sciendo
DOI: 10.2478/ssa-2018-0018

SOIL SCIENCE ANNUAL
Vol. 69 No. 3/2018: 177–183

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Influence of biomass ash, lime and gypsum fertilization on macro- and microelement contents in the soil and grains of spring wheat

Abstract: The addition of lime and gypsum to wood ash and straw ash were used in the studies. The subject of the study was estimation of the fertilization effect of biomass, ash, gypsum and lime on the content of macro- and microelements in soil and grain of spring wheat. The experiment was carried out in 2016 in the West Pomeranian Voivodeship in Poland. The study compared three factors: wood ash of deciduous and coniferous trees and cereal straw ash (I. factor), two types of ash additions: lime or gypsum (mixture composition: 60% ash and 40% lime or gypsum) (II. factor), three doses of ash with lime or gypsum mixture: 2, 4, 6 $Mg \cdot ha^{-1}$ and control (III. factor). The analysis of the microelements contents (copper, chromium, nickel and lead) in the soil shows that the application of fertilizer in a form of wood or straw ash as well as PROFITKALK lime or SulfoPROFIT gypsum did not exceed the threshold values for the soil from the first group of land specified in Regulation of the Minister of the Environment of September 1, 2016 on the manner of assessing the pollution of the earth's surface. After application of biomass ashes (wood or straw) an increase of some macroelements (potassium, phosphorus and calcium) in the soil was observed. The experiment did not reveal any influence of applied fertilization in the form of wood or straw ash nor PROFITKALK lime nor SulfoPROFIT gypsum on changes in iron, manganese and zinc abundance in grains of spring wheat.

Keywords: Biomass ash, lime, gypsum, macro- and microelements, soil properties, grain quality, spring wheat

INTRODUCTION

Fertilization of soil is supposed to maintain the correct soil parameters and to obtain good quality crop yields. Adjustment of the composition and quantity of applied fertilizers is an important factor that determines yields of the appropriate quality and maintenance of the correct condition of the cultivated soil. For this purpose, the use of biomass ash as a fertilizer becomes widespread (Ohno and Erich 1990, Park et al. 2005, Yeledhalli et al. 2008, Xiao et al. 2011, Piekarczyk 2013, Sharifi et al. 2013, Stankowski et al. 2014). Ash from biomass burning can be a valuable material for fertilizing the soil and plants. It contains potassium, phosphorus, magnesium and a number of micronutrients useful for plants and is characterized by high pH value. If the biomass is not contaminated, the amount of heavy metals usually does not exceed the established standards. However, the composition of biomass ash is often quite varied. Füzesi et al. (2015) point out that the application of wood ash can cause rapid changes in the chemical properties of the soil, especially in the top layer. Spring wheat does not belong to plants with a high demand for sulphur; however, its shortages adversely affect the use of nitrogen, which in consequence leads to a reduction in grain yield and quality.

Both of these raw materials are of post-industrial origin and have been registered and marketed. The purpose of adding the lime to the ash was to increase the de-acidification capacity of the soil, while gypsum, in addition to the introduction of lime and sulphur into the soil. The subject of the study was estimation of the fertilization effect of biomass, ash, gypsum and lime on the content of macro and microelements in soil and grain of spring wheat.

MATERIALS AND METHODS

Experimental characteristics

The experiment was carried out in 2016 in the village Noskowo (54°38′N, 16°82′S) located in the West Pomeranian Voivodeship in Poland. The soil was strong loamy sand characterized by pH_{H2O}=6.4, organic matter=49.0 $g \cdot kg^{-1}$, P_{avail}=27.0 $mg \cdot kg^{-1}$, $K_{avail.}$=197 $mg \cdot kg^{-1}$, $Mg_{exch.}$=165 $mg \cdot kg^{-1}$.

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The study compared three factors: wood ash of deciduous and coniferous trees and cereal straw ash (I. factor), two types of ash additions: lime or gypsum (mixture composition: 60% ash and 40% lime or gypsum) (II. factor), three doses mixture (2, 4, 6 $Mg \cdot ha^{-1}$) of ash with lime or gypsum and control (III. factor). Total number of experimental combinations was 12 and one control variant in two replications. Fertilization was carried out in autumn 2015. Ashes made of wood and straw were characterized by the following parameters (Table 1).

TABLE 1. The pH and contents of macro- and microelements ($mg \cdot kg^{-1}$) in wood and straw ash

Parameters	Type of ash	
	wood	straw
pH in H_2O	12.3	10.2
pH in KCl	12.5	10.0
Phosphorus /P	10 000	1 610
Potassium /K	6 790	80 900
Magnesium / Mg	6 360	3 900
Calcium / Ca	35 400	15 600
Iron / Fe	829	988
Manganese / Mn	9 220	351
Zinc / Zn	1 830	966
Miedź / Cu	157	61.2
Chrome / Cr	35.2	2.64
Lead / Pb	34.5	33.0
Nickel / Ni	26.4	2.97

The used lime fertilizer is a post-cellulose calcareous fertilizer, type 07, with the trade name PROFITKALK, which is imported by the Polish company Agro Trade Ltd. from Scandinavia. The lime contained in the fertilizer is carbonate and its content is 28.0% Ca. The fertilizer contains phosphorus and magnesium in the amounts of 0.25% P, 0.42% Mg (website 1). Another fertilizer lime form was gypsum with a market name SulfoPROFIT, which is a solid, dusty fertilizer with a Ca content of 19.3% and S 12.3%. The experiment was established applying a random block method in 2 replicates on strong loamy sand. The plot area was 500 m^2. The material for analysis was grain of a spring wheat cv. Żura (*Triticum aestivum var. Żura*), which belongs to the bread quality of group A. The wheat was bred by HRR "Nasiona Kobierzyce" Ltd., entered into the National Register of Varieties on February 01, 2002, while its registration will expire on December 31, 2022. It is a variety of wheat useful for milling and baking purposes. The forecrop was rape. Sowing date was on April 6, 2016. Nitrogen fertilizers were sown on April 2–4, 2016 in an amount of 70 kg N in urea form and on May 28, in an amount of 70 kg N in urea form per hectare. The wheat was harvested on August 15, 2016. Care treatments of the crop were carried out in accordance with the principles of Good Agricultural Practice.

Methodology of chemical analyses

The pH of soil was determined potentiometrically in accordance with the standard (ISO 10390/1997P). The amount of organic carbon was determined using oxidation with dichromate (VI) combined with sulphuric(VI) acid (ISO 14235:2003). The coefficient 1.724 was used to calculate the organic matter content. Nitrogen was determined in solutions after mineralization of soil samples in sulphuric (VI) acid with H_2O_2 by the Kjeldahl method (ISO 11261:2002). The available forms of phosphorus and potassium in the soil were determined using the Egner-Riehm method (Egner et al. 1960). In order to determine the exchangeable forms of magnesium and calcium contents in the soil, a buffered barium chloride solution was used (pH 8.1) (ISO 13536:2002P). When determining the total content of metals, potassium, calcium, magnesium, iron, manganese, zinc, sodium, nickel, lead, copper, cobalt, chromium and cadmium, soil samples and grains were wet mineralized in a mixture of nitric(V) and chloric(VII) acids at 1:1 ratio (ISO 6869:2000). Analyses were performed using Atomic Absorption Spectrometer (Thermo Fisher Scientific iCE 3000 Series). After mineralization of the grain in the solution of sulphuric(VI) acid in combination with H_2O_2, nitrogen content was determined using Kjeldahl method (ISO 20483:2013), whereas phosphorus content by means of colorimetric method using ammonium molybdate at 470 nm wavelength (ISO 6491:2000P).

Statistical analysis

Obtained results were statistically processed using the 3-factorial variance of random blocks analysis. Confidence intervals were calculated using Tukey's multiple test assuming significance level p=0.05. Statistical analysis of the results was performed applying the Statistica 10.0 software.

Climatic conditions

The Central Statistical Office assessing the meteorological conditions in the vegetation period in 2016 concluded that the weather in March was conducive to drying the fields and heating the soil as well as to vegetation growth. April's cool days with deficient precipitation inhibited the rate of growth and development of plants. The lack of rainfall caused that the water requirements of crops were not fully satisfied. At the beginning of May, warm and sunny weather favoured the growth and development of crops. As a result of spring rainfall deficiency, many crops have deteriorated. Rainfall recorded in June improved the condition of soil moisture level (website 2).

RESULTS AND DISCUSSION

The content of macro- and microelements in the soil

After the experiment was completed, the soil from the control object was characterized by a slightly acidic reaction of pH_{H2O} 6.31. The applied fertilizers were characterized by alkaline pH (Table 1), but no influence on the soil pH changes was observed during the study period (Tables 2, 3 and 4). Similarly, in previous studies, no alkalisation of soil fertilized with biomass ash and bio-compost BIOTOP was recorded (Gibczyńska et al. 2014). Explanation of the above relationships may be due to the fact that the largest alkalizing effect is noted in the second year after liming the soil (Gibczyńska 2000, Kotowska et al. 2003).

Soil organic matter is a basic indicator of soil quality that determines its physicochemical properties and biological processes. The average content of organic matter in the soil from the experiment was 46.5 $g \cdot kg^{-1}$, whereas nitrogen was 1.10 $g \cdot kg^{-1}$. Fertilization with ash, PROFITKALK lime and SulfoPROFIT gypsum did not affect any changes in the amount of these parameters in the soil (Tables 2, 3 and 4).

As a result of the large amount of phosphorus in the wood ash (Table 1), the available phosphorus content in the soil was increased to 28.4 $mg \cdot kg^{-1}$, which is 18.9% higher than that for the untreated soil. Application of the remaining fertilizer materials and increasing the doses did not cause significant changes in the amount of this macroelements in the experimental soil. In general, the wood has a high potassium content reaching 0.7% (Fromm, 2010). However, among the nutrients in the straw, the level of potassium is the highest at up to 1.7% counted as pure

TABLE 2. The pH and content of macro- and microelements in soil depending on the type of ash from biomass

Parameters	Control	Type of ash			
		wood	straw	average	$LSD_{0.05}$
pH in H_2O	6.31	6.30	6.36	6.33	n.s.
pH in KCl	6.00	6.26	5.96	6.11	n.s.
Organic matter [$g \cdot kg^{-1}$]	46.5	44.8	47.5	46.2	n.s.
Nitrogen / N [$g \cdot kg^{-1}$]	1.05	1.10	1.11	1.10	n.s.
Available phosphorus [$mg \cdot kg^{-1}$]	23.9	28.4	22.7	25.5	1.83
Available potassium [$mg \cdot kg^{-1}$]	195	203	241	222	22.1
Exchangeable calcium [$mg \cdot kg^{-1}$]	664	863	739	801	73.4
Exchangeable magnesium [$mg \cdot kg^{-1}$]	154	160	166	163	n.s.
Iron / Fe [$g \cdot kg^{-1}$]	10.6	10.2	10.5	10.4	n.s.
Manganese / Mn [$mg \cdot kg^{-1}$]	364	427	443	435	40.5
Zinc / Zn [$mg \cdot kg^{-1}$]	35.6	36.5	34.5	35.5	n.s.
Copper / Cu [$mg \cdot kg^{-1}$]	5.64	7.28	7.79	7.53	n.s.
Chrome / Cr [$mg \cdot kg^{-1}$]	18.5	15.7	18.6	17.2	n.s.
Nickel / Ni [$mg \cdot kg^{-1}$]	12.3	13.3	12.0	12.7	n.s.
Lead / Pb [$mg \cdot kg^{-1}$]	11.1	11.9	12.3	12.1	n.s.

n.s. – not significant difference.

TABLE 3. The pH and content of macro- and microelements in soil depending on the type of fertilizer

Parameters	Control	Type of fertilizer		
		lime	gypsum	$LSD_{0.05}$
pH in H_2O	6.31	6.31	6.35	n.s.
pH in KCl	6.00	6.12	6.10	n.s.
Organic matter [$g \cdot kg^{-1}$]	46.5	45.5	46.8	n.s.
Nitrogen / N[$g \cdot kg^{-1}$]	1.05	1.08	1.13	n.s.
Available phosphorus [$mg \cdot kg^{-1}$]	23.9	26.0	25.0	n.s.
Available potassium [$mg \cdot kg^{-1}$]	195	223	220	n.s.
Exchangeable calcium [$mg \cdot kg^{-1}$]	664	778	824	n.s.
Exchangeable magnesium [$mg \cdot kg^{-1}$]	154	172	154	14.7
Iron / Fe [$g \cdot kg^{-1}$]	10.6	10.6	10.2	n.s.
Manganese / Mn [$mg \cdot kg^{-1}$]	364	452	418	42.2
Zinc / Zn [$mg \cdot kg^{-1}$]	35.6	36.6	34.4	n.s.
Copper / Cu [$mg \cdot kg^{-1}$]	5.64	7.30	7.77	n.s.
Chrome / Cr [$mg \cdot kg^{-1}$]	18.5	17.4	17.1	n.s.
Nickel / Ni [$mg \cdot kg^{-1}$]	12.3	13.6	11.8	n.s.
Lead / Pb [$mg \cdot kg^{-1}$]	11.1	12.1	12.1	n.s.

n.s. not significant difference.

TABLE 4. The pH and content of macro- and microelements in soil depending on the amount of ash dose

Parameters	Control	Ash dose [t·ha^{-1}]			
		2.0	4.0	6.0	$LSD_{0.05}$
pH in H_2O	6.31	6.29	6.34	6.35	n.s.
pH in KCl	6.00	6.08	6.15	6.11	n.s.
Organic matter [g·kg^{-1}]	46.5	46.3	45.9	46.3	n.s.
Nitrogen / N [g·kg^{-1}]	1.05	1.11	1.06	1.14	n.s.
Available phosphorus [mg·kg^{-1}]	23.9	23.2	25.2	28.2	n.s.
Available potassium [mg·kg^{-1}]	195	203	213	249	33.2
Exchangeable calcium [mg·kg^{-1}]	664	722	766	915	110.3
Exchangeable magnesium [mg·kg^{-1}]	154	166	156	166	n.s.
Iron / Fe [mg·kg^{-1}]	10.6	10.4	10.3	10.4	n.s.
Manganese / Mn [mg·kg^{-1}]	364	424	422	459	42.8
Zinc / Zn [mg·kg^{-1}]	35.6	36.4	33.8	36.4	n.s.
Copper / Cu [mg·kg^{-1}]	5.64	6.84	8.06	7.71	0.772
Chrome / Cr [mg·kg^{-1}]	18.5	18.1	15.0	18.6	n.s.
Nickel / Ni [mg·kg^{-1}]	12.3	12.9	12.2	12.9	n.s.
Lead / Pb [mg·kg^{-1}]	11.1	12.1	10.9	13.2	n.s.

n.s. not significant difference.

element. Olanders and Steenari (1995) report that the potassium content in straw ash was 3 times higher than in wood ash. A large amount of potassium in wood and straw has a direct effect on the content of this element in the ash. In the experiment, the straw ash contained much more potassium (Table 1), which was a factor causing a significant increase in the available potassium content in the soil to 241 mg·kg^{-1} and at an increased dose of to 249 mg·kg^{-1}. In the experiment, the soil was characterized by very high abundance of available potassium (Egner et al. 1960).

Unlike potassium, the wood contains more calcium than straw and it is the range from 0.8 to 2.7 g·kg^{-1} (Szász-len et al. 2016). As a result of ash fertilization, a significant increase in the amount of exchangeable calcium in the soil (respectively by 30% and 11%) was achieved. Using the maximum dose of fertilizers in the amount of 6.0 Mg·ha^{-1}, as much as 38% increase in the amount of exchangeable calcium in the soil was recorded. The obtained results are confirmed by a series of works by other authors (Merino et al. 2006, Ochecova et al. 2014). After the wheat harvest, the content of exchangeable magnesium in the soil from the control object was 154 mg Mg·kg^{-1} of soil (Table 2). The application of wood or straw ash as well as increasing the dose did not significantly change the amount of this macroelement in the experimental soil, which ranged from 156 to 166 Mg·kg^{-1} of soil (Tables 2 and 4). The use of lime fertilizer PROFITKALK resulted in an increase in the exchangeable magnesium content in the soil by 11%, which is the result of fertilizer composition (Table 3).

Iron, due to the concentration in which it occurs in soils, is in the intermediate position between macro- and microelements. In the arable layer of the soil, the iron content average was 3,5% (Kabata-Pendias 2011). The amount of iron in the soil from experiment was at the level of 10 g Fe·kg^{-1} of soil and no effect of the applied fertilization on changes in the soil fertility with respect to iron, was recorded (Tables 2 and 4).

Manganese and iron undergo similar geochemical processes. Manganese is an element for which no permissible limit values characterizing the soil are given. Kabata-Pendias (2011) states that manganese content in worldwide soils varies from 411 to 550 mg Mn·kg^{-1}. The content of manganese in wood biomass ash is in the range from 4.5 to 5.5 g Mn·kg^{-1} DM (Ciesielczuk et al. 2011). The amount of manganese in the control variant soil amounted to 364 mg Mn·kg^{-1} of soil. The fertilization applied in all ariants resulted in an increase in the soil content maximum to 459 mg Mn·kg^{-1}, which was the result of higher manganese content in ash as compared to soil abundance (Tables 1, 2, 3 and 4).

Total zinc in sandy soils ranges within 7–150 mg Zn·kg^{-1} of soil (Kabata-Pendias 2011). The average zinc content in the soil of the non-fertilized variant was approximately 35 mg Zn·kg^{-1} of soil. The applied fertilization did not increase its amount in the experimental soil.

The copper content in the soil of control object reached 5.64 mg Cu·kg^{-1} of soil. The amount of total copper in wood ash was about thirty times higher than in the experimental soil, while in straw ash – 10-fold higher (157 and 61.2 mg Cu·kg^{-1}, respectively). Increasing the fertilizer dose to 4.0 and 6.0 t·ha^{-1} resulted in statistically confirmed 40% increase in copper content in the soil (Table 4). Similar results were obtained by Piekarczyk et al. (2013) by examining contents of copper and zinc in sandy soil fertilized by barley, wheat and rape straw ash.

According to Kabata-Pendias (2011), average amount of the following microelements in soil (chromium, nickel and lead) is: 60.0 mg Cr·kg^{-1}, 29.0 mg Ni·kg^{-1}, 27.0 mg Pb·kg^{-1}. Soil from the experiment was characterized by lower contents of these metals, i.e. 18.5, 12.3 and 11.1 mg·kg^{-1} of soil respectively.

No influence of the applied fertilizers presence on changes in the soil abundance in chromium, nickel and lead was recorded (Tables 2, 3 and 4). Analysed samples of experimental soil contain cadmium and cobalt below the limit of quantification.

Analysis of individual microelements in the experimental soil reveals that despite of this fertilization, the soil still fulfils requirements for the first class grounds specified in Regulation of the Minister of the Environment of September 1, 2016 on the way of assessing the pollution of the earth's surface (Dz. U. from 2016 pos. 1395).

Contents of macro- and microelements in grains of spring wheat

The content of mineral components in wheat grain depends on cultivar specific characteristics as well as soil-climatic and agrotechnical conditions (Woźniak and Makarski 2012). The standard wheat cv. Tonacja is characterized by macroelements contents in grain dry matter at the levels of: phosphorus 3.8 g·kg^{-1}, potassium 4.2 g·kg^{-1}, magnesium 1.3 g·kg^{-1}, and calcium 0.34 g·kg^{-1} (Rachoń and Szumiło 2009). Assessment of these macroelements in grains of wheat reveals that it was very similar to the standard. The obtained results of this investigation indicate a lack of significant differences in grain yield independent of fertilizing variants.

The amount of sodium in wheat grain amounted from 0.0416 to 0.046 g·kg^{-1}, which was lower than the range reported by Souci et al. (2008) – 66–90 g·kg^{-1}. Changes in the macroelement contents in the soil due to the fertilization using wood ash, straw ash, lime and gypsum did not cause any changes in their levels in grain of wheat.

The appropriate amount of micro elements in wheat grain is a qualitative feature; their deficiency remarkably alters its nutritional value. Iron is considered the key metal in energy transformations needed for syntheses and other life processes of cells (Kabata-Pendias 2011). Iron content in wheat grain varies depending on the cultivar and ranges from 21.9 to 40.3 mg Fe·kg^{-1} (Pieczyńska et al. 2011, Woźniak and Makarski 2012). The iron quantity determined in wheat grains cv. Żura was from 30.5 to 40.3 mg Fe· kg^{-1} (Tables 5, 6 and 7), which is comparable to the abundance of the standard cv. Tonacja (Rachoń and Szumiło 2009).

Skinner et al. (2005) reported that its transport across the soil-root interface is in the reduced, Mn^{2+}, state, apparently in a way similar to that of other divalent cation species such as Mg^{2+} and Ca^{2+}. And

TABLE 5. Content of macro- and microelements in wheat grains depending on the type fertilizer

Parameters	Control	Type of fertilizer			
		wood ash	straw ash	average	$LSD_{0.05}$
Nitrogen /N [g·kg^{-1}]	24.1	23.8	23.5	23.7	n.s.
Phosphorus /P [mg·kg^{-1}]	5.48	5.00	5.20	5.10	n.s.
Potassium /K [mg·kg^{-1}]	4.23	4.36	4.42	4.39	n.s.
Calcium / Ca [mg·kg^{-1}]	0.50	0.50	0.58	0.54	n.s.
Magnesium / Mg[mg·kg^{-1}]	1.19	1.19	1.19	1.19	n.s.
Sodium/ Na [mg·kg^{-1}]	40.6	43.4	45.4	44.4	n.s.
Iron / Fe [mg·kg^{-1}]	29.6	24.2	30.5	27.4	n.s.
Manganese / Mn [mg·kg^{-1}]	11.8	11.8	12.9	12.3	n.s.
Zinc / Zn [mg·kg^{-1}]	36.6	35.6	35.7	35.6	n.s.

TABLE 6. Content of macro- and microelements in wheat grains depending on the type of fertilizer

Parameters	Type of fertilizer		
	lime	gypsum	$LSD_{0.05}$
Nitrogen /N [g·kg^{-1}]	23.8	23.5	n.s.
Phosphorus /P [mg·kg^{-1}]	5.02	5.19	n.s.
Potassium /K [mg·kg^{-1}]	4.44	4.34	n.s.
Calcium / Ca [mg·kg^{-1}]	0.56	0.53	n.s.
Magnesium / Mg [mg·kg^{-1}]	1.23	1.16	n.s.
Sodium/ Na [mg·kg^{-1}]	43.3	45.5	n.s.
Iron / Fe [mg·kg^{-1}]	29.0	25.8	n.s.
Manganese / Mn [mg·kg^{-1}]	11.8	12.8	n.s.
Zinc / Zn [mg·kg^{-1}]	35.8	35.5	n.s.

TABLE 7. Content of macro- and microelements in wheat grains depending on the ash dose

Parameters	Control	Type of fertilizer			
		wood ash	straw ash	average	$LSD_{0.05}$
Nitrogen /N [g·kg^{-1}]	24.1	23.8	23.5	23.7	n.s.
Phosphorus /P [mg·kg^{-1}]	5.48	5.00	5.20	5.10	n.s.
Potassium /K [mg·kg^{-1}]	4.23	4.36	4.42	4.39	n.s.
Calcium / Ca [mg·kg^{-1}]	0.50	0.50	0.58	0.54	n.s.
Magnesium / Mg[mg·kg^{-1}]	1.19	1.19	1.19	1.19	n.s.
Sodium/ Na [mg·kg^{-1}]	40.6	43.4	45.4	44.4	n.s.
Iron / Fe [mg·kg^{-1}]	29.6	24.2	30.5	27.4	n.s.
Manganese / Mn [mg·kg^{-1}]	11.8	11.8	12.9	12.3	n.s.
Zinc / Zn [mg·kg^{-1}]	36.6	35.6	35.7	35.6	n.s.

n.s. not significant difference.

in such a form, this element was supplied to the soil along with the ash. The range of manganese contents for wheat grown in Poland, according to Szteke et al. (2004), is 24–29 mg Mn·kg^{-1}. Rachoń and Szumiło (2009) reported that manganese content in grain of wheat cv. Tonacja amounted to 36.9 mg Mn·kg^{-1}. Grain of experimental cv. Żura contained only one-third of that amount, i.e. 12.3 mg Mn·kg^{-1}, on average. In general, iron and manganese are interrelated in their metabolic functions. The present experiment did not show any impact of applied fertilization on the iron and manganese abundance in grain of wheat (Tables 5, 6 and 7).

Soluble forms of Zn are readily available to plants, and the uptake of Zn has been reported to be linear with metal concentration in the nutrient solution and in soils (Kabata-Pendias 2011). The lack of influences of applied fertilization on changes in zinc content in wheat grains are an effect of analogous dependence referring to this soil parameter (Tables 5, 6 and 7). Average zinc content in wheat was 35.6 mg Zn·kg^{-1}, which was at the same level as for grain of wheat cv. Tonacja (34.9 mg Zn·kg^{-1}) (Rachoń and Szumiło 2009).

CONCLUSIONS

1. Fertilization using ash, lime PROFITKALK and gypsum SulfoPROFIT had no effect on the change in the reaction and organic matter contents as well as nitrogen in experimental soils.
2. Using wood ash characterized by high content of phosphorus caused significant increase in its soil level.
3. Application of straw ash as a fertilizer resulted in a soil characterized by very high available potassium abundance, which results from very high concentration of this element in the straw ash.
4. As a result of fertilization with wood or straw ash, a significant increase in the exchangeable calcium content of the soil was observed, and the increase in dose was a factor leading to an even greater fertilizer efficiency.
5. The use of ash from wood or straw as well as an increase in the dose did not cause significant changes in the amount of exchangeable magnesium in experimental soil. The presence of fertilizer in the form of PROFITKALK lime was a factor causing an increase in the content of exchangeable magnesium in the soil.
6. The analysis of the microelements contents (copper, chromium, nickel and lead) in the soil shows that the application of fertilizer in a form of wood or straw ash as well as PROFITKALK lime or SulfoPROFIT gypsum did not exceed the threshold values for the soil from the first group of land specified in Regulation of the Minister of the Environment of September 1, 2016 on the manner of assessing the pollution of the earth's surface.
7. The experiment did not reveal any influence of applied fertilization in the form of wood or straw ash nor PROFITKALK lime nor SulfoPROFIT gypsum on changes in iron, manganese, and zinc abundance in wheat grains.

ACKNOWLEDGMENTS

The work was financed from research contract no.515-07-037-72-02-05/15.

REFERENCES

Ciesielczuk T., Kusza G., Nemś A., 2011. Fertilization with biomass ashes as a source of trace elements for soils. Ochrona Środowiska i Zasobów Naturalnych 49: 219–227 (in Polish).

Egner H., Riehm H., Domingo W., 1960. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. Chemische Extraktions – methoden zur Phosphor – und Kalium Bestimmung. Kungliga Lantbrukshögskolans Annaler 26: 199–215.

Fromm J., 2010. Wood formation of trees in relation to potassium and calcium nutrition. Tree Physiology 30(9): 1140–1147.

Füzesi I., Heil B., Kovács G., 2015. Effects of Wood Ash on the Chemical Properties of Soil and Crop Vitality in Small Plot Experiments. Acta Silvatica & Lignaria Hungarica 11(1): 55–64.

Gibczyńska M., 2000. The long lasting effects of liming on soil chemical properties in sandy soil. (Ed.), AR Szczecin: 1–112 pp. ISSN 0239-6467 (in Polish).

Gibczyńska M., Stankowski S., Hury G., Kuglarz K., 2014. Effect of limestone, ash from Biomass and Compost Use on Chemical Properties of Soil. Soil Science Annual 65(2): 59–64.

ISO 10390/1997P Soil quality – Determination of pH.

ISO 11261:2002 Soil quality – Determination of total nitrogen – Modified Kjeldahl method.

ISO 13536:2002P Soil quality – Determination of the potential cation exchange capacity and exchangeable cations using barium chloride solution buffered at pH=8.1.

ISO 14235:2003 Soil quality – Determination of organic carbon by sulfochromic oxidation.

ISO 20483:2013 Cereals and pulses – Determination of the nitrogen content and calculation of the crude protein content – Kjeldahl method.

ISO 6491:2000P. – Animal feeding stuffs – Determination of phosphorus content – Spectrometric method.

ISO 6869:2000. – Animal feeding stuffs – Determination of the contents of calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc – Method using atomic.

Kabata-Pendias A., 2011. Trace elements in soil and plants. (Ed.), 4. CRC Press, Taylor&Francis 280: 253–254 pp.

Kotowska J., Gibczyńska M., Wybieralski J., 2003. Long of Duration of the Influence of Liming on Soil Reaction and Exchangeable Aluminium Content in Soil. Chem. Inżynieria Ekologiczna 10(S1): 91–99 (in Polish).

Merino A., Otero W., Omil B., Lastra B., Pińero V., Gallego P.P., 2006. Application of wood ash compared with fertigation for improving the nutritional status and fruit production of kiwi vines. Journal of Plant Nutrition and Soil Science 169(1): 127–133.

Ochecova P., Tlustos P., Szakova J., 2014. Wheat and Soil Response to Wood Fly Ash Application in Contaminated Soils. Agronomy Journal 106(3): 995–1002.

Ohno T., Erich M.S., 1990. Effect of wood ash application on soil pH and soil test nutrient levels. Agriculture, Ecosystems and Environment 32: 223–239.

Olanders, B., Steenari, B.M., 1995. Characterization of ashes from wood and straw. Biomass Bioenergy 8(2): 105–115.

Park B.B., Yanai R.D., Sahm J.M., Lee D.K., Abrahamson L.P., 2005. Wood ash effects on plant and soil in a willow bioenergy plantation. Biomass Bioenergy 28: 355–365.

Pieczyńska J., Prescha A., Weber R., Biernat J., Grajeta H., 2011. The effect of cultivation intensity on mineral content in grain, flakes and bran of winter wheat (*Triticum aestivum* L.) preliminary study. Roczniki PZH 62(2): 199–203 (in Polish).

Piekarczyk M., 2013. Effect of winter wheat straw ash on the some macro- and microelements available forms content in light soil. Fragmenta Agronomica 30(1): 92–98.

Piekarczyk M., Kobierski M. Kotwica K., 2013. Contents of copper and zinc in sandy soil fertilized by barley, wheat and rape straw ash. Soil Science Annual 64: 93–97 (in Polish).

Rachoń L., Szumiło G., 2009. Comparison of chemical composition of selected winter wheat species. Journal of Elementology 14(1): 135–146.

Regulation of the Minister of the Environment of September 1, 2016 on the way of assessing the pollution of the earth's surface (Dz.U. from 2016 pos. 1395).

Sharifi M., Cheema M., Mahoney K., LeBlanc L., Fillmore S., 2013. Evaluation of liming properties and potassium bioavailability of three Atlantic Canada wood ash sources. Canadian Journal of Plant Science 93: 1209–1216.

Skinner W.M., Martin R.R., Naftel S.J., Macfie S., Courchesne F., Seguin V., 2005. Multi-technique studies of the distribution of metals between the soil, rhizosphere and roots of Populus tremuloides growing in forest soil. ICOBTE, 8 International Conferance Book Abstract Adelaide: 488–489.

Souci S.W., Fachmann W., Kraut H., 2008. Food Composition and Nutrition Tables, 7th revised and completed edition. 7th Edition MedPharm Taylor & Francis 1300 pp., ISBN 9780849341410.

Stankowski S., Hury G., Gibczyńska M., Jurgiel-Małecka G., 2014. Impact of lime, biomass ash and compost as well as preparation of em applications on grain yield and yield components of wheat. Inżynieria Ekologiczna 38: 17–25.

Szász-len A.M., Holonec L., Pamfil D., 2016. Mineral Substances in Stem Wood Tissue of European Beech (*Fagus sylvatica* L.). ProEnvironment 9: 41–55.

Szteke B., Jędrzejczak R., Ręczajska W., 2004. Iron and manganese in selected edible plants. Annales of National Institute of Hygiene, Supplement 55: 21–27 (in Polish).

Woźniak A., Makarski B., 2012. Content of minerals in grain of spring wheat cv. Koksa depending on cultivation conditions. Journal of Elementology 17(3): 517–523.

Xiao R., Chen X., Wang F., Yu G., 2011. The physicochemical properties of different biomass ashes at different ashing temperature. Renewable Energy 36: 244–249.

Yeledhalli N.A, Prakash S.S., Ravi M.V., Narayanarao K., 2008. Long-term effect of fly ash on crop yield and soil properties. Karnataka Journal of Agricultural Sciences 21(4): 507–512.

website 1: http://agrotradegrupa.com/pl/produkty/wapno-profit-kalk

website 2: http://old.imgw.pl/extcont/biuletyn_monitoringu/.

Received: April 23, 2018
Accepted: September 24, 2018
Associated editor: B. Rutkowska

Wpływ nawożenia popiołem z biomasy, wapnem i gipsem na zawartość makro- i mikroskładników w glebie oraz ziarnie pszenicy jarej

Streszczenie: W przeprowadzonych badaniach oprócz popiołu z drewna i popiołu ze słomy zastosowano wapno oraz gips. Tematem badań było działanie materiału nawozowego na zmiany zawartości makro- i mikroskładników w glebie oraz w ziarnie pszenicy jarej. Doświadczenie zrealizowano w roku 2016 we wsi Noskowo, zlokalizowanej w powiecie sławieńskim w województwie zachodniopomorskim. W badaniach porównywano trzy czynniki: popiół z drewna drzew liściastych i iglastych oraz popiół ze słomy zbożowej (I. czynnik), 2 rodzaje dodatku do popiołu: wapno lub gips (skład mieszaniny: 60% popiołu i 40% wapna lub gipsu) (II. czynnik), 3 dawki mieszaniny popiołu z wapnem lub gipsem: 2, 4, 6 $t \cdot ha^{-1}$ oraz kontrola (III. czynnik). Z analizy zawartości w glebie mikroskładników (miedzi, chromu, niklu i ołowiu) wynika, że zastosowanie materiału nawozowego, w postaci popiołów z drewna lub słomy oraz wapna PROFITKALK lub gipsu SulfoPROFIT, nie spowodowało przekroczenia wartości progowych dla gleby z pierwszej grupy gruntów określonych w rozporządzeniu Ministra Środowiska z dnia 1 września 2016 roku w sprawie sposobu prowadzenia oceny zanieczyszczenia powierzchni ziemi. Ogólnie po zastosowaniu popiołów z biomasy (drewno lub słoma) stwierdzono wzrost zawartości w glebie wybranych makroskładników (potas, fosfor i wapń). W zrealizowanym doświadczeniu nie stwierdzono wpływu zastosowanego nawożenia w postaci popiołów z drewna lub słomy oraz wapna PROFITKALK lub gipsu SulfoPROFIT, na zmiany zasobności żelaza, manganu i cynku w ziarnie pszenicy.

Słowa kluczowe: popiół z biomasy, wapno, gips, makro- i mikroskładniki, właściwości gleby, jakość ziarna pszenicy