MARZENA GIBCYŃSKA*¹, SŁAWOMIR STANKOWSKI², GRZEGORZ HURY²
KRZYSZTOF KUGLARZ²

¹*Zakład Chemii Ogólnej i Ekologicznej, ²Katedra Agronomii
Zachodniopomorski Uniwersytet Technologiczny w Szczecinie, 71-434 Szczecin, Słowackiego 17, Poland*

Effects of limestone, ash from biomass and compost use on chemical properties of soil

Abstract: The aim of this research was to assess the use of biomass ash for fertilisation of mineral soil. The study involves the analysis of the effects of biomass ash applied to soil on the changes of pH and the content of the available forms of phosphorus, potassium and magnesium as well as on total content of zinc, copper, manganese, nickel, cadmium and lead. The field experiment was conducted in 2013 in Duninowo near Ustka. In experiment grown two plants spring: Spring barley – var. Sebastian, and wheat – var. Bombona. The use of ash from biomass and Biotop compost as fertilisers did not result in any significant changes of soil pH. The use of ash from biomass and Biotop compost caused a significant increase in the contents of available phosphorus, potassium and magnesium in soil. The threshold values of the analysed trace elements in soil, as specified by the Regulation of the Minister of Environment, were not exceeded in any of the fertilising variants in the experiment.

Key words: ash from biomass, Biotop compost, macroelements, trace elements, soil properties

INTRODUCTION

Waste produced as a result of intensive urbanisation and industrialisation processes must be adequately managed in order to prevent contamination of environment. Biomass is a waste material which can be processed by means of combustion as a result of which energy is produced and the obtained ash can become a valuable raw material for fertilisation or soil recultivation purposes (Kalembasa et al. 2008; Antonkiewicz 2009). Obtained ash is to be treated as mineral waste. The Regulation of the Minister of Environment of 5 April 2011 on R10 recovery process (Dz.U. 2011 No. 86, item 476) specifies the conditions of the recovery by means of distribution on the surface of ground for soil fertilisation or enhancement purposes. Ash originating from biomass includes fly ash from peat and untreated wood not subjected to chemical treatment, code: 10 01 30. The conditions specified in the regulation must be met in order to use the ash. Waste is to be applied only to soils in which the admissible values of concentration of the substances, as specified in the Regulation of the Minister of Environment of 9 September 2002 on soil and land quality standards, are not exceeded (Dz.U. 2002 No. 165, item 1359). It should be used in such a way and in such amount so as not to exceed the admissible values of heavy metals concentration (Cr, Pb, Cd, Hg, Ni, Zn, Cu), as specified in the Regulation

of the Minister of Environment of 13 July 2010 on municipal sewage sludge (Dz.U. 2010 No. 137, item 924), even in long term use. The use of waste must also meet the requirements concerning the admissible values of pollutants for calcium and calcium-magnesium fertilisers as specified in the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 on implementation of some provisions of the Act on fertilisers and fertilisation (Dz.U. 2008 No. 119, item 765). In order to determine the dosage of waste to be applied to soil in congruence with the provisions of the Act, a research should be carried out by the producers of waste in the laboratories which have the accreditation certificate or the certificate of the implementation of a quality management system within the meaning of the Act of 30 August 2002 on the system of assessment of compliance (Dz.U. 2004 No. 204, item 2087).

The aim of this research was to assess the use of biomass ash for fertilisation of mineral soil. The assessment was based on the comparison of the effect of fertilisation with biomass ash with the effect of BIOTOP compost. The study involves the analysis of the effects of biomass ash applied to soil on the changes of pH and the content of the available forms of phosphorus, potassium and magnesium as well as on total content of zinc, copper, manganese, nickel, cadmium and lead.

* marzena.gibczynska@zut.edu.pl

MATERIALS AND METHODS

The field experiment was conducted in 2013 in Duninowo near Ustka. Based on data from the Regional Agrochemical Station in Koszalin soil defined as agronomically light.

Factors examined were variants of fertilization and 2 species of spring cereals – barley and wheat (Table 1). Spring barley – variety Sebastian, and wheat – variety Bombona were sown on 26th April 2013 in the amount of 170 kg·ha⁻¹. During the vegetation period the following has been used: Pragma herbicide (25g·ha⁻¹), Soprano fungicide (0.4 dm³·ha⁻¹), magnesium sulphate(VI) and manganese sulphate(VI) in the amount of 1kg·ha⁻¹. Fertilisation with nitrogen and sulphur was the same for both of spring corn species – 170 and 25 kg respectively per hectare. Such fertilization is used because of the clearer demonstration of the effect of fertilizers examined. The analysis in order to characterise soil parameters was done after harvesting.

TABLE 1. Fertilisation variant number and components used

Variant	Fertilization
1	Control
2	Lime 3.0 t·ha ⁻¹
3	Ash from biomass 1.5 t·ha ⁻¹
4	Lime 3.0 t·ha ⁻¹ +ash from biomass 1.5 t·ha ⁻¹
5	Ash from biomass 1.5 t·ha ⁻¹ +Biotop compost 20 t·ha ⁻¹
6	Lime 3.0 t·ha ⁻¹ +ash from biomass 1.5 t·ha ⁻¹ +Biotop compost 20 t·ha ⁻¹

The soils pH_{KCl} was determined potentiometrically according to PN-ISO 10390/1997 standards. The available forms of phosphorus and potassium in soil were determined using Egner-Riehm method (PN-R-04023:1996; PN-R-04022:1996; PN-R-04020:1994/ Az1:2004) Available magnesium was determined by means of extraction with calcium chloride(II) (PN-R-04020:1994). The soil samples were analysed in the certified laboratory of the Regional Agrochemical Station in Szczecin. Total content of zinc, copper, manganese, nickel, cadmium and lead was determined by means of mineralisation of the samples in the mixture of nitric(V) and chloric(VIII) acids followed by measurements done with the use of atomic absorption spectrometry SOLAAR AA SERIES.

The statistical analysis was done using the two-factor analysis of variance, and confidence half-intervals (LSD_{0.05}) were calculated using Tukey's test. Statistica ver.10 software was used for the calculations.

Characteristics of lime

The lime fertiliser used in the experiment was a postcellulose lime fertiliser, variety 07, brand name PROFITKALK. The analysis of lime was done in the Main Laboratory of Chemical Analysis of the Institute of Soil Science and Plant Cultivation in Puławy (IUNG). Approximate 3 kg of solid sample of light-gray colour was handed over to the laboratory on 09th July 2012. The calcium content expressed as CaO was 39.2%. The content of the metals in dry mass of lime was the following: lead < 5.0 mg Pb·kg⁻¹, cadmium <1.0 mg Cd·kg⁻¹.

Characteristics of biomass ash

On the basis of the Regulation of the Minister of Environment of 22 April 2011 on emission standards for installations (Dz.U. 2011 No. 95, item 558), biomass is to be understood as products comprising plant substances from agriculture or forestry origin incinerated in order to recover energy. The biomass ash used in this experiment was obtained from the combustion of wood material.

The analysis of ash from biomass was done in the Central Laboratory of the Institute of Industrial Areas in Katowice. The granulometric composition of ash was determined using the aerometric analysis by Prószyński and was the following: the content of sand fraction 32% d.m., silt fraction 41% d.m. and clay fraction 27% d.m. The findings allowed for determining the soil classification of ash – heavy loam.

Ash pH (in water) was 13.2. The content of available phosphorus expressed as mg P·kg⁻¹ d.m was < 0.04, available potassium –89g K·kg⁻¹. The content of available magnesium in the analysed ash from biomass was 1.2 g Mg·kg⁻¹. The content of the remaining metals in dry mass of ash was the following: zinc 563 mg Zn·kg⁻¹, copper 78.9 mg Cu·kg⁻¹, nickel 23.7 mg Ni·kg⁻¹, chromium 15.4 mg Cr·kg⁻¹, lead 12.1 mg Pb·kg⁻¹, cadmium 2.7 mg Cd·kg⁻¹, arsenic 2.0 mg As·kg⁻¹, mercury < 0.4 mg Hg·kg⁻¹.

The characteristics of Biotop compost

The Biotop compost was produced by Water Pipelines Ltd. in Słupsk. The composted ingredients were the following: straw 32%, stabilised sediment 32%, green waste 25%, bark waste 11%. The content of the product is the following: nitrogen, phosphorus and potassium – 2.5, 1.0, 0.2% respectively. The content of metals does not exceed the following values: zinc 600 mg Zn·kg⁻¹, copper 40 mg Cu·kg⁻¹, nickel 9.5 mg Ni·kg⁻¹, chromium 5.0 mg Cr·kg⁻¹, lead 20.0

mg Pb·kg⁻¹, cadmium 0.8 mg Cd·kg⁻¹, mercury < 0.01 mg Hg·kg⁻¹. The compost's pH (in water) was 7.4. Applied compost meets the standards for organic fertilizers in terms of the macro and micro ingredients (Norma Branzowa BN-89 9103-08 Kompost kl. 1)

Meteorological data

The content of macrocomponents in soil in assimilable forms is to a large extent determined by the amount of precipitation which provides adequate moisture content especially during the vegetation period. The vegetation period of 2013 was assessed as moist due to precipitation in May and June which markedly exceeded the long-term average (www.ogimet.com).

RESULTS AND DISCUSSION

Soil pH, content available phosphorus, potassium and magnesium in soil

The pH of non-fertilised soils on which spring barley and wheat were cultivated was near-neutral (7.1 and 6.6). Soil deacidification as a result of combustion waste use has been widely acclaimed in the literature on the subject (Ciećko et al. 2009; Gibczyńska et al. 2009). Both for barley as well as wheat the use of lime combined with ash from biomass (var. 4) resulted in the highest pH values, yet the increase was not significant (Table 2). This can be partly attributed to the fact that the experiment was carried out during one vegetation period and the changes in soil pH as a result of the use of deacidifying fertilisers are recorded in the following years (Gibczyńska et al. 2007).

After the harvest of barley and wheat the content of available phosphorus in non-fertilised soil was 49.9 and 32.2 mg P·kg⁻¹ of soil, using the 5-point grading scale the content of available phosphorus in soil was determined as medium (Table 2). The analysis of the effect of the ash from biomass and Biotop compost on soil shows the increase in available phosphorus content and has been confirmed by the results of the statistical calculations. In previously conducted studies have shown that (Gibczyńska and Siwek 2012) the use of sewage sludge fertilization together with straw significantly increased the exchangeable content of magnesium in the soil beddings.

As a result of fertilization with lime combined with ash and Biotop compost (var. 6) the increase of mean content of available phosphorus was the highest – most probably due to increased content of this element in the compost which during cultivation trans-

TABLE 2. Changes in soil pH, content of available phosphorus, potassium and magnesium depending on the variant of fertilizer, (F)

Macro-elements	Variant	Plant species		Average
		Barley	Wheat	
Reaction pH in KCl	1	7.1	6.6	6.78
	2	7.2	6.0	6.27
	3	6.9	6.7	6.79
	4	7.3	7.1	7.19
	5	7.1	6.4	6.62
	6	7.0	7.0	7.00
	Average	7.1	6.7	6.77
LSD _{0.05} for		F – n.s.; S – 0.39		
Available phosphorus (mg P·kg ⁻¹)	1	49.9	32.2	41.1
	2	43.0	27.1	35.1
	3	34.8	53.7	44.3
	4	65.4	36.1	50.8
	5	48.2	72.2	60.2
	6	50.7	82.1	66.4
	Average	48.7	50.6	49.7
LSD _{0.05} for		F – 5.3		
Available potassium (mg K·kg ⁻¹)	1	106.0	107.1	106.6
	2	115.4	102.9	109.2
	3	114.5	143.6	129.1
	4	113.7	107.9	110.8
	5	109.6	163.5	136.6
	6	149.4	129.5	139.5
	Average	118.1	125.7	121.9
LSD _{0.05} for		F – 15.0		
Available magnesium (mg Mg·kg ⁻¹)	1	52.2	32.4	42.3
	2	60.0	34.8	47.4
	3	61.2	42.0	51.6
	4	64.8	36.0	50.4
	5	72.0	53.4	62.7
	6	72.0	48.6	60.3
	Average	63.7	41.2	52.5
LSD _{0.05} for		F – 12.2		

formed to a greater degree into form that is easily assimilable for plants (Table 2).

After the harvest of the plants the content of available potassium in non-fertilised soil was 106.0 and 107.1 mg K·kg⁻¹ of soil respectively (Table 2). Using the 5-point grading scale the content of available potassium in soil was determined as medium. The content of assimilable potassium in biomass ash used in the experiment was also reflected in a significant increase in the content of available form of this macrocomponent in soil (var. 3, 5 and 6). Moreover, the results of the analysis do not allow for determination of other relationships between the fertilizing variants applied in the experiment and the changes of available potassium content in soil.

Magnesium is well assimilable for plants in the form of Mg²⁺ ion in soil solution and as such is adsorbed exchangeable with cations. After the harvest of barley and wheat the content of available magnesium in soil on which lime fertilizer has not been

used was 52.2 and 32.4 mg Mg·kg⁻¹ of soil (Table 2). Using the 5-point grading scale the content of assimilable magnesium in soil was determined as high. Higher content of available magnesium in ash used for fertilisation caused the increase in the content of this element in soil. However, the effect of fertilisation with ash from biomass was not so evident due to high initial content of available magnesium in soil. The use of Biotop compost led to an increase in the content of available magnesium in soil of fertilising variants 5 and 6. The maximum content of this element was recorded in soil with spring barley – 72.0 mg Mg·kg⁻¹ of soil. Similarly, the results by Piekarczyk et al. (2011) indicate that the use of ash from spring barley straw in the pot experiment resulted in a significant increase in the content of assimilable forms of phosphorus, potassium as well as magnesium in light soil. Sadej and Namiotko (2010) applying for fertilization of composted urban green waste, an increase in concentrations of available phosphorus, potassium and magnesium in soil was noted. In the first year after the application. Total content of manganese, zinc, lead, nickel, copper and cadmium in soil

The ability to assimilate the trace elements depends on various factors, mainly pH of the environment. Due to their solubility at low pH levels manganese and zinc can accumulate in soil in amounts which are toxic for plants. At high pH levels the trace elements can become immobilised in soil. The trace elements are mostly elements indispensable for physiological functions of both plants and people. According to the current state of knowledge only cadmium and lead do not play a role in any physiological functions (Chaney et al. 2000). The content of trace elements is determined for agricultural purposes using the three grading scale of their content – low, medium and high (Świącicki 2001).

Manganese plays a significant role in photosynthesis and respiration. It is present in soil in large amounts – from 20 to 5000 mg per 1 kg of soil. Average content of manganese in soil of the control variant was 340 mg Mn·kg⁻¹ of soil. The use of ash from biomass resulted in the increase of the content of this element in soil due to the greater content of manganese in ash than in the soil under experiment (Table 3). The content of manganese in ash from wood biomass ranged from 5462 to 45197 mg Mn·kg⁻¹ d.m. (Ciesielczuk 2011). The admissible threshold values of manganese content in soil are not determined.

Unlike cadmium and lead, zinc is an indispensable element which plays a significant role in metabolism. Low pH values of soil facilitate the assimilation of zinc by plants and other organisms. Therefore, the

application of soil alkalising fertilisers facilitates the accumulation of this element in soil. Total content of zinc in sandy soil ranges from 7 to 150 mg Zn·kg⁻¹ of soil (Kabata-Pendias 2011). Despite the increase in content of this element in soil following the use of fertilizers, the threshold value 300 mg Zn·kg⁻¹ (Dz.U. 2002 No. 165, item 1359) was not exceeded in any of the variants of the experiment (Table 3).

The results of the analysis conducted by IUNG indicate that the natural lead content in soils for example, the Wielkopolska Region does not exceed 20 mg Pb·kg⁻¹ (Świącicki 2001). The content of lead in control soil was approximately 8.0 mg Pb·kg⁻¹ of soil. The content of lead in the fertilizers used in the experiment was similar to that of the soil under experiment. It should be noted that the amount of lead in soil under experiment varied greatly from 1.4 to 14.6 mg Pb·kg⁻¹ of soil. However, the threshold value of 100 mg Pb·kg⁻¹ of soil (Dz.U. 2002 No. 165, item 1359) was not exceeded in any of the variants of the experiment (Table 3). No markedly direct influence of the used fertilizers on the content of lead in soil was found.

The content of nickel in soil is determined mostly by its content in bedrock. Nickel is an essential element which takes part in many physiological processes of plants; it also regulates the processes of free-nitrogen binding by soil bacteria. Nickel mobility in soil depends on its granulometric and mineralogical

TABLE 3. Changes in soil content of manganese, zinc and lead depending on the variant of fertilizer, (F)

Trace elements	Variant	Plant species		Average
		Barley	Wheat	
Manganese (mg Mn·kg ⁻¹)	1	316	365	340
	2	377	405	391
	3	391	423	407
	4	518	392	455
	5	401	428	414
	6	405	631	518
	Average	401	441	421
LSD _{0.05} for F – n.s.;				
Zinc (mg Zn·kg ⁻¹)	1	84.4	44.7	64.5
	2	88.3	47.5	67.9
	3	90.3	54.3	72.3
	4	104.7	48.1	76.4
	5	100.7	58.3	79.5
	6	101.5	56.5	79.0
	Average	95.0	47.5	71.2
LSD _{0.05} for F – n.s.;				
Lead (mg Pb·kg ⁻¹)	1	14.1	2.0	8.0
	2	13.1	2.1	7.6
	3	13.4	4.8	9.1
	4	13.5	1.4	7.4
	5	14.6	3.2	8.9
	6	12.2	5.4	8.8
	Average	13.5	3.1	8.3
LSD _{0.05} for F – n.s.;				

composition, pH and the content of organic matter (Siebielec 2012). Mean content of nickel in sandy soils ranges from 8 to 33 mg Ni·kg⁻¹ (Święcicki 2001). The average content of nickel in control soil amounted to 14.1 mg Ni·kg⁻¹ of soil, that is approximately ten times smaller than the admissible value (Dz.U. 2002 No.165, item 1359). The use of ash from biomass led to a significant increase in the content of this element in soil due to, among others, higher amount of nickel in the material (23.7 mg Ni·kg⁻¹ d.m.). However, the threshold value of 100 mg Ni·kg⁻¹ of soil (Dz.U. 2002 No. 165, item 1359) was not exceeded in any of the variants of the experiment (Table 4).

The average content of copper in sandy soils in Poland is 6.5 milligrams per 1 kg of soil (Kabata-Pendias 2011) and the soil under experiment was characterized by similar content –from 7.8 to 10.8 mg Cu·kg⁻¹ of soil (Table 4). The use of the fertiliser caused an increase in the content of the element in soil due to higher content of copper in ash from biomass and Biotop compost–78.9 mg Cu·kg⁻¹ in ash and copper 40 mg Cu·kg⁻¹ in compost respectively. Similarly, the results by Piekarczyk et al. (2013) indicate that the use of ash from spring barley straw in the pot experiment resulted in a significant increase in the content of copper and zinc in light soil. Sądej and Namiotko (2011) report that fertilization with municipal solid waste composts raised the total content of copper, zinc in soil.

TABLE 4. Changes in soil content of nickel, copper and cadmium depending on the variant of fertilizer, (F)

Trace elements	Variant	Plant species		Average
		Barley	Wheat	
Nickel (mg Ni·kg ⁻¹)	1	14.1	14.1	14.1
	2	14.5	14.5	14.5
	3	19.1	19.1	19.1
	4	16.4	16.4	16.4
	5	16.5	17.7	17.1
	6	16.4	16.5	16.4
	Average	16.2	16.4	16.3
	LSD _{0.05} for	F–1.46		
Copper (mg Cu·kg ⁻¹)	1	9.0	7.8	8.4
	2	9.2	8.4	8.8
	3	9.9	10.4	10.2
	4	9.4	9.6	9.5
	5	10.2	10.8	10.5
	6	9.8	10.5	10.2
	Average	9.6	9.6	9.6
	LSD _{0.05} for	F – n.s.		
Cadmium (mg Cd·kg ⁻¹)	1	1.34	1.09	1.21
	2	1.39	1.14	1.26
	3	1.29	1.19	1.24
	4	1.49	1.24	1.36
	5	1.44	1.29	1.36
	6	1.44	1.33	1.38
	Average	1.40	1.22	1.30
	LSD _{0.05} for	F – n.s.		

However, the threshold value of 150 mg Cu·kg⁻¹ of soil (Dz.U. 2002 No. 165, item 1359) was not exceeded in any of the variants of the experiment (Table 4).

In terms of chemical properties cadmium is similar to zinc, yet unlike zinc it is not a biologically significant element. The content of cadmium in agricultural soils in Poland ranges from 0.01 to 49.73 mg·kg⁻¹ – the average content is 0.21 mg·kg⁻¹ (Święcicki 2001). The increase in assimilability of cadmium for plants is proportional to the increase of alkali pH of soil; therefore the use of soil alkalizing fertilisers seems valid. The amount of cadmium in soil was not varied and ranged from 1.09 to 1.49 mg Cd·kg⁻¹ of soil (Table 4). The results of the field experiment do not indicate any marked effect of the applied fertiliser on the content of cadmium. According to the Regulation of the Minister of Environment of 9 September 2002 on soil and land quality standards (Dz. U. 2002 No.165, item 1359), the admissible threshold value of cadmium content – 4 mg Cd·kg⁻¹ of soil, was not exceeded in any of the variants despite the fact that the amount of this element in ash from biomass – 2.7 mg Cd·kg⁻¹ d.m., was higher than that in soil under experiment.

CONCLUSIONS

1. The use of ash from biomass and Biotop compost as fertilisers did not result in any significant changes of soil pH.
2. The use of ash from biomass and Biotop compost in the field experiment caused a significant increase in the contents of available phosphorus, potassium and magnesium.
3. The use of ash from biomass and Biotop compost resulted in the increase in total content of manganese, zinc, nickel and copper.
4. No markedly direct effect was found between the used fertilizers and the changes in the total content of lead and cadmium in soil.
5. The threshold values of the analysed microcomponents in soil, as specified by the Regulation of the Minister of Environment, were not exceeded in any of the fertilising variants in the experiment.

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Wpływ stosowania wapna, popiołu z biomasy i kompostu na właściwości chemiczne gleby

Streszczenie: Przedmiot badań stanowiła analiza wpływu popiołów z biomasy oraz biokompostu Biotop wprowadzonych do gleby, na zmiany odczynu i zawartości w glebie przyswajalnych form fosforu, potasu oraz magnezu, jak również ogólnej zawartości: cynku, miedzi, manganu, niklu, kadmu i ołowiu. Doświadczenie polowe przeprowadzono w 2013 roku w Duninowie koło Ustki. Badany czynnik stanowiło 6 wariantów nawożenia. W doświadczeniu uprawiano dwie rośliny jare: jęczmień odm. Sebastian i pszenicę odm. Bombona. Zastosowane doświadczenie nawożenia, w postaci popiołu z biomasy i kompostu Biotop, nie spowodowało istotnej zmiany odczynu gleby oraz spowodowało istotny wzrost zawartości w glebie przyswajalnego fosforu, potasu i magnezu. Progowa zawartość w glebie, określona w Rozporządzeniu Ministra Środowiska dotycząca analizowanych mikroskładników, nie została przekroczona w żadnym z wariantów nawozowych doświadczenia.

Słowa kluczowe: popiół z biomasy, kompost Biotop, makroskładniki, mikroskładniki