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The effect of hard coal ashes on the amount and quality of maize yield

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The research was conducted in 2003 – 2005 as a pot experiment on mineral soil to which ash doses of between 13.33 g and 800.0 g · pot^{-1} were supplied in proportions corresponding to the amounts of between 10 and 600 t · ha^{-1}. The investigations aimed at learning the effect of diversified ash doses upon the content, ionic relations and the uptake of Mg, Ca, Na and P by maize. Macroelement concentrations in maize were diversified depending on the object and the plant part, fluctuating from 1.52 – 7.49 g Mg; 3.79 – 11.01 g Ca; 8.07 – 23.86 g K; 0.17 – 1.52 g Na; 1.23 – 3.16 g P · kg^{-1} d.m. It was found that with the growing ash dose the contents of Mg, Ca, K and Na in maize were increasing systematically, whereas P concentrations were decreasing. Magnesium and potassium content in maize aboveground parts met the requirements for a good quality fodder. The level of calcium, sodium and phosphorus in maize did not remain within the optimal range. A systematic increase in Mg uptake but a decline in P absorption by the aboveground parts were registered in maize in effect of growing ash doses.

Keywords: maize, Mg, Ca, K, Na, ratios, uptake, ash, mineral soil.

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INTRODUCTION

Ashes, slag-ashes and furnace wastes used for environmental management must be safe materials, previously analysed for potential hazard they may pose to the environment. This applies primarily to the ashes supplied to arable soils as fertilizers [Kiryluk 2004; Bender, Gilewska 2004; Kuczyńska 2005]. The use of ashes from hard coal burning as mineral fertilizers has been presented in the scientific literature by many authors [Bogacz et al 1995; Ciećko, Nowak 1984; Kabata-Pendias et al 1987]. On the other hand, the relationships between the applied ash dose and the changes in plant chemical composition have been less recognized.

Ash is a heterogenous material, whose chemical composition and properties depend on the quality of burnt coal and the method of its storage. For these reasons also its environmental applications in arable soils require determining the chemical composition of ashes from individual portions of coals used for burning [Bender, Gilewska 2004; Bogacz et al 1995; Gilewska 2004]. High alkalinity of ash rock is conditioned by the presence of alkaline metals – calcium, potassium, magnesium and sodium. They occur mainly in very hardly and hardly soluble forms. Calcium is a dominant element and its content exceeds many times its mineral soil concentrations. The amounts of other alkaline elements are also significant and exceed the quantities encountered in mineral soils [Gilewska 2004, Wojcieszczuk et al 2001].

High amounts of ashes in the soil do not constitute a good environment for plant development. The development of vegetal cover may be made difficult by irregular arrangement of elements, especially in alkaline soils and water deficiency. Therefore, the investigations aimed to learn the effect of growing doses of furnace ashes on the content, ionic relations and uptake of Mg, Ca, K, Na and P by maize.

MATERIALS AND METHODS

Studies on ash effect on the yield and macroelement uptake by maize were conducted in 2003 – 2005 as a pot experiment. Mineral soil with a texture of light loamy sand and furnace ash was used for the experiment (Tab. 1). It contained 71% sand, 6% coarse ash, 10% fine ash, 6% coarse silty clay, 4% fine silty clay and 3% colloidal clay [Systematyka 1989]. The soil revealed acid reaction, while the ash was strongly alkaline, rarely encountered in arable soils.

The furnace ash used for the experiment originated from hard coal burning. High alkalinity of ashes is conditioned by the presence of alkaline metals – calcium, sodium, potassium and magnesium. The total content of alkaline metals in ash exceeds their concentrations in mineral soil many times. The experiment was conducted in four replications in polyethylene pots – 4 kg in volume, filled with mineral soil and increasing doses of furnace ash amounting to between 13.33 and 800.0 g · pot^{-1}. The ash doses corresponded to between 10 and 600 t · ha^{-1}. The experimental design also comprised the control object with the solely mineral soil and the object where furnace ash was used separately, without any admixtures (Tab. 2). All pots received fixed annual NPK treatment in the following doses: 0.3 g N, 0.08 g P and 0.2 g K · kg^{-1} soil d.m. as NH_4NO_3, KH_2PO_4 and KCl. The mineral

Table 1. The physico-chemical characteristics of the soil and ash used for the experiment

Parameter	Unit	Soil	Ash
$pH_{(KCl)}$	pH	4.66	9.85
$pH_{(H2O)}$	pH	5.67	10.06
Texture		lls*	ssl**
Mg	g · kg^{-1} d.m.	0.27	10.95
Ca		0.35	21.27
K		0.38	1.09
Na		0.09	0.82
P		0.45	1.95

*lls – light loamy sand, **ssl – sandy silty loam

Table 2. Content and uptake of Mg, Ca, K by maize

No treatment	Ash doses		Mg						
	g/pot	t/ha	Content [g · kg^{-1} d.m.]			TI****	Uptake [g · pot^{-1}]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0,00	0	1,52	1,58	1,53	0,96	0,136	0,031	0,167
II	13,33	10	2,15	2,50	2,22	0,86	0,209	0,062	0,270
III	26,67	20	2,77	3,10	2,84	0,89	0,255	0,068	0,324
IV	66,67	50	3,22	3,41	3,25	0,94	0,246	0,057	0,303
V	133,33	100	3,38	3,97	3,49	0,85	0,248	0,065	0,313
VI	266,67	200	3,69	4,54	3,85	0,81	0,256	0,069	0,325
VII	533,33	400	4,14	5,26	4,34	0,79	0,271	0,074	0,345
VIII	800,00	600	4,40	6,29	4,76	0,70	0,238	0,082	0,321
IX	4000,00	Ash	4,95	7,49	5,61	0,66	0,130	0,069	0,200
LSD$_{(\alpha=0,01)}$			0,25	0,33	0,19	–	0,028	0,011	0,031
V%*****			32,55	44,16	35,82	12,25	23,85	22,18	21,64
No treatment	Ash doses		Ca						
	g/pot	t/ha	Content [g · kg^{-1} d.m.]			TI****	Uptake [g · pot^{-1}]		
			Ap*	R**	Wa***		Ap*	R**	Sum
I	0,00	0	3,79	6,64	4,31	0,57	0,339	0,132	0,471
II	13,33	10	4,13	7,29	4,77	0,57	0,401	[redacted]	[redacted]
III	26,67	20	4,36	7,50	[redacted]	[redacted]	[redacted]	[redacted]	0,567
IV	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
V	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
VI	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
VII	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
VIII	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
IX	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
No treatment	[redacted]		[redacted]						
	[redacted]	[redacted]	[redacted]			[redacted]	[redacted]		
			[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	Sum
I	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,454
II	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,623
III	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,569
IV	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,555
V	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,335
VI	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,395
VII	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,431
VIII	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,303
IX	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0,810
[redacted]			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0,159
[redacted]			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	7,09

*Abo [redacted]

fer [redacted] K:Na, ye [redacted] equiva- th [redacted] i [redacted] fo [redacted] ect [redacted] rst pa [redacted] Ca, K [redacted]

[redacted] iment [redacted] ement [redacted] in the [redacted] 003 – [redacted] versi- [redacted] nging [redacted] 23.86 g K; 0.17-1.52 g Na and 1. [redacted] (Tab. 2,3). Magnesium concentratio [redacted] parts were the most diversified (V=3 [redacted] ssium the least (V=18.40%), whereas in ro [redacted] diver- sification was also registered for magne [redacted] .16%) and the least for calcium (V=16.94%). A [redacted] tic in-

[redacted] Th [redacted] e above me [redacted] tigations. The si [redacted] the compared ave [redacted] ssessed by the Du [redacted] The ana [redacted] riance and the Duncan [redacted] performed [redacted] cance level α =0.01 [Ul [redacted] a [redacted] 7]. Variabilit [redacted] ents for the content of studied macroelements [redacted] plant yield were computed. The present work als [redacted] vides the relationships between the

Table 3. The content and uptake of Na and P by maize and rations between the elements

No treatment	Ash doses g/pot	Ash doses t/ha	Na Content [g · kg^{-1} d.m.] Ap*	R**	Wa***	TI****	Uptake [g · pot^{-1}] Ap*	R**	Sum
I	0,00	0	0,17	1,52	0,41	0,11	0,015	0,030	0,045
II	13,33	10	0,18	1,61	0,47	0,11	0,017	0,040	0,057
III	26,67	20	0,18	1,67	0,47	0,11	0,017	0,037	0,054
IV	66,67	50	0,19	1,72	0,46	0,11	0,014	0,029	0,043
V	133,33	100	0,21	2,00	0,53	0,10	0,015	0,033	0,048
VI	266,67	200	0,23	2,02	0,56	0,12	0,016	0,031	0,047
VII	533,33	400	0,26	2,12	0,59	0,12	0,017	0,030	0,047
VIII	800,00	600	0,31	2,60	0,75	0,12	0,017	0,034	0,051
IX	4000,00	Ash	0,34	3,00	1,04	0,11	0,009	0,028	0,037
$LSD_{(\alpha=0,01)}$			0,05	0,43	0,14	–	0,004	0,009	0,010
V%*****			26,85	24,28	33,37	5,09	16,87	12,18	12,40

No treatment	Ash doses g/pot	Ash doses t/ha	P Content [g · kg^{-1} d.m.] Ap*	R**	Wa***	TI****	Uptake [g · pot^{-1}] Ap*	R**	Sum
I	0,00	0	3,16	2,92	3,11	1,08	0,282	0,058	0,340
II	13,33	10	2,85	2,58	2,79	1,11	0,276	0,063	0,340
III	26,67	20	2,75	2,43	2,69	1,13	0,253	0,054	0,307
IV	66,67	50	2,72	1,82	2,56	1,50	0,208	0,030	0,238
V	133,33	100	2,52	1,71	2,37	1,47	0,184	0,028	0,212
VI	266,67	200	2,16	1,58	2,06	1,37	0,150	0,024	0,174
VII	533,33	400	1,91	1,39	1,82	1,37	0,125	0,020	0,144
VIII	800,00	600	1,89	1,31	1,78	1,44	0,102	0,017	0,120
IX	4000,00	Ash	1,61	1,23	1,51	1,31	0,043	0,011	0,054
$LSD_{(\alpha=0,01)}$			0,42	0,25	0,36	–	0,031	0,006	0,033
V%			21,87	32,39	23,42	12,39	45,90	56,84	47,25

No treatment	Ash doses g/pot	Ash doses t/ha	Ratios between elements Ca:P	Ca:Mg	K:Mg	K:Ca	K:Na	K(Ca+Mg)
I	0,00	0	1,20	1,52	2,96	1,95	51,45	1,18
II	13,33	10	1,45	1,17	2,10	1,80	48,06	0,97
III	26,67	20	1,58	0,95	1,67	1,76	48,58	0,86
IV	66,67	50	1,70	0,87	1,50	1,73	48,78	0,80
V	133,33	100	1,91	0,86	1,46	1,69	45,18	0,78
VI	266,67	200	2,38	0,84	1,47	1,75	44,19	0,80
VII	533,33	400	2,97	0,83	1,43	1,73	43,42	0,78
VIII	800,00	600	3,47	0,90	1,43	1,58	39,00	0,75
IX	4000,00	Ash	4,64	0,92	1,50	1,64	41,39	0,78
V%			47,70	22,73	29,54	6,01	8,76	15,92

*Notes see table 2

crease in magnesium, calcium, potassium and sodium contents in maize aboveground parts and roots was noted in effect of growing ash doses. In maize aboveground parts a significant increase in macroelement concentrations was detected for magnesium at the dose of 13.33 g ash · pot^{-1}, corresponding to 10 t ash per 1ha, whereas for calcium at the dose of 20 t ash per 1ha and for potassium and sodium at 200 t ash per 1 ha. In roots a marked increase in magnesium content was noted at the dose of 10 t ash per 1 ha, for calcium and potassium at 50t as per 1 ha and for sodium at 100 t ash per 1 ha. Increases in Mg, Ca, K and Na concentrations in maize aboveground parts at the highest ash dose supplied to the soil (Object VIII, 600 t · ha^{-1}) were 190%, 73%, 40% and 85% respectively, in comparison with the control. In roots the quantities of these macroelements raised in the above mentioned object respectively by: 298%, 50%, 94% and 71% in comparison with the control. Furnace ash used separately had the strongest influence on the increase in maize Mg, Ca, K and Na concentrations, which in the aboveground parts were respectively: 226%, 97%, 65% and 105%, whereas in roots: 373%, 66%, 144% and 97% in comparison with the control. Considering the studied macroelements, at the highest ash supplement to the soil (Object VIII, 600 t · ha^{-1}), the highest increase in magnesium concentrations was registered in maize aboveground parts in relation to the control and the lowest increase for potassium. In the case of phosphorus, it was found that ashes supplied to the soil affected a decline in its concentrations both in maize aboveground parts and roots. A significant decrease in phosphorus level in maize aboveground parts was noted from 50 t ash per 1 ha and in roots from 10 t · ha^{-1}. The decline in phosphorus content in maize aboveground parts and roots at the highest ash dose in soil (Object VIII, 600 t · ha^{-1}) reached 40% and 55% respectively in relation to the control. Furnace ash used separately influenced a decline in phosphorus content in maize the most. The decrease in phosphorus concentrations in the aboveground parts was almost 50% and in roots 58% in comparison with the control.

Translocation index (TI). In the presented studies higher concentrations of magnesium, calcium and sodium were found in maize roots whereas phosphorus and potassium in the aboveground parts. The mobility of the analysed macroelements in the plant was determined using the translocation index (TI), which expresses the ratio of macroelement concentration in the aboveground parts to its content in roots. The translocation index for Mg, Ca ad Na in the analysed maize did not exceed one, whereas for K and P it exceeded one (Tab. 2 and 3). On the object where only ash was used (Object IX) the value of the macroelement translocation index in the plant was composed by the following order from the lowest to the highest values: Na(0.11)<Mg(0.66)<Ca(0.68)<K(1.21)<P(1.31). Analysis of values of macroelement translocation index in the maize cultivated in ash shows that the test plant roots absorbed the greatest amounts of sodium in comparison with the aboveground parts. Much higher sodium contents in the cultivated plant roots were reported also in other papers [Kabata-Pendias 1987; Maciak i in. 1976]. Moreover, furnace wastes are an important source of environment salinization [Bogacz et al 1995; Strzyszcz 1989]. The value of the macroelement translocation index pointed to a specific role of the plant root system, which to a considerable degree diminished sodium, magnesium and calcium translocation to maize aboveground parts.

Content assessment. Optimal concentrations of macroelements in plants destined for fodder have been determined in literature on the following levels: 2.0 g Mg; 7.0 g Ca, 17.0-20.0 g K; 1.5-2.5 g Na and 3.0 g P · kg^{-1} d.m. [Falkowski et al 2000; Underwood 1971]. The assessment of maize aboveground parts according to the assumed norms revealed that magnesium concentrations in maize cultivated in soil with furnace ash supplement were on the optimal level. Calcium content in maize grown in the soil with ash admixture was below the optimal value. Maize yield obtained from the object where only ash was used contained a sufficient amount of calcium. The optimal potassium level was registered in the objects where between 200 and 600 t ash was used per 1 ha. Sodium and phosphorus concentrations in maize cultivated in the soil with ash supplement was too low considering the requirements for fodder plants. Summing up, maize grown in the soil fertilized with the increasing doses of furnace ash may be destined for fodder use.

Macroelement ratios. Fodder quality is determined not only by optimal mineral contents, but also the proportions between them. From the nutritional value viewpoint K:Na ratio should be 10:1, whereas the optimal values of Ca:P and Ca:Mg ratios have been determined as 2:1 and 3:1, respectively. Moreover, good quality fodder should be characterized by optimal ratios of: K:(Ca+Mg) = 1.6-2.2; K:Mg = 6:1; K:Ca = 2:1 [Czuba, Mazur 1988; Falkowski et al 2000]. The above quoted values of the ratios between the studied elements in maize yield were most diversified and depended on furnace ash dose (Tab. 3). The ratios of K:Na; K:Mg, K:Ca, Ca:Mg and K:(Ca+Mg) computed in chemical equivalents were the widest in the control object and then narrowed systematically under the influence of increasing ash dose in soil. In result of ash application to the soil a higher Ca concentration in maize yield was obtained, which led to narrowing of K:(Ca+Mg) relation with a simultaneous widening of the Ca:P ratio, which are considered as more beneficial than the opposite relationships [Płodzik 1996]. The K:Na ratio was unfavourable, since it exceeded the permissible value 10. Many authors [Czuba, Mazur 1988; Gorlach et al 1985] report that greater K uptake by plants is often combined with a simultaneous decrease in sodium absorption. On the other hand, Underwood [1971] points to a lack of the convincing data about harmful effect of even 50:1 ratio of these elements for animals on condition that the fodder sodium concentrations ensure the proper course of physiological processes. The presented research confirmed a high content of potassium but a deficient content of sodium in maize aboveground parts. The gravimetrically calculated Ca:P ratio widened under the influence of applied ash. Ash does of 100 – 200 t · ha^{-1} caused that the value of this ratio in maize aboveground parts oscillated around the optimal number. The value of ionic ratios Ca:Mg, K:Mg and K:(Ca+Mg)remained on a relatively low level reported by Czuba and Mazur [1988], whereas the K:Na ratio exceeded the optimal value. The K:Ca proportion in maize yield approximated the optimum.

Macroelemnet uptake. Nutrient uptake by plants is a resultant of plant yield and its element concentrations. The amount of studied macroelements absorbed by maize depending on the object and plant part ranged between 0.031 and 0.271 g Mg; 0.102-0.401 g Ca; 0.160-1.410 g K; 0.009 and 0.040 g Na and 0.011-0.282 g P · pot^{-1} (Tab. 2, 3). Growing ash doses in the soil triggered off a significant increase in magnesium uptake by maize aboveground parts and roots.

Calcium, potassium and sodium uptake by maize in the objects fertilized with ash was relatively even. Furnace ash used separately (Object IX) significantly diminished Ca, K and Na uptake by maize aboveground parts. As a result of increasing ash doses a systematic decline in P uptake by both maize aboveground parts and roots was registered. The decrease in phosphorus absorption by maize aboveground parts and roots in the object where solely furnace ash was applied was 85% and 80%, respectively in relation to the control. A decline in phosphorus uptake was connected mainly with a decline in yield and this element concentration in maize. The highest Mg taken up by maize aboveground parts was registered with the dose of 400 t ·ha^{-1}, Ca and K at 10 – 20 t ash per 1 ha, whereas phosphorus uptake was the highest in the control where no ash was used. Maize aboveground parts had a greater share in Mg, Ca, K and P absorption, whereas roots in sodium uptake.

DISCUSSION

On the basis of the obtained results and literature data [Ciećko, Nowak 1984] hard coal ash should be considered a good source of magnesium, calcium, potassium and sodium for plants. Studies conducted by Kabata-Pendias et al [1987] demonstrated that an admixture of furnace ashes to the soil causes an evident increase in the main element concentrations in plants. The author's own investigations showed a raise in Mg, Ca, K and Na concentrations in maize due to increasing ash supplements to the soil. Among the analysed elements the highest increase in maize concentrations were registered for magnesium. The studies of Ciećko and Nowak [1984] revealed that increasing ash doses raised Mg and K content in maize but slightly decreased calcium content, while phosphorus concentrations did not undergo any major changes. In the other authors' studies [Nowak et al 1993] a distinct effect of growing hard coal ash doses on the increase in potassium concentrations was observed in various plant species. In the author's own investigations increasing ash doses in the soil affected a decline in phosphorus concentrations in maize. The decrease in phosphorus content in maize was probably caused by the chemical sorption of phosphates in the soils which involves a formation of insoluble calcium and magnesium phosphates. The fact has been confirmed also by the studies conducted by Łączny [1983]. The chemical properties of furnace ashes cause that doses of phosphorus used under the plants grown in the soil fertilized with ash should be higher than normally used because of phosphorus retardation occurring at high alkalinity of the environment and a large amount of calcium and magnesium in ash (Tab. 1). Łączny [1983] does not exclude either the presence of phosphorus in aluminium or iron phosphate forms, which are practically unavailable for plants.

The value of the macroelement translocation index points to a specific role of maize root system, which to a considerable degree diminished sodium, magnesium and calcium translocation to the plant aboveground parts. The fact was corroborated by the studies of Bereśniewicz and Nowosielski [1982].

The quality of the obtained fodder is determined not only by the contents of individual mineral components but also their gravimetric or ionic ratios [Płodzik 1996]. The author's own investigations showed that after ash supplement to the soil, the values of Ca:Mg, K:Mg and K:(Ca+Mg) ratios in maize yield were narrowing and remained below the optimum. On the other hand, the K:Na ratio exceeded the optimal value, while the K:Ca proportion approximated the optimum. The effect of ash application for soil deacidification on narrowing of Ca:Mg, K:Mg and K:(Ca+Mg) ratios in plants was also found in the studies conducted by Koter et al [1982], where on the other hand a widening of the K:Na ratio was registered in effect of furnace ash application.

Magnesium uptake by maize increased apparently in effect of growing ash doses, whereas calcium, potassium and sodium absorption was relatively regular, and phosphorus uptake diminished. In the studies of Nowak and Ciećko [1983] it was found that under the influence of increasing ash doses and tree bark the amount of nutrients absorbed with yield was visibly declining, which was mainly connected with a decrease in maize yield. On the other hand, a different research [Ciećko, Nowak 1984] demonstrated a clear effect of growing ash doses on the increase in yield and uptake of Mg, Ca, K and P by maize.

RESULTS

1. Growing doses of furnace ash in the soil significantly affected an increase in Mg, Ca, K and Na concentrations, whereas they lowered P content in maize in comparison with the control.

2. Magnesium content in maize aboveground parts was on the optimal level and met the requirements for the good quality fodder. Ash doses between 200 and 600 $t \cdot ha^{-1}$ influenced the optimal content of potassium. The levels of calcium, sodium and phosphorus in maize was not on the optimal level.

3. The values of ionic ratios: Ca:Mg, K:Mg and K:(Ca+Mg) in maize yield remained below the optimum. The K:Na ratio exceeded the optimal value, while the K:Ca ratio approximated the optimum.

4. A systematic increase in Mg uptake but a lower P absorption by maize aboveground parts were registered under the influence of growing ash supplements to the soil.

5. Furnace ash used separately significantly diminished the macroelement uptake by maize aboveground parts and roots.

6. Mineral fertilization is recommended to achieve the optimal chemical composition of plants cultivated in the soil with ash supplement because of specific physicochemical properties of ashes with a particular regard to phosphorus treatment.

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