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CHANGES IN MACRO- AND MICROELEMENTS CONTENT IN SOIL AS WELL AS GRAINS OF WINTER WHEAT OF RGT KILIMANJARO CV. (*TRITICUM AESTIVUM VAR. KILIMANJARO*) UNDER THE INFLUENCE OF BIOMASS ASH AND LIME FERTILIZATION

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Abstract

Present paper analyzes the effect of biomass ash and lime fertilization on changes in macro- and microelements content in soil and in winter wheat grain of RGT Kilimanjaro cv. (*Triticum aestivum var. Kilimanjaro*). Fertilization with wood or straw ash had no influence on changes in the pH and content of organic carbon, nitrogen and available phosphorus in the soil from experiment. As a result of fertilization with ash from wood or straw, a significant increase in the soil abundance was achieved in relation to: available potassium and exchangeable calcium. Increasing the dose was a factor that resulted in even higher efficiency of fertilizers. Analysis of the content of microelements in the soil (copper, chromium, nickel and lead) shows that the application of fertilization in the form of wood or straw ashes and lime PROFITKALK did not exceed the threshold values for soil from the first group of ground Results concerning the impact of ashes from wood or straw and lime PROFITKALK on changes in the content of macro- and microelements indicate that when cultivating wheat of Kilimanjaro cv., it is justified to use them as a fertilizing material.

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Introduction

Ashes from biomass are increasingly treated as a fertilizer. The biomass ash is one of the oldest mineral fertilizers. They contain almost all nutrients except nitrogen (FÜZESI et al. 2015, ZAPAŁOWSKA et al. 2017). The impact of used ashes from wood and straw of crops is the subject of many studies emphasizing the beneficial effect on both the quality of soil and plants (BAKISGAN 2009, SCHIEMENZ and EICHLER-LÖBERMANN 2010, PIEKARCZYK et al. 2017, OCHECOVA et al. 2014, BRADNA et al. 2016).

The composition of ash from biomass is generally very diverse and depends on the type of biomass combusted (PIEKARCZYK et al. 2011, PIEKARCZYK et al. 2017). The reduction in the resources of biomass from forestry and the wood industry induces attempts to look for other plant materials that constitute energy, as for example straw. In Poland, it is predicted that in 2020 year straw production will amount 30.5 million tones, of which 17.4 million tones will be used for agricultural purposes, and the remaining 13.1 million tones may be used for energy purposes (MADEJ 2016). Literature data indicate higher calcium and magnesium contents in wood ash as compared to straw ash (KAJDA-SZCZEŚNIAK 2014).

As you know use of biomass ash can cause changes in soil chemical properties, especially in the upper layer. The use of ash is possible only if it does not threaten the quality of the soil and the obtained crops of plants are of good quality.

Winter wheat of RGT Kilimanjaro cv. is a cultivar recently introduced into cultivation, which justifies conducting thorough studies on the impact of using different fertilizers on changes in the chemical composition of the grain.

Present paper analyzes the effect of biomass ash from wood and ash from straw and lime fertilization on changes in macro- and microelements content in soil and in wheat grain of RGT Kilimanjaro cv. (*Triticum aestivum var. Kilimanjaro*).

Materials and Methods

Experimental characteristics

The experiment was carried out in 2016 in Wrześnica (54°40’N, 16°77’E), the Sławno County in the West Pomeranian province. The study compared two factors: wood ash and straw ash (I. factor), 4 doses of ash and lime mixture (mixture composition in the proportion of 70% ash and

30% lime) (factor II). The subsequent doses were as follows: *a* – 0; *b* – 7 + 2.1; *c* – 14 + 4.2; *d* – 21 + 6.3 Mg ha^{-1}. The fertilizer lime used is a calcium post-cellulose fertilizer, variety 07, with the trade name PROFITKALK and imported by the Polish company Agro Trade Ltd. from Scandinavia. The lime contained in the fertilizer is in the form of carbonate and its content is 28.0% Ca. The fertilizer contains phosphorus and magnesium in the amount of 0.25% P i 0.42% Mg (*Wapno PROFITKALK…* 2019). Value of pH and content of macro- and microelements in ash from wood and straw are given in Table 1.

Table 1

Value of pH and content of macro- and microelements in ash from wood and straw

Parameter	Type of ash	
	wood	straw
pH in H_2O	12.3	10.2
pH in KCl	12.5	10.0
g kg^{-1}		
Phosphorus/P	13.6	20.8
Potassium/K	6.8	80.9
Calcium/Ca	35.4	15.6
Magnesium/Mg	6.4	3.9
mg kg^{-1}		
Iron/Fe	8290	988
Maganese/Mn	9220	351
Zinc/Zn	1830	966
Copper/Cu	157	61.2
Chrome/Cr	35.2	2.64
Lead/Pb	34.5	33.0
Nickel/Ni	26.4	2.97

Fertilization was applied in autumn 2015 before wheat sowing, on 25 September. The experiment was established by means of a random block method in 4 replicates The soil was loamy sand (USDA 2006). The soil from the experiment was characterized by the following parameters: pH_{KCl} = 6.4, C_{org} = 11.0 g kg^{-1}, P_{avail} = 37.0 mg kg^{-1}, $K_{avail.}$ = 177 mg kg^{-1}, $Mg_{exch\ .}$= 165 mg kg^{-1}. It was the soil contained an average level of available phosphorus and potassium and very high exchangeable magnesium (EGNER et al. 1960, *Soil quality…* ISO 13536:1995).

The area of the plot was 500 m^2. Material for analysis consisted of winter wheat of Kilimanjaro cv. grain (*Triticum aestivum var. Kilimanjaro*). In Poland, winter wheat RGT Kilimanjaro has been entered into the National Register of Varieties on 19.09.2014 and the expiration date is

31.12.2024 (Polish National List of Agricultural Plant Varieties 2017). RGT Kilimanjaro is currently one of the highest yielding winter wheat cultivars available in Poland; it is very highly evaluated for winter hardiness – the score 4 classifies it in the forefront of the most winter-resistant cultivars. Good quality results of the grain resulted in qualifying it to the quality group *A*.

Wheat was grown on a post after winter oilseed rape. Nitrogen fertilizers were sown on 2 April 4, 2016 in an amount of 120 kg of ammonium sulfate (25.5 kg of N) and 300 kg of urea, (140 kg of N) per ha and on May 28 – 150 kg of urea (70 kg of N) per hectare. Wheat was harvested on August 15, 2016. Care treatments for sowing were carried out in accordance with the principles of Good Agricultural Practice.

Methodology of chemical analyses

Soil samples were taken after winter wheat rape harvest, using Egner-Riehm's cane from a 0–20 cm layer in accordance with the standard (*Analiza chemiczno-rolnicza*… PN-R-04031:1997) from each plot. The pH of the soil was determined potentiometrically in accordance with the standard (*Soil quality*… ISO 10390:1997). The amount of organic carbon was determined using dichromate(VI) oxidation and combined with sulfuric(VI) acid (*Soil quality*… ISO 14235:1998). Nitrogen was determined in solutions after mineralization of soil samples and in sulfuric(VI) acid with H_2O_2 by means of Kjeldahl method (*Soil quality*… ISO 11261:2002). Available forms of phosphorus and potassium in the soil were determined using the Egner-Riehm method (Egner et al. 1960). In order to determine exchangeable forms of magnesium and calcium contents in the soil, a buffered barium chloride solution was used (pH = 8.1) (*Soil quality*… ISO 13536:1995). Determining the total content of metals: potassium, calcium, magnesium, iron, manganese, zinc, sodium, nickel, lead, copper and chromium in soil samples and grains were wet digested in a mixture of nitric(V) and chloric(VII) acids at 1:1 ratio (*Animal feeding*… ISO 6869:2000). Analyses were performed using the Atomic Absorption Spectrometer Apparatus (Thermo Fisher Scientific iCE 3000 Series). After grain mineralization in sulfuric(VI) acid in combination with H_2O_2, nitrogen content was determined applying the Kjeldahl method (*Cereals and pulses*… ISO 20483:2013) and phosphorus by the colorimetric method using ammonium molybdate at 470 nm (*Animal feeding*… ISO 6491:1998).

Statistical treatment of data

The results were statistically processed using the variance analysis in a 2-factor system of random blocks. Confidence sub-intervals were calculated using Tukey's multiple test, assuming a significance level of $p = 0.05$. In addition, the analysis of variance with regression for the quantitative factor – the dose of mixture – was performed for selected soil features. The significance of regression equations was determined using the F-Fisher-Snedecor test. Regression lines are shown in diagrams. Statistical analysis of results was carried out using the Statistica 10.0 software.

Climatic conditions

The fairly high air temperature maintained in November 2015, on the one hand, created favorable conditions for emergence, growth and development of winter crops, on the other hand, deficiencies of moisture in the soil occurring in this period caused weaker growth of plants before winter. January frosts in the absence of snow cover, caused losses in winter cereal crops. The weather course in February 2016 posed a slight threat to plants, and the high temperature of air and soil that persisted during the month caused disturbances in the winter dormancy of plants. Weather in March favored drying up of fields and heating the soil, as well as vegetation. The cold rainy days occurring in April inhibited the growth and development of plants. Shortage of rainfall caused that the water needs of crops were not fully satisfied. The warm and sunny weather at the beginning of May favored the growth and development of plants. As a result of the spring shortage of rainfall, the condition of many crops has deteriorated. Rainfall recorded in June improved the condition of soil moisture (*Serwis IMGW-PIB*... 2019).

Results and Discussion

Soil acidity, organic carbon and nitrogen in soil

After the experiment was completed, the soil from the control object was characterized by slightly acidic reaction – pH in KCl = 6.36 (*Soil quality*... ISO 10390:1997P). The introduced fertilizing materials were characterized by alkaline reaction (Table 1), however, fertilization with ash from wood or straw did not cause soil alkalization (Table 2). As a result of the use of combined fertilization with ash and lime PROFITKALK, however, an increase in the soil pH to 6.75 was recorded (Table 3 and Figure 1). The alkalizing effect of lime as a fertilizer is confirmed in the literature on this subject (Eichler-Löbermann et al. 2008, Gibczyńska et al. 2014, Goulding 2016).

Table 2

Value of pH and content of macro- and microelements in the soil depending on the type of ash

Parameter	Control	Type of ash			
		wood	straw	average	$LSD_{0.05}$
pH in KCl	6.36	6.61	6.62	6.62	n.s.
$g\ kg^{-1}$					
Organic carbon	12.5	12.6	12.7	12.6	n.s.
Nitrogen/N [$mg\ kg^{-1}$]	0.94	0.97	1.01	0.99	n.s.
Iron/Fe	8.21	8.62	8.73	8.67	n.s.
$mg\ kg^{-11}$					
Available phosphorus/P_{avail}	37.2	40.8	39.4	40.1	n.s.
Available potassium/K_{avail}	173	210	225	217	18.3
Exchangeable calcium/Ca_{exch}	780	1020	946	983	105.3
Exchangeable magnesium/Mg_{exch}	188	205	177	191	n.s.
Manganese/Mn	470	458	447	452	n.s.
Zinc/Zn	40.7	40.9	39.8	40.3	n.s.
Copper/Cu	6.19	6.37	6.74	6.56	n.s.
Chrome/Cr	21.2	21.2	20.7	20.9	n.s.
Nickel/Ni	7.47	8.09	7.00	7.54	n.s.
Lead/Pb	13.1	15.0	10.7	12.8	1.729

n.s. – not significant difference

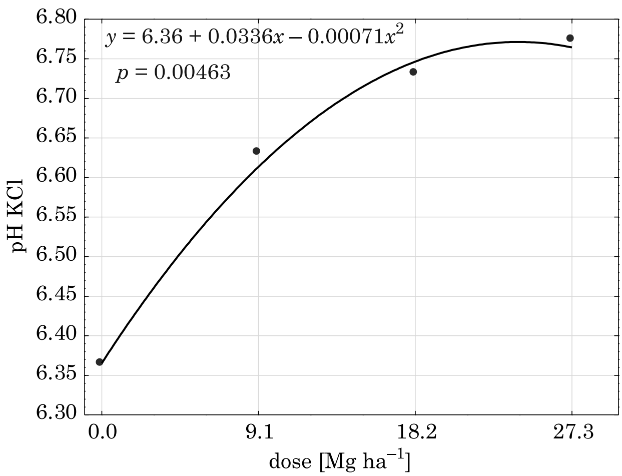

Fig. 1. Regression equation between dose of mixture and pH in the soil

The average organic carbon content in the soil from the experiment was 12.5 g C kg^{-1} while the nitrogen content was 0.94 g N kg^{-1}. Fertilization with biomass ashes and PROFITKALK lime did not affect changes in the amount of these parameters in the soil (Table 2 and Table 3).

Table 3

Value of pH and content of macro- and microelements in the soil depending on the ash doses

Parameter	Dose of ash [Mg ha^{-1}]					
	0	7 + 2.1	14+4.2	21+6.3	average	$LSD_{0.05}$
pH in KCl	6.36	6.63	6.73	6.75	6.62	0.283
g kg^{-1}						
Organic carbon	12.5	12.4	12.6	13.0	12.6	n.s.
Nitrogen/N	0.937	1.046	1.010	0.957	0.987	n.s.
Iron/Fe	8.21	9.20	8.57	8.72	8.67	n.s.
mg kg^{-1}						
Available phosphorus/P_{avail}	37.2	41.5	42.2	44.4	41.3	4.53
Available potassium/K_{avail}	173	219	232	246	217	45.3
Exchangeable calcium/Ca_{exch}	780	1009	1039	1104	983	226.4
Exchangeable magnesium/Mg_{exch}	188	191	195	193	192	n.s.
Manganese/Mn	470	440	454	447	452	n.s.
Zinc/Zn	40.7	40.6	40.1	40.0	40.3	n.s.
Copper/Cu	6.19	6.34	7.32	6.39	6.56	n.s.
Chrome/Cr	21.2	21.8	20.2	20.6	20.9	n.s.
Nickel/Ni	7.47	7.58	6.76	8.37	7.54	n.s.
Lead/Pb	13.1	12.2	12.6	13.5	12.8	n.s.

n.s. – not significant difference

Available phosphorus and potassium in soil

The content of available phosphorus in the soil from the experiment was 37.2 mg P kg^{-1}. Ashes from biomass were characterized by relatively large amount of this element (Table 1), however, there was no effect of their presence on changes in the amount of phosphorus available to plants in the soil. Soil alkalization resulting from the use of lime was a factor responsible for a dose-proportional, significant increase in available phosphorus to the level of 44.4 mg P kg^{-1} (Table 2 and Figure 2).

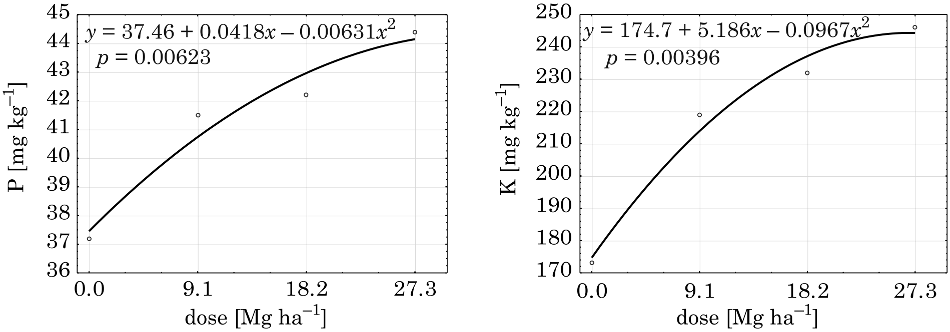

Fig. 2. Regression equation between dose of mixture and phosphorus and potassium content in the soil

In the experiment, ash from straw contained about ten times more potassium than wood ash (Table 1). For comparison, JAGUSTYN et al. (2011) show that the potassium content in ash from straw was as much as 19.9%. The abundance of ashes relative to potassium was a factor causing significant increase in the content of available potassium in the soil, after the completion of Kilimanjaro cv. wheat cultivation to 225 mg K kg^{-1}. As a result of a gradual increase in the doses of both fertilizer materials, the amount of available potassium in the soil amounted to 246 mg K kg^{-1} and the soil was characterized by very high available potassium level (Table 2 and Figure 2).

Exchangeable calcium and magnesium

Unlike potassium, wood contains more calcium than straw, and it ranges from 0.8 to 2.7 g K kg^{-1} (SZÁSZ-LEN et al. 2016) and the above dependence is reflected in the abundance of ashes (Table 1). As a result of fertilization using ash, a significant increase in the amount of exchangeable calcium in the soil was obtained: by 31 and 21%, respectively.

By using the combined fertilization with PROFITKALK ash and lime, a proportional significant increase in the content of exchangeable calcium in the soil was observed by as much as 41% at the maximum dose (Table 3 and Figure 3). FÜZESI et al. (2015) explain the above relationship that the calcium oxide present in fertilizers getting into the soil, in combination with water, transforms into calcium hydroxide. The hydroxide reacts with carbon dioxide from the air, which results in the formation of more easily soluble calcium carbonate. Higher amount of magnesium in wood ash, as a result of its use as a fertilizer, caused significant increase in the content

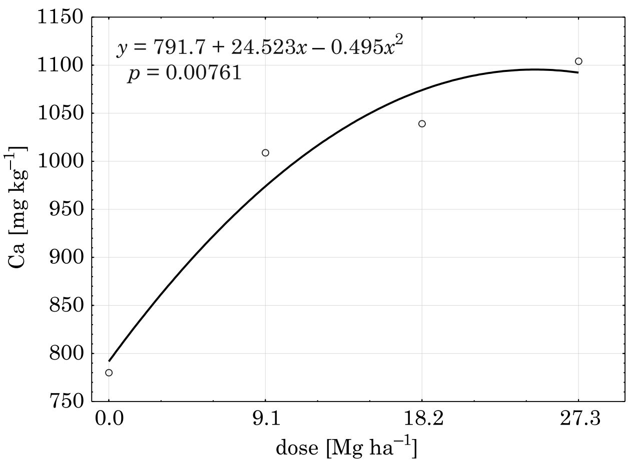

Fig. 3. Regression equation between dose of ash and calcium content in the soil

of this macroelements from 188 to 205 g Mg kg^{-1} of soil (Table 2). The increase in ash doses in combination with lime was not reflected in changes in the amount of exchangeable magnesium in the soil from experiment (Table 3). PROFITKALK fertilizer in its composition contains little magnesium (0.7% MgO) and the increase in soil pH value as a result of fertilization may be a factor that inhibits the solubility of magnesium compounds.

Iron, manganese, zinc, copper, chromium, nickel and lead

Manganese and iron undergo analogous geochemical processes. The amount of iron in wood ash was many times higher than in ash from straw. The soil from the experiment was characterized by an iron content of 8.21 g Fe kg^{-1} and manganese 470 mg Mn kg^{-1} soil.

Wood ash contained twice as much zinc as compared with straw ash, i.e. 1830 and 966 mg Zn kg^{-1}. General abundance of zinc in light soils varies between 7 and 150 mg Zn kg^{-1} soil (KABATA-PENDIAS 2011). The average content of zinc in the soil of variant without fertilization was low – about 35 mg Zn kg^{-1} soil.

The amount of total copper in wood ash was about twenty times higher than in the studied soil, whereas in ash straws – tenfold and were respectively 157 and 61.2 mg Cu kg^{-1}. Soil from the control object contained much less copper, i.e. 6.19 mg Cu kg^{-1} soil.

Wood ash is richer in terms of chromium in comparison with ash from straw (Table 1). The content of chromium in soils is generally low. The range of mean concentrations of chromium varies from 7 to 150 mg Cr kg^{-1} and its content and distribution in the soil largely depends on the type of the soil's mother rock (JANKIEWICZ and PTASZYŃSKI 2005). The amount of chromium in the soil from the experiment was 20.0 mg Cr kg^{-1} and it was lower than the average content of 60.0 mg Cr kg^{-1} soil (KABATA-PENDIAS 2011).

Nickel plays an important role in regulating the assimilation of free nitrogen in soil by bacteria; its content in the soil from the control object was 7.47 mg Ni kg^{-1} soil, and this is a level many times lower than permissible standard for the first class soil (Rozporządzenie Ministra Środowiska… DZ.U. 2016, pos. 1395).

Soil fertilization with biomass ashes, as well as increasing their doses in combination with lime did not cause significant changes in the soil fertility in relation to iron, manganese, zinc, copper, chromium and nickel.

The average amount of lead in Poland's soils is 27.0 mg Pb kg^{-1} soil (KABATA-PENDIAS 2011). Soil from the experiment was characterized by lower lead content, i.e. 13.1 mg Pb kg^{-1} soil. As a result of soil fertilization with wood ash, an increase in lead in soil by 15% was obtained. As a result of soil fertilization with straw ash, an decrease in lead in soil by 18% was obtained. In view of the results of lead content in soil as a result of fertilization with biomass ashes, there is no indication against their use as fertilizers.

Macro and microelements in Kilimanjaro winter wheat grain

KOZLOVSKÝ et al. (2009) reported that the average amount of nitrogen in wheat grain is 2.18%. The content of nitrogen in the wheat grain from the experiment was on a similar level, i.e. 23.8 g N kg^{-1}. The lack of influence of ash fertilization from biomass and lime on changes in soil was confirmed by uniform amount of nitrogen in wheat grain cultivated in the experiment (Table 4 and Table 5).

Table 4

Content of macro- and microelements in the wheat grains depending on the type of ash from biomass

Parameter	Control	Type of ash			
		wood	straw	average	$LSD_{0,05}$
Nitrogen/N [g kg^{-1}]	23.4	23.8	23.8	23.8	n.s.
mg kg^{-1}					
Phosphorus/P	4.40	4.25	4.65	4.45	0.346
Potassium/K	3.90	3.86	4.04	3.95	n.s.
Calcium/Ca	0.467	0.539	0.535	0.537	n.s.
Magnesium/Mg	1.02	1.02	1.00	1.01	n.s.
Sodium/Na	38.1	38.5	38.1	38.3	n.s.
Iron/Fe	25.9	29.1	28.2	28.7	n.s.
Manganese/Mn	7.21	7.96	6.02	6.99	1.15
Zinc/Zn	31.6	27.7	29.2	28.4	n.s.
Lead/Pb	0.047	0.055	0.055	0.055	n.s.

n.s. – not significant difference

Table 5

Content of macro- and microelements in the wheat grain depending on the ash doses

Parameter	Dose of ash [Mg ha^{-1}]					
	0	7 + 2.1	14+4.2	21+6.3	average	$LSD_{0.05}$
Nitrogen/N [g kg^{-1}]	23.4	23.9	24.1	23.8	23.8	n.s.
mg kg^{-1}						
Phosphorus/P	4.40	4.56	4.46	4.38	4.45	n.s.
Potassium/K	3.90	4.08	3.84	3.98	3.95	n.s.
Calcium/Ca	0.467	0.551	0.559	0.571	0.537	n.s.
Magnesium /Mg	1.02	1.05	0.99	0.99	1.01	n.s.
Sodium/Na	38.1	37.5	37.4	40.3	38.3	n.s.
Iron/Fe	25.9	30.6	30.1	28.0	28.7	n.s.
Manganese/Mn	7.21	6.53	6.90	7.31	6.99	n.s.
Zinc/Zn	31.6	27.9	26.7	27.6	28.4	n.s.
Lead/Pb	0.047	0.054	0.056	0.063	0.055	0.011

n.s. – not significant difference

The standard wheat of Tonacja cv. is characterized by the content of macroelements in the dry mass of grain in the amount of: phosphorus 0.38%, potassium 0.42%, magnesium 0.13% and calcium 0.034% (RACHOŃ and SZUMIŁO 2009). Assessment of the abundance of the aforementioned macroelements in grain cultivated in the Kilimanjaro wheat cultivar shows that it was very similar to data characterizing the standard wheat, with the exception of phosphorus, the content of which was higher. Changes due to fertilization, soil content, available phosphorus and potassium, and exchangeable calcium and magnesium were not reflected in the abundance of wheat grain of Kilimanjaro cv.

The amount of sodium in Kilimanjaro wheat grain was on average 38.3 mg Na kg^{-1} which was, close to 32 mg Na kg^{-1} given by NABIPOUR et al. (2007) for wheat of Chamran cv.

Content of iron in wheat grain varies and depends on the cultivar ranging from 21.9 to 40.3 mg Fe kg^{-1} (WOŹNIAK and MAKARSKI 2012). The amount of iron determined in the wheat grain of Kilimanjaro cv. was on the level from 25.9 to 30.6 mg Fe kg^{-1} (Tables 4 and Table 5).

The average content of zinc in wheat was 28.4 mg Zn kg^{-1} which was at a lower level than in wheat grain of Tonacja cv. (34.9 mg Zn kg^{-1}) (RACHOŃ and SZUMIŁO 2009).

The lack of influence of the applied fertilization on changes in the amount of iron and zinc in the wheat grain results from an analogous dependence on this parameter in the soil (Table 2–5).

The range of manganese content for wheat cultivated in Poland according to SZTEKE et al. (2004) is 24–29 mg Mn kg^{-1}. Grain of Kilimanjaro wheat cultivated in the experiment contained one fourth of this value, on average 6.99 mg Mn kg^{-1}. Many times smaller amount of manganese in ash from the straw compared to wood ash probably caused a reduction of this element in the grain to the level of 6.02 mg Mn kg^{-1} (16%) (Table 4).

Wheat grain cultivated in the control object contained 0.047 mg Pb kg^{-1}. Increasing the ash doses in combination with lime resulted in a 34% increase in the amount of lead in grain, and its maximum content was 0.063 mg Pb kg^{-1} (Table 5). Permissible lead content in cereals and legumes determined in COMMISSION REGULATION (EU) 2015/1005 of 25 June 2015 amending Regulation (EC) No. 1881/2006 as regards maximum levels of lead in certain foodstuffs, amounts to 0.2 mg Pb kg^{-1}, therefore, there are no contraindications for introducing ashes from biomass or lime into the soil (Official Journal of the European Union L 161/9. 26.6.2015).

Conclusions

1. Fertilization with wood or straw ash had no influence on changes in the pH and content of organic carbon, nitrogen and available phosphorus in the soil from experiment.

2. As a result of fertilization with ash from wood or straw, a significant increase in the soil abundance was achieved in relation to: available potassium and exchangeable calcium. Increasing the dose was a factor that resulted in even higher efficiency of fertilizers.

3. As a result of soil fertilization with wood ash, an increase and straw ash, an decrease in lead in soil and was obtained.

4. The presence of lime fertilizer PROFITKALK was a factor causing as the dose increases proportional in the content of available phosphorus, potassium and exchangeable calcium in the soil.

5. Analysis of the content of microelements in the soil (copper, chromium, nickel and lead) shows that the application of fertilization in the form of wood or straw ashes and lime PROFITKALK did not exceed the threshold values for soil from the first group of ground defined in the Regulation of the Minister of Environment of 1 September 2016 on the way of assessing the pollution of the earth's surface.

6. Results concerning the impact of ashes from wood or straw and lime PROFITKALK on changes in the content of macro- and microelements indicate that when cultivating wheat of Kilimanjaro cv., it is justified to use them as a fertilizing material.

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