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# THE EFFECT OF HARD COAL ASHES ON THE AMOUNT AND QUALITY OF MAIZE YIELD. PART 1. HEAVY METALS

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**Abstract**

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The studies aimed at identification of various ash doses effect on the amount of yield and concentrations of Cr, Zn, Pb, Cu, Cd and Ni in maize. The studies were conducted as a pot experiment on mineral soil, to which ash doses of between 13.33 and 800.0 g·pot$^{-1}$ were supplied in proportions corresponding to quantities between 10 and 600 t·ha$^{-1}$. The amount of maize yield was diversified and depending on the treatment ranged between 35.59–121.64 g d.m.·pot$^{-1}$. Ash dose of 13.33 g.pot$^{-1}$ significantly affected an increase in maize yield, while the dose over 26.67 g.pot$^{-1}$ and equivalent to over 20 t.ha$^{-1}$ applied to the soil markedly declined maize yield. Element concentrations in maize was diversified, depending on the treatment and plant part, and fluctuated from 0.32–3.48 mg Cr; 13.45–341.19 mg Zn; 0.50–5.02 mg Pb; 1.83–22.10 mg Cu; 0.02–1.71 mg Cd and 0.15–6.07 mg Ni·kg$^{-1}$d.m. It was found that with increasing ash dose Cr and Cu content increased systematically, whereas Zn, Pb, Cd and Ni concentrations in maize decreased. The content of investigated heavy metals in maize aboveground parts fulfilled the norms for good quality fodder. Under the influence of growing ash doses added to the soil a regularly declining Cr, Zn, Pb, Cd and Ni uptake by maize aboveground parts was observed.

maize, yield, Cr, Zn, Pb, Cu, Cd, Ni, ash, mineral soil

Growing amounts of deposited furnace wastes pose a serious hazard for chemical balance in some ecosystems KABATA-PENDIAS et al. (1987). Furnace wastes, whose main quantitative components are fly ashes may become a nuisance because of their high concentrations of heavy metals and migration in the environment QUANT (2000). One of suggested ways of partial disposal of these wastes is their application for treatment of mineral soils or reclamation of landfills ANTONKIEWICZ (2005a) SHIMAOKA and HANASHIMA (1996). Furnace wastes generally have a loose consistency, similar to silt deposits and can be easily supplied in large doses to the arable soil layer GIEDROJĆ and FATYGA (1985), STRĄCZYŃSKA and STRĄCZYŃSKI (2004). The main disadvantage of some ashes, as has been mentioned before, may be their high concentrations of heavy metals QUANT (2000). Therefore it is necessary to observe the proper norms and doses when using ashes for land reclamation of arable soils or fertilization of agronomic plants.

If not utilised, the deposited furnace wastes should be subjected to biological reclamation. Fixation of furnace ashes landfill surface by vegetation prevents among others dusting and limits heavy metal migration into the landfill profile. Many-year research BOGACZ (1995), MELLER et al. (2001), WOJCIESZCZUK et al. (1996) demonstrated that in typical conditions of fly ashes deposition there is a possibility to leach c.a. 1/3 of total heavy metal contents from the ashes, at the utmost. On the other hand, one should realise that depositing ashes in the way enabling water filtration through the layer of this material considerably enhances potential component leaching exceeding even 80% of total content of individual metals.

The research was conducted to learn the effect of increasing furnace ash doses on the yield and concentrations of Cr, Zn, Pb, Cu, Cd and Ni in maize.

## MATERIAL AND METHODS

The research on the effect of ashes on yield and heavy metal uptake by maize was conducted in 2003–2005 as a pot experiment on a mineral soil with texture of light loamy sand and furnace ash (Tab. I). It contained 71% sand, 6% coarse silt, 10% fine silt, 6% coarse silty clay, 4% fine silty clay and 3% colloidal clay SYSTEMATYKA (1989). The soil revealed acid reaction. The soil on which the experiment was set up had natural contents of Cr, Pb and Cu but elevated concentrations of Zn, Cd and Ni KABATA-PENDIAS et al. (1996).

The furnace ash used for the experiment originated from hard coal burning. Heavy metal concentrations in ashes, as compared to the soil, were not high enough to provide potential threats. The experiment was conducted in four replications in polyethylene pots, 4 kg in volume, filled up with mineral soil and increasing doses of furnace ash in the amounts of between 13.33 and 800.0 g·pot$^{-1}$. As doses were equivalent to between 10 and 600 t·ha$^{-1}$. The experimental design considered also the control object with only mineral soil and object where only furnace ash was used (Tab. II). All pots were receiving annual, fixed NPK fertilization dosed: 0.3 g N, 0.08 g P and 0.2 g K·kg$^{-1}$ d.m. of soil as $NH_4NO_3$, $KH_2PO_4$ and KCl. Mineral fertilizers were applied as solutions every year two weeks prior to plant seeding and thoroughly mixed with the substratum. Vegetation period for maize (Kosmo c.v.) in 2003–2005 was respectively: 91, 99 and 92 days. During vegetation period the plants were watered with redistilled water and soil moisture maintained at 60% of maximum water capacity. Maize aboveground parts and roots were harvested each year from each pot (replication) and subsequently, after drying in a dryer at 75 °C, dry matter yield was assessed in g d.m. per pot$^{-1}$. Samples of 5 g plant material dry matter were collected for chemical analyses from each pot. After dry mineralization Cr, Zn, Pb, Cu, Cd and Ni were assessed in plant material from each replication by inductively coupled plasma (ICP-AES) method. Statistical computations were conducted using Microsoft Excel 7.0 calculation sheet. Significance of differences between compared mean maize yields and element concentrations were determined by Duncan test. The ANOVA and Duncan test were conducted on significance level $\alpha = 0.01$ ULIŃSKA (1957). Variability coefficients were computed pointing to the variability of studied element contents in the plant yield. The paper presents weighed means of the above mentioned element contents for three years of the experiment.

## RESULTS

Yield. Summary maize yield for the experimental period (2003–2005) has been given. The amount of maize aboveground part yield, depending on treatment, fluctuated from 26.34 and 97.02 g d.m. and roots between 9.25 and 24.62 g d.m.·pot$^{-1}$ (Fig. 1). A supplement to the soil of 13.33g ash per pot influenced significantly a raise of maize aboveground and roots yield in comparison with the control. A double ash dose (26.67 g·pot$^{-1}$) did not apparently affect an increase in maize aboveground part yield, however a slight increase in comparison with the control was registered. On the other hand the subsequent ash doses of between 66.67 and 800 g·pot$^{-1}$added to the soil markedly affected a decline in maize aboveground part and root yield in comparison with the control object. A decrease in maize aboveground part mass at the highest ash dose (object VIII, 600 t·ha$^{-1}$) reached 39.33% and in roots 34.19% in relation to the control. Furnace ash applied alone (treatment IX) also significantly affected a decrease in maize yield. The declines in maize aboveground part and roots yield on the treatment where only ash was used were respectively: 70.56% and 53.35% in comparison with the control. It was found that with increasing ash doses the value of maize aboveground parts ratio to its roots was also growing, which may point to a greater sensibility of the roots system to toxic effect of the ash.

Heavy metals. The results of studies were presented as weighed mean content of heavy metals in the aboveground parts and roots, and in the whole plant for the experimental period (2003–2005). The element concentrations in maize were diversified, depending on the treatment and plant part. Cadmium content was the most diversified in the aboveground parts (V = 93.38%) and chromium the least (V = 11.39%), whereas in roots the highest diversification was registered for zinc (V = 89.57%) and the lowest for chromium and lead (V = 22.10; 22.81%). Chromium. Mean weighed chromium content in maize ranged, depending on the object and plant part, between 0.32–3.48 mg·kg$^{-1}$ d.m. (Tab. II). It was found that furnace ashes applied in the amount of more than 200 t·ha$^{-1}$ caused a significant increase in chromium concentrations in maize aboveground parts as compared with the control, whereas in maize roots an apparent raise in this element content was noted already above 100 t/ha$^{-1}$ of ash. A growth in chromium content in maize aboveground parts and roots, at the highest ash supplement to the soil (600 t·ha$^{-1}$) was respectively: 33.88% and 55.73% in comparison with the control. Ash applied alone (treatment IX) also markedly affected the increase in chromium concentrations in maize aboveground parts and roots. A growth in chromium content in maize aboveground parts and roots on the treatment where only ash was used reached respectively: 36.68% and 98.65% in relation to the control. Zinc. Mean weighed zinc content fluctuated from 13.45 to 341.19 mg·kg$^{-1}$d.m. (Tab. II). Furnace ash applied in the amount of even 10 t ·ha$^{-1}$ led to a marked decline in zinc concentration in maize aboveground parts and roots. Subsequent ash doses added to the soil caused further significant decrease in zinc content in the tested plant. A fall of zinc content in maize aboveground parts and roots at the highest ash supplement to the soil (600 t·ha$^{-1}$) reached respectively: 68.95% and 89.37% in comparison with the control. Furnace ash used alone most influenced a decline in zinc concentrations in maize. The decrease in zinc was 79.27% in the aboveground parts and 93.96% in roots in comparison with the control. Lead. Mean weighed lead content ranged between 0.50 and 5.02 mg·kg$^{-1}$ d.m. depending on the treatment and plant part (Tab. II). Like in case of zinc furnace ashes added to the soil markedly affected a decrease in lead content in maize aboveground parts and roots. The decrease in lead concentrations at the highest ash dose in soil in the aboveground parts and roots exceeded 40% in comparison with the control. Also ash used in the experiment alone influenced a decline in this element content in maize. The decline in lead content under the influence of solely ash exceeded 50% in comparison with the control. In the conducted research greater amounts of lead were found in maize roots than its aboveground parts. Copper. Mean weighed content of copper fluctuated from 1.83 to 22.10 mg·kg$^{-1}$ d.m. (Tab. III) in different plant parts and objects. An increase in copper content in maize was registered in effect of growing ash supplement to the soil. A significant increase in this microelement content in maize aboveground parts was noted at the dose exceeding 13.33 g ash/pot equivalent to 10t ash per ha. On the other hand a marked increase in copper concentrations in roots occurred above 50t ash per ha. Copper content in maize aboveground parts and roots grew at the highest ash supplement to the soil respectively by 51.07% and 175.74% in relation to the control. On the other hand on solely ash treatment the growth in copper concentrations in maize was greater reaching 69.75% for the aboveground parts and 368.02% for roots as compared with the control. Cadmium. Mean weighed cadmium content, depending on the treatment and plant part, ranged between 0.02 and 1.71 mg·kg$^{-1}$d.m. (Tab. III). Ash dose of 10 t·ha$^{-1}$ caused an apparent decline in cadmium concentrations in maize aboveground parts. The decrease, compared with the control, was observed in roots from the dose of 20 t.ha$^{-1}$. A decline in cadmium content at the highest ash dose in soil was 91.33% for aboveground maize parts and 62.82% for its roots in comparison with the control. Ash applied alone also visibly decreased this metal concentration in the tested plant. The decrease in cadmium content in maize aboveground parts was 96.37%,whereas in roots 88.49% in relation to the control treatment. Nickel. Mean weighed nickel content ranged between 0.15 and 6.07 mg·kg$^{-1}$ d.m. (Tab. III) depending on the treatment and plant part. Ashes applied to the soil significantly affected a decline in nickel concentrations in maize aboveground parts and roots as compared with the control. Presented experiment demonstrated that even a small ash supplement to the soil (10 t·ha$^{-1}$) markedly influenced a lowering of nickel content in maize aboveground parts and roots. The decrease in nickel content at the highest ash dose added to the soil (600 t·ha$^{-1}$) exceeded 50% for the aboveground parts and 73% for roots in comparison with control. Furnace ash applied alone decreased nickel concentrations even more: by 58.25% in the aboveground parts and by 80.99% in roots in relation to the control.

Presented research revealed higher concentrations of chromium, nickel, lead, copper, cadmium and nickel in maize roots than in its aboveground parts. At the highest ash supplement to the soil (treatment VII, 600 t·ha$^{-1}$) the greatest decline in concentrations in maize aboveground parts, as compared with the control, was registered for cadmium – 91.33%, then for zinc – 68.95% and nickel – 51.215%, while the smallest for lead 46.60%.

The permissible contents of heavy metals in plant material destined for fodder are as follows: Cd ≤0.5mg; Zn ≤ 100.0mg; Pb ≤ 10mg; Cu ≤ 30mg; Ni ≤ 50mg; Cr < 20mg/kg d.m. GORLACH (1991), KABATA-PENDIAS et al. (1993). The assessment of maize aboveground parts according to this criterion showed that it met the requirements considering the content of Cr, Zn, Pb, Cu, Cd and Ni posed for good quality fodders. It should be emphasized that only Cd concentrations in the aboveground parts of maize grown in the control excluded it from use for fodder. The presented studies demonstrated that applied furnace ashes visibly limited Zn, Pb, Cd and Ni uptake by maize and therefore did not affect the exceeding of permissible heavy metal content in the harvested yield. Moreover, it should be emphasized that the obtained yield of maize aboveground parts from the treatments where solely ash was the substratum was characterised by heavy metal concentrations below the threshold values.

Metal mobility in plants was determined using translocation coefficient (TC) which expresses the ratio of metal concentrations in plant aboveground parts to its content in roots. The translocation coefficient of heavy metals in the tested maize did not exceed one (Tab. II, III). On the object where only ash was used (treatment IX) the value of heavy metal translocation coefficient in plants was formed by the following order from the lowest to the highest value: Cr – 0.12, Cd – 0.12, Ni – 0.13, Cu – 0.14, Pb – 0.21 and Zn 0.65. The analysis of heavy metal translocation coefficient in maize cultivated in the ash reveals that the tested plant roots absorbed the greatest amounts of chromium and cadmium as compared with the aboveground parts. The value of translocation coefficient for the analysed heavy metals points to a specific role of maize root system, which to a considerable degree diminished heavy metal translocation to the aboveground parts. The obtained TC values were corroborated by studies of GRZEBISZ et al. (1998), which revealed that flax roots inhibited heavy metal translocation to the aboveground organs.

Uptake of heavy metals. The quantity of heavy metals taken up by maize depended on the treatment, the crop yield and individual element contents. The uptake of heavy metals per pot ranged, depending on the treatment and plant part, between 0.011 and 0.047 mg Cr; 0.191–6.767 mg Zn; 0.013–0.115 mg Pb; 0.082–0.204 mg Cu; 0.001–0.060 mg Cd; 0.004–0.134 mg $Ni \cdot pot^{-1}$ (Tab. II, III). Increasing ash doses added to the soil caused a systematic decrease in the uptake of Cr, Zn, Pb, Cd and Ni by maize aboveground parts and roots. Decreased heavy metal uptake was mainly connected with a decline in maize yield. The largest uptake of Cr, Zn, Pb and Ni by maize aboveground parts was noted at the dose of 10 $t \cdot ha^{-1}$, while Cd in the control where no ash was applied. A decrease in the uptake of analysed metals by maize aboveground parts, at the largest ash dose applied to the soil (object VIII) was 15.75% chromium; 81.15% zinc; 67.63% lead; 94.76% cadmium and 70.45% nickel in relation to the control. Increase in ash supplement to the soil had no significant effect on either decrease or increase copper uptake by maize aboveground parts. The studies demonstrated that maize roots removed Cr, Pb and Ni in larger amounts than its aboveground parts. On the other hand, larger amounts of zinc and copper were absorbed by maize aboveground parts. Furnace ash used without any admixtures (treatment IX) markedly lowered the uptake of Cr, Zn, Pb, Cd, and Ni by maize aboveground parts and roots. On the other hand in the case of copper, ash used separately apparently influenced this microelement uptake by roots but decreased absorption by maize aboveground parts in comparison with the control.

## DISCUSSION

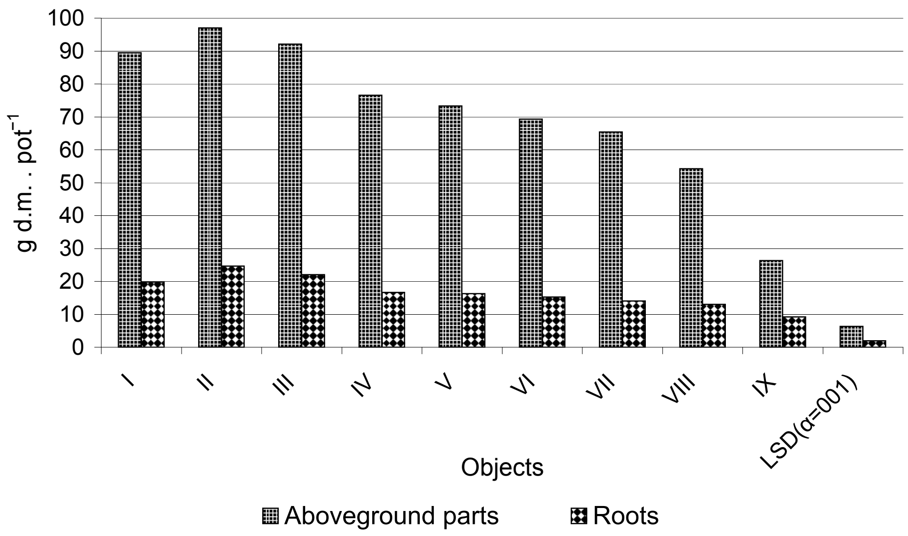
Furnace ash applied in the experiment dosed 13.33 $g \cdot pot^{-1}$ and equivalent to 10 $t \cdot ha^{-1}$ significantly influenced an increase in maize yield, whereas the double dose had no effect on a decline in yield. Literature GÓRA (1987), TERELAK and ŻÓRAWSKA (1979) reveals that too large ash mass supplied to soil may disturb the balance of heavy metal ions in the soil and negatively affect crop yielding. This is true especially for light soils with poor buffer properties. The results of Authors' own research show that more than 20 t ash per 1 ha lowered maize yielding. Positive effect of small ash doses on crop yielding was also proved by results of other investigations ANTONKIEWICZ (2005b), CIEĆKO and NOWAK (1984), KABATA-PENDIAS et al. (1987), TERELAK and ŻÓRAWSKA (1979). However, there are also some controversial reports in literature GÓRA (1987), MACIAK et al. (1976) on ash toxicity, which prove that further research on ash-soil-plant system is necessary ANTONKIEWICZ (2005a), QUANT (2000). Monitoring of heavy metal content in ashes and their potential accumulation in the soil and crops will be also inevitable.

Presented research demonstrated an apparent dependence between the level of ash fertilization and heavy metal concentrations in maize. The results reveal that furnace ashes applied to the soil influenced a decrease in Zn, Pb, Cd and Ni contents but increased Cr and Cu quantities in maize. Toxic elements present in ashes are mostly bound in poorly soluble compounds such as aluminosilicates CZURDA and HAUS (2002), MELLER (2001). Generally heavy metals do not enter the trophic chain because of their poor solubility or metabolic barriers characteristic for plants ANTONKIEWICZ and RAPACZ (2006), GÓRA (1987). Studies of GÓRA (1987) showed that under the influence of increasing ash supplements to the soil, in the amount of between 400 and 800 $t \cdot ha^{-1}$,Cr, Zn and Cd concentrations in maize revealed a decreasing tendency. On the other hand Pb, and Cu content in maize was growing, whereas nickel content remained on the same level. However, these results were not clearly regular. Studies of KABATA-PENDIAS et al. (1987) revealed that in light soils fertilized with ash a decline in Zn concentration is perceptible, but a an increase in the quantities of Cu, Pb and Cd. The above mentioned author found that in many cases better solubility of trace elements in soil occurs under the influence of ash application. Studies conducted by CURYŁO and JASIEWICZ (1998) revealed that reculter – fertilizer containing among other furnace ash decreased heavy metal uptake by crops. Author's own research demonstrated that limited heavy metal uptake by plants resulted from deteriorating metal solubility due to application of ash with high $pH_{H2O}$ = 10.06 (Tab. I). Furnace ash applied to the soil in the amount of 600 $t \cdot ha^{-1}$ most limited cadmium uptake (over 90%) and least lead uptake (46.60%). As demonstrated by HERMS and BRÜMMER (1980), with growing pH value, heavy metal availability in soils diminishes in the following order Cd > Zn > Ni > Cu > Pb. Obtained results show that heavy metal uptake by maize was most limited by neutralisation of soil acidity.

Despite a negative effect of high ash doses on a decline in yields and increase in Cr and Cu concentrations in maize, one cannot exclude this waste potential utilisation for reclamation of soils degraded by chemicals. The results presented in this paper allow for a conclusion that maize cultivated on increasing doses of furnace ash may be used for fodder, land reclamation, energy production or for industrial processing because it does not take up heavy metals in the amounts exceeding the norms for fodder.

## CONCLUSIONS

Ash dose equivalent to 10t/ha supplied to the soil affected a significant increase in maize yield. Ash supplement exceeding 20t/ha caused a marked decline in maize yield. Significantly lowering Zn, Pb, Cd and Ni concentrations and increasing Cr and Cu content in maize in comparison with the control were registered in maize as effect of increasing ash doses. Heavy metal concentrations in maize aboveground parts met the requirements for good quality fodder. Systematically decreasing uptake of Cr, Zn, Pb, Cd and Ni by maize aboveground parts was registered in effect of increasing ash supplements to the soil. Furnace ash applied alone significantly diminished uptake of Cr, Zn, Pb, Cd and Ni by maize aboveground parts and roots. Monitoring studies on heavy metal concentrations in ashes and control on their potential accumulation in soil and crops are also necessary.




1: *Yield of maize*
Legend:
I – control, II – 13,33 g/pot (10 t/ha), III – 26,67 g/pot (20 t/ha), IV – 66,67 g/pot (50 t/ha), V – 133,33 g/pot (100 t/ha), VI – 266,67 g/pot (200 t/ha), VII – 533,33 g/pot (400 t/ha), VIII – 800 g/pot (600 t/ha), IX – Only Ash

I: *Physico-chemical characteristics of soil and ash used for the experiment*

| Parameter | Unit | Soil | Scale IUNG*** | Permissible | Ash |
|---|---|---|---|---|---|
| $pH_{(KCl)}$ | pH | 4.66 | - | | 9.85 |
| $pH_{(H2O)}$ | pH | 5.67 | - | | 10.06 |
| Texture | | lls* | - | | ssls** |
| Cr | $mg \cdot kg^{-1}$ d.m. | 17.95 | 0 | 150 | 33.85 |
| Zn | | 65.25 | I | 300 | 93.75 |
| Pb | | 25.25 | 0 | 100 | 18.65 |
| Cu | | 4.35 | 0 | 150 | 74.50 |
| Cd | | 0.43 | I | 4 | 0.28 |
| Ni | | 11.43 | I | 100 | 39.98 |

*lls – light loamy sand, **ssls – sandy silty loam silt, *** 0 – Natural content, I – elevated content

II: *Content and uptake of Cr, Zn, Pb by maize*

| No Treatment | Ash doses | | Cr | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 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 | 0.32 | 1.75 | 0.58 | 0.18 | 0.028 | 0.035 | 0.063 |
| II | 13.33 | 10 | 0.33 | 1.92 | 0.65 | 0.17 | 0.032 | 0.047 | 0.079 |
| III | 26.67 | 20 | 0.35 | 2.04 | 0.68 | 0.17 | 0.032 | 0.045 | 0.077 |
| IV | 66.67 | 50 | 0.36 | 2.14 | 0.68 | 0.17 | 0.027 | 0.036 | 0.063 |
| V | 133.33 | 100 | 0.37 | 2.23 | 0.71 | 0.17 | 0.027 | 0.036 | 0.064 |
| VI | 266.67 | 200 | 0.37 | 2.43 | 0.74 | 0.15 | 0.026 | 0.037 | 0.063 |
| VII | 533.33 | 400 | 0.41 | 2.60 | 0.79 | 0.16 | 0.027 | 0.036 | 0.063 |
| VIII | 800.00 | 600 | 0.44 | 2.73 | 0.88 | 0.16 | 0.024 | 0.036 | 0.059 |
| IX | 4000.00 | Ash | 0.43 | 3.48 | 1.23 | 0.12 | 0.011 | 0.032 | 0.044 |
| $LSD_{(\alpha=0,01)}$ | | | 0.07 | 0.57 | 0.12 | - | 0.006 | 0.008 | 0.007 |
| V%***** | | | 11.39 | 22.10 | 24.93 | 10.15 | 23.60 | 12.99 | 16.09 |
| No Treatment | Ash doses | | Zn | | | | | | |
| | 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 | 64.89 | 341.19 | 115.06 | 0.19 | 5.801 | 6.767 | 12.568 |
| II | 13.33 | 10 | 60.22 | 241.12 | 96.82 | 0.25 | 5.844 | 5.934 | 11.778 |
| III | 26.67 | 20 | 48.63 | 194.62 | 76.81 | 0.25 | 4.480 | 4.287 | 8.767 |
| IV | 66.67 | 50 | 33.12 | 107.42 | 46.45 | 0.31 | 2.535 | 1.798 | 4.333 |
| V | 133.33 | 100 | 28.12 | 81.19 | 37.81 | 0.35 | 2.058 | 1.325 | 3.383 |
| VI | 266.67 | 200 | 23.17 | 54.79 | 28.89 | 0.42 | 1.604 | 0.838 | 2.442 |
| VII | 533.33 | 400 | 20.87 | 38.02 | 23.91 | 0.55 | 1.364 | 0.534 | 1.898 |
| VIII | 800.00 | 600 | 20.15 | 36.27 | 23.27 | 0.56 | 1.093 | 0.473 | 1.566 |
| IX | 4000.00 | Ash | 13.45 | 20.61 | 15.31 | 0.65 | 0.357 | 0.191 | 0.548 |
| $LSD_{(\alpha=0,01)}$ | | | 5.46 | 19.40 | 6.76 | - | 0.484 | 0.406 | 0.674 |
| V%***** | | | 53.77 | 89.57 | 69.64 | 41.43 | 73.92 | 102.72 | 87.14 |
| No treatment | Ash doses | | Pb | | | | | | |
| | 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 | 1.02 | 5.02 | 1.75 | 0.20 | 0.092 | 0.099 | 0.191 |
| II | 13.33 | 10 | 0.78 | 4.66 | 1.56 | 0.17 | 0.075 | 0.115 | 0.190 |
| III | 26.67 | 20 | 0.73 | 4.03 | 1.36 | 0.18 | 0.067 | 0.089 | 0.156 |
| IV | 66.67 | 50 | 0.73 | 3.76 | 1.27 | 0.19 | 0.056 | 0.063 | 0.118 |
| V | 133.33 | 100 | 0.63 | 3.54 | 1.16 | 0.18 | 0.046 | 0.058 | 0.104 |
| VI | 266.67 | 200 | 0.59 | 3.39 | 1.09 | 0.17 | 0.041 | 0.052 | 0.092 |
| VII | 533.33 | 400 | 0.56 | 3.08 | 1.00 | 0.18 | 0.036 | 0.043 | 0.080 |
| VIII | 800.00 | 600 | 0.55 | 2.94 | 1.01 | 0.19 | 0.030 | 0.038 | 0.068 |
| IX | 4000.00 | Ash | 0.50 | 2.40 | 1.00 | 0.21 | 0.013 | 0.022 | 0.035 |
| $LSD_{(\alpha=0,01)}$ | | | 0.10 | 0.97 | 0.20 | - | 0.012 | 0.021 | 0.023 |
| V%***** | | | 23.78 | 22.81 | 21.52 | 7.54 | 48.07 | 47.54 | 47.18 |

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

III: *Content and uptake of Cu, Cd, Ni by maize*

| No | Ash doses | | Cu | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | 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 | 1.83 | 4.72 | 2.36 | 0.39 | 0.164 | 0.094 | 0.258 |
| II | 13.33 | 10 | 1.92 | 4.98 | 2.54 | 0.39 | 0.187 | 0.123 | 0.309 |
| III | 26.67 | 20 | 2.01 | 5.26 | 2.64 | 0.38 | 0.185 | 0.116 | 0.301 |
| IV | 66.67 | 50 | 2.23 | 6.73 | 3.04 | 0.33 | 0.171 | 0.112 | 0.283 |
| V | 133.33 | 100 | 2.35 | 7.75 | 3.33 | 0.30 | 0.172 | 0.126 | 0.298 |
| VI | 266.67 | 200 | 2.53 | 9.22 | 3.74 | 0.27 | 0.175 | 0.141 | 0.316 |
| VII | 533.33 | 400 | 2.68 | 10.66 | 4.09 | 0.25 | 0.176 | 0.149 | 0.325 |
| VIII | 800.00 | 600 | 2.77 | 13.02 | 4.76 | 0.21 | 0.150 | 0.170 | 0.321 |
| IX | 4000.00 | Ash | 3.11 | 22.10 | 8.05 | 0.14 | 0.082 | 0.204 | 0.286 |
| LSD-NRI $_{(\alpha=0,01)}$ | | | 0.18 | 2.29 | 0.46 | - | 0.022 | 0.033 | 0.035 |
| V%***** | | | 17.97 | 58.92 | 45.90 | 28.93 | 19.75 | 24.56 | 7.10 |
| No | Ash doses | | Cd | | | | | | |
| Treatment | 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 | 0.67 | 1.71 | 0.85 | 0.39 | 0.060 | 0.034 | 0.093 |
| II | 13.33 | 10 | 0.54 | 1.64 | 0.76 | 0.33 | 0.052 | 0.041 | 0.093 |
| III | 26.67 | 20 | 0.37 | 1.39 | 0.57 | 0.27 | 0.034 | 0.031 | 0.065 |
| IV | 66.67 | 50 | 0.24 | 1.32 | 0.43 | 0.18 | 0.018 | 0.022 | 0.040 |
| V | 133.33 | 100 | 0.15 | 1.03 | 0.31 | 0.14 | 0.011 | 0.017 | 0.027 |
| VI | 266.67 | 200 | 0.11 | 0.90 | 0.25 | 0.12 | 0.007 | 0.014 | 0.021 |
| VII | 533.33 | 400 | 0.07 | 0.80 | 0.20 | 0.09 | 0.005 | 0.011 | 0.016 |
| VIII | 800.00 | 600 | 0.06 | 0.63 | 0.17 | 0.09 | 0.003 | 0.008 | 0.011 |
| IX | 4000.00 | Ash | 0.02 | 0.20 | 0.07 | 0.12 | 0.001 | 0.002 | 0.002 |
| LSD-NRI $_{(\alpha=0,01)}$ | | | 0.07 | 0.22 | 0.07 | - | 0.007 | 0.005 | 0.009 |
| V% | | | 93.38 | 46.28 | 68.45 | 57.53 | 104.95 | 64.75 | 84.33 |
| No | Ash doses | | Ni | | | | | | |
| Treatment | 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 | 0.36 | 6.07 | 1.40 | 0.06 | 0.032 | 0.120 | 0.153 |
| II | 13.33 | 10 | 0.27 | 5.44 | 1.31 | 0.05 | 0.026 | 0.134 | 0.160 |
| III | 26.67 | 20 | 0.26 | 3.45 | 0.87 | 0.07 | 0.024 | 0.076 | 0.100 |
| IV | 66.67 | 50 | 0.22 | 2.42 | 0.61 | 0.09 | 0.017 | 0.040 | 0.057 |
| V | 133.33 | 100 | 0.21 | 1.92 | 0.52 | 0.11 | 0.015 | 0.031 | 0.047 |
| VI | 266.67 | 200 | 0.20 | 1.90 | 0.50 | 0.10 | 0.013 | 0.029 | 0.042 |
| VII | 533.33 | 400 | 0.19 | 1.67 | 0.45 | 0.11 | 0.013 | 0.023 | 0.036 |
| VIII | 800.00 | 600 | 0.18 | 1.59 | 0.45 | 0.11 | 0.009 | 0.021 | 0.030 |
| IX | 4000.00 | Ash | 0.15 | 1.15 | 0.41 | 0.13 | 0.004 | 0.011 | 0.015 |
| NRI $_{(\alpha=0,01)}$ | | | 0.04 | 0.42 | 0.10 | - | 0.003 | 0.008 | 0.009 |
| LSD-V% | | | 27.77 | 62.41 | 52.63 | 29.05 | 51.47 | 84.13 | 75.50 |

*Notes see table II

SOUHRN

Vliv uhelných popelů na úroveň výnosu a kvalitu kukuřice. Část 1. Těžké kovy.

V příspěvku je posuzován vliv různých dávek popela na úroveň výnosu a obsah Cr, Zn, Pb, Cu, Cd a Ni v rostlinách kukuřice. V nádobovém pokusu se zeminou byly aplikovány dávky popela mezi 13,33 až 800 g na nádobu, což odpovídá množství 10 až 600 $t.ha^{-1}$. Výše výnosu kukuřice kolísala v závislosti na variantě mezi 35,59–121,64 g sušiny na nádobu. Dávka popela 13,33 g na nádobu signifikantně zvýšila výnos kukuřice, zatímco dávka přes 26,67 g na nádobu a tedy ekvivalentně přes 20 $t.ha^{-1}$ aplikovaná do půdy značně redukovala výnos kukuřice. Obsah prvků v kukuřici kolísal a to v závislosti na variantě a části rostliny, přičemž se pohyboval v následujícím rozpětí: 0,32–3,48 mg Cr; 13,45–341,19 mg Zn; 0,50–5,02 mg Pb; 1,83–22,10 mg Cu; 0,02–1,71 mg Cd a 0,15–6,07 mg $Ni·kg^{-1}$sušiny. Bylo zjištěno, že s narůstající dávkou popela se lineárně zvyšoval obsah Cr a Cu v rostlinách, zatímco obsahy Zn, Pb, Cd a Ni klesaly. Obsah sledovaných těžkých kovů v nadzemních částech kukuřice splňoval normy pro dobrou kvalitu píce. Se vzrůstajícími dávkami popela dodanými do půdy pravidelně klesal odběr Cr, Zn, Pb, Cd a Ni v nadzemních částech rostlin kukuřice.

kukuřice, výnos, Cr, Zn, Pb, Cu, Cd, Ni, popel, zemina

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REFERENCES

ANTONKIEWICZ, J.: Utilisation of sewage sludge for biological management of ash disposal site. Content of selected heavy metals in plants. Ecological Chemistry and Engineering. 2005a, 12, 3, 209–215. ISSN 1231-7098.

ANTONKIEWICZ, J.: The effect of sewage sludge and furnace ashes and their mixtures on Fielding and nitrogen content in plant of grases and legumes mixture. Fragm. Agronom., 2005b, 22, 1(85), 336–345. PL ISSN 0860-4088.

ANTONKIEWICZ, J., RAPACZ, M.: Photosynthetic activity of plants growing on soil supplemented with sewage sludge and furnace ashes. Zesz. Probl. PNR, 2006, 509, 187–196. ISSN 0084-5477.

BOGACZ, A.: Influence of hard coal ash reclaming rates on some physicochemical and chemical properties of sandy soil of fresh pine forest site. Zesz. Probl. PNR, 1995, 418, 677–684. ISSN 0084-5477.

CIEĆKO, Z., NOWAK, G.: Reaction of maize, oats and rape on increasing rates of hard coal ash. Roczn. Glebozn. 1984, 35, 3/4, 51–61. PL ISSN 0080-3642.

CURYŁO, T., JASIEWICZ, CZ.: Effect of some organic-mineral fertilizers on uptaking heavy metals by vegetables. Rocz. AR Pozn., 1998, 304, Ogrod. 27, 39–49. PL ISSN 0137-1738.

CZURDA, K.A., HAUS, R.: Reactive barriers with fly ash zeolites for in situ groundwater remediation. Applied Clay Science, 2002, 21, (2002), 13–20.

GIEDROJĆ, B., FATYGA, J.: Effect of the fertilization with ash from the thermal electric power plant Czechnica one some properties of sandy soil and yields of crops. Roczn. Glebozn., 1985, 36, 3, 155–163. PL ISSN 0080-3642.

GORLACH, E.:. The content of trace elements in fodder plants as a measure of their quality. Zesz. Nauk. AR w Krakowie, 1991, 262, Sesja Nauk., 34, 13–22. ISSN 0239-9342.

GÓRA, E.: The effect of power ashes on the yield and chemical composition of plants on heavy soils. Zesz. Nauk. AR Kraków 1987, 219, Roln. 27, 39–55. ISSN 0239-9342.

GRZEBISZ, W., POTARZYCKI, J., CIEŚLA, L.: Heavy metal extraction by fibrous plants from soils polluted with copper works emissions. P. 2. Linseed. Zesz. Probl. PNR., 1998, 460, 697–708. ISSN 0084-5477.

HERMS, U., BRÜMMER, G.: Einfluß der Bodenreaktionen auf Löslichkeit und tolerierbare Gesamtgekalte an Nickel, Kupfer, Zink, Cadmium, und Blei in Böden und kompostierten Siedlungsabfällen. Landwirtsch. Forsch., 1980, 33/4, 408–423.

KABATA-PENDIAS, A., PIOTROWSKA, M., WIĄCEK, K.: Impact of coal ashes on soils and plants. Archives of Environmental Protection. 1987, 1–2, 97–104. ISSN 0324-8461.

KABATA-PENDIAS, A., MOTOWICKA-TERELAK, T., PIOTROWSKA, M., TERELAK, H., WITEK, T.: Ocena stopnia zanieczyszczenia gleb i roślin metalami ciężkimi i siarką. Ramowe wytyczne dla rolnictwa. Puławy, 1993, P. (53), IUNG, ss. 20.

KABATA-PENDIAS, A., PIOTROWSKA, M., MOTOWICKA-TERELAK, T., MALISZEWSKA-KORDYBACH, T., FILIPIAK, K., KRAKOWIAK, A., PIETRUCH, CZ.: Podstawy oceny chemicznego zanieczyszczenia gleb – metale ciężkie, siarka i WWA. Państwowa Inspekcja Ochrony Środowiska. Bibliot. Monit. Środ., Warszawa, 1995, ss. 41. ISBN 83-86676-35-3.

MACIAK, F., LIWSKI, S., BIERNACKA, E.: Agricultural recultivation of furnace waste (ash) dumps from brown and hard coal. Part II. Chemical composition of plants cultivated on brown and hard coal ash dumps. Roczn. Glebozn., 1976, 27, 4, 171–187. PL ISSN 0080-3642.

MELLER, E., NIEDŹWIECKI, E., WOJCIESZCZUK, T.: Oddziaływanie popiołów ze spalania węgla kamiennego na środowisko w świetle badań własnych i literatury. Mat. VIII Międzynar. Konf. „Popioly z energetyki“. Międzyzdroje, 24–26 października 2001, 215–225. ISBN 83-87588-02-4.

QUANT, B.: Sludge from municipal waste water treatment plants in retreating the grate waste storage yards. Ekologia i Technika, 2000, VIII, 4, 95–99. ISSN 1230-462X.

ROZPORZĄDZENIE MINISTRA ŚRODOWISKA Z DNIA 9 WRZEŚNIA 2002 R. w sprawie standardów jakości gleby oraz standardów jakości ziemi. Dz. U. RP, Nr 165, Poz. 1359 z dnia 4 października 2002 r.

SHIMAOKA, T., HANASHIMA, M.: Behavior of stabilized fly ashes in solid waste landfills. Waste Management, 1996, 16, 5/6, 545–554.

STRĄCZYŃSKA, S., STRĄCZYŃSKI, S. Characteristics of the habitat of black locust (Robinia pseudacacia L.) plantings on furnace discard dump. Zesz. Probl. PNR, 2004, 501, 417–423. ISSN 0084-5477.

SYSTEMATYKA GLEB POLSKI.: PTG. Roczn. Glebozn., 1989, 40, 3/4, 1–150. PL ISSN 0080-3642.

TERELAK, H., ŻÓRAWSKA, B.: Effect of brown coal ash and of hard coal and peat furnace wastes on properties of light soils and yielding of crops. Roczn. Glebozn., 1979, 30, 3, 109–122. PL ISSN 0080-3642

ULIŃSKA, M.: Technika obliczeń przy opracowywaniu wyników doświadczeń rolniczych. IUNG 59. Wyd. PWRiL, Warszawa, 1957, ss.108.

WOJCIESZCZUK, T., NIEDŹWIECKI, E., MELLER, E.: Changes in the soil chemical composition and in filtrates obtained from soil treated with various doses of ashes from the “Dolna Odra” power plant. Roczn. Glebozn., 1996, 47, 3/4, 213–221. PL ISSN 0080-3642.

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