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THE INFLUENCE OF THE APPLICATION OF BARLEY, WHEAT AND RAPE STRAW ASH INTO SANDY SOIL ON THE CHANGES OF SOIL REACTION AND THE CONTENT OF AVAILABLE PHOSPHORUS, POTASSIUM AND MAGNESIUM

Mariusz Piekarczyk[1]✉, Mirosław Kobierski[2], Lech Gałęzewski[1]

[1]Department of Plant Production and Experimenting, UTP University of Science and Technology in Bydgoszcz
prof. S. Kaliskiego 7, 85-796 Bydgoszcz, **Poland**
[2]Department of Soil Science and Soil Protection, UTP University of Science and Technology in Bydgoszcz
Bernardyńska 6, 85-029 Bydgoszcz, **Poland**

ABSTRACT

Background. Combustion of agricultural crop biomass results in generation of furnace waste that may be used in agriculture. The aim of this study was to determine changes in pH and the content of available phosphorus, potassium and magnesium in soil under the influence of varied doses of ash from barley, wheat and rape straw.
Material and methods. In 2010-2011 a two-factorial pot experiment was carried out at the Research Station at Mochełek, established in a completely randomized design with four replications. The first factor was the type of ash from the burnt straw of: barley, wheat, rape. The other factor was the dose of applied ash: 0.08; 0.17; 0.25; 0.34; 0.67; 1.34; 2.68 $g \cdot kg^{-1}$ of soil.
Results. Applying ash from the straw of cereals and rape into soil caused a systematic increase in pH value in line with the applied dose of ash. As compared with the control treatment (pH – 6.6) the application of dry ash obtained from cereal and rape straw in a dose of 2.68 $g \cdot kg^{-1}$ increased the pH value of soil to a level of 7.7-7.8. The use of straw ash in a dose of 2.68 $g \cdot kg^{-1}$ of soil significantly increased the content of available phosphorus, potassium and magnesium by 63%, 483% and 93.3%, respectively.
Conclusion. Ash from burnt barley, wheat and rape straw can act as a soil fertilizer. Its application causes deacidification of soil and an increase in the quantity of phosphorus, potassium and magnesium in forms available for plants.

Key words: magnesium, pH, phosphorus, potassium, straw ash

INTRODUCTION

Negative environmental effects caused by the production and combustion of fossil fuels has encouraged the search for other, more environmentally friendly ways of generating energy (Hein and Bemtgen, 1998; McKendry, 2002; Abbasi and Abbasi, 2010). One of the possible solutions, however controversial for many, is the use of energy derived from burning the biomass of cultivated crops (Budzyński and Bielski, 2004; Demirbas, 2005; Zeng *et al.*, 2007). Furnace wastes generated during combustion are usually non-toxic (Sander and Andren, 1997; Lima *et al.*, 2008; Piekarczyk *et al.*,

✉ mapiek@utp.edu.pl, kobierski@utp.edu.pl, Lech.Galezewski@utp.edu.pl

2011a). They may find an application in the production of building materials (Rajamma *et al*., 2009; Kosior-Kazberuk and Lelusz, 2010) and in fertilizing agricultural and forest land, as well as in reclaimed areas (Hermann and Harasimowicz--Hermann, 2005; Stankowski and Bielińska, 2009; Ingerslev *et al*., 2011; Piekarczyk *et al*., 2014).

Due to its alkaline reaction and its considerable content of biogenic elements, as well as the scanty concentration of trace elements in ash obtained from the burning of agricultural crop biomass, the most recommended utilization of this waste is for agricultural use (Stankowski and Bielińska, 2009; Piekarczyk *et al*., 2011a). Previous study results indicate an alkalinisation of the soil environment and an increase in the content of macro- and microelements after the application of straw ash into soil (Piekarczyk *et al*., 2011b; Meller and Bilenda, 2012; Stankowski *et al*., 2014).

The research hypothesis assumes that ash from burnt barley, wheat and rape straw favourably affects the pH reaction and chemical properties of sandy soil. The aim of this study was to determine changes in pH and the content of forms of phosphorus, potassium and magnesium available for plants under the influence of varied doses of ash from barley, wheat and rape straw.

MATERIAL AND METHODS

In the years 2010-2011 a two-factorial pot experiment was carried out at the Research Station in Mochełek (53°13' N; 17°51' E) of the University of Life Science in Bydgoszcz, established in a completely randomized design with four replications. The first factor (A) was the type of ash from burnt straw: barley, wheat, rape. The other factor (B) was the dose of the applied ash: 0.08; 0.17; 0.25; 0.34; 0.67; 1.34; 2.68 $g \cdot kg^{-1}$ of soil, which corresponds to doses of 0.25; 0.5; 0.75; 1.0; 2.0; 4.0; 8.0 $Mg \cdot ha^{-1}$.

The granulometric composition of soil material was determined with laser diffraction, using a particle size analyser (Mastersizer 2000 by Malvern). The pH value was determined potentiometrically in 1M KCI solution in the ratio of soil/solution 1:2.5. Organic carbon content was determined with the analyser Vario Max CN – Elementar. The value of electrolytic conductivity (EC) was determined by measurement of resistance in soil/distilled water suspensions in a ratio of 1:5. The content of total exchange bases (TEB) was calculated by adding the content of exchangeable cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, after extraction in barium chloride solution according to PN-EN ISO 11260 (2011). Concentrations of individual cations were determined with the method of atomic absorption spectrometry, using the apparatus Philips PU 9100 X. The content of forms of phosphorus and potassium available for plants in the soil was determined according to the Egner-Riehm method (Egner *et al*., 1960), while for magnesium it was with the Schachtschabel method. The total content in the ashes of potassium was determined according to PN-R-04022:1996+Az1 (2002), and for calcium and magnesium in ashes according to PN-R-04020:1994 +Az1 (2004), with the atomic absorption spectrometry method, whereas for phosphorus it was determined by spectrophotometer according to PN-R-04023 (1996).

Pots with a perforated bottom and a depth of 0.22 m and an area of 0.05 m^2 were filled with soil material and then in autumn 2009 they were placed in the top layer of a cultivated field. Taking into consideration the pots parameters and the average volumetric density of sandy soil in the arable layer – ash was added twice to the same pots (at the beginning of April 2010 and 2011) in amounts according to the scheme of the experiment. After the application of ash, soil in the pots was stirred to a depth of about 10 cm, as in simplified soil cultivation. There was no vegetation in the pots during the experiment, it was removed manually.

The soil material used in the pot experiment was collected from the humus horizon of Luvisols (IUSS Working Group WRB, 2014) with the particle size of fine-grained sandy loam which contained: 78.1% of sand fraction (2.0-0.05 mm): 19.9% silt fraction (0.05-0.002 mm) and 2.0%. clay fraction (<0.002 mm). Based on the grain size, the studied soil was classified in the agronomic category of light soil. Organic carbon content determined according to PN-EN ISO 17184:2014-08E (2014) was 7.9±0.16 $g \cdot kg^{-1}$, and pH was 6.6±1.4. Concentration of basic cations amounted to 7.3±0.34 $cmol \cdot kg^{-1}$. The value of electrolytic conductivity was at a level of 117.4±3.58 $mS \cdot cm^{-1}$.

The ashes from burnt barley, wheat and rape straw used in the experiment were characterized by alkaline reaction with pH values: 10.0; 10.2; 10.7, respectively. The total content of phosphorus in the ashes amounted to 20.7; 16.7; 22.6 $g \cdot kg^{-1}$, of potassium 247.3; 232.4; 90.5 $g \cdot kg^{-1}$, of magnesium 5.2; 5.4; 7.4 $g \cdot kg^{-1}$, and of calcium 80.1; 71.5; 207.3 $g \cdot kg^{-1}$. The amounts of phosphorus, potassium, magnesium and calcium introduced into soil with one ton of ash are presented in Table 1.

Soil material samples were collected four times during season, separately in each year of the study. The presented results are the mean from the two years. According to the accepted experimental scheme, the obtained study results were statistically calculated using the analysis of variance and synthesis. The significance of differences between the means was estimated with Tukey's test at the significance level p = 0.05. The statistical software package FR – ANALWAR 5.2 was used in the calculations. Simple correlation coefficients between the dose of ash from barley, wheat and rape straw and the content of available forms of phosphorus, potassium and magnesium in soil were calculated using the spreadsheet Microsoft Office Excel.

Table 1. The amount of macroelements ($kg \cdot ha^{-1}$) introduced at a single rate with 1 ton straw ash into soil (0–10 cm)

Specification	Straw ash		
	Barley	Wheat	Rape
Phosphorus (P)	20.7	16.7	22.6
Potassium (K)	247.3	232.4	90.5
Magnesium (Mg)	5.2	5.4	7.4
Calcium (Ca)	80.1	71.5	207.3

RESULTS

The application of ash from burnt cereal and rape straw resulted in significant changes in some chemical properties of the studied light soil. Soil in the control pots throughout the study period was characterized by a neutral reaction (pH – 6.6). Introduction of cereal and rape straw ash into the soil caused a systematic increase in pH values in line with the applied dose of ash (Table 2). After the application of 2.68 $g \cdot kg^{-1}$ (calculated for 8.0 $Mg \cdot ha^{-1}$) of dry ash obtained from the straw of each of the studied plants, the pH value of the soil was at a level of 7.7-7.8.

In soil not fertilized with ash the content of phosphorus (P) available for plants was very high (135 $mg \cdot kg^{-1}$). A significant increase in the concentration of available phosphorus in soil as a result of ash application was observed already from a dose of 0.17 $g \cdot kg^{-1}$ (0.5 $Mg \cdot ha^{-1}$). The application of straw ash in doses 0.67; 1.34 and 2.68 $g \cdot kg^{-1}$ significantly increased the content of this element by 34, 53 and 85 $mg \cdot kg^{-1}$, respectively, which means an increase by 25.2%; 39.3% and 63.0% (Table 3). This experiment showed a significantly higher (by 7 $mg \cdot kg^{-1}$ i.e. by 4.3%) content of available phosphorus after mixing soil with rape straw ash than with barley straw ash. However, no significant interaction was found between the type and dose of ash. Additionally, a positive correlation between the content of available phosphorus and the dose of ash was confirmed.

Soil from the control treatment was characterized by a very high content of available potassium (173 $mg \cdot kg^{-1}$). The use of ash from cereal and rape straw caused a systematic increase in the content of this microelement that was dependent on the dose (Table 4). After the application of ash in an amount of 0.25 and 0.34 $g \cdot kg^{-1}$ the content of available potassium had increased significantly, by 73 $mg \cdot kg^{-1}$ (42.2%) and 117 $mg \cdot kg^{-1}$ (67.6%), respectively, in relations to the control treatment. And the application of ash in doses of 0.67; 1.34 and 2.68 $g \cdot kg^{-1}$ caused an increase in the content of available potassium by 227, 445 and 836 $mg \cdot kg^{-1}$, respectively, that is by 131%, 257% and 483%. In this study, a larger increase in the content of available potassium forms was noted after the application of cereal straw ash to the soil, as compared with the effect of application of ash from rape straw. Based on the statistical analysis of the study results, a positive correlation was observed between the content of potassium available for plants and the ash dose applied to the soil.

Ash from cereal and rape straw had a favourable effect on the content of magnesium available for plants. After the application of ash in a dose of 0.34 $g \cdot kg^{-1}$ the Mg content compared with the amount determined in soil without the application of ash increased significantly, by 4.4 mg·kg^{-1} (21.1%). After the application of ash in doses of 1.34 and 2.68 g·kg^{-1} soil the content of forms of this element available for plants increased significantly to the level that corresponds to a content of 34.6 and 40.4 mg·kg^{-1} (increased by 65.6% and 93.3%, respectively). This resulted in a change in the class of available magnesium abundance from low to medium for light soil (Table 5). In the experiment, it was found that the content of available magnesium was on average significantly higher, by 2.6 mg·kg^{-1} (by 10.1%), when rape straw ash was applied to the soil, in relation to barley straw ash. No interaction, however, was found between the studied factors. A positive correlation was observed in this experiment between the content of magnesium available for plants and dose of straw ash.

Table 2. pH in 1 M KCl in the soil fertilised with straw ash

Straw ash	The dose of ash, g·kg^{-1}							
	0	0.08	0.17	0.25	0.34	0.67	1.34	2.68
Barley	6.6	6.6	6.8	6.8	6.9	6.9	7.1	7.8
Wheat	6.6	6.7	6.9	6.9	7.0	7.0	7.2	7.7
Rape	6.6	6.8	6.9	7.0	7.0	7.0	7.3	7.7

Table 3. Content of available phosphorus in the soil fertilised with straw ash, mg·kg^{-1}

The dose of ash, g·kg^{-1} (B)	Straw ash (A)			Mean
	barley	wheat	rape	
0	135	135	135	135
0.08	139	143	142	141
0.17	146	152	153	150
0.25	151	158	160	156
0.34	155	167	167	163
0.67	160	175	172	169
1.34	184	186	194	188
2.68	221	218	219	220
Mean	161	167	168	165
$LSD_{0.05}$	A 7; B 14; A × B ns			
Coefficient of simple correlation	0.992	0.956	0.955	0.974

ns – non significant differences

Table 4. Content of available potassium in the soil fertilised with straw ash, mg·kg^{-1}

The dose of ash, g·kg^{-1} (B)	Straw ash (A)			Mean
	barley	wheat	rape	
0	173	173	173	173
0.08	197	181	187	188
0.17	234	209	190	211
0.25	273	254	211	246
0.34	307	308	256	290
0.67	471	436	292	400
1.34	714	743	397	618
2.68	1217	1176	633	1009
Mean	448	435	292	392
$LSD_{0.05}$	A 51; B 108; B × A 186; A × B 143			
Coefficient of simple correlation	0.999	0.996	0.997	0.998

Table 5. Content of available magnesium in the soil fertilised with straw ash, mg·kg^{-1}

The dose of ash, g·kg^{-1} (B)	Straw ash (A)			Mean
	barley	wheat	rape	
0	20.9	20.9	20.9	20.9
0.08	20.9	21.6	22.0	21.5
0.17	21.5	22.9	22.9	22.4
0.25	22.6	23.7	24.5	23.6
0.34	23.9	25.6	26.5	25.3
0.67	27.2	28.0	30.6	28.6
1.34	31.2	34.7	38.0	34.6
2.68	38.1	41.2	41.8	40.4
Mean	25.8	27.3	28.4	27.2
$LSD_{0.05}$	A 1.8; B 3.8; A × B ns			
Coefficient of simple correlation	0.988	0.983	0.951	0.976

DISCUSSION

Using renewable energy contained in plant biomass, including also arable crops, requires the identification, development and implementation of solutions that will allow the management of furnace waste as a substitute for mineral fertilizers (Meller *et al*., 2009; Vamvuka and Karakas, 2011). Due to the alkaline reaction of ashes, their application result in soil deacidification observed in studies (Ohno and Erich, 1990; Park *et al*., 2005), while the presence of nutrients easily available for plants indicates their potential for application in arable crop fertilization (Yeledhalli *et al*., 2008; Piekarczyk *et al*., 2011a; Vassilew *et al*., 2013). Fertilizer properties of ash have long been known, as it was the basis of slash-and-burn cultivation in primary agriculture. It is necessary, however, to thoroughly investigate the currently obtained ashes and their effect on soil and arable crops.

After the application of ashes in a dose higher than 0.34 $g \cdot kg^{-1}$ (corresponding to 1.0 $Mg \cdot ha^{-1}$) an increase in pH value was observed, and the abundance of available forms of phosphorus, potassium and magnesium in the soil also clearly increased. This indicates the relatively large availability of these components in ash, which has been confirmed also by other studies (Lima *et al*., 2008). The properties of straw ash enable rapid revelation of its effects after application and an increase in soil fertility (Park *et al*., 2005; Meller and Bilenda, 2012; Gibczyńska *et al*., 2014).

In the present experiment, small differences in the effect of particular types of ash on the abundance in soil of available phosphorus and magnesium were observed, mainly due to their chemical composition. However, large differences in the potassium content between cereal and rape ashes contributed to a differentiation of the available potassium content in soil. The range of changes in soil mineral abundance depends on the amount of ash introduced into soil, as well as on the source of its origin and elemental composition (Olanders and Steenari, 1995; Blander and Pelton, 1997; Bakisgan *et al*., 2009; Komorowicz *et al*., 2009). After the use of high ash doses in the present experiment, a clear increase in the content of potassium available for plants was observed. Therefore, ash from straw of the studied plants should be treated as a "potassium fertilizer", and the amount of a dose used in fertilization should be dependent on the content of potassium in it (Borkowska and Lipiński, 2007; Xiao *et al*., 2011; James *et al*., 2012; Piekarczyk *et al*., 2012). Also the lack of plants in the pots favoured very clear changes in the abundance in light soil of available forms of potassium, phosphorus and magnesium. In the situation where nutrients are taken up by arable crops, changes in soil mineral abundance will proceed in a different way as a result of the assimilation of macroelements by plants (Rautaray *et al*., 2003; Piekarczyk *et al*., 2015).

The high content of alkaline elements in biomass ashes guarantees effective deacidification, which is clearly visible after the application of doses of ash improving the soil fertility, exceeding 10-20 $Mg \cdot ha^{-1}$ (Park *et al*., 2005; Yeledhalli *et al*., 2008). The use of ash from straw or other plant biomass even in such large amounts is safe, since this material has a negligible natural content of trace elements, and these are mostly heavy metals (Olanders and Steenari, 1995; Pels *et al*., 2005; Piekarczyk *et al*., 2011a).

CONCLUSIONS

1. Ash from burnt barley, wheat and rape straw can act as a soil fertilizer. Its application results in deacidification of soil and an increase in the content of phosphorus, potassium and magnesium in forms available for plants.
2. Clear and systematic increase in the content of available forms of phosphorus, potassium and magnesium was observed after the application of ash doses from 0.34 $g \cdot kg^{-1}$ (1.0 $Mg \cdot ha^{-1}$) to 2.68 $g \cdot kg^{-1}$ (8.0 $Mg \cdot ha^{-1}$).
3. Ash from barley, wheat and rape straw in a similar way alkalised the soil environment and improved the abundance in soil of phosphorus and magnesium available for plants. High differences in the potassium content between cereal and rape ashes contributed to a differentiation of the available potassium content in soil.

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WPŁYW STOSOWANIA POPIOŁU ZE SŁOMY JĘCZMIENIA, PSZENICY I RZEPAKU DO GLEBY PIASZCZYSTEJ NA ZMIANY ODCZYNU GLEBY ORAZ ZAWARTOŚĆ PRZYSWAJALNYCH FORM FOSFORU, POTASU I MAGNEZU

Streszczenie

W latach 2010-2011 w Stacji Badawczej w Mochełku przeprowadzono eksperyment wazonowy, którego celem było określenie pH gleby oraz zawartości przyswajalnych dla roślin form fosforu, potasu i magnezu po zastosowaniu popiołu ze spalania słomy jęczmienia, pszenicy i rzepaku w dawkach od 0.08 do 2.68 $g \cdot kg^{-1}$ gleby, to jest odpowiadającym dawkom 0.25-8.0 $Mg \cdot ha^{-1}$. Wazony wypełniano materiałem glebowym (15 kg) o składzie granulometrycznym piasku gliniastego. Na podstawie dwuletnich badań stwierdzono, że popiół ze słomy jęczmienia, pszenicy i rzepaku może spełniać rolę nawozu doglebowego, ponieważ jego zastosowanie (w zależności od dawki i rodzaju popiołu) wpłynęło na zwiększenie wartości pH (z 6.6 do 7.7) oraz zawartości przyswajalnych form fosforu, potasu i magnezu. Różnice w skutkach aplikacji poszczególnych rodzajów popiołów wynikały z ich zróżnicowanego składu chemicznego oraz wielkości zastosowanej dawki.

Słowa kluczowe: fosfor, magnez, pH, popiół ze słomy, potas