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THE EFFECT OF HARD COAL ASHES ON THE QUALITY OF MAIZE YIELD. PART 2. MICROELEMENTS

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Abstract

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Studies on the effect of ashes on maize were conducted as a pot experiment on mineral soil, to which between 13.33 and 800.0 g ash·pot^{-1} was added, corresponding to the doses of between 10 and 600 t·ha^{-1}. The research aimed to learn the effect of diversified ash doses on the content, uptake and proportions between Fe, Co, Mn, Al and Si in maize. It was found that with increasing ash dose in soil were significantly increasing the concentration of Fe and Si in plants (Fe: 110.15–209.96 mg.kg^{-1} d.m.; Si: 40.60–76.10 mg.kg^{-1}), whereas concentrations of Co, Mn and Al in maize were decreasing (Co: 0.30–0.11 mg.kg^{-1} d.m.; Mn: 207.83–44.65 mg.kg^{-1}; Al: 300.09–179.80 mg.kg^{-1} d.m). Higher contents of the studied elements were detected in maize roots than in its aboveground parts. Obtained yield of maize aboveground parts from the objects where solely ash was used as the substratum was characterized by the optimal content of Fe (104.61 mg.kg^{-1} d.m.), but deficient concentration of Mn (29.69 mg.kg^{-1} d.m.) and Co (0.01 mg.kg^{-1} d.m.). In effect of growing ash doses in soil Fe:Co, Fe:Mn, Fe:Al and Mn:Co ratios were widening, whereas Fe:Si, Mn:Al, Mn:Si and Al:Si ratios were narrowing. Growing ash doses in soil influenced a decreased uptake of Co, Mn and Al and increased Si absorption by maize.

maize, Fe, Co, Mn, Al, Si, content, uptake, ash, mineral soil

Stored furnace wastes originating from hard coal burning may be arduous for the environment because of dusting. In order to diminish this hazard a biological reclamation of landfill sites is recommended GILEWSKA (2004), PACEWICZ et al. (2006). However, physicochemical properties of furnace ashes make impossible self-induced growth and development of crops ROGALSKI et al. (2001). One of the methods of diminishing the amount of deposited furnace wastes is their application for fertilization or reclamation of postindustrial areas SIUTA (1998), STRĄCZYŃSKA and STRĄCZYŃSKI (2004). It generally considered that furnace ashes of hard coal constitute a valuable recycled raw material, which may be also used in agriculture to improve the quality of soil and crop yield BOGACZ (1996), GREGORCZYK (2001). The advantage of furnace ash is its considerable content of calcium and microelements indispensable for plants, the disadvantages are sometimes excessive concentrations of chromium, nickel, lead and cobalt which may be toxic for plants CZERNIAK (2004), FERDYN and STRZYSZCZ (2002), FERRAIOLO et al. (1990). Furnace wastes contain amounts of calcium, aluminium, iron and boron, which are excessive for plant needs HERMAN (1996), MACIAK (1976), so the problem of harmful effect on plants of chemical elements present in ashes in readily soluble forms should be explained. Therefore the aim of the research was an assessment of Fe, Co, Mn, Al and Si in maize cultivated in soil with furnace ash supplement.

MATERIAL AND METHODS

Studies on ash influence on the uptake of Fe, Co, Mn, Al and Si by maize were conducted in 2003–2005 as a pot experiment on mineral soil with light loamy sand texture and furnace ash (Tab. I). The soil contained 71% sand, 6% coarse silt, 10% fine silt, 6% coarse silt clay, 4% fine silt clay and 3% colloidal clay SYSTEMATYKA (1989). The soil reaction was acid, whereas ash reaction was strongly alkaline, seldom encountered in arable soils.

I: *Physicochemical characteristics of soil and ash used for the experiment*

Parametr	Unit	Soil	Ash
$pH_{(KCl)}$	pH	4.66	9.85
$pH_{(H2O)}$	pH	5.67	10.06
Texture		lls*	ssls**
Fe		4392.5	39950.0
Co		2.5	16.3
Mn	$mg \cdot kg^{-1}$ d.m.	250.0	857.5
Al.		4195.0	13775.0
Si		421.5	884.75

* lls – light loamy sand, ** ssls – sandy silty loam silt

The furnace ash used for the experiment originated from hard coal burning. Total concentrations of iron, cobalt, manganese, aluminium and silicon in ash exceeded their concentrations in mineral soil. The experiment was conducted in four replications, in polyethylene pots, 4kg in volume, filled with mineral soil and increasing doses of furnace ash between 13.33 and 800.0 $g{\cdot}pot^{-1}$. Ash doses corresponded to between 10 and 600 $t{\cdot}ha^{-1}$. The experimental design included also the control with solely mineral soil and the object where only furnace ash was used (Tab. II). The same, permanent NPK fertilization regime was applied every year in all pots: 0.3 g N, 0.08 g P and 0.2 g $K{\cdot}kg^{-1}$ soil d.m. as NH_4NO_3, KH_2PO_4 and KCl. Mineral fertilizers, in the form of solutions, were applied every year two weeks before plant sowing and thoroughly mixed with the substratum. Maize, Kosmo 230 c.v. vegetation period in 2003–2005 was respectively: 91, 99 and 92 days. During vegetation the plants were watered with redistilled water and soil moisture was maintained at 60% of the maximum water capacity. The aboveground parts and roots of maize were harvested every year from each pot (replication) and after drying in a dryer at 75 °C the dry mass was assessed and expressed in g d.m. per pot^{-1}. A sample of 5 g d.m. of plant material was collected from each pot for chemical analyses and after its dry mineralization Fe, Co, Mn, Al and Si concentrations were assessed in the plant material from each replication with AES method. Statistical computations were conducted using Microsoft Excel 7.0 calculation sheet. The paper presents weighed average contents of the above mentioned elements for three years of the research. The significance of differences between the compared mean concentrations of elements were determined with Duncan method. The analysis of variance and Duncan test were conducted on the significance level $\alpha = 0.01$ ULIŃSKA (1957). Variability coefficients of the analyzed element concentrations in the plant yields were computed. The paper presents also the ratios between the analyzed components in plant. Fe:Co, Fe:Mn, Fe:Al, Fe:Si, Mn:Co, Mn:Al, Mn:Si and Al:Si ratios were calculated gravimetrically.

RESULTS

Element concentrations. The results of research were presented as weighed average contents of Fe, Co, Mn, Al and Si in the aboveground parts, roots and in the whole plant for the 3-year period of the experiment (2003–2005). Concentrations of selected elements in maize were diversified and depending on the object and plant part ranged between 60.37 and 1978.7 mg Fe; 0.01–1.00 mg Co; 29.69–275.54 mg Mn; 32.38–1436.6 mg Al; 36.24–106.88 mg $Si{\cdot}kg^{-1}$ d.m. (Tab. II, III). Among the studied elements cobalt concentrations were the most diversified in the aboveground parts (V = 80.03%) and aluminium the least (V = 14.24%), whereas in roots the highest differentiation was registered for iron (V = 79.89%) and the lowest for silicon (V = 20.94%).

A systematic increase in the contents of silicon and iron in maize aerial parts and roots was noticed in effect of growing ash doses. A supplement of 13.33 g $ash{\cdot}pot^{-1}$ to the soil, corresponding to 10 $t{\cdot}ha^{-1}$, significantly affected elevated silicon concentrations in maize aboveground parts, whereas a marked increase in iron concentration was detected at the dose of 50 t ash per ha. In roots a significant increase in silicon content was noted at the dose of 100 t ash per ha and iron at 200 t ash per ha. At the highest ash addition to the soil, i.e. 600 $t.ha^{-1}$ the increases in silicon and iron concentrations in maize aerial parts were respectively: 94.33% and 46.25% in comparison with the control. In roots the increases in the above mentioned element concentrations were respectively: 65.32% and 113.50% in relation to the control. Maize cultivated only on ash (object IX) revealed the highest content of silicon and iron. Growth in silicon and iron concentrations in the aboveground parts, as compared with the control was respectively: 108.59% and 73.28%. In roots the increase in silicon concentrations was 77.37%, while iron content was almost five times higher (491.67%) as compared with the control.

II: *Content and uptake of Fe, Co, Mn by maize*

No Treatment	Ash doses		Fe						
	g/pot	t/ha	Content [mg · kg⁻¹ d.m.]			TI****	Uptake [mg · pot⁻¹]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0.00	0	60.37	334.43	110.15	0.18	5.40	6.64	12.04
II	13.33	10	64.22	361.53	124.41	0.18	6.23	8.90	15.13
III	26.67	20	68.71	393.93	131.48	0.17	6.33	8.68	15.01
IV	66.67	50	77.10	417.04	138.02	0.18	5.90	6.97	12.87
V	133.33	100	78.07	449.15	145.56	0.17	5.72	7.34	13.05
VI	266.67	200	79.22	542.53	163.00	0.15	5.49	8.28	13.77
VII	533.33	400	83.38	621.24	178.42	0.13	5.45	8.71	14.16
VIII	800.00	600	88.30	713.99	209.96	0.12	4.79	9.35	14.14
IX	4000.00	Ash	104.61	1978.70	592.02	0.05	2.76	18.32	21.08
LSD-NRI $_{(\alpha=0,01)}$			8.86	140.45	30.04	-	0.65	2.32	2.55
V%*****			17.10	79.80	75.48	28.39	20.09	38.17	18.05
No Treatment	Ash doses		Co						
	g/pot	t/ha	Content [mg · kg⁻¹ d.m.]			TI****	Uptake [mg · pot⁻¹]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0.00	0	0.15	1.00	0.30	0.15	0.013	0.020	0.033
II	13.33	10	0.12	0.91	0.28	0.13	0.012	0.022	0.034
III	26.67	20	0.07	0.86	0.23	0.09	0.007	0.019	0.026
IV	66.67	50	0.06	0.70	0.17	0.08	0.004	0.012	0.016
V	133.33	100	0.04	0.58	0.14	0.07	0.003	0.009	0.013
VI	266.67	200	0.04	0.56	0.13	0.07	0.003	0.009	0.011
VII	533.33	400	0.03	0.51	0.11	0.05	0.002	0.007	0.009
VIII	800.00	600	0.02	0.47	0.11	0.04	0.001	0.006	0.007
IX	4000.00	Ash	0.01	0.27	0.08	0.04	0.0003	0.002	0.0023
LSD-NRI $_{(\alpha=0,01)}$			0.01	0.10	0.02	-	0.001	0.002	0.003
V%			80.03	36.17	46.55	49.10	94.47	58.31	68.03
No Treatment	Ash doses		Mn						
	g/pot	t/ha	Content [mg · kg⁻¹ d.m.]			TI****	Uptake [mg · pot⁻¹]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0.00	0	192.83	275.54	207.83	0.70	17.23	5.47	22.70
II	13.33	10	177.38	253.42	192.78	0.70	17.20	6.24	23.44
III	26.67	20	149.06	211.86	161.19	0.70	13.73	4.67	18.40
IV	66.67	50	103.21	169.16	115.02	0.61	7.91	2.83	10.74
V	133.33	100	68.98	139.00	81.78	0.50	5.05	2.27	7.32
VI	266.67	200	65.62	111.55	73.94	0.59	4.55	1.70	6.25
VII	533.33	400	59.99	103.68	67.72	0.58	3.92	1.45	5.38
VIII	800.00	600	36.81	77.19	44.65	0.48	2.00	1.01	3.00
IX	4000.00	Ash	29.69	54.22	36.12	0.55	0.78	0.50	1.29
LSD-NRI $_{(\alpha=0,01)}$			13.17	26.26	13.53	-	0.97	0.64	1.35
V%			62.04	50.28	58.63	14.44	79.63	71.08	77.27

*Aboveground parts; **Roots; ***Weighed average; ****(TI) – Translocation index; *****Variability coefficient.

III: *Content and uptake of Al and Si by maize*

No Treatment	Ash doses		Al						
	g/pot	t/ha	Content [mg · kg^{-1} d.m.]			TI****	Uptake [mg · pot^{-1}]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0.00	0	47.89	1436.64	300.09	0.03	4.29	28.50	32.79
II	13.33	10	43.99	1339.22	306.23	0.03	4.27	32.98	37.25
III	26.67	20	40.87	1244.14	273.17	0.03	3.77	27.42	31.19
IV	66.67	50	39.16	1090.59	227.48	0.04	3.00	18.25	21.24
V	133.33	100	38.02	1016.94	216.76	0.04	2.79	16.62	19.40
VI	266.67	200	34.86	987.61	207.20	0.04	2.41	15.09	17.50
VII	533.33	400	33.06	888.28	183.81	0.04	2.16	12.44	14.60
VIII	800.00	600	32.56	790.18	179.80	0.04	1.77	10.35	12.12
IX	4000.00	Ash	32.38	456.33	142.66	0.07	0.85	4.22	5.08
LSD-NRI $_{(\alpha=0,01)}$			3.10	179.43	41.24	-	0.40	4.30	4.38
V%*****			14.34	29.17	24.92	30.34	41.23	51.17	49.78
No Treatment	**Ash doses**		**Si**						
	g/pot	t/ha	Content [mg · kg^{-1} d.m.]			TI****	Uptake [mg · pot^{-1}]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0.00	0	36.24	60.26	40.60	0.60	3.24	1.20	4.44
II	13.33	10	42.75	62.99	46.85	0.68	4.15	1.55	5.70
III	26.67	20	47.94	65.48	51.34	0.73	4.41	1.45	5.86
IV	66.67	50	52.63	69.41	55.62	0.76	4.03	1.16	5.18
V	133.33	100	57.88	76.45	61.22	0.76	4.24	1.25	5.49
VI	266.67	200	62.18	82.14	65.78	0.76	4.30	1.25	5.56
VII	533.33	400	64.83	88.64	69.04	0.73	4.24	1.24	5.48
VIII	800.00	600	70.43	99.62	76.10	0.71	3.82	1.30	5.12
IX	4000.00	Ash	75.60	106.88	83.74	0.71	1.99	0.99	2.98
LSD-NRI $_{(\alpha=0,01)}$			6.11	11.83	6.22	-	0.51	0.25	0.63
V%			22.90	20.94	22.92	7.05	20.20	12.83	17.56

*Notes see table II

IV: *Weight relations between elements*

No Treatment	Ash doses		Fe : Co	Fe : Mn	Fe : Al	Fe : Si	Mn : Co	Mn : Al	Mn : Si	Al : Si
	g/pot	t/ha								
I	0.00	0	404.48	0.31	1.26	1.67	1291.92	4.03	5.32	1.32
II	13.33	10	530.15	0.36	1.46	1.50	1464.43	4.03	4.15	1.03
III	26.67	20	931.23	0.46	1.68	1.43	2020.29	3.65	3.11	0.85
IV	66.67	50	1353.01	0.75	1.97	1.46	1811.17	2.64	1.96	0.74
V	133.33	100	1873.29	1.13	2.05	1.35	1655.29	1.81	1.19	0.66
VI	266.67	200	2088.29	1.21	2.27	1.27	1729.82	1.88	1.06	0.56
VII	533.33	400	3202.02	1.39	2.52	1.29	2303.90	1.81	0.93	0.51
VIII	800.00	600	4960.62	2.40	2.71	1.25	2067.97	1.13	0.52	0.46
IX	4000.00	Ash	9998.40	3.52	3.23	1.38	2837.31	0.92	0.39	0.43
Variability coefficient V%			108.37	83.03	29.53	9.42	24.43	49.65	84.20	40.53

Unlike iron and silicon, the contents of cobalt, manganese and aluminium in maize were decreasing under the influence of ash applied to the soil. Ash supplement of 13.33 g·pot^{-1}, corresponding to 10 t·ha^{-1} significantly affected a decline in Co, Mn, and Al concentrations in maize aerial parts and roots. Decreases in Co, Mn and Al contents in maize aboveground parts observed at the highest ash dose in soil (object VIII, 600 t·ha^{-1} were respectively: 80.91% and 32.02% in relation to the control. Furnace ash used without soil had the greatest influence on diminishing the contents of the above mentioned elements in maize. Decreases in the contents of Co, Mn and Al in maize aboveground parts were respectively: 92.99%, 84.60% and 32.39%, and for roots 73.12%, 80.32%, 68.24% in comparison with the control.

Translocation index (TI). Translocation of the studied elements in plant was determined using translocation index (TI), which was expressed as the ratio of Fe, Co, Mn, Al and Si concentrations in the aboveground parts to their contents in roots. Translocation index for the studied elements did not exceed one (Tab. II, III). The index analysis shows that maize roots, irrespective of the object, absorbed greater amounts of the studied elements in comparison with the aboveground parts. The highest value of the translocation index for Fe, Co and Mn was obtained on the control, whereas for aluminium in the object where only ash was applied. Growing ash doses in soil affected a systematic increase in translocation index value for Si and Al, which evidences a faster translocation of these elements from roots to maize aboveground parts. On the object where solely ash was applied (object IX) value of translocation index of selected elements in maize formed a following order: Co (0.04) < Fe (0.05) < Al(0.07) < Mn (0.55) < Si (0.71). Analysis of element translocation value in maize cultivated on ash shows that the roots of the tested plant absorbed the greatest quantities of cobalt, iron and aluminium in comparison with the aboveground parts.

Assessment of contents. Optimal contents of Fe, Mn and Co in plants destined for fodder should be respectively: 40–250 mg Fe; 40–60 mg Mn; 0.3–1.0 mg Co·kg^{-1}d.m. FALKOWSKI et al. (2000), GORLACH (1991), PREŚ and KINAL (1996). An assessment of maize aboveground parts according to the assumed standards revealed that iron concentrations in maize cultivated in soil with increasing doses of furnace ash were on the optimal level. Maize aboveground parts obtained on the control and objects where low ash doses were applied (10–50 t·ha^{-1}) contained manganese quantities exceeding fodder plant requirements. Higher doses of furnace ash apparently limited Mn uptake by maize and therefore influenced the optimal concentration of manganese in maize aerial parts. BERGMANN (1966) distinguished 3 classes of cobalt content in fodder plants: unsatisfactory cobalt concentration – below 0.07 mg; medium abundant content between 0.07 and 0.12 mg and satisfactory content over 0.12 mg·kg^{-1} d.m. If we compare the obtained results with German norms used for the assessment of plant fodder value BERGMANN (1966), maize aboveground parts obtained on the control and on the object where 10 t of ash per ha was applied revealed Co content on the sufficient level. Higher does of ash in soil caused cobalt deficiency in maize aboveground parts. The assessment of plant abundance in silicon considers some amount of silicon which animals may accumulate in the form of kidney stones, therefore attempts were made to establish the limit of safe silicon concentrations in fodder and the value of 0.9% in d.m. was considered as permissible FALKOWSKI et al. (2000). Maize obtained in the experiment contained chromium quantities below the permissible value. Estimating the yield of maize aboveground parts from the objects where solely ash was applied as a substratum, it was found that it revealed optimal Fe concentrations but deficient Mn and Co content.

Proportions of elements. Beside element contents, the wok presented also proportions between the studied elements, which usually are not computed (Tab. IV). The stated ratios between elements have only cognitive value. They were presented to highlight the considerable range of proportions variability. A huge variability of proportions found in the experiment points to considerable maize tolerance to ratios between elements. The computed Fe:Co, Fe:Mn, Fe:Al and Mn:Co weight ratios were widening. The highest values of these ratios were obtained on the object where only furnace ash was applied. Opposite relationships were obtained for Fe:Si, Mn:Al, Mn:Si and Al:Si ratios. The widest ratio of the above mentioned proportions was characteristic for maize aboveground parts obtained on the control. Fe:Si, Mn:Al, Mn:Si and Al:Si ratios were narrowing systematically with increasing ash supplement in soil. Usually only selected proportions between elements are presented in literature, considering nutritional needs of animals. Optimal Fe to Mn ratio is 1.5–2.5:1 FALKOWSKI et al. (2000). According to KABATA-PENDIAS and PENDIAS (1999) at the value of this ratio below 1.5 symptoms of manganese toxicity and iron deficiency would appear, whereas when Fe to Mn ratio exceeds 2.5, manganese deficiency and excessive concentrations of iron are registered in plant. The conducted research shows that only ash dose of 400–600 t·ha^{-1} led the optimal content of this ratio in maize aboveground parts (Tab. IV). The value of Fe:Mn ratio in maize cultivated on the control and on objects with between 10 and 200 t·ha^{-1} ash supplement to the soil testifies a definite excess of Mn and Fe deficiency. Presented experiments show that proportions between elements in maize aboveground parts were clearly modified by ash fertilization.

Element uptake. Nutrient uptake by plants is a resultant of plant yield and their element concentrations. The quantity of tested elements absorbed by maize, depending on the object and plant part, ranged between 12.04–21.08 mg Fe; 0.0023–0.034 mg Co; 1.29–23.44 mg Mn; 5.08–37.25 mg Al and 2.98–5.86 mg Si·pot^{-1} (Tab. II, III). A supplement of 10–20 t·ha^{-1} to the soil caused a significant raise in Fe uptake by maize aboveground parts, whereas in roots a notable increase in this element uptake was registered only at the dose of 600 t·ha^{-1}. A marked increase of silicon uptake by maize aboveground parts was noted under the influence of growing ash doses. Unlike iron and silicon, increasing doses of ash in soil significantly affected a decrease in the uptake of cobalt, manganese and aluminium by maize aboveground parts and roots. A decrease in the uptake of the above mentioned elements was mainly connected with a decline in yield and decreasing content of these elements in maize. Furnace ash used separately in the presented experiment (object IX) significantly decreased the uptake of Fe, Co, Mn, Al and Si by maize aboveground parts. The decrease in the uptake of the above mentioned elements by maize aboveground parts on the object where only ash was applied was respectively: 48.86%; 97.91%; 95.46%, 80.08% and 38.63% in relation to the control. Furnace ash also affected greater uptake of Fe in comparison with the control. The highest summary Fe uptake by maize (both the aboveground parts and roots) was found on the object where only ash was applied, whereas Si uptake at the dose of 20 t ash per 1 ha. Presented experiment revealed that maize aboveground parts have a greater share in Mn and Si uptake, whereas roots in Fe, Co and Al uptake.

DISCUSSION

Beside magnesium and calcium a number of macro- and microelements crucial for the plant life occur in furnace wastes HERMAN (1996), MACIAK et al. (1976), MELLER et al. (2001). Negative opinions about ashes as fertilizer materials are motivated by accumulation of excessive quantities of silica, aluminium and iron oxides, and trace elements KWIATKOWSKA et al. (2006); SMOŁKA-DANIELOWSKA (1999). Present paper examines the effect of furnace ashes originating from hard coal burning on the content and uptake of Fe, Co, Mn, Al and Si by maize. A significant effect of increasing ash doses in soil on elevated content of Fe and Si was revealed but a decrease in Co, Mn and Al concentrations in maize aboveground parts and roots. In the opinion of some authors too large mass of ash supplied to the soil may lead to alkalinization of the environment and disturb its chemical balance KABATA-PENDIAS et al. (1987). The studies of KABATA-PENDIAS (1987) demonstrated a decrease in Fe and Mn content in plants under the influence of increasing doses of ash in soil. On the other hand, in their own studies the Authors found that furnace ashes influenced increase in Fe but a decrease in Mn concentrations in maize. The cause of greater absorption of Fe by maize may be among others high, over nine times higher content of Fe in the applied ash than in the mineral soil. Moreover, ashes originating from hard coal burning are composed mainly of silica, aluminium or iron SMOŁKA-DANIELOWSKA (1999). A decrease in Co content in maize in effect of increasing ash supplements in soil was caused mainly by an increase in the soil reaction because ash used for the experiment revealed alkaline reaction (Tab. I). It is a fact known from the literature that ashes are alkaline and after application to the soil have an de-acidifying effect GILEWSKA (2004), MELLER et al. (1999), KABATA-PENDIAS et al. (1987), KOTER et al. (1984). Acid environment increases cobalt solubility and at the same time its availability to plants. On the other hand in neutral and alkaline soils cobalt undergoes a strong sorption and passes into a sparingly soluble form CURYŁO (1981), GREINERT (1972). Research conducted by KANIUCZAK (2004) also shows that cobalt is better available to plants from acidified than limed soil and that roots contain greater amounts of this element than plant aboveground parts.

Presented work registered a systematic increase in Si concentrations but a decrease in Mn and Al contents in plants under the influence of growing ash doses in soil. Numerous investigations demonstrated that furnace ashes are a potential source of silica for plants MELLER et al. (2006). Research of PANOV et al. (1982) revealed that soil fertilization of appropriate forms of silicon reduces toxic effect of mobile silicon in soils. It results from the fact that active silica raises soil pH and monosilic acid is adsorbed by aluminium hydroxides, which weakens aluminium mobility and at the same time raises plant tolerance to aluminium presence. Moreover monosilic acid binds heavy metals and microelements forming sparingly soluble silicates, therefore diminishing their mobility and bioavailability to plants KACZOREK and SOMMER (2004), LINDSAY (1979). Higher amounts of Fe, Co, Mn, Al and Si were found in the presented work in roots than in maize aboveground parts. Greater contents of Fe, Mn and Al in cultivated plants were also detected by BADORA (1999). Research conducted by KABATA-PENDIAS et al. (1987) revealed that under the influence of soil fertilization with ash, manganese concentrations in plants decreased. Optimal content of Fe but deficiency of Mn and Co were registered in the Author's own investigations. On the other hand, field experiments carried out by MELLER et al. (2001) revealed that none of the crops (spring barley, rye or potatoes) cultivated in soil fertilized with ashes accumulated among others Fe and Mn in quantities exceeding their permissible contents in fodders. The results obtained by the above mentioned author were confirmed by the Author's own investigations.

CONCLUSIONS

An increase in Fe, Si but a decrease in Co, Mn and Al concentrations in maize aboveground parts and roots were registered with increasing ash dose in soil.

Maize roots absorbed greater quantities of studied elements than its aboveground parts.

Under the influence of growing ash supplements to the soil, Fe:Co, Fe:Mn, Fe:Al and Mn:Co ratios were widening, whereas Fe;Si, Mn:Al, Mn:Si and Al:Si ratios were narrowing.

Increasing ash doses in soil caused systematic increase in Fe and Si uptake but a decrease in Co, Mn and Al uptake by maize aboveground parts and roots. On the other hand furnace ash applied separately significantly decreased Fe, Co, Mn, Al and Si uptake by maize aboveground parts in comparison with the control.

Maize aboveground parts had greater share in Mn and Si uptake, whereas roots in Fe, Co and Al absorption.

SOUHRN

Vliv uhelných popelů na kvalitu kukuřice. Část 2. Mikroelementy.

V nádobovém experimentu se zeminou byly aplikovány dávky popela mezi 13,33 až 800 g na nádobu, což odpovídá množství 10 až 600 $t.ha^{-1}$. Cílem výzkumu bylo sledování vlivu různých dávek popela na obsah, odběr a vzájemné poměry mezi Fe, Co, Mn, Al a Si u rostlin kukuřice. Bylo zjištěno, že s narůstající dávkou popela do půdy se v kukuřici signifikantně zvyšoval obsah Fe (110,15–209,96 $mg.kg^{-1}$ sušiny) a Si (40,60–76,10 $mg.kg^{-1}$ sušiny), zatímco obsah Co (0,30–0,11 $mg.kg^{-1}$ sušiny), Mn (207,83–44,65 $mg.kg^{-1}$ sušiny) a Al (300,09–179,80 $mg.kg^{-1}$ sušiny) klesal. Vyšší zastoupení sledovaných elementů bylo zjištěno v kořenech oproti nadzemní biomase. U varianty, kde byl substrátem v nádobě výhradně popel, byl zjištěn v nadzemní hmotě rostlin optimální obsah Fe (104,61 $mg.kg^{-1}$ sušiny), ale deficitní obsah Mn (29,69 $mg.kg^{-1}$ sušiny) a Co (0,01 $mg.kg^{-1}$ sušiny). U variant s narůstajícími dávkami popela v zemině se rozšiřovaly poměry Fe:Co, Fe:Mn, Fe:Al a Mn:Co v rostlinách kukuřice, zatímco poměry Fe:Si, Mn:Al, Mn:Si a Al:Si se zužovaly. Zvyšující se dávky popela v zemině redukovaly odběr Co, Mn a Al a stimulovaly příjem Si kukuřicí.

kukuřice, Fe, Co, Mn, Al, Si, obsah, odběr, popel, zemina

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