ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 16, No. 10 2009

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YIELDING AND THE CONTENTS OF CALCIUM, MAGNESIUM AND SODIUM IN MAIZE FERTILIZED WITH ORGANIC MATERIALS

PLONOWANIE ORAZ ZAWARTOŚĆ WAPNIA, MAGNEZU I SODU W KUKURYDZY NAWOŻONEJ MATERIAŁAMI ORGANICZNYMI

Abstract: The use of sewage sludge for plant fertilization seems to be the most rational method of their management, which does not imply their advantageous effect on the yield biological value. Because of the necessity of balancing minerals in animal nutrition, the investigations aimed at an assessment of the contents of calcium, magnesium and sodium in maize biomass fertilized with sewage sludge and mixtures sewage sludge and peat, cultivated in soils with diversified texture. Over the three year period of the experiment, fertilization with sewage sludge and sludge mixtures with peat, had a more favourable effect on maize biomass yield than treatment with mineral salts.

Maize fertilization with sewage sludge and sludge mixtures with peat did not cause any significant increase in the contents of the analyzed macroelements, except for calcium in maize shoots, in comparison with farmyard manure. Fodder value of the obtained maize shoots was low with respect to the investigated elements. Low value of Ca:Mg ratio evidences that the analyzed maize biomass contained too small amounts of calcium in relation to magnesium. While using the plant biomass fertilized with sewage sludge or other waste materials for animal feeds, one should remember about supplementing mineral components, such as Ca, Mg and Na because the amounts of these elements taken up by animals may be insufficient.

Keywords: calcium, magnesium, sodium, maize, sewage sludge

Fertilization is a factor, which among the cultivation measures, such as tillage, crop rotation or application of plant protection chemicals, most strongly affects plant chemical composition. It is difficult to assess fertilization effect on crop quality because of the proper selection of quality indices, whereas the comparison of nutritional results and an assessment based on the chemical composition of the forage fed to animals are not always fully compatible [1].

Plant fertilization with waste materials, including sewage sludges may play an important role in supplying them with mineral components such as: calcium, magnesium or sodium. These elements are crucial for animal nutrition and fulfill various physical, chemical or biological functions in their organisms. Their occurrence in animal organism depends mainly on feed abundance in these elements and their bioavailability [2].

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The use of sewage sludge for plant fertilization seems to be the most rational way of their utilization, which however does not imply their beneficial effect on biological value of yield. Because of the necessity of balancing the quantity of mineral components in animal nutrition, the research aimed at an assessment of the contents of calcium, magnesium and sodium in biomass of maize fertilized with sewage sludge and mixtures sewage sludge and peat cultivated in soils with diversified texture.

Materials and methods

The assessment of fertilization effect on the contents of calcium, magnesium and sodium in maize biomass was conducted in a two-factor pot experiment (factors: soil and fertilization) in 2003–2005. The investigations were carried out on three soils and the experimental design was the same for each soil. It comprised the following treatments (in four replications on each soil): unfertilized (0); mineral treatment (NPK); farmyard manure – (OB); sewage sludge A (OŚA); mixture of sewage sludge A and peat – (MOŚA); sewage sludge B (OŚB) and a mixture of sewage sludge B and peat (MOŚB). The following soil material was used for the experiment: weakly loamy sand (psg), sandy silt loam (gpp) and medium silt loam (gśp), which were collected from the arable layer (0–20 cm) of ploughlands near Krakow. Sewage sludge obtained from two different mechanical-biological municipal treatment plants and their mixtures with peat were used for the experiment (sewage sludge were mixed with peat in weight ratio 1 : 1 per dry mass of organic materials). Peat with dry mass content 408 g · kg^{-1} contained: 88 g · kg^{-1} ash; 13.6 g Ca · kg^{-1} d.m.; 0.74 g Mg · kg^{-1} d.m. and 0.16 g Na · kg^{-1} d.m. The characteristics of chemical composition of the organic materials and soil material (values per dry mass assessed at 105 ^{o}C) were given in Tables 1 and 2.

PVC pots used for the experiment contained 5.50 kg of air-dried soil material. Before the experiment outset the soils were gradually moistened to 30 % of maximum water capacity. After moistening sandy silt loam and medium silt loam were limed to obtain the soil pH required by the decree [3]. The measure was applied separately in each pot. Chemically pure CaO was used in a dose calculated on the basis of soil hydrolytic acidity. Subsequently all soils were left for 4 weeks and water loses were supplemented occasionally. After this period organic materials were introduced in the amount corresponding to 1.20 g N · pot^{-1}. Phosphorus and potassium quantities introduced to the soil with organic materials were equalized with solutions of chemically pure salts [$Ca(H_2PO_4)_2$ · H_2O and KCl]. On mineral (NPK) treatment the identical nitrogen, phosphorus and potassium doses were used as on the organic material treatments, respectively: 1.20 g N · pot^{-1} as NH_4NO_3, 1.26 g P · pot^{-1} as $Ca(H_2PO_4)_2$ · H_2O and 1.48 g K · pot^{-1} as water solution of KCl. Considering the consequent fertilizer effect and the soils' abundance in bioavailable phosphorus and potassium, in the second and third year of the experiment, the following doses of fertilizer components were applied: 0.80 g N; 0.2 g P and 1.40 g K · pot^{-1} · $year^{-1}$ as solutions of chemically pure salts.

Maize, 'San' c.v. (FAO 240), was cultivated as a test plant each year and 5 pieces per pot were left. Maize (for green forage) was harvested at the 7–9 leaves stage. Growing periods were respectively: 47 days in the first year, 66 days in the second and 54 days in the third one. 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. Dried biomass was crushed in a laboratory mill and mineralized in a muffle furnace (at 450 °C for 5 hours). The remains were dissolved in diluted nitric(V) acid 1 : 2 (v/v) [4]. In the obtained plant material solutions, calcium and sodium were determined with flame photometry method (FES) and magnesium with atomic absorption spectrometry (AAS) on Philips PU 9100X apparatus. Plant reference material NCS DC73348 (China National Analysis Center for Iron & Steel) and soil reference material *Agro*MAT AG-2 (SCP Science) was attached to each analytical series. The results were verified statistically using a fixed model (factors: fertilization, soil). The statistical computations considered one-way or two-way ANOVA and the significance of differences was estimated using LSD Fisher test at significance level $p < 0.05$ [5].

Results and discussion

The organic materials applied in the experiment differed with their chemical composition including calcium, magnesium and sodium content. Calcium content in sewage sludge was higher than assessed in farmyard manure, whereas the quantities of magnesium and sodium were smaller (Table 1).

Table 1

Chemical composition of materials used in experiment

Determination		FYM (OB)	Sewage sludge (OŚA)	Sewage sludge + peat (MOŚA)	Sewage sludge (OŚB)	Sewage sludge + peat (MOŚB)
Dry matter [g · kg^{-1}]		189	310	343	418	372
pH (H_2O)		6.22	6.12	5.57	5.73	5.20
Organic matter [g · kg^{-1} d.m.]		679	353	652	552	771
Total content						
N	[g · kg^{-1} d.m.]	21.6	17.0	24.7	37.4	35.1
S		7.24	8.81	6.23	14.62	7.85
P		22.60	5.48	3.00	19.32	7.64
K		26.69	2.71	1.88	2.81	1.64
Ca		4.83	15.66	13.31	9.22	11.95
Mg		6.26	4.86	2.82	2.55	1.59
Na		4.60	0.54	0.40	0.70	0.44
Cr	[mg · kg^{-1} d.m.]	6.07	19.74	10.25	37.88	17.47
Zn		531	899	488	1684	821
Pb		3.99	65.9	38.2	29.4	17.5
Cu		338	78.3	40.6	119.4	51.8
Cd		1.28	2.71	1.45	2.25	1.03
Ni		11.74	13.32	7.14	25.36	12.07
Hg		trace	3.58	1.80	2.29	1.07
Mn		379	129	102	277	163

Peat supplement to the sludge generally diminished the contents of most elements in the mixture in comparison with their contents in the sludge, except for calcium content in sewage sludge B mixture (MOŚB), which resulted from higher content of this element in peat.

The soil material used for the experiment belonged to various texture groups but also significantly differed with chemical properties (Table 2).

Table 2

Some properties of soils before the establishment of the experiment

Determination			Soil (psg)	Soil (gpp)	Soil (gśp)
Granulometric composition ∅	1.0–0.1 mm	[%]	78	42	28
	0.1–0.02 mm		13	33	29
	< 0.02 mm		9	25	43
pH KCl			6.21	5.69	5.30
Hydrolitic acidity		[mmol(+) · kg^{-1} d.m.]	11.2	23.4	33.2
Sum of alkaline cation			39.9	86.8	128.4
Total N		[g · kg^{-1} d.m.]	0.96	1.25	1.72
Organic C			9.37	13.36	17.68
Total S			0.16	0.28	0.32
Available forms					
P		[mg · kg^{-1} d.m.]	79	217	29
K			166	359	138
Mg			134	154	126
S-SO_4			13.4	11.9	11.4

Analysis of variance confirmed a significant effect of fertilization with organic materials on maize biomass yield (Fig. 1).

Treatment with sewage sludge or their mixtures with peat and farmyard manure fertilization allowed to obtain significantly greater yields than gathered on treatments fertilized exclusively with mineral compounds. In case of sewage sludge mixture with peat application (except for MOŚA mixture on sandy silt loam) larger yields were produced than when solely sewage sludge was used. This result cannot be fully ascribed to the consequent fertilizer effect of sewage sludge or their mixtures with peat. Supplementary fertilization with mineral salts in the second and third year of the experiment also had a significant influence on the biomass yield. Supplying to the soil with organic materials components such as sulphur, magnesium or microelements, whose quantities were not balanced, might have been also the factor determining maize yielding. Application of natural or organic fertilizers not always leads to an increase in crop yields in result of the consequent effect. Wiater et al [6] obtained worse direct effect of sewage sludge granulate on maize yield in comparison with mineral fertilization, but the consequent fertilizer effect of sewage sludge was better. Drab and Derengowska [7] proved a positive influence of sewage sludge fertilization on crop yields and at the same time demonstrated that the amount of plant yields, irrespective of the soil was also conditioned by sewage sludge dose.

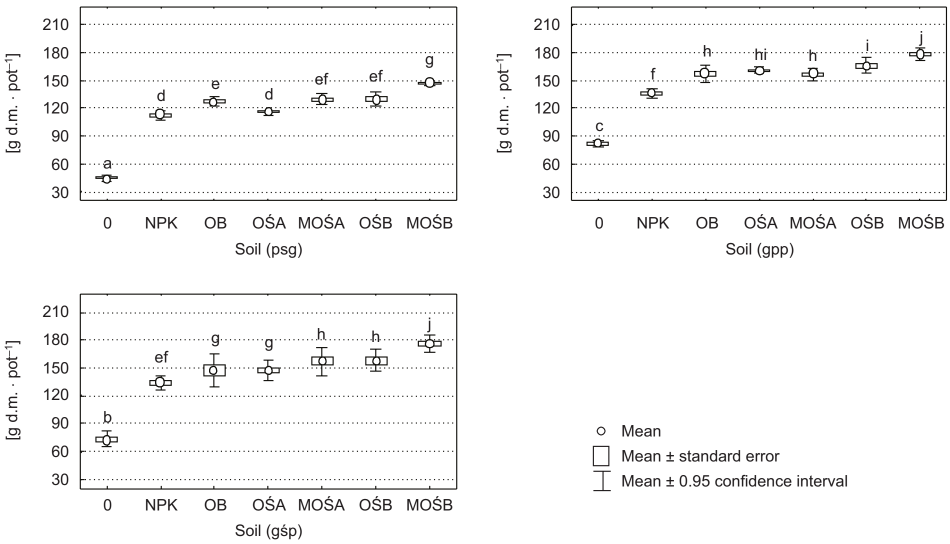

Fig. 1. Yield of aboveground parts of maize (sum of dry matter from three years)
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test

Disturbed relationships between nutrients, particularly when their quantity supplied with fertilization is not balanced, may affect plant mineral economy and condition biological value of the produced yield.

Indispensability of calcium in animal feeds results in the first place from the key role this element plays in bone formation process. Moreover, it is crucial for proper functioning of muscle and nervous system, the heart, cell membrane permeability and blood coagulation [2]. Calcium contents in maize biomass were diversified depending mainly on the plant part (Table 3).

Table 3

3-year period weighted average content of macroelements
in aboveground parts and roots of maize (for soils)

Object	Ca		Mg		Na	
	[g · kg^{-1} d.m.]					
	Cz.n.	K	Cz.n.	K	Cz.n.	K
Control (0)	1.52d	2.18a	2.53b	1.94a	0.23a	1.10b
NPK (NPK)	1.23bc	6.38e	1.85a	2.78b	0.26a	0.72a
FYM (OB)	0.96a	3.25ab	1.63a	2.24ab	0.31b	1.99c
Sewage sludge (OŚA)	1.36cd	5.99de	1.88a	2.55ab	0.33b	0.81a
Sewage sludge + peat (MOŚA)	1.25bc	4.89cd	1.83a	2.31ab	0.27ab	0.75a
Sewage sludge (OŚB)	1.32bcd	4.62c	1.97a	2.45ab	0.33b	0.78a
Sewage sludge + peat (MOŚB)	1.12b	3.94bc	1.70a	2.25ab	0.28ab	0.70a

Cz.n. – aboveground parts; K – roots; Means followed by the same letters in columns did not differ significantly at $p < 0.05$ according to the Fisher test.

Greater amounts of this element were detected in maize biomass with no fodder value, ie in roots. Maize fertilizing with sewage sludge and mixtures of sewage sludge with peat affected calcium content in the plant shoots more than farmyard manure treatment (Fig. 2).

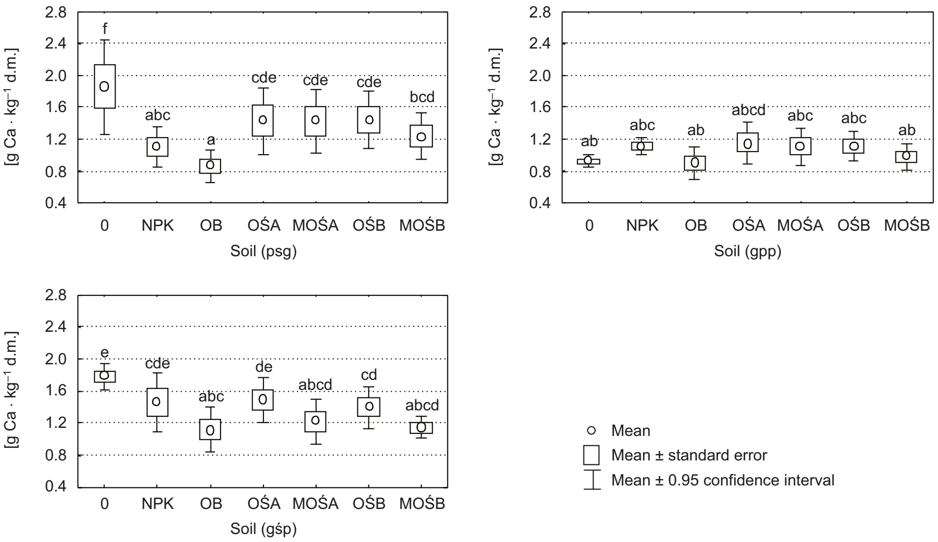

Fig. 2. Weighted average content of calcium in aboveground part of maize (from three years)
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test, factors soil x fertilisation

No significant diversification in calcium content was found in maize shoots cultivated in individual soils, excepts the unfertilized treatments. Woloszyk [8] found that one should not expect increasing calcium content in plants fertilized with organic materials either as a consequent effect or in result of a greater dose. On the other hand Lekan and Winiarska [9] think that plants fertilized with sewage sludge may accumulate considerable quantities of among others calcium, which should be associated with a substantial amount of this element in sewage sludge. In their previous investigations Gondek and Filipek-Mazur [10] proved that application of sewage sludge for plant fertilization significantly increased their calcium contents. However, it should be mentioned that the applied sewage sludge contained much bigger amounts of this element. Estimation of maize shoot biomass with respect to calcium content, revealed a low calcium content from the perspective of maize destination for fodder [11].

Magnesium content is important for plant fodder utility. In animal organism magnesium is the element constructing the skeleton and together with potassium is the most important mineral component of cell, and additionally also activator of many enzymes [2]. Maize root system contained greater amounts of magnesium (similar as calcium) than the shoots (Table 3). Although maize roots system has no fodder value, its magnesium content can signalize the quantity of this element which may be released in result of harvest residue mineralization and provide a source of this element for the consecutive plant. On the basis of the obtained results it was found that the applied fertilization did not diversify magnesium contents in maize tops (Fig. 3).

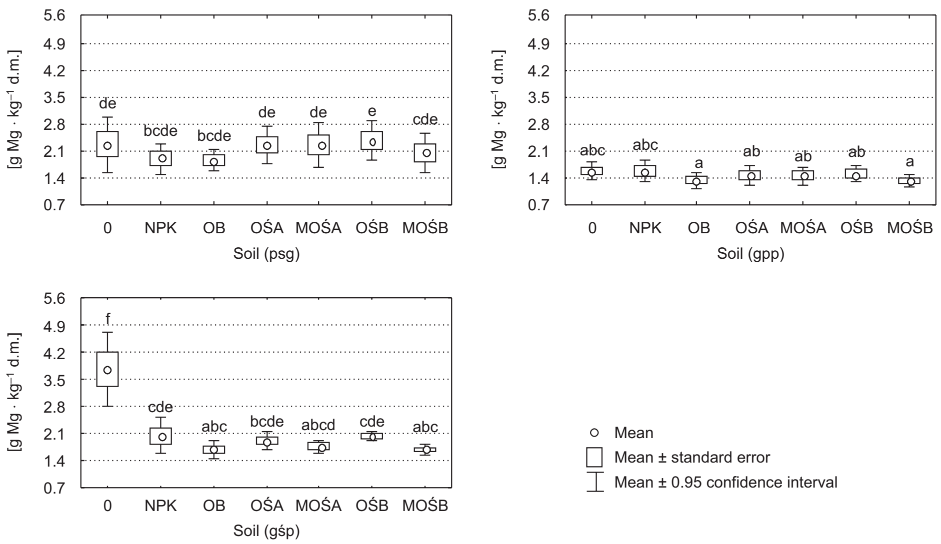

Fig. 3. Weighted average content of magnesium in aboveground part of maize (from three years)
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test, factors soil x fertilisation

However, magnesium content in maize shoots was markedly diversified depending on the kind of soil. The smallest amounts of this element were detected in maize shoots cultivated in sandy silt loam (gpp). Lekan and Winiarska [10] also assessed comparable contents of magnesium in plants fertilized with industrial-municipal sewage sludge and industrial sludge. As results from the quoted investigations there is no unanimous opinion on the influence of fertilization, particularly with organic materials, on macroelement contents in plant biomass. It may be due to a considerable variability of properties of organic materials used for the treatment, but mainly by the degree of their processing if they are waste materials. In the earlier Authors' investigations a relatively difficult access to nutrients from the applied organic materials might have actually limit magnesium uptake by plants. The analysis of magnesium contents in maize shoots in view of fodder value revealed its very low content, except its content in biomass of plant cultivated in weakly loamy sand (psg) fertilized with sewage sludge and mixtures of sewage sludge and peat [11].

Plant sodium requirement is small. Its functions comprise primarily effects on physicochemical soil properties and water economy in plants. Sodium content in plants has been considered mainly with respect to animal nutritional needs to which this element is necessary in considerably larger amounts. Sodium in animal organism is present almost exclusively in ionized form, mainly in extracellular liquids [2]. Sodium content in maize shoots fertilized with organic materials (sewage sludge, mixtures of sludge and peat) was over twice smaller than assessed in plant roots (Table 3). For comparison, shoots of maize fertilized with farmyard manure contained over 6 times less sodium than the roots. The applied fertilization diversified sodium content mostly in maize shoots cultivated in weakly loamy sand (psg) (Fig. 4).

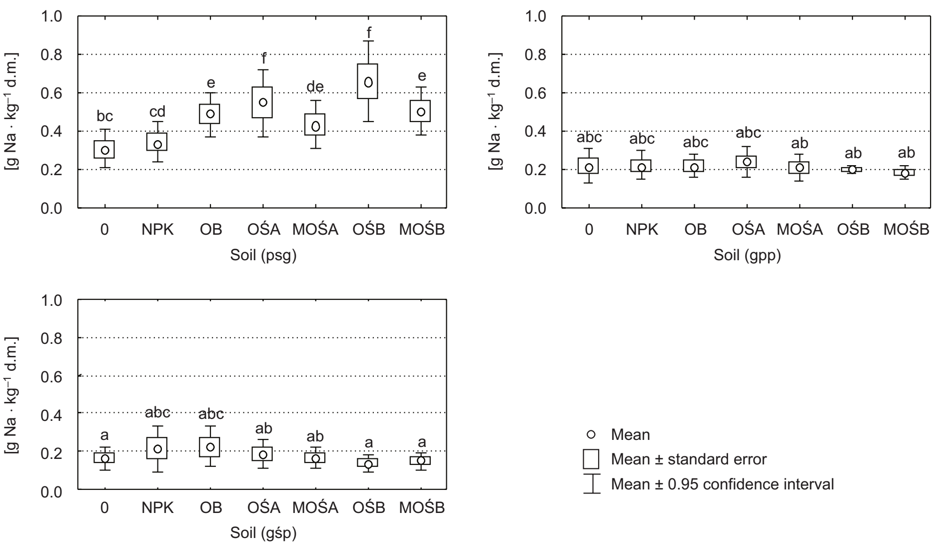

Fig. 4. Weighted average content of sodium in aboveground part of maize (from three years)
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test, factors soil x fertilisation

Significantly greatest amounts of this element were registered in the biomass of plants fertilized with sewage sludges. Sodium content in shoots of maize cultivated in sandy silt loam (gpp) and in medium silt loam differed significantly, irrespective of the applied fertilization. In previous investigations conducted by Gondek and Filipek--Mazur [10] no major changes were noted in sodium content in biomass of plants fertilized with sewage sludge. Sodium contents determined in the plant yield were comparable with the quantities assessed in the plants receiving mineral salts. Kopec et al [12] found greater sodium contents in the plants fertilized with sewage sludge but originating from tanneries with much higher content of Na. Studies of Mazur and Koc [10] revealed that plant fertilization with tannery sludge particularly affects sodium contents because of high concentration of this element, but does not influence calcium or magnesium contents. Considering fodder value, sodium content in maize shoots was low [11].

Quantitative relationships between nutrients are a good indicator of feed quality. According to Czuba and Mazur [14] one of such indicators is Ca : Mg ratio, which should equal 3 : 1. In the presented Authors' own investigations mean value of this ratio was the smallest, irrespective of the soil, in maize shoots fertilized with farmyard manure (Fig. 5).

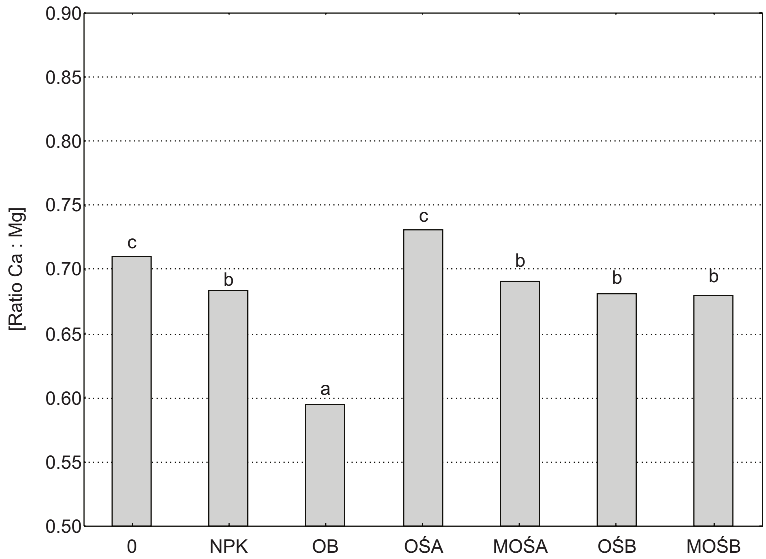

Fig. 5. Mean (for year and soils) value of the weight ratio Ca : Mg in aboveground part of maize
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test, factors soil x fertilisation

Ca : Mg value in the biomass maize shoots fertilized with sewage sludge and their mixtures with peat did not exceed the value of 0.75. The highest value of Ca : Mg ratio was registered in maize shoots fertilized with sewage sludge A (OŚA). Low value of Ca : Mg ratio testifies the fact that the analyzed maize shoot biomass contained too small quantities of calcium in comparison with magnesium.

Conclusions

1. Fertilization with sewage sludge and mixtures of sewage sludge with peat, applied over the three years of the experiment, had a more advantageous effect on maize biomass yield than treatment with mineral salts.
2. Maize fertilization with sewage sludge and mixtures of sewage sludge and peat did not cause any significant increase in the analyzed macroelements, except calcium, in maize shoots in comparison with farmyard manure treatment.
3. Fodder value of the maize shoot biomass was low in respect of the content of the analyzed elements.
4. Low value of Ca : Mg ratio evidences that the analyzed maize biomass contained too little calcium in relation to magnesium.
5. When using biomass of plants fertilized with sewage sludge or other waste materials for fodder purposes one should remember about supplementing mineral components such as Ca, Mg and Na because the quantity of these components absorbed by animals with fodder may prove insufficient.

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PLONOWANIE ORAZ ZAWARTOŚĆ WAPNIA, MAGNEZU I SODU W KUKURYDZY NAWOŻONEJ MATERIAŁAMI ORGANICZNYMI

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Abstrakt: Wykorzystanie osadów ściekowych do nawożenia roślin wydaje się najbardziej racjonalnym sposobem ich utylizacji, co nie jest równoznaczne z ich korzystnym działaniem na wartość biologiczną plonu. Wobec konieczności bilansowania ilości składników mineralnych w żywieniu zwierząt, celem przeprowadzonych badań była ocena zawartości wapnia, magnezu i sodu w biomasie kukurydzy nawożonej osadami ściekowymi i mieszaninami osadów ściekowych z tordem, uprawianej na glebach o zróżnicowanym składzie granulometrycznym.

Nawożenie osadami ściekowymi i mieszaninami osadów ściekowych z torfem w trzyletnim okresie badań działało korzystniej na plon biomasy kukurydzy niż nawożenie solami mineralnymi. Nawożenie kukurydzy osadami ściekowymi i mieszaninami osadów ściekowych z torfem nie spowodowało znacznego zwiększenia zawartości badanych makroskładników, poza wapniem w częściach nadziemnych kukurydzy, w porównaniu z nawożeniem obornikiem. Wartość paszowa uzyskanej biomasy części nadziemnych kukurydzy pod względem zawartości badanych pierwiastków była mała. Mała wartość stosunku Ca : Mg świadczy, że analizowana biomasa kukurydzy zawierała za mało wapnia w stosunku do magnezu. Przy wykorzystaniu biomasy roślin nawożonych osadami ściekowymi lub innymi materiałami pochodzenia odpadowego do celów paszowych należy pamiętać o uzupełnieniu składników mineralnych, takich jak Ca, Mg i Na, ponieważ ilość tych składników pobrana przez zwierzęta z paszą może okazać się niewystarczająca.

Słowa kluczowe: wapń, magnez, sód, kukurydza, osady ściekowe