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POTASSIUM CONTENT IN MAIZE AND SOIL FERTILIZED WITH ORGANIC MATERIALS

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Abstract

Since potassium is essential for plant nutrition, should this element be deficient in sewage sludge used for plant fertilization supplementary mineral potassium fertilization is necessary. The aim of the present study has been to evaluate the effect of fertilization with organic materials on maize yield, its potassium concentrations and the content of bioavailable forms of potassium in soil of different grain size distribution. The impact of fertilization on potassium concentrations in maize was examined in a 3-year, two-factor pot experiment (the factors were soil and fertilization). The grain size distribution of the test soil material was weakly loamy sand (psg), sandy silt loam (gpp) and medium silt loam (gśp). Sewage sludge originated from two different municipal mechanical and biological sewage treatment plants. Mixtures of sewage sludge with peat were prepared at a gravimetric ratio 1:1 converted to material dry matter. For chemical analyses the plant material was mineralized in a muffle furnace (at 450°C for 5 hrs) and the remains were dissolved in diluted nitric acid. Bioavailable potassium was determined with Egner-Riehm method in the soil material, which was dried and sifted through a 1mm mesh sieve. Potassium was determined by flame photometry in solutions of the plant material and soil extracts. Fertilization with sewage sludge and mixtures with peat had a more positive effect on maize yield than fertilization with mineral salts. In comparison with organic materials supplied to the soil, mineral salt treatment significantly increased potassium content in maize biomass. Mineral supplementation of potassium introduced with organic materials and its balancing did not increase soil abundance in bioavailable potassium in comparison with the initial abundance, although a diversified soil response to the applied fertilization was observed.

Key words: potassium, sewage sludge, maize.

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ZAWARTOŚĆ POTASU W KUKURYDZY I GLEBACH NAWOŻONYCH MATERIAŁAMI ORGANICZNYMI

Abstrakt

Biorąc pod uwagę niezbędność potasu w żywieniu roślin, deficytowa zawartość tego składnika w osadach ściekowych wykorzystywanych do nawożenia roślin wymaga jego uzupełnienia w formie mineralnej. Celem badań była ocena wpływu nawożenia materiałami organicznymi na plon części nadziemnych i korzeni kukurydzy, zawartości w nim potasu oraz zawartości form przyswajalnych tego składnika w glebach o różnym składzie granulometrycznym. Ocenę wpływu nawożenia na zawartość potasu w kukurydzy przeprowadzono w 3-letnim dwuczynnikowym doświadczeniu wazonowym (czynniki: gleba, nawożenie). Do badań użyto materiału glebowego o składzie granulometrycznym piasku słabo gliniastego (psg), gliny piaszczystej pylastej (gpp) i gliny średniej pylastej (gśp). Osady ściekowe pochodziły z dwóch różnych komunalnych oczyszczalni mechaniczno-biologicznych. Mieszaniny osadów ściekowych z torfem sporządzono w stosunku wagowym 1:1, w przeliczeniu na suchą masę materiałów. W celu oznaczenia potasu materiał roślinny mineralizowano w piecu muflowym (temp. 450°C, 5 h), pozostałość roztworzono w rozcieńczonym kwasie azotowym. W materiale glebowym wysuszonym i przesianym przez sito o średnicy oczek 1 mm potas przyswajalny oznaczono metodą Egnera-Riehma. W uzyskanych roztworach materiału roślinnego oraz ekstraktach glebowych potas oznaczono metodą fotometrii płomieniowej. Nawożenie osadami ściekowymi i mieszaninami osadów z torfem działało korzystniej na plony kukurydzy niż nawożenie solami mineralnymi. W porównaniu z zastosowanymi doglebowo materiałami organicznymi, nawożenie solami mineralnymi istotnie zwiększyło zawartość potasu w biomasie kukurydzy. Zrównoważenie solami mineralnymi ilości potasu wprowadzanego z materiałami organicznymi i jego zbilansowanie nie zwiększyło zasobności gleby w potas przyswajalny, w porównaniu z zasobnością wyjściową, chociaż zaobserwowano różne zmiany w glebach po zastosowanym nawożeniu.

Słowa kluczowe: potas, osady ściekowe, kukurydza.

INTRODUCTION

Good fertilization value of sewage sludge has been confirmed in numerous investigations (Mazur 1995, Wołoszyk and Krzywy 1999, Krzywy et al. 2004). Sewage sludge can be used for soil and plant fertilization mainly because of the significant concentrations of organic matter and nutrients it contains (Baran et al. 2002). If all rules for safe application of sewage sludge in agriculture are observed, this material may supplement or replace farmyard manure.

Sewage sludge may have a highly different chemical composition, sometimes comprising high amounts of nitrogen or phosphorus content but having little potassium (Mazur 1996, Kalembasa et al. 2001). Such low concentrations of this element in sewage sludge are due to the fact that potassium occurs in the form of easily soluble salts (Kalembasa et al. 1999) which dissociate in water solutions, and this favours retention of potassium in sewage waters during the technological process of sludge separation.

Considering the crucial role of potassium in animal nutrition, deficit of this element in sewage sludge used for plant fertilization requires its supplementation in the mineral form.

The present research intended to asses the effect of fertilization with organic materials on the yield of maize shoot and root dry mass, their potassium concentrations and the content of bioavailable forms of this element in soils different in the grain size composition.

MATERIAL AND METHODS

The effect of fertilization on potassium content in maize was assessed in a two-factor (factors: soil and fertilization) pot experiment conducted in 2003--2005. The research was carried out on three soils and the experimental design, identical for each soil, comprised 7 treatments in three replications: without fertilization – (0); fertilization with chemically pure salts – (NPK); farmyard manure – (OB); sewage sludge A (OŚA); mixture of sewage sludge A with peat – (MOŚA); sewage sludge B (OŚB) and mixture of sewage sludge B with peat (MOŚB). The following soil material was used for the experiment: weakly loamy sand (psg), sandy silt loam (gpp) and medium silt loam (gśp), all collected from the arable layer (0-20 cm) of plough lands near Krakow. Sewage sludge originating from two different mechanical and biological municipal treatment plants and mixtures with peat were used for the experiment. Sewage sludge was mixed with peat at a weight ratio 1:1 per dry mass of organic materials. Peat containing 408 $g \cdot kg^{-1}$ d.m. comprised 88 $g \cdot kg^{-1}$ ash, 34.4 g $N \cdot kg^{-1}$d.m., 0.91g $P \cdot kg^{-1}$d.m. and 1.14 g $K \cdot kg^{-1}$d.m. The chemical composition of the organic materials and soil material (values per dry mass assessed at 105°C) is given in Tables 1 and 2.

Plastic pots used for the experiment contained 5.50 kg of air-dried soil material. Before the experiment, the soils were gradually moistened to 30% of maximum water capacity. Afterwards, sandy loam and medium silt loam were limed to obtain the reaction recommended in the Ministry decree (soil pH in agricultural areas no less than 5.6) (*Rozporządzenie*… 2002). Liming was applied separately in each pot. Chemically pure CaO was used in a dose calculated on the basis of soil hydrolytic acidity. Next, all the soils were left for 4 weeks and water loss was occasionally supplemented. Finally, organic fertilization was carried out in doses corresponding to 1.20 g $N \cdot pot^{-1}$. Phosphorus and potassium were supplemented with solutions of chemically pure salts [P – $Ca(H_2PO_4)_2 \cdot H_2O$ and K – KCl] to equalize quantities of these elements supplied with the organic materials. In the mineral (NPK) treatment the doses of nitrogen, phosphorus and potassium were identical to the ones in the organic material treatments. Doses of N, P and K were, respectively, 1.20 g $N \cdot pot^{-1}$ as NH_4NO_3, 1.26 g $P \cdot pot^{-1}$ as $Ca(H_2PO_4)_2 \cdot H_2O$ and

Table 1

Chemical composition of materials used in the experiment

Specification		FYM (OB)	Sewage sludge (OŚA)	Sewage sludge + peat (MOŚA)	Sewage sludge (OŚB)	Sewage sludge + peat (MOŚB)
Dry matter ($g \cdot kg^{-1}$)		189	310	343	418	372
pH (H_2O)		6.22	6.12	5.57	5.73	5.20
Organic matter ($g \cdot kg^{-1}$ d.m.)		679	353	652	552	771
Total forms						
N	$g \cdot kg^{-1}$ 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	$mg \cdot kg^{-1}$ 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		338.0	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		*	3.58	1.80	2.29	1.07

*trace

1.48 g $K \cdot pot^{-1}$ as KCl. In the second and third year of the experiment, because of the subsequent fertilizer effect and the abundance of the soils in bioavailable phosphorus and potassium, the applied doses were as follows: 0.80 g N; 0.2 g P and 1.40 g $K \cdot pot^{-1} \cdot year^{-1}$ as chemically pure salts.

Maize cv. San (FAO 240) was cultivated as a test plant, with five plants per pot left to grow. Maize (grown for green forage) was harvested at the 7-9 leaves stage. The growing season lasted 47 days in the first year, 66 days in the second year and 54 days in the third year. Throughout the experiment the plants were watered with distilled water to 50% of maximum water capacity. Once harvested, the plants were dried (at 70°C) to constant weight and the yield of dry mass of shoots and roots was determined. After crushing in a laboratory mill, the plant material was mineralized for 5 hours in a muffle furnace at 450°C. The remains were dissolved in diluted nitric acid 1:2 (v/v) (Ostrowska et al. 1991). The soil material collected each year

Table 2

Some properties of soils before the establishment of the experiment

Specification			Soil		
			(psg)	(gpp)	(gśp)
Granulometric composition Ø	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		$mmol(+) \cdot kg^{-1}$ d.m	11.2	23.4	33.2
Sum of alkaline cations			39.9	86.8	128.4
Total N		$g \cdot kg^{-1}$ 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		$mg \cdot kg^{-1}$ d.m.	79	217	29
K			166	359	138
Mg			134	154	126
$S\text{-}SO_4$			13.4	11.9	11.4

after the growing season was analyzed to determine changes in the physicochemical properties caused by the fertilization. In the dried material sifted through a 1mm mesh sieve, bioavailable potassium was determined using Egner-Riehm method (Ostrowska et al. 1991). In the plant material solutions and soil extracts, potassium was determined with the flame photometry method (FES) on a Philips PU 9100X apparatus. Plant reference material NCS DC73348 (China National Analysis Center for Iron & Steel) and soil reference material AG-2 (*Agro*MAT) were attached to each analytical series. The results were verified statistically using a fixed model, in which soil or fertilization was the factor. The statistical computations involved one-way ANOVA and the significance of differences was estimated using NIR Fisher test at significance level $p < 0.05$ (Stanisz 1998).

RESULTS AND DISCUSSION

The organic materials used for the experiment differed in the chemical composition, including potassium content, which was very small in sewage sludge and its mixtures with peat (Table 1). Peat added to sludge generally diminished the contents of individual elements in comparison with their concentrations in sludge alone.

The soil material used for the experiment belonged to various texture groups. In addition, it significantly differed in the chemical properties, including the content of available potassium forms (Table 2). A considerably high potassium content was assessed in the medium soil.

Yields of maize biomass (roots and shoots), as averages for all the treatments in the three years, were significantly smaller on the light soil (psg) (over 20% irrespective of the plant part) than the yields on the other two (heavier) soils (Figure 1). The difference in the yield harvested from sandy loam (gpp) and medium loam (gśp) was not significant for the shoots, where-

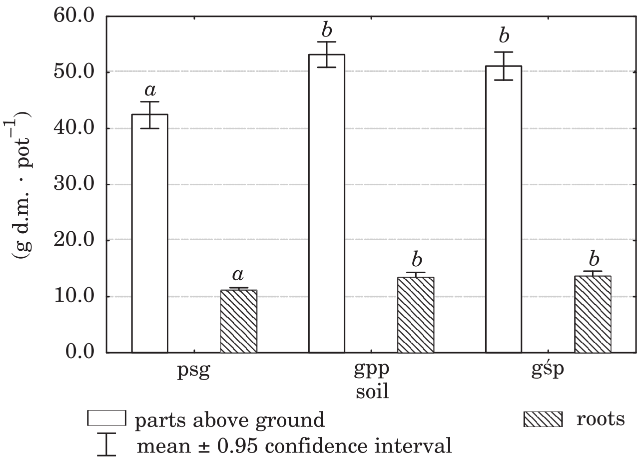

Fig. 1. Yields of aerial parts and roots of maize from fertilization objects (3-year period mean). Means followed by the same letters did not differ significantly at $p < 0.01$ according to Fisher test

as the average root biomass yield did not differ at all between these soils. Analysis of variance confirmed a favourable effect of organic fertilization on maize biomass yield (Table 3). Treatment with sewage sludge or its mixtures with peat as well as fertilization with farmyard manure produced much higher yields than exclusive mineral fertilization. Larger yields from the mineral salt treatments occurred only in the first year of the experiment (Figure 2). In the subsequent years, the response to fertilization with organic materials was positive despite the differences noticed on the lighter soils, which obscured the overall effect. Larger yields were produced when sewage sludge and peat mixture was applied compared to sludge alone. Fertilization efficiency of organic materials is determined mainly by their nitrogen content, particularly nitrogen mineral forms (SZULC et al. 2004). Nitrogen largely determines biomass yield. However, limited availability of other fer-

Table 3

Yields of dry mass of parts above ground and roots plants, total potassium content in maize and potassium available in soils (3-year period mean)

Object	Yield of biomass (g d.m.·pot^{-1})		K in the plant (g K·kg^{-1} d.m.)		K available in the soil (mg K·kg^{-1} d.m.)
	(Cz.n.)	(K)	(Cz.n.)	(K)	
Control (0)	22.1 ^{a}	7.4 ^{a}	17.5 ^{a}	9.9 ^{a}	80 ^{a}
NPK	42.5 ^{b}	10.1 ^{b}	37.5 ^{d}	18.9 ^{c}	127 ^{bc}
FYM (OB)	48.0 ^{c}	13.1 ^{cd}	30.5 ^{c}	16.8 ^{bc}	143 ^{c}
Sewage sludge (OŚA)	47.3 ^{c}	11.8 ^{c}	29.4 ^{bc}	16.8 ^{bc}	109 ^{abc}
Sewage sludge+peat (MOŚA)	49.3 ^{cd}	11.8 ^{c}	29.1 ^{bc}	15.9 ^{b}	116 ^{abc}
Sewage sludge (OŚB)	50.4 ^{cd}	14.1 ^{de}	28.7 ^{bc}	15.4 ^{b}	99 ^{ab}
Sewage sludge+peat (MOŚB)	55.6 ^{d}	15.8 ^{e}	25.6 ^{b}	15.6 ^{b}	108 ^{abc}

(Cz.n.) – aerial parts; (K) – roots
Means followed by the same letters in columns did not differ significantly at $p < 0.01$ according to Fisher test.

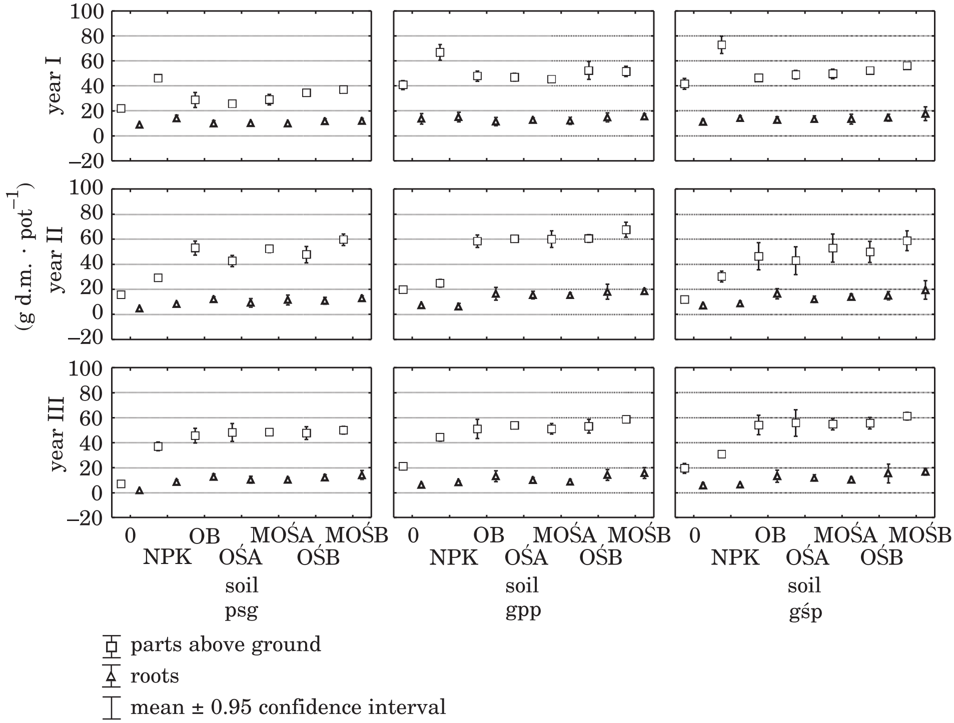

Fig. 2. Yield of aerial parts and roots of maize in each year of the experiment

tilizer components, such as potassium, directly influences mineral economy in crops. Over the three-year period of our investigations, fertilization with organic materials produced better results expressed by the biomass yields than treatments with mineral salts. This effect is not fully attributable to the activity of the applied sewage sludge or its mixtures with peat. It is also a subsequent effect of the activity of organic materials and supplementary fertilization with mineral salts in the second and third year of the experiment. Plant yields might have been affected by other components, such as sulphur, magnesium or microelements supplied to soil with organic materials, whose amounts were not balanced. According to WOŁOSZYK (2003) application of natural or organic fertilizer, due to the so-called subsequent effect, does not always raise crop yields. DRAB and DERENGOWSKA (2003) demonstrated a positive effect of sewage sludge on crop yielding while proving that yield, irrespective of the soil type, was conditioned by a dose of sewage sludge. According to WIATER et al. (2004), immediate fertilizer effect of sewage sludge on maize yield may be worse than that produced by mineral fertilization, although the subsequent effect of sewage sludge fertilizer activity could be more beneficial.

Irrespective of the type of soil and year of the experiment, the highest amounts of potassium were found in shoots and roots of maize fertilized with mineral salts (Table 3, Figures 3 and 4). The mean potassium content for the three years in this treatment was 37.5 g $K \cdot kg^{-1}$d.m. in shoots, thus being over 7 $g \cdot kg^{-1}$ d.m. larger than the content determined in shoots of plants fertilized with organic materials. Smaller differences occurred in the

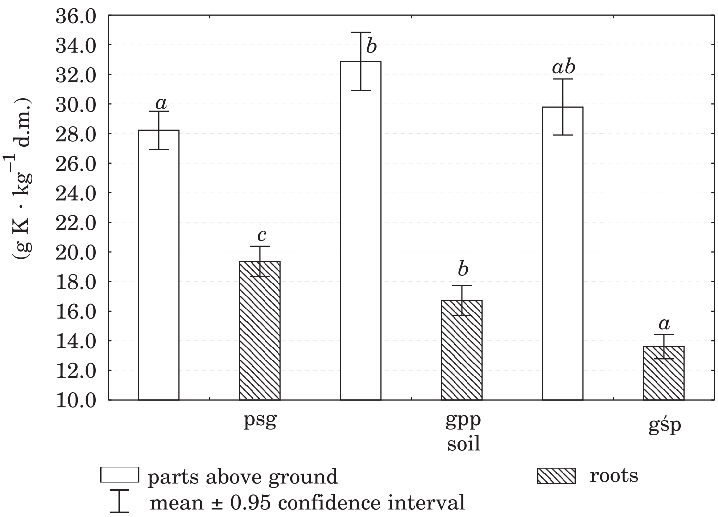

Fig. 3. Content of potassium in aerial parts and roots of maize from fertilization objects (3-year period mean). Means followed by the same letters did not differ significantly at $p < 0.01$ according to Fisher test

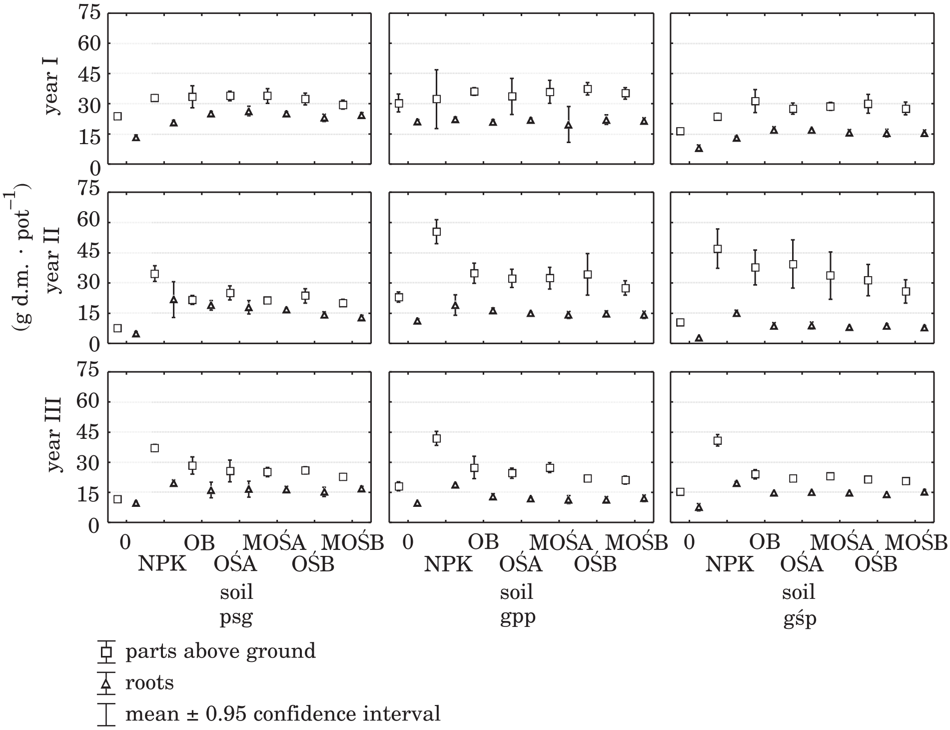

Fig. 4. Content of potassium in aerial parts and roots of maize in each year of the experiment

potassium content in roots. Significant variation was also noticed in the potassium content in maize biomass depending on the kind of soil (Figure 3). The content was the highest in sandy silt loam (gpp), but the average potassium content for all the treatments and years did not differ significantly in biomass of maize cultivated on weakly loamy sand (psg) and medium silt loam (gśp). This effect was certainly produced by the content of bioavailable potassium in soil. Application of macroelements as mineral fertilizers usually affects their concentrations in plants to a greater degree than fertilization with these elements in the form of natural and organic fertilizers or waste materials. It is so mainly because of the form in which the elements occur in these fertilizers as well as due to their occasionally low content (Kalembasa et al. 2001). According to Kalembasa and Symanowicz (1999), sewage sludge has a beneficial effect on the content of macroelements in plants. Wołoszyk (2003) claims that even when sewage sludge contains little potassium, it is not always necessary to supplement this component in the mineral form, and this depends on soil abundance in bioavailable potassium forms and the kind of crop. Drab and Derengowska (2003) revealed that even if nitrogen and phosphorus content in plants increased proportionately to the applied dose of sewage sludge, potassium content in the plant biomass did not change much, also when an additional dose of this element in the mineral form was used. On the other hand, WIATER et al. (2004) demonstrated a subsequent effect of fertilization with sewage sludge granulate on potassium content in maize.

The mean content of bioavailable potassium in the soil from all the treatments differed significantly (Figure 5). The highest amount of bioavailable forms of this element was determined in the soil amended with farmyard manure, whereas the lowest level of bioavailable potassium, apart from

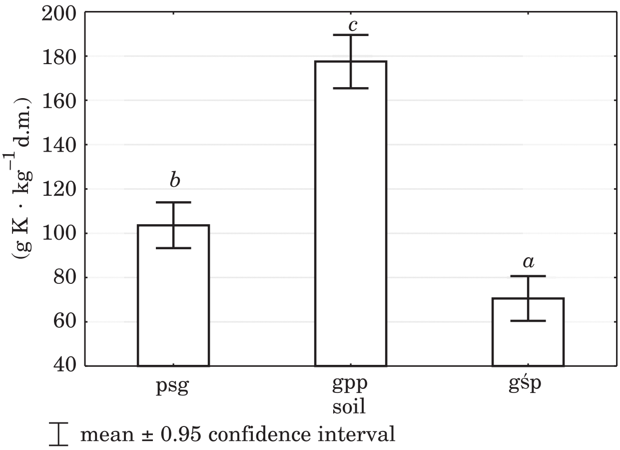

Fig. 5. Content of available potassium forms in soils from fertilization objects (3-year period mean). Means followed by the same letters did not differ significantly at $p < 0.01$ according to Fisher test

the control treatments, occurred after application of sewage sludge. Considerable variation was also observed in the content of bioavailable potassium forms in the soil in individual years (Figure 6). The research reveals that on average the content of bioavailable potassium in soil after the application of organic materials, particularly sewage sludge (OŚA and OŚB), was smaller in the soil amended with mineral salts (NPK) (Table 3). However, the analysis of variance did not confirm the significance of differences. The highest mean content of bioavailable potassium in soil, in comparison with the unfertilized treatment, was found after farmyard manure application (OB). Likewise, WOŁOSZYK (2003), who tested composts and sewage sludge, noticed that the content of bioavailable potassium forms diminished in comparison with the bioavailable forms of this element in soil prior to the experiment.

According to MCLEAN and BRYDON (1971), small doses of potassium do not always ensure proper plant supply with this element and the causes of this phenomenon are connected with unchangeable sorption of potassium ions.

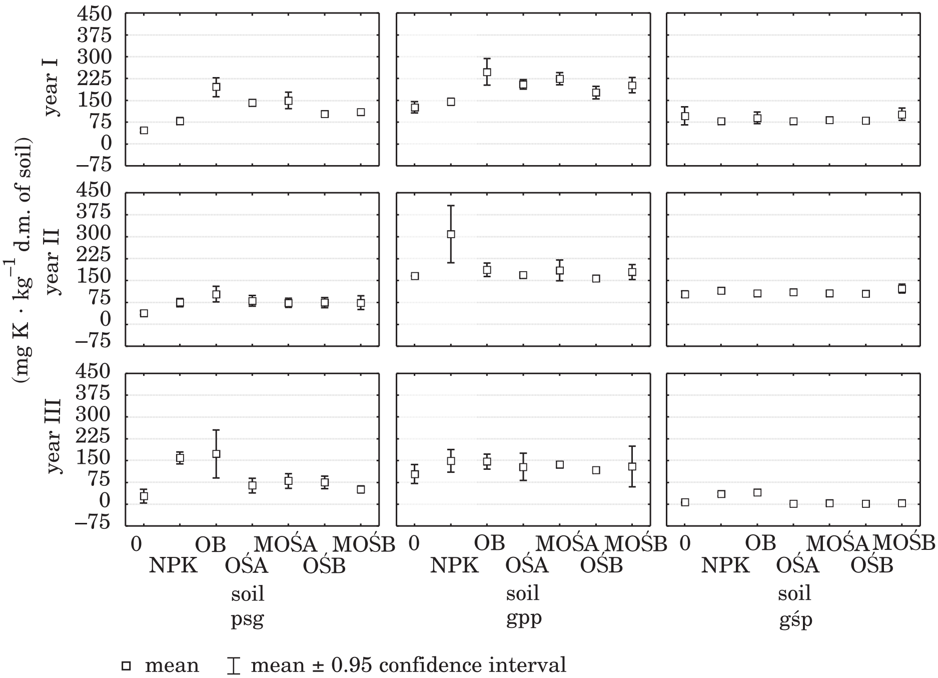

Fig. 6. Content of available potassium forms in soils in each year of the experiment

CONCLUSIONS

1. Fertilization with sewage sludge and mixtures of sludge with peat affected maize yields more favourably than mineral salt treatment.

2. Sludge mixtures with peat (in comparison with sludge used separately) influenced slightly more advantageously maize biomass yield and comparative potassium content in the plant biomass.

3. In comparison with the organic materials applied to the soil, mineral salt fertilization significantly increased potassium content in maize biomass.

4. Equalizing potassium quantities supplied with the organic materials by mineral salts and its balancing did not increase the soil abundance in bioavailable potassium in comparison with the initial abundance, although various changes were observed in the soils after the applied fertilization.

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