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CHANGES IN THE CONTENT OF SOME MACROELEMENTS IN MAIZE (*ZEA MAYS* L.) AFTER APPLICATION OF FUEL OIL AND DIFFERENT NEUTRALIZING SUBSTANCES TO SOIL*

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Abstract

The aim of the present study was to determine the effect of incremental doses of heating oil (0-20 g kg of soil) and neutralizing substances – mineral and organic ones – on the content of some macronutrients in maize (*Zea mays* L.). The effect of heating oil and neutralizing substances on concentrations of the analyzed macronutrients in maize was varied. The content of phosphorus in maize was positively correlated to incremental doses of heating oil; the accumulation of sodium, calcium and magnesium in maize assumed a parabolic function, while changes in the content of potassium were irregular. All the substances applied to soil had a limiting effect on the content of phosphorus but stimulated (except nitrogen) the accumulation of potassium in maize grown on soil contaminated with heating oil. Out of the tested soil-amending substances, bentonite was the most stimulating one with respect to sodium and the most limiting to calcium in maize. Zeolite and calcium oxide showed a stimulating effect and increased the content of calcium and magnesium in maize. Compost had a similar effect on the content of calcium, whereas nitrogen stimulated the accumulation of magnesium in maize.

Key words: fuel oil contamination, nitrogen, compost, bentonite, zeolite, calcium oxide, maize, macroelements.

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ZMIANY ZAWARTOŚCI WYBRANYCH MAKROSKŁADNIKÓW W KUKURYDZY (*ZEA MAYS* L.) PO APLIKACJI OLEJU OPAŁOWEGO I RÓŻNYCH SUBSTANCJI NEUTRALIZUJĄCYCH DO GLEBY

Abstrakt

Celem badań było określenie wpływu wzrastających dawek oleju opałowego (0-20 $g \cdot kg^{-1}$ gleby) i substancji neutralizujących – mineralnych i organicznych na zawartość wybranych makroskładników w kukurydzy (*Zea mays* L.). Wpływ oleju opałowego i substancji łagodzących na zawartość badanych makropierwiastków w kukurydzy był zróżnicowany. Zawartość fosforu w kukurydzy była dodatnio skorelowana ze wzrastającymi dawkami oleju opałowego, nagromadzenie sodu, wapnia i magnezu przybierało funkcję paraboliczną, a zmiany zawartości potasu nie były jednoznacznie ukierunkowane. Wszystkie zaaplikowane do gleby substancje działały ograniczająco na zawartość fosforu, a także stymulująco (oprócz azotu) na akumulację potasu w kukurydzy uprawianej na glebie zanieczyszczonej olejem opałowym. Bentonit był dodatkiem najbardziej stymulującym zawartość sodu i najbardziej ograniczającym nagromadzenie wapnia w kukurydzy. Wykazano, że zeolit i tlenek wapnia działały stymulująco i wpłynęły na zwiększenie zawartości wapnia i magnezu w kukurydzy. Podobny wpływ na zawartość wapnia miał kompost, a na nagromadzanie magnezu w kukurydzy – azot.

Słowa kluczowe: zanieczyszczenie olejem opałowym, azot, kompost, bentonit, zeolit, tlenek wapnia, kukurydza, makroskładniki.

INTRODUCTION

Petroleum products become a problem when they turn into soil and water environment pollutants. In Poland, former military grounds, petroleum refinery facilities, petrol stations, intermediate pumping stations or pipelines can be contaminated with petroleum substances. Contamination at such locations exceeds permissible values and can be found as deep as 30 meters underground, for example on airfields formerly occupied by the Soviet Army. These contaminants cause modifications in soil properties (Wyszkowska, Wyszkowski 2006, 2010, Ziółkowska, Wyszkowski 2010, Wyszkowski, Sivitskaya 2012, 2013) and threaten surface and ground waters (Nowak 2008). Regardless of the source of contamination, petroleum substances which permeate into soil enter the soil-plant-animal-human chain (Przybulewska 2005, Wyszkowski, Ziółkowska 2013). Hydrocarbons from petroleum products form a fatty film on underground and aerial parts of plants, which depresses the plant's transpiration and respiration rates, impairs the permeability of plant membranes and causes disorders in metabolic processes, leading to changes in the chemical composition of plants (Wyszkowska, Wyszkowski 2006, Wyszkowski et al. 2004, Wyszkowski, Ziółkowska 2009, 2011, Ziółkowska, Wyszkowski 2010). Petroleum compounds are responsible for disorders in the growth of plants, weaker tolerance to pests, disruptions of the growth rate (Ziółkowska, Wyszkowski 2010). They block enzymatic systems, which causes physiological changes and necrosis of tissues and cells (Przybulewska 2005). It is therefore important to restrain the effect of petroleum on plants.

The aim of present study was to determine the effect of incremental doses of heating oil and alleviating substances – mineral and organic ones – on the content of magnesium and other macronutrients in maize (*Zea mays* L.).

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at the University of Warmia and Mazury in Olsztyn (north-eastern Poland), on soil of the grain-size distribution of loamy sand (fractions in mm: <0.002 – 1.89%, 0.002--0.005 – 2.46%, 0.005-0.010 – 2.87%, 0.010-0.020 – 4.39%, 0.020-0.050 – 8.89%, 0.050-0.100 – 14.08%, 0.100-0.250 – 36.90%, 0.250-0.500 – 22.78%, 0.500-1.000 - 5.74%). The soil properties were as follows: pH in 1 mol KCl dm^{-3} 4.52, hydrolytic acidity (Hh) 25.4 mmol(+) kg^{-1}, sum of the exchange capacity of cations Ca^{++}, Mg^{++}, K^{+} and Na^{+} (S) 29.1 mmol(+) kg^{-1}, total exchangeable bases (T) 54.5 mmol(+) kg^{-1}, percent base saturation (V) 53%, $C_{org.}$ content 11.3 g kg^{-1}, the content of available forms of phosphorus 71.9 mg kg^{-1}, potassium 118.6 mg kg^{-1} and magnesium 104.2 mg kg^{-1} of soil. The soil was contaminated with heating oils in the amounts of 0, 5, 10, 15 and 20 g kg^{-1}. In order to reduce the effect of fuel oil on soil, the following neutralizing substances were applied: nitrogen as urea (200 mg N kg^{-1} of soil), compost (3%), bentonite and zeolite (2% relative to the mass of soil) and 50% calcium oxide in a dose corresponding to one full hydrolytic acidity (10.93 g Ca kg^{-1} of soil). Compost was prepared from leaves (44%), manure (33%) and peat (23%) composted for six months. The concentration of macroelements in these substances (in g kg^{-1}) was as follows: compost: P – 2.32, K – 1.33, Mg – 1.47, Ca – 15.86, Na – 0.12; bentonite: P – 0.47, K – 2.43, Mg – 5.03, Ca – 26.72, Na – 12.11; calcium oxide: P – 0.10, K – 0.77, Mg – 2.65, Ca – 347.99, Na – 0.07. Apart from heating oil and the alleviating substances, the soil (9 kg in each pot) was enriched with macro- and micronutrients, added in the following doses: 100 mg N, 30 mg P, 100 mg K, 50 mg Mg, 0.33 mg B, 5 mg Mn and 5 mg Mo per kg of soil. Once the soil was prepared as described above, cv. Reduta maize (*Zea mays* L.) was sown. The trials were conducted on 8 plants per pot. Maize plants were harvested during the intensive stem elongation phase and plant samples were taken for laboratory analyses.

The plant material was dried at 60°C, ground and mineralized in concentrated sulphuric (VI) acid with hydrogen peroxide added as a catalyst. The solution thus prepared underwent the following determinations: content of phosphorus (P^{5+}) by colorimetry with the vanadium-molybdenum method; content of potassium (K^{+}), sodium (Na^{+}) and calcium (Ca^{2+}) – by the atomic emission spectrometry method – ESA and the content of magnesium (Mg^{2+}) – with atomic absorption spectrometry ASA (Ostrowska et al.

1991). The grain-size distribution in the soil was determined with the laser method using a Mastersizer 2000 meter. Prior to the establishment of the trials, the soil was also tested for its reaction (pH) with the potentiometric method in KCl aqueous solution of the concentration of 1 mol dm^{-3}, hydrolytic acidity (Hh) and sum of the exchange capacity of cations (S) with Kappen method, content of organic carbon (C_{org}) with Tiurin method, content of available phosphorus and potassium with Egner-Riehm method, available magnesium with Schachtschabel method (LITYŃSKI et al. 1976), and trace elements according to the US-EPA3051 methodology (1994). The results were processed statistically by means of two-factor analysis of variance ANOVA from a Statistica software package (StatSoft, Inc. 2010).

RESULTS AND DISCUSSION

The content of macronutrients in the maize plants depended on both the dose of heating oil and soil amending substances (Tables 1-2). In the non-amended treatments, the content of phosphorus in maize tended to increase (r=0.885), especially in response to high doses of heating oil. No such tendency existed for potassium, although the treatment contaminated with 20 g of heating oil per kg of soil contained 33% less potassium than the control (no heating oil). Under the influence of increasing doses of heating oil, the sodium concentration increment (+19%) in maize in the objects with non-amended soil was parabolic, with the peak content at the dose of 15 g of heating oil per kg of soil. Analogously, the content of calcium and magnesium increased up to the dose of 10 g of heating oil per 1 kg of soil, but fell in the aerial parts of maize in response to the highest dose of the contaminant (20 g kg^{-1} of soil).

Petroleum substances modify the accumulation of most of macronutrients in plants. DIMITROV and MITOVA (1998) found that concentrations of phosphorus and calcium in plants do not change significantly under the effect of diesel oil. WYSZKOWSKI and ZIÓŁKOWSKA (2009) observed a stimulating effect of petrol in the amount of 10 g kg^{-1} of soil on the content of magnesium and calcium in maize, a finding which is confirmed by the present study. An observation that is contradictory to the results reported by the above authors was made for calcium and magnesium, as in the current research the dose of 10 g of heating oil per kg of soil stimulated the accumulation of these elements in maize. In another study, conducted by KRZEBIETKE and SIENKIEWICZ (2010), soil contamination with anthracene and pyrene caused an increase in the content of calcium and sodium in butterhead lettuce. The experiment completed by WIECZOREK et al. (2006) showed that anthracene resulted in an increased content of magnesium in yellow lupine. These relationships were partly confirmed in the authors' own research. The effect of

Table 1

Content of phosphorus, potassium and sodium in maize *Zea mays* L. (g kg^{-1} d.m.)

Dose of heating oil (g kg^{-1} of soil)	Type of substance neutralizing the effect of heating oil						
	without additions	nitrogen	compost	bentonite	zeolite	CaO	average
Phosphorus							
0	1.07	1.09	0.78	0.90	0.79	0.73	0.89
5	0.88	0.96	0.85	0.83	0.77	0.70	0.83
10	1.19	0.99	0.92	1.05	1.00	0.73	0.98
15	1.77	0.93	1.32	1.41	1.74	1.35	1.42
20	1.80	0.91	1.66	1.39	1.27	1.91	1.49
Average	1.34	0.98	1.11	1.12	1.11	1.08	1.12
r	0.885**	-0.873**	0.943**	0.908**	0.754**	0.887**	0.913**
LSD	a – 0.12**, b – 0.13**, $a \cdot b$ – 0.30**						
Potassium							
0	34.95	29.55	34.70	39.13	33.23	38.14	34.95
5	28.32	20.70	35.69	33.72	30.53	33.23	30.36
10	37.16	22.42	36.42	38.39	37.90	33.23	34.25
15	31.27	24.63	37.16	30.28	33.23	34.95	31.92
20	23.65	31.76	36.67	29.30	27.58	26.35	29.22
Average	31.07	25.81	36.13	34.16	32.49	33.18	31.07
r	-0.580	0.281	0.892**	-0.809**	-0.356	-0.802**	-0.638*
LSD	a – 1.40**, b – 1.54**, $a \cdot b$ – 3.44**						
Sodium							
0	1.06	1.12	1.09	4.01	1.26	1.23	1.06
5	1.14	1.12	1.29	2.17	1.14	1.26	1.14
10	1.17	1.17	1.12	1.74	1.06	1.14	1.17
15	1.26	1.17	1.29	2.36	1.09	1.17	1.26
20	1.14	1.31	1.23	3.30	1.23	1.09	1.14
Average	1.16	1.18	1.20	2.72	1.16	1.18	1.16
r	0.630*	0.883**	0.477	-0.209	-0.207	-0.861**	-0.114
LSD	a – 0.08**, b – 0.09**, $a \cdot b$ – 0.20**						

LSD for: a – heating oil dose, b – type of neutralizing substance, $a \cdot b$ – interaction;
significant for: *P=0.05, **P=0.01, r – correlation coefficient

Table 2

Content of magnesium and calcium in maize *Zea mays* L (g kg^{-1} d.m)

Dose of heating oil (g kg^{-1} of soil)	Type of substance neutralizing the effect of heating oil						
	without additions	nitrogen	compost	bentonite	zeolite	CaO	average
Calcium							
0	5.73	9.40	9.16	6.71	8.18	11.11	8.38
5	6.22	7.44	7.93	3.78	7.20	9.16	6.96
10	6.71	4.76	6.22	3.53	8.42	6.96	6.10
15	6.71	5.24	5.98	3.78	5.98	6.71	5.73
20	5.24	5.73	6.47	3.78	6.71	5.00	5.49
Average	6.12	6.52	7.15	4.32	7.30	7.79	6.53
r	-0.121	-0.791**	-0.856**	-0.691*	-0.646*	-0.977**	-0.944**
LSD	a – 0.45**, b – 0.50**, $a \cdot b$ – 1.11**						
Magnesium							
0	4.34	5.10	4.37	4.97	5.00	5.41	4.87
5	4.80	5.94	4.75	5.05	6.41	5.95	5.48
10	4.93	6.25	4.19	4.71	6.21	5.51	5.30
15	4.85	6.03	4.47	4.32	5.25	5.36	5.05
20	4.55	5.65	4.69	4.75	4.81	4.18	4.77
Average	4.69	5.79	4.50	4.76	5.54	5.28	5.09
r	0.314	0.422	0.242	-0.644*	-0.337	-0.730*	-0.333
LSD	a – 0.12**, b – 0.13**, $a \cdot b$ – 0.29*						

LSD for: a – heating oil dose, b – type of neutralizing substance, $a \cdot b$ – interaction;
significant for: *P=0.05, **P=0.01,, r – correlation coefficient

rising doses of diesel oil in the content of macronutrients has also been investigated by WYSZKOWSKI and WYSZKOWSKA (2005), who concluded that diesel oil stimulated the accumulation of sodium, potassium and calcium in aerial parts of maize. The results of the present study confirm this dependence only for calcium and sodium in soil contaminated with the lower doses of heating oil.

The soil amending substances applied to soil not contaminated with heating oil had little effect on the content of phosphorus in maize (Tables 1-2). Their reducing effect was observed in the treatments enriched with calcium oxide, zeolite and compost. The lowest concentrations of phosphorus in maize were found in the treatment with calcium oxide. Most of the soil-amending substances also depressed the content of potassium in maize. The only substances which caused an increase in the content of potassium were ben-

tonite and calcium oxide. Compared with the objects without soil amending substances, the content of sodium in maize rose by a few to less than twenty per cent following the application of nitrogen, zeolite or calcium oxide, but was four-fold higher when the soil had been enriched with bentonite. In maize grown on soil not polluted with heating oil, all the alleviating substances stimulated an increase in the content of calcium and magnesium. The most effective proved to be calcium oxide, which contributed to a double rise in the content of calcium and a 25% increase in content of magnesium.

All the soil-amending substances were shown to have a negative effect on the content of phosphorus in maize grown on soil contaminated with heating oil (Figure 1), whose content fell by 33% in the objects with nitrogen, 17% in the treatments with bentonite and calcium oxide, and 16% when compost or zeolite had been added, all compared to the objects with no soil alleviating substances. All the substances except nitrogen (-17%) caused an increase in the content of potassium in maize. Its highest rise was observed in the objects with compost (+21%) compared to the non-amending objects. The other soil amending substances caused a non-significant increase in potassium (less than 10%). Bentonite was the only substance which caused an increase (double) in the content of sodium in maize. Compost, zeolite and calcium oxide contributed to an increase in the content of calcium (7, 14 and 12%, respectively) and a decrease in the content of these element in maize (-40%) versus the objects without soil amending substances. The substances which had a beneficial effect on the content of magnesium in maize were nitrogen (+25%), zeolite (+19%) and calcium oxide (+10% versus the objects without alleviating substances).

Filipek-Mazur and Gondek (2006) observed a stimulating effect of mineral fertilizers on the content of potassium, as well as organic fertilizers on the content of phosphorus in oat straw. The negative effect of nitrogen on the content of phosphorus and potassium in crops was recorded by Wyszkowski and Wyszkowska (2005). These authors confirmed the stimulating effect of nitrogen on the accumulation of calcium and magnesium in aerial parts of plants. The present results show an increase in the content of magnesium in maize caused by nitrogen, zeolite and CaO. Rabikowska (1999) found more phosphorus and potassium in maize fertilized with farmyard manure than in the control plants. She also reported that nitrogen fertilization had no effect on the content of potassium in plants. These observations have been verified in the present study in the objects with compost. The effect of FYM fertilization on the content of macronutrients decreased in the following order: P > K > N > Ca > Mg, while that of nitrogen was as follows: N > Ca > Mg > K > P (Rabikowska 1999). Wyszkowski and Ziółkowska (2009) observed a stimulating influence of bentonite (7-, 9- and 11-fold increase) on the content of sodium and noticed a positive effect of calcium oxide on the content of calcium in plants, as well as a negative effect of both substances on the content of magnesium (Wyszkowski, Ziółkowska 2009), observations which

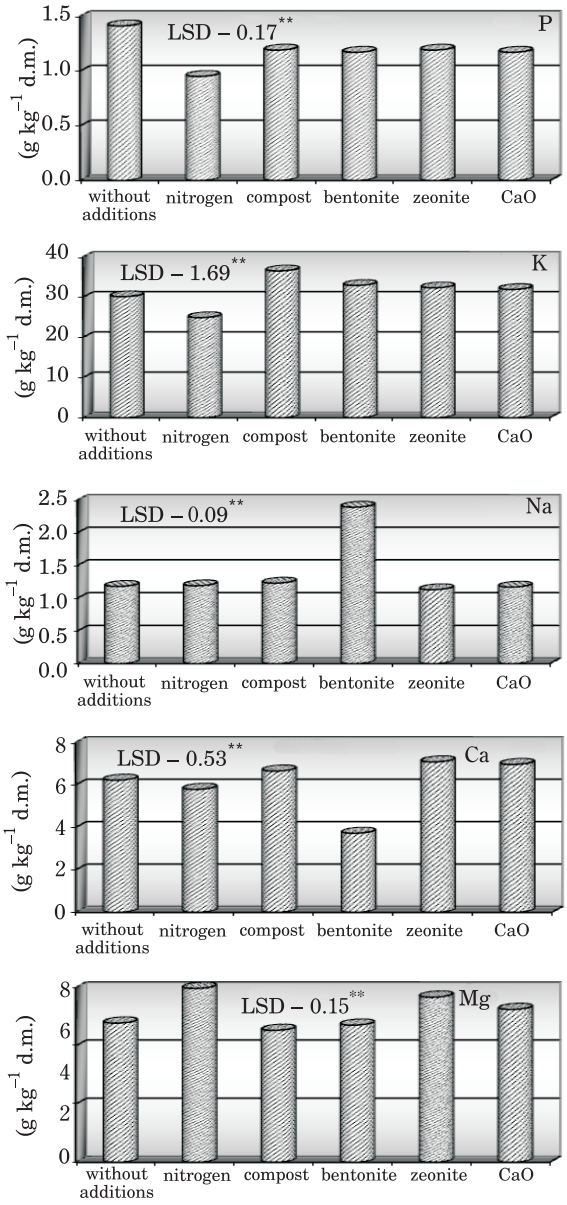

Fig. 1. Content of macroelements in maize *Zea mays* L. (average from objects contaminated with 5-20 g heating oil per kg of soil)

have been partly confirmed by the present research. According to WYSZKOWSKI and RADZIEMSKA (2009), among all the tested neutralizing substances, calcium oxide had the strongest effect on the content of macronutrients, mainly calcium and sodium, in plants. CIEĆKO et al. (2004, 2005) observed a stimulating influence of compost, lime and bentonite on the content of magnesium (CIEĆKO et al. 2005), and reverse effect on the content of potassium (CIEĆKO et al. 2004) in the majority of the parts of the examined plants. In another study conducted by WYSZKOWSKI (2007), application of CaO depressed concentrations of macronutrients (except calcium) in aerial parts of plants, including the content of magnesium, which was most strongly reduced.

CONCLUSIONS

1. The effect of heating oil and alleviating substances on concentrations of the analyzed macronutrients in maize was varied.

2. The content of phosphorus in maize was positively correlated to incremental doses of heating oil; the accumulation of sodium, calcium and magnesium in maize assumed a parabolic function while changes in the content of potassium were irregular.

3. All the substances applied to soil had a limiting effect on the content of phosphorus but stimulated (except nitrogen) the accumulation of potassium in maize grown on soil contaminated with heating oil.

4. Out of the tested soil-amending substances, bentonite was the most stimulating one with respect to sodium and the most limiting to calcium in maize.

5. Zeolite and calcium oxide showed a stimulating effect and increased the content of calcium and magnesium in maize. Compost had a similar effect on the content of calcium, whereas nitrogen stimulated the accumulation of magnesium in maize.

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