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Full Length Research Paper

The effect of furnace ash on crop yields and macroelement content in selected grass species

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The research aimed at identification of furnace ash effect on crop yield and contents of Mg, Ca, K, Na and P in various grass species. Application of a dose of 0.533 kg pot^{-1} affected a significant decline in grass species yield. From among the cultivated grass species perennial ryegrass and meadow fescue produced the greatest yield, whereas meadow-grass gave the smallest. Perennial ryegrass and meadow fescue, proved the most resistant grasses then timothy and red fescue, whereas the meadow-grass proved the most 'sensitive' to ash application. The investigations demonstrated a significant effect of 0.533 kg·pot^{-1} furnace ash dose on the increase in Mg, Ca and Na contents in grass species, whereas phosphorus concentrations decreased. Furnace ash influenced also an increase in potassium content in timothy, red fescue and perennial ryegrass, while it decreased these element concentrations in meadow grass and to meadow fescue. Contents of magnesium, potassium and phosphorus in the studied grass species corresponded to the standards stated for good quality forage. The level of calcium and sodium in tested grasses was not within the optimal ranges. A decreased uptake of Ca, K, Na and P by grass species was registered under the influence of ash application to the soil.

Key words: Ash, reclamation, yield, macroelements, grass species.

INTRODUCTION

Ash produced in result of hard coal burning should be managed in some way. The most frequently such ash is deposited in landfills.

According to the data provided by the Central Statistical Office (Environmental protection, 2006) over 120 million tonnes of industrial wastes is generated each year, including 14.8 million wastes from power engineering. A total amount of ashes deposited on landfills in 2005 reached almost 279 million tonnes. Such large quantities of ashes pose a grave hazard to the natural environment due to their negative physicochemical properties. Therefore, a necessity arises to conduct research on biological reclamation of disposal sites where ashes produced by power industry are deposited.

Research conducted so far on reclamation of furnace ash landfills revealed a possibility of growing many plant species on them, despite unfavourable growing conditions (Antonkiewicz, 2005; Maciak et al., 1976; Rogalski et al., 1998). The other direction of furnace ash management is treating them as calcium-magnesium fertilizers for soil treatment. The latter method is not new, as has been evidenced by numerous research papers (Ciecko et al., 1993; Nowak and Ciecko, 1983; Maciak, 1981). There are grass species and their mixtures best suitable for agricultural ash management. Grasses develop fast and sod the surface. There are grass species "resistant" to difficult conditions, whereas the other undergoes recession under these conditions (Kiryluk, 2004; Wiater, 2004). Therefore new grass species or varieties are sought which would be suitable for agricultural management of furnace ashes (Antonkiewicz, 2007). Application of furnace ashes to soil leads to considerable changes in mineral contents in grasses. These changes determine development of relationships among minerals. Czuba and Mazur (1988) state that proportions among basic minerals in grasses are of a far greater importance than absolute content of these constituents.

A three-year pot experiment was conducted to test possibilities of furnace ash management. The investigations aimed at an assessment of yield, Mg, Ca, K, Na and P concentrations and proportions between these components in selected grass species cultivated in soil with fur-

Table 1. Physicochemical characteristics of soil and ash used in the experiment

Parameter	Unit	Soil	Ash
$pH_{(KCl)}$	pH	4.66	9.85
$pH_{(H2O)}$	pH	5.67	10.06
Texture		lls*	ssl**
Mg	$g \cdot kg^{-1}$ d.m	0.28	10.95
Ca		0.35	21.27
K		0.39	1.09
Na		0.09	0.82
P		0.45	1.95

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

nace ash supplement.

MATERIAL AND METHODS

Research on the effect of ashes on crop yield and macroelement uptake by selected grass species was conducted in 2003 - 2005 as a pot experiment. Mineral soil with light loamy sand texture was used for the tests (Table 1) . It contained 71% of sand, 6% of coarse silt, 10% of fine silt, 6% of coarse silt clay, 4% of fine silt clay and 3% of colloidal clay (Systematics, 1989). The soil reaction was acid.

Furnace ash, that is, an ash-slag mixture from wet furnace waste removal, with a catalogue number 100180 (Act on wastes, 2001) was used for the experiment. Considering its texture, the furnace ash used for the experiment was counted to silt sandy loams (Table 1). It was a two-factor experiment in completely randomized design. The first experimental factor was ash dose (0.533 $kg \cdot pot^{-1}$) and control treatment (soil without ash supplement). The second factor was grass species: timothy (*Phleum pratense* L.), red fescue (*Festuca rubra* L.), meadow fescue (*Festuca pratensis* Huds.), meadow grass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.). The experiment was conducted in four replications in polyethylene pots with a volume of 4 kg. Each year the same NPK fertilization was applied for all pots in the following doses: 0.3 g N, 0.08 g P, and 0.2 g K kg^{-1} as: NH_4NO_3 , KH_2PO_4 and KCl. Mineral fertilizers in the form of solutions were applied (thoroughly mixed with the substratum) in the first year two weeks before plant sowing. In the second and third year of the experiment the fertilizers were spread on the surface in early spring before the grass vegetation started. Tested grass species were sown on 30 April 2003 in the amount of 30 seeds per pot. During vegetation the plants were watered with redistilled water and soil moisture was maintained on the level of 60% maximum water capacity. Grasses were harvested from each pot (replication) and after drying in a dryer at 75^{o}C dry matter yield was determined and expressed in g d.m. pot $^{-1}$. Chemical analysis was conducted on a mean sample of plant material from each pot from three cuts. Mg, Ca, K, Na and P concentrations were assessed in the plant material from each replication using ICP-AES method after dry mineralization. Statistical computations were conducted using Microsoft Excel 7.0 calculation sheet. Significance of differences between compared means of grass species yields and element contents were determined by Duncan method. The analysis of variance and Duncan test were conducted on the significance level = 0.01. Variation coefficients showing variability of tested element content in the plant yield were computed. Present paper shows also relationships between tested constituents in the grass species. Proportions of K:Na, K:Ca, K:Mg, K(Ca+Mg) and Ca:Mg were calculated equivalently, while Ca:P gravimetrically.

RESULTS

Yield: The yield of grass species was stated as the total for the investigated period (2003 -2005). The amount of yield on the control fluctuated depending on species and treatment between 35.3 and 131.3 g and on the ash treatments between 18.2 and 100.8 g d.m. pot (Table 2). Among the tested grasses meadow fescue and perennial ryegrass were characterized by the largest yield, both in the control and on the treatment with ash supplement, whereas meadow grass had the smallest yield. A supplement of 0.533 kg ash per pot significantly affected a decline in the yield of tested grass species in comparison with the control. The greatest decrease in yield was registered for meadow grass and red fescue. A drop in yield of the above mentioned species after ash admixture reached almost 50% (48.5 and 48.7%) in comparison with the control. Ash supplements to the soil the least affected decline in the yield of meadow fescue and perennial ryegrass. The decrease in yields of both species exceeded 21% (21.3 and 23.2%) in comparison with the control. In the case of timothy a stronger effect of ashes on crop yield was observed. The decrease in yield of this species under the influence of ash reached almost 40% as compared to the control. Perennial ryegrass and meadow fescue proved the most resistant to ash effect, timothy and red fescue placed next, whereas meadow grass proved the most "sensitive" to ash effect.

Macroelement concentrations: The work presents mean weighed macroelement concentrations for the whole period of investigations (2003 - 2005). Macroelement content in grass species was diversified depending on the species and treatment and fluctuated between 2.53- 4.56 g Mg; 3.98-6.07 g Ca; 15.72-26.90 g K; 0.34-2.50 g Na; 3.15-4.95 g P kg^{-1} d.m. (Table 2). The results presented in Table 2 points to quite big differences in the macroelement content in the tested grass species. The highest macroelement variability in grass species was registered for Na (V= 83.34%) and the lowest for Ca (V = 12.44%). Among grasses cultivated under control conditions, without ash admixture, the largest quantities of magnesium were found in meadow grass, perennial ryegrass and meadow fescue, calcium and sodium amounts in perennial ryegrass, whereas the most of potassium and phosphorus was assessed in meadow fescue. Analysis of macroelement concentrations in grass species cultivated in soil with ash supplement revealed that meadow grass accumulated the highest quantities of Mg, perennial ryegrass had the most of Ca and Na, K was most cumulated in timothy and perennial ryegrass, while P in red fescue. Addition of 0.533 kg ash per pot to the soil significantly affected an increase in Mg, Ca and Na contents in all grass species in comparison to the control. The highest increase in magnesium and calcium concentrations under the influence of ash applied to the soils was noted in timothy (respectively 46.27% and 22.99% in relation to the con-

Table 2. Yield [g · pot^{-1}] and content of macroelements in grass species [g · kg^{-1} d.m.]

Element	Yield			Mg			Ca		
	Ash doses		Mean for	Ash doses		Mean for	Ash doses		Mean for
Species	0 kg	0.533 kg	species	0 kg	0.533 kg	species	0 kg	0.533 kg	species
Timothy	109.7g	66.3d	88.0c	2.53a	3.70c	3.11a	3.98a	4.89cd	4.43a
Red fescue	94.2e	48.3c	71.3b	2.65a	3.73c	3.19a	4.63b	5.55e	5.09b
Meadow-grass	35.3b	18.2a	26.7a	3.30b	4.56f	3.93d	4.76bc	5.75e	5.25b
Meadow fescue	119.7h	94.2e	106.9d	3.18b	4.11d	3.64b	4.69bc	5.57e	5.13b
Perennial ryegrass	131.3i	100.8f	116.0e	3.22b	4.27e	3.74c	5.02d	6.07f	5.55c
Mean for ash dose	98.0b	65.5a	81.8	2.97a	4.07b	3.52	4.61a	5.57b	5.09
NIR(0.01) for ash dose	2.3			0.08			0.14		
NIR(0.01) for species	3.7			0.13			0.23		
NIR(0.01) for interaction	5.2			0.19			0.32		
Element	**K**			**Na**			**P**		
	Ash doses		**Mean for**	**Ash doses**		**Mean for**	**Ash doses**		**Mean for**
Species	**0 kg**	**0.533 kg**	**species**	**0 kg**	**0.533 kg**	**species**	**0 kg**	**0.533 kg**	**species**
Timothy	22.86c	26.85g	24.86c	0.34a	0.45abc	0.40a	4.66ef	3.58bc	4.12b
Red fescue	23.38c	24.75e	24.07b	0.62c	0.96d	0.79b	4.52e	3.87d	4.19b
Meadow-grass	18.39b	15.72a	17.05a	0.57bc	0.82d	0.70b	3.82d	3.15a	3.48a
Meadow fescue	25.51f	24.20d	24.85c	0.41ab	0.43ab	0.42a	4.95g	3.72cd	4.33c
Perennial ryegrass	25.08ef	26.90g	25.99d	2.20e	2.50f	2.35c	4.75f	3.50b	4.12b
Mean for ash dose	23.05a	23.69b	23.37	0.83a	1.03b	0.93	4.54b	3.56a	4.05
NIR(0.01) for ash dose	0.32			0.10			0.09		
NIR(0.01) for species	0.50			0.15			0.14		
NIR(0.01) for interaction	0.71			0.22			0.20		

trol). Ash admixture to the soil lowered this element concentration most in perennial ryegrass, where it reached 26.45% in comparison with the control, whereas the lowest decrease was observed in red fescue (14.56% in relation to the control). Similarly as in case of Mg, Ca and Na a notable effect was observed of ash supplement to the soil on increased K content in grass species. The exceptions were meadow grass and meadow fescue, in which significantly lower potassium concentrations were assessed under the influence of ash added to the soil (respectively 14.52 and 5.16% in relation to the control).

Assessment of chemical composition: It is assumed that good quality forage should contain about 3.0 g Mg; 7.0 g Ca; 17-20 g K; 1.5-2.5 g Na; 3.0 g P kg^{-1} d.m. (Czuba and Mazur, 1988; Falkowski et al., 2000). Estimating grass species cultivated in the soil with ash supplement according to the above mentioned criterion, it was found that they fulfilled the criteria for good quality forage with respect to their Mg, P and K concentrations. Despite a significant increase in calcium and sodium concentrations under the influence of ash admixture to the soil, low, deficient contents of the above mentioned macroelements were found in tested grases. Perennial ryegrass was the exception, since an optimal content of sodium was found in it both on the control and in soil with ash addition. Presented research found that furnace ash applied to the soil evidently limited P uptake by grass species but did not influence a deficient content of this element in the harvested yield. In some other paper authors found that grass species grown in soil with ash addition were unpolluted with heavy metals, therefore the obtained yield could be used for forage (Antonkiewicz, 2007).

Macroelement ratios: Forage quality is determined not only by optimum content of minerals but by also the proportions between them. From the nutritional value of forage K:Na ratio should be 10:1, while the optimum value of Ca:P and Ca:Mg ratios has been determined on the level of respectively 2:1 and 3:1. Moreover good quality forage should be characterized by optimum ratios, that is., K:(Ca+Mg) = 1.6-2.2; K:Mg = 6:1; K:Ca =2:1 (Czuba and Mazur, 1988; Falkowski et al., 2000). Values of relationships between macroelements in the harvested plant yields were diversified and depended on grass species and treatment (Table 3). Proportions of K:Na, K:Mg, K:Ca, Ca:Mg and K:(Ca+Mg) computed in chemical equivalents were the widest on the control and were narrowing under the influence of ash dose applied

Table 3. Element ratios in grass species

Species	Ash doses	Element ratios					
	$g \cdot pot^{-1}$	Ca:P	Ca:Mg	K:Mg	K:Ca	K:Na	K(Ca+Mg)
Timothy	0	0.85	0.95	2.81	2.95	39.10	1.44
	0.533	1.37	0.80	2.26	2.81	34.82	1.25
Red fescue	0	1.02	1.06	2.74	2.59	22.20	1.33
	0.533	1.44	0.90	2.06	2.29	15.21	1.08
Meadow	0	1.25	0.87	1.73	1.98	18.96	0.92
grass	0.533	1.83	0.76	1.07	1.40	11.26	0.61
Meadow	0	0.95	0.89	2.49	2.79	37.00	1.32
fescue	0.533	1.50	0.82	1.83	2.23	33.13	1.00
Perennial	0	1.06	0.95	2.42	2.56	6.72	1.24
ryegrass	0.533	1.74	0.86	1.96	2.27	6.33	1.05
V%		25.56	9.61	24.55	19.33	56.54	21.74

Table 4. Uptake of macroelements by grass species [$g \cdot pot^{-1}$]

Element	Mg		Ca		K		Na		P	
	Ash doses		Ash doses		Ash doses		Ash doses		Ash doses	
Species	0 kg	0,533 kg	0 kg	0,533 kg	0 kg	0,533 kg	0 kg	0,533 kg	0 kg	0,533 kg
Timothy	0,28	0,25	0,44	0,32	2,51	1,78	0,038	0,030	0,51	0,24
Red fescue	0,25	0,18	0,44	0,27	2,20	1,20	0,059	0,046	0,43	0,19
Meadow grass	0,12	0,08	0,17	0,10	0,65	0,29	0,020	0,015	0,13	0,06
Meadow fescue	0,38	0,39	0,56	0,52	3,05	2,28	0,049	0,041	0,59	0,35
Perennial rygrass	0,42	0,43	0,66	0,61	3,29	2,71	0,289	0,252	0,62	0,35
$NIR_{(0,01)}$ for doses ash	0,02		0,04		0,14		0,027		0,03	
V%	45,31		46,01		50,43		118,91		55,70	

to the soil. In result of ash addition to the soil higher Ca concentrations were obtained in grass species, which led to narrowing of K:(Ca+Mg) ratio at simultaneous widening of Ca:P ratio. K:Na proportion as unfavourable since it exceeded the permissible value of 10. Numerous authors (Czuba and Mazur, 1988; Gorlach et al., 1985) reported that higher K uptake by plants is often associated with simultaneously lower sodium absorption. On the other hand, Underwood (1971) points to a lack of convincing data about the harmfulness 50:1 ratio of these elements for animals, however on condition that Na amount in forage is enough to ensure proper course of physiological processes. Presented investigations corroborated high content of potassium and deficient of sodium in grass species. Value of Ca:Mg, K:Mg, K:(Ca+Mg) ratios remained on a relatively low level stated by Czuba and Mazur (1988). Value of K:Ca proportion in grass yields was over the optimum value, whereas in meadow grass it approximated the optimum.

Macroelement uptake: The amount of macroelements taken up by the tested grass species depended on the crop yield and individual element content (Table 4). The highest variability in macrolement uptake in grass species was registered for Na (V= 118.91%) and the lowest for Mg (V=45.315) . An addition of 0.533 kg ash per pot to the soil influenced a significantly lower uptake of Ca, K, Na and P by grass species. The lowest decline in the above mentioned elements uptake was registered for meadow grass, where it was 37.78% for calcium; 56.04% for potassium, 25.98% for sodium and 57.55% for phosphorus in relation to the control. A decrease in macroelement uptake was connected mainly with a decline in tested grass yield. In case of magnesium it was found that ash supplement did not have any significant influence on a decline or increase in magnesium uptake by meadow fescue and perennial ryegrass. The highest uptake of macroelements by tested grass species was registered on the control, where no ash was added to the oil. Among the tested grass species the largest quantities of studied macroelements were absorbed by perennial ryegrass and meadow fescue, while the smallest by meadow grass.

DISCUSSION

The studies revealed significant differences in the tested grass species yields and their macroelement concentrations. The yield of tested grasses grown in soil fertilized with ash was markedly dependent on the species. Perennial ryegrass and meadow fescue produced the largest yield, whereas meadows grass the smallest. Studies of Gos (1999) on growth and development of plant species revealed that perennial ryegrass grown in ash with biohumus addition produced optimum yields, whereas meadow fescue and red fescue produced even better yields. It was caused by the fact that enrichment of the ash surface layer with biohumus improved the conditions of substratum trophicity and therefore meadow fescue and red fescue developed better. On the other hand in Authors' own investigations here ash was supplied to light soil, perennial ryegrass and meadow fescue responded with the lowest decline in yield, timothy and red fescue placed next, whereas meadow fescue responded with the greatest decrease in yield. Studies of Rogalski and Kardynska (1999) demonstrated that an admixture of 50% of ash to the medium soil affected growth and development of *Festulolium* more positively than perennial ryegrass. Subsequent research conducted by Rogalski et al. (2001) on some grass species usefulness for reclamation of furnace ash landfills pointed to best yielding *Festulolium* and perennial ryegrass but the most poorly yielding meadow grass and red fescue.

Also the effect of ash supplement to the soil on Mg, Ca, K, Na and P concentrations in grass species was analyzed in the experiment. Furnace ash applied in the experiment contained much more macroelements than the soil (Table 1). Because of considerable quantities of macroelements often present in ashes, some authors (Maciak, 1981; Wojcieszczuk et al., 2001) recommend their use as a calcium-magnesium fertilizer. Presented experiment demonstrated that under the influence of ash applied to the soil Mg, Ca and Na concentrations in the tested grasses were growing. Studies of Maciak and Liwski (1981) showed an increase in magnesium and calcium content in plants fed with ash. Numerous investigations have shown a growth in potassium concentrations in plants fertilized with ash (Ciecko and Nowak, 1984; Nowak et al., 1993). Author's own research demonstrated different response of tested grass species to potassium content. Under the influence of ash supplement to the soil a decline in potassium concentrations was noted in meadow grass and meadow fescue, whereas in the other species a significant increase in this element content was registered. The decrease in potassium quantity in meadow grass and meadow fescue might have been influenced by a higher calcium content in soil, since as it is commonly known this element inhibits potassium ion uptake (Gregorczyk, 1998). Ciecko and Nowak (1984) who applied ashes from hard coal burning, observed an increase in potassium content in crops, however potassium concentrations in maize after application of a small dose of ash was slightly lower in comparison with the control. Also Maciak and Liwski (1981) and Kabata-Pendias et al. (1987) obtained an increase in potassium content in plants. Diminishing phosphorus content in tested grass species can be *inter alia* explained by a chemical sorption which occurs in soil under the influence of ash supplement to the soil (Łaczny 1983). Total phosphorus content in the applied furnace ash was over 4.3 times higher in comparison with its soil concentration. In ashes phosphorus occurs in compounds whose structure, according to Łaczny (1983) oscillated between hydroxylapatite and hydroxyapatite. In these compounds phosphorus is unavailable to plants. Łaczny (1983) does not exclude the presence of phosphorus in the forms of aluminium and iron phosphates practically unavailable to plants. Phosphorus deficiency connected with this element retardation by aluminium and calcium in ashes was revealed in the experiments on reclamation of brown and hard coal ashes (Maciak et al., 1976).

The investigations on the effect of ash supplement to the soil aimed also at an assessment of selected grass species in view of their chemical composition and potential use of the obtained biomass. Because the grass species yield obtained from furnace ash dumping sites is safe concerning its heavy metal concentrations, it may be destined for forage or composting (Antonkiewicz, 2005, 2007).Biomass, irrespective of ecological or soil forming function may be processed into compost, which will be later used for fertilization of subsequent dumping sites or degraded areas, which require biological reclamation. The compost applied on ash substratum will decrease the environment alkalinity and will supply plants with a necessary quantity of nutrients.

A decrease in macroelement uptake by the tested grass species under the influence of applied ash dose was found in the presented experiment, which was mainly connected with a decline in yield. Also Stankowski and Cyran (1996) reported a relatively slight utlization of macroelements from fly ashes. Research conducted by Nowak and Ciecko (1983) also revealed a diminished uptake of components with the crop yield obtained on soil fertilized with ash. On the other hand, some other studies (Ciecko and Nowak 1984) found a visible increase in macroelemnt uptake by crops under the influence of growing ash doses.

In result of applied furnace ash the soil pH increased by over one unit. The soil with ash supplement was characterized by better bioavailability of macroelements for the studied grass species. Despite an increase in soil phosphorus concentrations, this element content in grass species was declining due to chemical sorption.

Conclusions

Perennial ryegrass and meadow fescue were the most resistant to ash effect from among the analyzed grass species, timothy and red fescue were next and meadow grass proved the most sensitive.

Ash application to the soil caused a significant increase in Mg, Ca and Na in all tested grass species but the decline in P content.

An estimation of grass species cultivated in soil with ash supplement showed that they met the requirements regarding Mg, P and K content for good quality forage, but their calcium and sodium concentrations were deficient.

In view of crop yield and macroelement concentrations in selected grass species perennial ryegrass and meadow fescue may prove the most useful for ash sodding.

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