Effect of combustion wastes and sewage sludge compost on the chemical properties of soil

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A field experiment was conducted univariate in 2008–2010 in the Variety Assessment Station in Szczecin – Dąbie. The soil on which the experience was based is made of light loamy sand (pgl). In terms of granulometric composition it includes it into the category of light soils, agricultural suitability complex IV b, good (5). The experiment included, inter alia, waste compost produced with municipal sewage sludge produced by *GWDA and ash from brown coal (waste grate). No normal ranges for heavy metals being specified in the ministerial regulations were used for environmental purposes, which are maximum 20, 500, 750, 300, 1000 and 16 mg per 1 kg dry matter for cadmium, chromium, lead, nickel, copper and mercury, respectively16 were exceeded in the sewage sludge being used to produce the compost. The field experiment design consisted of 6 fertilisation objects. A test plant was Virginia fanpetals (*Sida hermaphodrita Rusby*). The content of available phosphorus, potassium and magnesium in the soil, being fertilised with municipal SSC with and without an addition of high-calcium BCA, changed after three years. There was an increase in the content of available phosphorus, potassium and magnesium forms, on average by 8.5%, 16.0% and 9.0%, respectively. When analysing the chemical properties of soil before and after this study, it may be stated that respective systems of municipal sewage sludge compost and high-calcium brown coal ash application differently affected most soil richness indices. The best fertilisation effects were obtained in the system with municipal sewage sludge compost being applied at a dose corresponding to 250 kg N · ha^{-1} as well as with high-calcium brown coal ash at a dose corresponding to 1.5 Mg CaO · ha^{-1} being introduced into soil in the first year of study and at a dose corresponding to 0.75 Mg CaO · ha^{-1} in successive years. Fertilisation with municipal sewage sludge compost without and with addition of high-calcium brown coal ash favourably affected the preservation of soil environment stability and improvement of soil chemical composition.

Keywords: soil, pH value, organic carbon, total content of macroelements, available forms of phosphorus, potassium and magnesium.

INTRODUCTION

Fossil fuel combustion by-products are used for different purposes, among others for land reclamation, land levelling or flood embankment construction. Considering the fact that they contain substantial quantities of macro- and microelements, such as calcium, magnesium, potassium, sodium, phosphorus, boron, manganese, copper, zinc and molybdenum, they are used as a material being suitable for application[1–4]. Due to a relatively high content of calcium oxide in them, a characteristic feature of combustion ashes is the well-known sanitising effect of fossil fuel ash addition on sewage sludge, limiting the leaching of chemical pollutants as well as improving the physical properties of sewage sludge or composts being produced from it[5].

Municipal sewage sludge and composts being produced from it are reach in organic matter and abundant with some nutrients[6–11]. Therefore, they are characterised by high manurial value and recommended for use as organic fertilisers in soil enrichment since they positively affect soil properties[12–15]. They must, however, meet the standards stated in the Regulation of the Minister of Environment[16] to have no negative impact on the environment. As shown by many studies, they favourably affect relationships between the "soil tilth" and the soil microbial activity and physicochemical properties[17–18]. There is a high potential in Poland to use municipal sewage sludge and composts produced from it to fertilise arable soils.

Biological disposal of combustion ashes, municipal sewage sludge and composts produced from them will allow improvement of the physicochemical properties of environmental components, which incorporate, among others, the soil. Changes in the soil reaction induce activation or retrogradation of many nutrients in soil, required by plants for their growth and development.

Considering the above aspects, studies were taken up aiming at determination of the effect of compost with municipal sewage sludge and high-calcium brown coal ash on the changes in the physicochemical properties of mineral soils after a three-year cultivation of the test plant.

MATERIAL AND METHODS

The basis for examinations was a single-factor field experiment situated at the Cultivar Evaluation Station in Szczecin-Dąbie. The soil on which this experiment was started is formed from light loamy sand. In terms of soil granulometric composition, it is classified into the category of light soils, soil quality class IV b and good rye complex (5). Examinations were carried out in 2008–2010 on 33 m^2 plots, with four replications per each

* GWDA compost is a compost prepared by means of the technological process of compost production from municipal sewage sludge with addition of straw or sawdust using the static forced-aeration method of composting being developed by the GWDA Sp. z o.o. (GWDA Water Supply and Wastewater Disposal Services Co. Ltd) in Piła, Poland.

experimental object. A test plant was Virginia fanpetals (*Sida hermaphrodita rusby*). The field experiment design consisted of 6 fertilisation objects.

In spring 2008, municipal sewage sludge compost produced by the *GWDA method, calcium carbonate and high-calcium brown coal ash were introduced into soil, while mineral fertilisers specified below were applied in the same doses over the whole experimental area. In the first year of the experiment (2008), 42.5 kg N · ha^{-1} as well as 28 kg P · ha^{-1} and 66.4 kg K · ha^{-1} were introduced into the soil on 5 May, prior to planting test plants, in the form of ammonium nitrate and multi-component fertiliser SuproFoska 20 (400 kg fertiliser per · ha^{-1}), respectively. Six weeks after planting Virginia fanpetals seedlings, 42.5 kg N · ha^{-1} were introduced into soil in the form of ammonium nitrate as the top dressing. In the second year of experiment (2009), a complex fertiliser Polimag S was introduced into soil at a dose of 1000 kg · ha^{-1}. This corresponded to 100 kg N · ha^{-1}, 35 kg P · ha^{-1}, 125 kg K · ha^{-1}, 30 kg Mg · ha^{-1} and 140 kg S · ha^{-1}. In addition, this fertiliser contained copper, zinc, boron and manganese. Eight weeks later, 34 kg N · ha^{-1} were introduced into soil in the form of ammonium nitrate. In the third year of the experiment (2010), a complex fertiliser Polimag S was introduced into the soil in the same dose as in 2009. Eight weeks later, 34 kg N · ha^{-1} were introduced into the soil in the form of ammonium nitrate. High-calcium brown coal ash was introduced into the soil in the fertilisation objects with an annual application on 8 April 2009 and 9 April 2010.

The harvest of Virginia fanpetals in 2008, 2009 and 2010 was carried out between 15 and 20 December. The crop yield of Virginia fanpetals was determined and its representative biomass samples were collected for the purpose of carrying out laboratory analyses.

Each year, after harvesting Virginia fanpetals, the content of macroelements was determined in the soil in averaged samples from four replications for each fertilisation object. Nitrogen, organic carbon and sulphur contents were determined on a Coestech CNS elemental analyser, while that of available forms of phosphorus and potassium by the Egner-Riehm method, available magnesium content according to the Polish standard PN-R-04024, total phosphorus content according to the Polish standard PN-98/C-04537-14, total potassium content by the method of flame photometry, and total magnesium content by the method of atomic absorption spectrometry on a Perkin Elmer AAS 300 spectrometer. The stock solution was obtained after previous wet mineralisation of soil material according to the Polish standards PN–ISO 11466 and PN-ISO 11047, while the soil pH value was determined by potentiometry in 1 mol · dm^{-3} KCl solution according to the Polish standard PN-75/C-04540/05/01. The study results were processed statistically by the analysis of variance in accordance with Statistica 8.0 PL computer software. In the case of significant differences, the Tukey's test was used at the significance level p = 0.05.

RESULTS AND DISCUSSION

The high-calcium brown coal ash used in this study came from the Pątnów-Adamów-Konin Power Plant Complex. It contained more potassium (5.50 g · kg^{-1} d.m.) than phosphorus (2.52 g · kg^{-1} d.m.). This ash partly supplemented potassium deficiency in the compost. It was characterised by high value of pH_{KCl} (11.0) and contained 986 g · kg^{-1} dry matter as well as 145 g Ca · kg^{-1} d.m. and 12.5g Mg · kg^{-1} d.m. No nitrogen or organic carbon was found in the ash. High calcium content in the ash used in this study (145 g Ca · kg^{-1} d.m.) allowed it to be classified into the group of high-calcium ashes. The total content of cadmium (2.77 mg · kg^{-1}), manganese (265 mg · kg^{-1}), nickel (12.6 mg · kg^{-1}), zinc (231.0 mg · kg^{-1}) and chromium (20.6 mg · kg^{-1}) in the examined high-calcium brown coal ash used in experiment was higher than in municipal sewage sludge compost. On the other hand, copper and lead contents (27.6 and 16.2 in mg · kg^{-1}, respectively) were higher in the compost when compared to high-calcium brown coal ash[19–20]. Taking into consideration the standards referring to the content of heavy metals in fertilisers for soil de-acidification[21], high-calcium brown coal ash may by included among the factors affecting soil de-acidification without negative environmental impact.

The compost with municipal sewage sludge used in the experiment, produced by the *GWDA method at the Municipal Sewage Treatment Plant in Stargard Szczeciński, corresponded, in respect to its chemical composition, to the standards allowing it to be classified into the group of organic fertilisers[21]. This compost had a pHH_2O of 8.50 and therefore can be applied without fear on strongly acid and acid soils which constitute more than 50% in Poland[22]. The total content of nitrogen (18 g N · kg^{-1} d.m.) and phosphorus (10.2 g P · kg^{-1} d.m.) in this compost was clearly higher than that of potassium (3.58 g K · kg^{-1} d.m.) [19]. Therefore, deficiencies of this chemical element should be supplemented in it with potassium mineral fertilisers.

Due to long descriptions of fertilisation objects, acronyms were adopted for municipal Sewage Sludge Compost (SSC) and Brown Coal Ash (BCA) that were subsequently used in the discussion of research results. Tables 1, 2 and 3 present the results referring to some soil fertility indices after harvesting the Virginia fanpetals biomass.

The results of field study show that soil fertilisation with municipal sewage sludge with high-calcium BCA addition increased soil pH_{KCl} value from 5.30 to 6.40. Similar study results were obtained by other authors[23]. After three years of the experiment, the soil reaction increased by 1.1. The objects fertilised only with calcium carbonate or high-calcium BCA at a dose corresponding to 1.5 Mg CaO · ha^{-1} being applied at the beginning of study had their soil pH_{KCl} value increased to 5.60. High-calcium BCA being introduced into soil at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of study and to 0.75 Mg CaO · ha^{-1} in the following years increased soil pH_{KCl} value to 6.30 (fertilisation object V). Exclusive organic fertilisation (fertilisation object III) contributed to the increase in soil pH_{KCl} value by 0.70 when compared to its initial value (Table 1).

In the fertilisation objects with high-calcium BCA being introduced into soil at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of study and to 0.75 Mg CaO · ha^{-1} each year and with municipal SSC with high-calcium BCA addition being applied each year, soil

Table 1. The pH_{KCl} value, organic carbon and nitrogen contents (in g · kg^{-1} D.M.) and C:N ratio in soil after the cultivation of Virginia fanpetals

Parameters	Initial values	Study years	Fertilisation objects						$LSD_{0,05}$
			I*	II	III	IV	V	VI	
pH_{KCl}	5.30	2008	5.45	5.50	5.70	6.10	6.15	6.20	0.07
		2009	5.60	5.55	5.85	6.20	6.20	6.30	0.10
		2010	5.60	5.60	6.00	6.30	6.30	6.40	0.37
C org.	8.52	2008	8.68	8.70	9.10	8.95	8.60	9.15	0.17
		2009	8.67	8.52	8.85	8.77	8.53	9.10	n.s.
		2010	8.52	8.46	8.98	8.91	8.47	9.02	n.s
		mean	8.62	8,56	8,97	8.88	8.53	9.09	0.12
N	0.72	2008	0.75	0.72	0.83	0.88	0.76	0.92	0.08
		2009	0.71	0.70	0.79	0.82	0.73	0.89	n.s.
		2010	0.67	0.68	0.82	0.84	0.70	0.86	n.s.
		mean	0.71	0.70	0.81	0.84	0.73	0.89	n.s.
C:N	11.8	2008	11.6	12.1	10.1	10.1	11.3	9.94	n.s.
		2009	12.3	12.2	11.5	10.7	11.7	10.2	0.02
		2010	12.6	12.4	10.9	10.6	12.1	10.5	0.02
		mean	12.2	12.2	10.8	10.5	11.7	10.2	0.02

*Description of fertilisation objects: **I** – Carbonate lime ($CaCO_3$) at a dose corresponding to 1.5 Mg CaO · ha^{-1}, **II** – High-calcium brown coal ash (BCA) at a dose corresponding to 1.5 Mg CaO · ha^{-1}, **III** – Municipal sewage sludge compost (SSC) at a dose corresponding to 250 kg N · ha^{-1}, **IV** – Municipal sewage sludge compost (S SC) at a dose corresponding to 250 kg N · ha^{-1} + high-calcium brown coal ash (BCA) at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of experiment **V** – High-calcium brown coal ash (BCA) at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of the experiment, with 0.75 Mg CaO · ha^{-1} in next years each , **VI** – Municipal sewage sludge compost (SSC) at a dose corresponding to 250 kg N · ha^{-1} + high-calcium brown coal ash (BCA) at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of experiment, with 0.75 Mg CaO · ha^{-1} in next years each.

pH_{KCl} value was significantly higher when compared to those where calcium carbonate or high-calcium BCA had been introduced into the soil. Differences in soil pH_{KCl} value between the objects with municipal SSC and high-calcium BCA being introduced into the soil and those being fertilised with high-calcium BCA at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of study and to 0.75 Mg CaO · ha^{-1} being applied in the following years, were not significant. No significant differences were observed between the objects being fertilised only with calcium carbonate, high-calcium BCA or municipal SSC. Changes in the soil reaction were induced by considerable calcium and magnesium contents in the applied ash[24]. The studies conducted by Gilewska[25–26] show that introduction of high-calcium brown coal ash from the Pątnów-Adamów-Konin Power Plant Complex into the soil induced its de-acidification to the same extent as calcium fertilisers. The soil being fertilised with calcium carbonate or high-calcium brown coal ash was classified to the group of acid soils (pH = 5.60), while that being fertilised with municipal SSC with high-calcium BCA addition to slightly acid soils (pH from 6.10 to 6.40). Other researchers obtained similar study results, observing an increase in the soil reaction from acid to slightly acid[27].

Calcium carbonate and high-calcium BCA being introduced into the soil at a dose corresponding to 1.5 Mg · ha^{-1} at the beginning of study and applied each year at a dose of 0.75 Mg CaO · ha^{-}, as well as exclusive organic fertilisation at a dose corresponding to 250 kg N · kg^{-1}, did not significantly differentiate total nitrogen, potassium, magnesium and sulphur contents in soil when compared to the fertilisation objects II, IV and VI (Table 1 and 2).

The content of organic carbon in the object with high-calcium BCA being introduced into the soil at a dose corresponding to 1.5 Mg CaO · ha^{-1} after three years of study was almost the same when compared to that before starting the experiment. Calcium carbonate, high-calcium BCA and SSC did not significantly differentiate the content of organic carbon in the respective fertilisation objects. The organic fertilisation applied with and without an addition of high-calcium BCA and exclusive annual fertilisation with high-calcium BCA increased the content of this chemical element to the greatest extent in the first year of study (2008) when compared to 2009 and 2010. The highest increase, by 0.47, was observed between the object with municipal SSC with high-calcium BCA addition being introduced into soil and that being fertilised with calcium carbonate at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of study (Table 1). The results obtained in the second and the third year of study indicate a gradual decrease in the content of organic carbon in soil after harvesting the Virginia fanpetals biomass when compared to the first year of study.

In 2008–2009, an increase in the nitrogen content was observed in the soil of fertilisation objects being fertilised with municipal SSC at a dose corresponding to 250 kg N · ha^{-1} and high-calcium BCA addition applied in the first year of study and the following years, respectively by 15.0, 19.0 and 26.5%, when compared to the objects with calcium carbonate or high-calcium BCA introduced into soil and applied at the beginning of study. Differences in the nitrogen content in soil in other fertilisation objects were not significant (Table 1). When analysing the effect of applied fertilisation on the changes in the nitrogen content in the soil during the three-year experiment, a gradual decrease in the quantity of this chemical element was observed. The nitrogen content decreased by 7.0% between 2010 and 2008. The reason for a decrease in its content is, most probably, a fast mineralisation of nitrogen organic compounds and its uptake by the Virginia fanpetals biomass.

The applied fertilisation induced an average increase in the nitrogen content in soil, by 23.6%, when compared to its initial content. The fertilisation being applied with and without the addition of high-calcium BCA increased the average content of organic carbon and total nitrogen in the soil in the second and the third year of study after application when compared to their initial contents. The studies by Czyżyk at el.[28] and

Gondek[29] show an increase in organic carbon and the total nitrogen contents as affected by the soil fertilisation with municipal sewage sludge.

Before the beginning of the experiment the soil was characterised by the carbon-to-nitrogen ratio amounting to 11.8. After three years of study, the carbon-to-nitrogen ratio enlarged by 0.8 (12.6 and 12.4, respectively) in the objects with calcium carbonate or high-calcium BCA being applied at a dose corresponding to 1.5 Mg CaO · ha^{-1}. On the other hand, this ratio narrowed in the objects being fertilised with municipal SSC without and with addition of high-calcium BCA applied in the first year of study and each year and amounted to 10.9, 10.6 and 10.5, respectively (Table 1). The total magnesium and sulphur contents in the soil after three years of study slightly changed when compared to their initial values (Table 2).

Statistical analysis of the total phosphorus and calcium contents in soil being determined after three years of study showed a dependence of the quantity of these chemical elements on the fertilisation system. A significant increase in the phosphorus content was obtained in the objects being fertilised with municipal SSC with and without an addition of high-calcium BCA when compared to that with high-calcium BCA being introduced into the soil at a dose corresponding to 1.5 Mg CaO · ha^{-1}. A significant increase in the total potassium content in soil was obtained as affected by the organic fertilisation being applied with addition of high-calcium BCA when compared to the object with calcium carbonate being introduced into soil at a dose corresponding to 1.5 Mg CaO · ha^{-1}. A significant effect of organic fertilisation with and without an addition of high-calcium BCA on the calcium, magnesium and sulphur contents in the soil (fertilisation object VI) was also observed when compared to the object with calcium carbonate and high-calcium BCA being applied at a dose corresponding to 1.5 Mg CaO · ha^{-1}. An increase in the phosphorus, potassium, calcium and magnesium contents in the soil was observed in the second year of study when compared to the first and the third year (2008 and 2010).

An average increase in the phosphorus content in 2008–2010 was observed in the soil in the objects being fertilised with municipal SSC at a dose corresponding to 250 kg N · ha^{-1} with and without the addition of high-calcium BCA, by 23.0% and 18.7%, respectively, when compared to that with annual application of high-calcium BCA at a dose corresponding to 1.5 Mg CaO · ha^{-1} (fertilisation object II). The differences in the phosphorus content in the soil in other fertilisation objects after harvesting the Virginia fanpetals biomass were not significant (Table 2).

Most potassium was found in the soil in the second year of test plant cultivation (0.77 g · kg^{-1} D.M.), while a slight decrease in its content, to 0.68 g · kg^{-1} D.M., was observed in the third year of study. An average increase in the potassium content, by 9.0%, was observed in the soil between the object with exclusive organic fertilisation at a dose corresponding to 250 kg N · ha^{-1} and that with calcium carbonate application. Calcium carbonate and high-calcium BCA being applied at the beginning of study and each year and exclusive organic fertilisation did not have any significant effect on the changes in the total potassium content in the soil.

The average content of calcium in the soil after harvesting the Virginia fanpetals biomass was the highest in 2009 and amounted to 1.02 g · kg^{-1} D.M. The highest average increase in the calcium content in the soil, by 11.6%, was obtained in the object being fertilised with municipal SSC at a dose corresponding to 250 kg N · ha^{-1} applied with addition of high-calcium BCA in the first year of study and each year when compared to that with exclusive application of calcium carbonate. The calcium content in the soil in the objects with municipal SSC with and without the addition of high-calcium BCA being applied at the beginning of study and each year, as well as with high-calcium BCA being introduced into the soil each year, was significantly higher when compared to the object being fertilised with calcium carbonate only. The differences in the effect of calcium carbonate or high-calcium BCA and exclusive fertilisation with municipal SSC did not significantly differentiate the calcium content in soil (Tab. 2). The magnesium content

Table 2. The P, K, Ca, Mg and S contents (in g · kg^{-1} D.M.) in soil after cultivation of Virginia fanpetals

Parameters	Initial values	Study years	Fertilisation objects						$LSD_{0.05}$
			I*	II	III	IV	V	VI	
P	0.45	2008	0.56	0.51	0.60	0.56	0.52	0.56	0.06
		2009	0.50	0.48	0.66	0.62	0.59	0.54	0.03
		2010	0.45	0.45	0.52	0.52	0.46	0.53	n.s.
		mean	0.50	0.48	0.59	0.57	0.52	0.54	n.s.
K	0.62	2008	0.68	0.70	0.74	0.66	0.72	0.70	n.s.
		2009	0.74	0.75	0.77	0.79	0.77	0.78	n.s.
		2010	0.63	0.64	0.70	0.72	0.67	0.74	n.s.
		mean	0.68	0.70	0.74	0.72	0.72	0.74	n.i.
Ca	0.78	2008	0.86	0.92	0.90	0.96	0.93	0.92	0.02
		2009	0.90	0.96	0.98	1.00	1.03	1.10	0.97
		2010	0.82	0.81	0.84	0.87	0.84	0.87	0.03
		mean	0.86	0.89	0.91	0.94	0.93	0.96	0.07
Mg	0.62	2008	0.69	0.74	0.72	0.74	0.77	0.80	n.s.
		2009	0.74	0.77	0.78	0.80	0.85	0.90	n.s.
		2010	0.67	0.68	0.70	0.72	0.70	0.74	0.03
		mean	0.70	0.73	0.73	0.75	0.77	0.81	n.s.
S	0.08	2008	0.10	0.11	0.12	0.12	0.16	0.18	n.s.
		2009	0.08	0.09	0.10	0.10	0.12	0.15	0.05
		2010	0.08	0.09	0.12	0.13	0.11	0.14	n.s.
		mean	0.09	0.10	0.11	0.12	0.13	0.16	0.04

* Description of fertilisation objects is given in Table 1.

in the soil after harvesting the Virginia fanpetals biomass slightly increased during the three-year study. Calcium carbonate or high-calcium BCA being applied at a dose corresponding to 1.5 Mg CaO · ha^{-1}, as well as exclusive organic fertilisation at a dose corresponding to 250 kg N · ha^{-1}, did not have any significant effect on the increase in the magnesium content in the soil. High-calcium BCA being introduced into the soil, as well as municipal SSC with its addition, increased the magnesium content, by 10.0% and 15.7%, respectively, when compared to the object being fertilised only with calcium carbonate. The highest average magnesium content in the soil was observed in all fertilisation objects in the second year of study (0.81 g · kg^{-1} D.M.). An average increase in the content of that chemical element in the soil after harvesting the test plan biomass in the second year of study was higher by 10.0% when compared to the first year and by 31.0% when compared to its initial value.

The highest average sulphur content in the soil was observed in the objects being fertilised only with high-calcium BCA at a dose corresponding to 1.5 Mg CaO · ha^{-1} and municipal SSC with its addition see Table 2. The sulphur content in the soil in other fertilisation objects ranged from 0.08 to 0.13 g · kg^{-1} D.M. The least sulphur content in the soil after harvesting the Virginia fanpetals biomass was observed after an application of calcium carbonate at a dose corresponding to 1.5 Mg CaO · ha^{-1}. The municipal SSC with high-calcium BCA being applied increased the total sulphur content when compared to its initial value, by 63.0% and 100%, respectively.

The content of available phosphorus, potassium and magnesium in the soil of fertilisation objects with municipal SSC with and without an addition of high-calcium BCA changed after three years of study (Table 3). There was an increase in the content of available phosphorus, potassium and magnesium forms, on average by 8.50%, 16.0% and 9.0%, respectively.

The average content of available phosphorus forms in the soil in the objects with municipal SSC being introduced at a dose corresponding to 250 kg N · ha^{-1} with and without an addition of high-calcium BCA applied in the first year of study and each year was significantly higher when compared to those with high-calcium BCA being introduced into soil at the beginning of study and each year. The differences in the content of available phosphorus forms in the soil between these objects in the aforementioned groups were not significant (Table 3).

Sewage sludge and composts being produced from it are rich in phosphorus and therefore its content in the soil humus level increases after their application. This increase is being maintained in the first year of study and may continue in successive years after the introduction of organic fertilisation[30–31]. The possibility of total phosphorus accumulation in the soil should be also taken into account. This phenomenon is induced by high calcium and magnesium contents in high-calcium brown coal ash, which affects not only the pH_{KCl} value but also the formation of sparingly soluble phosphorus compounds[32].

Fertilisation with municipal sewage sludge compost at a dose corresponding to 250 kg N · ha^{-1} with annual addition of high-calcium BCA (fertilisation objects IV and VI) in the first year of study increased the content of available potassium in soil by 18.0% when compared to its initial value. On the other hand, its content in the following study years decreased. The decreases being observed in the content of available potassium in soil are related to its low content in sewage sludge and composts being produced from it as well as in combustion wastes[23, 33–35].

The content of available potassium in the soil was significantly smaller in 2009 and 2010 in the objects being fertilised with calcium carbonate and high-calcium BCA at a dose corresponding to 1.5 Mg CaO · ha^{-1} when compared to other fertilisation objects but it was slightly higher than the value from before starting the experiment (Tab. 3). The annual introduction of high-calcium BCA induced a significant increase in the content of available potassium forms in the soil when compared to the object with calcium carbonate.

Most available magnesium forms contained the soil of fertilisation objects being fertilised with municipal SSC with high-calcium BCA addition applied at the beginning of study and each year (51.4 and 51.7 mg · kg^{-1} D.M.). When compared to these objects, the soil of fertilisation objects with calcium carbonate and high-calcium BCA being applied at the beginning of study and each year contained significantly less available magnesium forms. Differences in the content of available magnesium forms in soil between the objects being fertilised with calcium carbonate and high-calcium BCA applied at the beginning of study and each year were not significant.

When evaluating the average content of available chemical elements in the soil with the method of threshold values, being used by Chemical and Agricultural Research

Table 3. The content of availlable P, K and Mg forms in soil after cultivation of Virginia fanpetals

Parameters	Initial values	Study years	I*	II	III	IV	V	VI	$LSD_{0.05}$
content availlable in mg · kg^{-1} D.M.									
P	24.8	2008	26.1	26.2	27.0	27.6	26.6	27.7	0.17
		2009	26.8	25.9	26.5	27.1	26.1	27.1	0.22
		2010	25.2	25.4	26.2	26.2	25.0	26.4	0.20
		mean	26.0	25.8	26.6	27.0	25.9	27.1	0.24
K	120	2008	132	134	140	148	139	147	0.54
		2009	128	130	135	141	132	142	0.25
		2010	122	121	130	134	124	136	0.31
		mean	127.3	128.3	135.0	141.0	131.6	141.6	0.91
Mg	47.0	2008	50.1	50.7	51.2	52.1	50.7	52.4	0.12
		2009	50.2	50.2	51.4	51.5	50.9	51.8	0.13
		2010	48.4	48.3	50.2	50.6	49.0	50.7	n.s.
		mean	49.5	49.7	50.9	51.4	50.2	51.7	0.12

* Description of fertilisation objects is given in Table 1.

Laboratories, it was found that the content of available phosphorus was low in the objects being fertilised with municipal SSC without and with addition of high-calcium BCA, which indicates that no changes in the soil richness class were observed. Available potassium and magnesium contents in the soil pointed to a medium class of its richness. As affected by the fertilisation being applied in this experiment, the classification of this soil in terms of the content of available potassium and magnesium forms changed, from medium soil richness class to a high one.

When analysing the chemical properties of the soil before and after this study, it may be stated that respective systems of municipal sewage sludge compost and high-calcium brown coal ash application had a different effect on most soil fertility indices. Fertilisation with municipal sewage sludge compost with and without an addition of high-calcium brown coal ash favourably affected preservation of the stability of the soil environment and improvement of the soil chemical composition.

CONCLUSIONS

The greatest positive effect on soil fertility indices was observed after the application of municipal SSC with annual introduction of high-calcium BCA into soil. Slightly weaker effects were observed when municipal SSC and high-calcium BCA had been introduced into soil at the beginning of study.

The pH_{KCl} value and the content of organic carbon, total nitrogen, phosphorus, potassium and sulphur, as well as that of available phosphorus, potassium and magnesium forms, increased in the soil of objects being fertilised with municipal SSC with and without the addition of high-calcium BCA.

As affected by the fertilisation with municipal SSC and high-calcium BCA, the classification of this soil in terms of the content of potassium and magnesium forms being available for plants changed from medium soil richness class to a high one.

The objects being fertilised only with calcium carbonate or high-calcium BCA did not significantly differentiate the content of macroelements in the soil under examination.

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