < 0.05$ according to Fisher's test

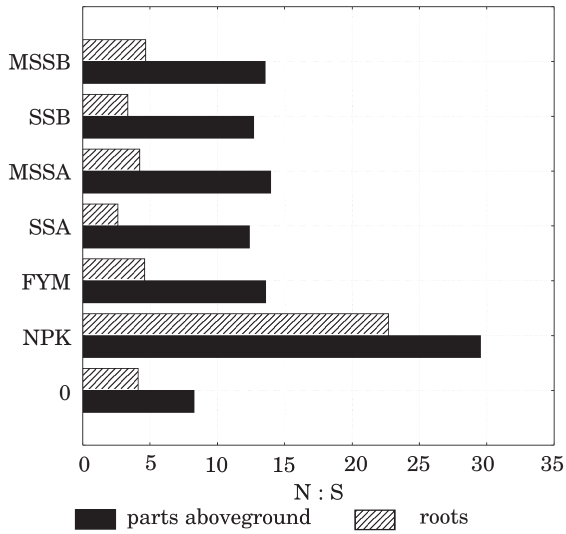

Fig. 7. An average (for 3 years and 3 soils) ratio N : S in aerial parts and roots
cf. Fig. 2 for the key

composts produced from sewage sludge did not have any marked influence on sulphur concentrations in plant biomass in the second year of the fertilizer effect of these materials.

According to Fotyma (2003), the optimal N:S ratio in plants depending on species is 15-10:1. In the conducted research, the values of the N:S ratio in maize aerial parts from the treatments fertilized with organic materials fell within the range of optimal values (means for soils and years) – Figure 7. Much smaller values of this parameter characterized maize root biomass, which resulted from much higher sulphur content in these plant parts and much lower nitrogen concentrations in roots than in aerial parts. The widest N:S ratio was found in the aerial parts and roots of maize receiving mineral fertilizers (NPK), which was determined by the soil depletion of bioavailable sulphur forms (Filipek-Mazur et al. 2006).

CONCLUSIONS

1. Over the three-year period of the research, fertilization with sewage sludge and mixtures of sludge with peat produced a significantly better effect on maize yields than a treatment with mineral salts.

2. In comparison with organic materials and farmyard manure applied to the soil, fertilization with mineral salts markedly increased nitrogen concentrations in maize biomass.

3. The sulphur content grew significantly in maize biomass fertilized with sewage sludge in comparison with concentrations of this element assessed in plants fertilized with farmyard manure.

4. Values of the N:S ratio in maize shoots from treatments fertilized with organic materials were within the range of optimal values. The widest N:S ratio was assessed in aerial parts and roots of maize receiving mineral fertilization (NPK).

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