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PRELIMINARY STUDIES OF THE PHYSICO-CHEMICAL PROPERTIES OF BASALT ROCK FLOUR FROM THE MĘCINKA MINE IN LOWER SILESIA

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Abstract: During prospecting, exploration and processing of basalts, mining waste and fractions which are hard to dispose are produced. Environmental protection and economic reasons make it necessary to manage as much of the extracted mineral as possible. There are various actions taken to use this raw material in many sectors of economy. Increasing the use of the natural soil remineralizer, produced of basalt rock flours, can reduce the accumulation of mining waste. The results of the researches on the physical and chemical properties of basalt rock flour from the Męcinka mine in Lower Silesia are described in this paper. The research was carried out to evaluate the soil remineralizer produced from rock material in agriculture. It turned out that the tested rock material contains significantly lower concentration of heavy metals than can be entered into the soil (lead, cadmium, arsenic and mercury). The rock material contains different microelements (Al, Si, S, Ti, Fe, Cu, Zn, Ba, Mn, Se, Mo), which are important components of cell molecules, necessary for proper growth and development of plants. The pH is alkaline, therefore a soil remineralizer produced from rock flour should be used mainly in acidic soils. The results of the granulometric tests of the rock flour grains showed that the rock material should be ground to a smaller fraction (i.e., 0.063 mm). It was found that adding basalt flour to soil improves respiration of soil microorganisms.

Keywords: *basalt flour, remineralizer, soil, respiration, agriculture*

1. INTRODUCTION

The basaltic formation in Lower Silesia constitutes a part of the Central European volcanic zone, an arc over 500 km long formed during the Alpine orogeny, stretching

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from Zgorzelec in the West to St. Anne's Mountain in the East. Over 300 basalt rocks occur in this area (Jerzmański, Śliwa 1979). These rocks have been exploited since the beginning of the 19th century. Macroscopically, Lower Silesian basalts are not very diverse – the most frequently found are dark grey, aphanite or fine porphyry varieties (Jerzmański, Śliwa 1979). Microscopically, basalts show a slightly greater differentiation which is determined by the mineral composition and the structure of the rock background (Badura et al. 2006). The mineral in different parts of the deposit often shows great variability in terms of physical and mechanical properties (Rembiś 2011).

Basalts are basic rocks used in different branches of construction industry for producing the most valued aggregates (road breakage, raw material for the production of mineral wool and wear-resistant mats, hardener for paving, paving stones, paving slabs, etc.). The wide use of basalt is due to the remarkable resistance of this rock to destructive factors, climatic as well anthropogenic. This stone had already been used in ancient times for building the Colosseum and the Roman Forum.

Basalt exploitation in Poland and Lower Silesia in 2010–2019 is summarized in the Table 1.

Table 1. Geological deposits and basalt extraction in Poland and Lower Silesia in 2010–2019

Geological deposits and basalt extraction (in thousand tonnes)[1]				
Year	Poland		Lower Silesia	
	deposits	extraction	deposits	extraction
2010	597,540	8,554	572,594	7,754
2011	586,743	11,555	562,858	10,497
2012	573,844	8,626	551,224	7,714
2013	586,604	6,966	561,329	6,197
2014	584,977	7,065	559,977	6,216
2015	582,516	6,661	559,389	5,852
2016	576,958	6,312	554,845	5,573
2017	563,416	7,648	542,291	6,866
2018	554,214	9,081	535,419	7,774
2019	547,639	7,239	529,697	6,371

[1] Based on: The balance of mineral deposits in Poland.

As Table 1 presents, almost all Polish basalts are extracted in Lower Silesia. During prospecting, exploration and processing of basalts, mining waste and fractions which are hard to dispose are produced. Minor fractions of mining waste, especially dusty ones, dispersed by wind over long distances, pose the most environmental problems. Environmental protection and the economic need to use as much of the extracted minerals as possible cause actions aiming at taking advantage of this raw material in various industrial sectors. Increasing the use of basalt rock flour as a natural soil remineralizer can reduce the accumulation of mining waste. The chemical composition of this material is identical to the extracted raw material, i.e., natural rock. Depending on the type, it contains various proportions of different chemical elements, such as: silicon, aluminum, iron, calcium, sodium, potassium and magnesium. It is worth emphasizing that natural rocks contain microelements (e.g., manganese, zinc, boron, molybdenum, chlorine, nickel) are important not only for plant production, but also for maintaining homeostasis of soil microorganisms (Kabała et al. 2019).

Improving soils with natural ingredients has been used in global agriculture for millennia. Enriching the arable areas in the Nile valley with sediments from its seasonal floods is an example of natural soil fertilization (Bednarek, Skiba 2015). In addition, there are examples of concentration of agriculture around inactive and active volcanoes, where the soil contains large amounts of micro- and macro-elements from volcanic sediments (ash and ash). Such soils are considered to be the best ones in the world (Kemp, Nicholson 2000).

There is the necessity to fertilize the soil with macro- and microelements in Poland caused by the limited use of manure and mineral fertilizers (Piwowar 2013). Moreover, it should be emphasized that the fertilizer industry is considered to be harmful to the natural environment as the production is performed mainly in large plants. It is estimated that about 30–40% of the waste generated by the chemical industry comes from the fertilizer industry (Cichy, Skulimowski 2010). During the production of fertilisers, large amount of NH_3 are emitted to the atmosphere and great quantity of N_2O may enter the ozone layer (Marcinkowski, 2010). Moreover, in the overall balance of energy used in the fertilizer industry and agriculture, the former consumes 40–60% of the required energy (Piwowar, Dzikuć 2020). The highest energy consumption is caused by the production of nitrogen fertilizers (Erisman et. al., 2008). Moreover, it is worth noting that the production of fertilizers requires phosphorus, potassium, sulfur and sodium, but the first two of which are imported by Poland.

The work presents preliminary studies of the physicochemical properties of basalt rock flour from the Męcinka mine in Lower Silesia which can be used as a soil remineralizer in agriculture and horticulture.

2. MATERIAL AND METHODS

2.1. RAW MATERIAL

Basalt rock flour from the processing plant in the Męcinka mine in Lower Silesia was used for the research (Fig. 1).

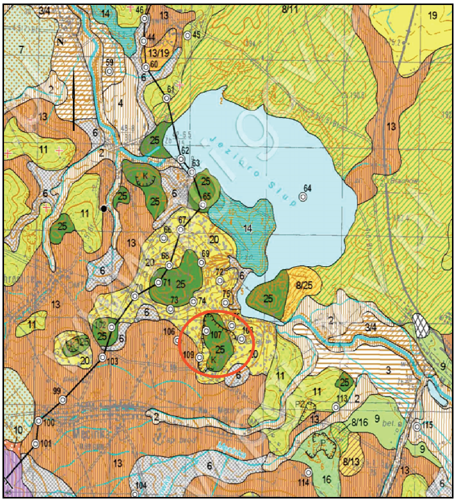

Fig. 1. Location of the Męcinka I basalt deposit
(taken from Urbański et al. 2009)

The quarry in Męcinka is extensive (Fig. 2). It is about 1.5 km long, and the walls are 10–35 m high. Basalts constitute a lava cover made up mainly of solid varieties that are quite homogeneous.

Fig. 2. Excavation in the Męcinka mine (author's photo)

The balance geological resources of the Męcinka I basalt deposit were estimated at 7 912 000 tonnes in 2019 (that year the extraction was 312 thousand tonnes). This mine produces the highest quality basalt aggregate, used in construction of asphalt and concrete roads and industrial construction (https://www.bartnica.com.pl/zaklady/kopalnia-bazaltu-w-mecince/ [accessed on June 14, 2021]).

2.2. RESEARCH METHODOLOGY

The evaluation of the physicochemical properties of basalt flour covered the designation of the following parameters: grain size distribution, pH, water-soluble potassium, total and water-soluble calcium, total and water-soluble magnesium, elemental composition of micronutrients. The respiratory activity of arable soil was also measured in the presence of basalt flour. The class V sandy arable soil, considered not very fertile, was used in the experiments. Such soil is very light and usually too dry. It can be used for planting rye and lupine and in rainy years it may also be suitable for cultivating potatoes and seradella. The soils are used in horticulture, though, only for some species of fruit trees (e.g., cherries).

2.3. ANALYTICAL METHODS

The mechanical method according to PN-B-04481:1988 standards was used for the granulometric analysis (Polish version – Construction land – Testing soil samples).

The evaluation of chemical composition of basalt flour was performed according to the standards for fertilisers.

pH – Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of October 13, 2003, App. III method 4:

- water-soluble potassium – PN-EN 15477: 2009,
- water-soluble calcium – PN-EN 15961: 2017-02 PN-EN 16196: 2013-05,
- total magnesium – PN-EN 15960: 2011 PN-EN 16197: 2013-05,
- magnesium soluble in water – PN-EN 15961: 2017 PN-EN 16197: 2013-05,
- lead, cadmium, arsenic, mercury – Regulation of the Minister of Economy of September 8, 2010, Annex 3 (Journal of Laws No. 183).

Energy dispersion X-ray fluorescence spectrometry was used to determine the elemental composition of the basalt flour (EDX) (Shimadzu, model EDX-7000) (Energy Dispersive X-ray Fluorescence, EDXRF).

The soil respiratory activity was measured with the use of OxiTop® – Control system (WTW, Weilheim, Germany). The method is based on the registration of the amount of oxygen consumed by aerobic organisms that decompose an organic substance (biological activity of the soil). The test was carried out for 5 days in a climate chamber at 20 °C according to the PN-EN ISO 16072:2011 standard (Soil Quality – Laboratory Methods for Determining the Respiration of Soil Microorganisms). The soil samples without addition of basalt flour were used as controls. The results were presented as the quantity of oxygen (mg) per dry mass (d.m) of soil.

3. RESULTS

The use of soil remineralizers in agriculture must meet two basic conditions: (1) the rock material must not contain too high concentration of heavy metals – lead, cadmium, arsenic and mercury, and (2) the proportion of grains with a diameter below 0.063 mm should exceed 70% of the rock flour weight (Maliszewski et al. 2019).

The concentration of heavy metals in the tested rock flour is presented in Table 2. As shown, the tested material contains low concentrations of heavy metals, permitted by the Regulation of the Minister of Economy of 8 September 2010. In the case of lead, the concentration of this metal is over 60 times lower than the acceptable limits. The analysis proved that the determined concentrations of cadmium, arsenic and mercury are more than 80, 24 and 600 times lower than acceptable. Consequently, it can be assumed that basalt flour complies with the criterion of acceptable concentration of heavy metals.

Table 2. The concentration of heavy metals in the basalt flour sample from the Męcinka mine

Basalt flour	Pb	Cd	As	Hg
	[mg/kg]			
	2.33 ± 0.47	0.56 ± 0.11	2.04 ± 0.41	0.00330 ± 0.00066
Limit values[1] (currently in force)	140	50	50	2,0

[1] Regulation of the Minister of Economy of 8 September 2010 (Journal of Laws No. 183).

The second criterion is the percentage of grains with a diameter below 0.063 mm in total mass of rock material. The quantitative results of the sieve analysis of the basalt flour sample from the Męcinka mine are presented in Fig. 3. Grains with a diameter below 0.063 mm accounted for 25.2%, fractions from 0.063 to 0.071 mm accounted for 18.24%, fractions from 0.071 to 0.090 mm accounted for 14.73%, fractions from 0.090 to 1.0 mm accounted for 15.3%, fractions from 1.0 to 2.0 mm accounted for 21.18%, and grains above 2.0 mm accounted for 5.35% of the total weight of basalt flour. As presented, the largest fraction (approx. 25%) constituted grains with a diameter of less than 0.063 mm. However, the criterion of at least 70% of this fraction content is not met.

Table 3 presents the results of determination of the content of potassium, calcium and magnesium oxides in basalt flour from the Męcinka mine. This composition is typical for basalt (Zagożdżon 2008). The high pH-value is worth noticing, considering the high acidity of soils in Poland. According to researches carried out by IUNG-PIB in Puławy, the acidification of soils in Poland varies and the most acid soils occur in the Podlaskie, Mazowieckie, Łódzkie and Małopolskie province (pH in the range of 5.50–5.65) (Rutkowska 2018).

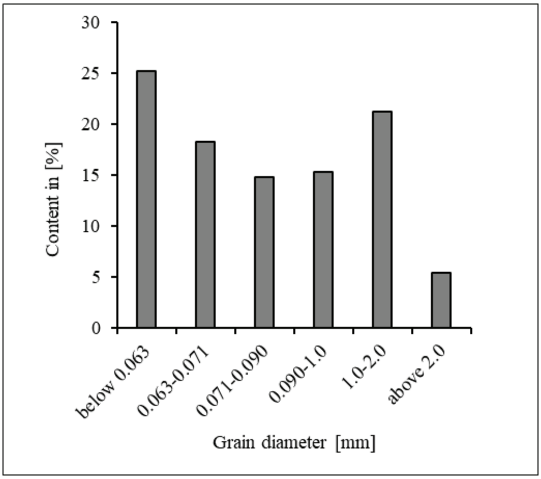

Fig. 3. Quantitative results of sieve basalt flour sample analysis from the Męcinka mine

Table 3. The content of potassium, calcium and magnesium oxides in basalt flour sample from the Męcinka mine

Basalt flour	pH	K_2O^1	CaO^2	CaO^1	MgO^2	MgO^1
		%				
	8.10±0.40	<1.0	1.90 ± 0.23	<1.0	6.00 ± 0.84	<1.0

[1] Dissolved in water, [2] total.

The results of soil acidification lead to decreasing the assimilability of basic ingredients vital for plant growth, such as nitrogen, phosphorus, potassium, magnesium, and molybdenum (Kocoń 2014). It was also stated that there are less other microelements in the acid soils (e.g., zinc, manganese, iron). It causes physiological diseases which in turn result in lower yield and poorer quality of grains (Dordas 2008).

Acidification of soil may lead to increased mobility of elements hazardous to plants and humans, mainly heavy metals, and their higher concentration in plants disqualifies them for consumption (Filipek, Skowrońska 2013).

Acidification of soil restricts metabolic activity of soil microorganisms, involved in decomposing organic matter (*Azotobacter* bacteria grow poorly) (Kozieł et al. 2018). Moreover, the decrease in the intensity of free nitrogen uptake from the air is observed (Nein 2019). In result, the fertility and quality of the soil decrease. These preliminary studies showed that the initial soil pH of 6.81 is increased to values of 6.86, 7.01, and 7.02 after adding 10, 50 and 100 g of basalt flour to 1000 g of soil, respectively. As shown in Table 4, the basalt flour is rich in various micronutrients, which are important components of plant cell molecules.

It is known that the key microelements in plant development are manganese, zinc, boron and molybdenum (Welch, Shuman 1995). Particular plant species differ in the sensitivity to their deficiency in the soil, but cereals are particularly sensitive to zinc and manganese deficiencies (Gallagher, Walsh 1943; Singh et al. 2005) and this can be supplemented by using basalt flour as a soil remineralizer.

An interesting use of basalt in agriculture was described by Ndepete and Sert (2016) and it concerned increasing the soil strength by adding basalt fibres. In triaxial tests without consolidation, the authors proved that adding 24 mm long fibres to the soil maximally improves its strength and optimal content of fibres (based on the dry weight of the soil) is 1.5%.

Some researchers (Kelland et al. 2020) indicate that land-based enhanced rock weathering (ERW) is a biogeochemical carbon dioxide removal strategy aiming at accelerating natural geological carbon sequestration by the use of crushed rock (such as basalt), in farmland and forest landscapes.

Table 4. Elemental composition of the microelements of basalt meal from the Męcinka mine

Element	ppm
Al	102.069
Si	264.675
S	775
Ti	11.772
Fe	89.939
Cu	205
Zn	115
Sr	647
Ba	34.017
Mn	1.734
Se	3
Mo	7.8

The authors described the results of experiments consisting in adding coarse-grained crushed basalt to clay soil and observing the yield (without the addition of P and K) of an important grain, which is two-colour sorghum (*Sorghum bicolour*). The increase in yield of 21 ± 9.4%, without accumulating potentially toxic trace elements in the seeds was observed. The concentration of silicon in shoots also increased by 26 ± 5.4%, which is important as far as the resistance of a plant to biotic and abiotic stress is concerned. Modelling of geochemical reactive transport showed CO_2 sequestration rates of 2–4 t CO_2/ha for 1–5 years after a single application of basalt rock dust, including newly formed carbonate minerals in the soil.

Intensive fertilization is necessary to achieve better yields, but it can endanger the natural environment of the soil and disrupt its homeostasis (Angulo et al. 2020). It is known that soil organisms mineralize organic plant and animal matter and the released minerals provide food for plants.

Soil microflora participates in the processes of detoxification of xenobiotics and shapes the physical properties of the soil, creating its lumpy structure with the help of metabolic products (bacterial or fungal mucilages) that positively affects the development of plant roots and soil resistance to air-water erosion (Aislabie, Deslippe 2013; Miller et al. 2014).

The proper physiological state of soil microorganisms limits the development of pests and plant pathogens and helps to create symbiotic systems, e.g., rhizobias with roots of legume plants (Rahman et al. 2018).

The soil microbial activity is assessed on the basis of various biological parameters. In the last two decades, the evaluation of biological parameters, i.e., respiratory activity, as well as physicochemical characteristics, has become the essential part of a description of ecological state of the soil and its fertility (Ryan et al. 2005). It was assumed that biological parameters are more sensitive and better describe the changes in soil caused by agro-technical treatments, fertilization, climatic conditions and anthropogenic factors (introduction of heavy metals or pesticides) (Corstanje and Reddy, 2006). Such attitude is consistent with the Resolution on Soil Protection issued on April 28, 2021 (Resolution on Soil Protection; 2021/2548 (RSP)).

Respiration is a process carried out by all heterotrophic organisms with the use of organic matter components available in the soil. Measurement of the amount of O_2 consumed and CO_2 released is a sensitive method of quantifying the metabolic activity of heterotrophic microorganisms (Hanson et al. 2000; Kuzyakov 2006). The effect of basalt flour on the respiration of soil microorganisms is shown in Fig. 4.

On the basis of the collected data it can be presumed that basalt flour affects the respiration of soil microorganisms and this effect depends on the concentration of rock material used in experiments. The amount of oxygen consumed after 5 days of incubation was 107 mg/d.m. in the case of soil without the addition of rock flour. After adding 10 or 50 g of rock flour to the soil, the amount of oxygen consumed by soil microorganisms was 132 mg/d.m. When the soil was enriched with 100 g of rock material, the amount of oxygen consumed was 95.7 mg/d.m. The data showed that the flour content of the soil at a dose of 50 g/1000 g increased the oxygen consumption by soil microorganisms proving that microbial respiration was more intense compared to the control (soil without basalt flour).

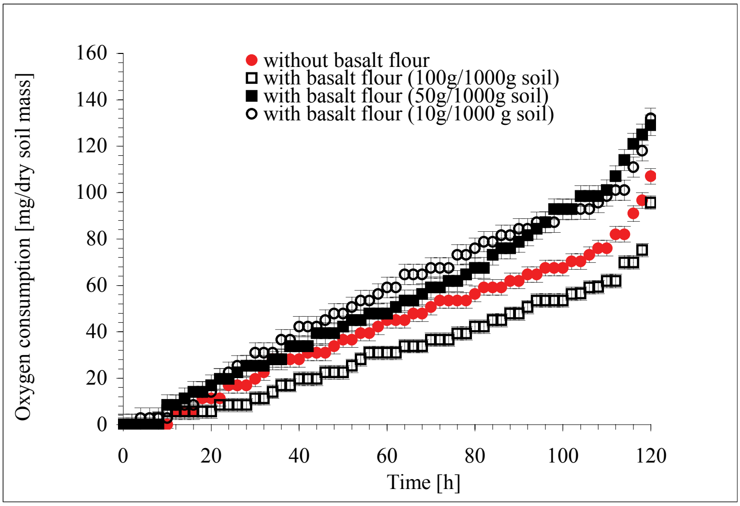

Fig. 4. The effect of the addition of basalt flour from the Męcinka mine on the soil respiration

It is known that the intensity of cellular respiration is determined by the physiological state of cells and depends on many factors, including the presence of toxic substances (Bünemann et al. 2006; Buchmann 2000). Soil respiration correlates with the content of organic matter and most physicochemical parameters, and can be modified by cultivation treatments, the use of pesticides or other toxic substances (Wainwright 1978; Bååth 1989). It is worth mentioning that basalt flour contains iron, which is a crucial element for their proper development and functioning. Bacteria present in the soil increase the plant iron absorption not only by increasing the root surface (they release phytohormones that affect the development of the root system), but also by stimulating chelators, i.e., ion absorption systems (Ali, Vidhale 2013). Iron is a biochemically active component of important cofactors that determine the activity and function of many proteins essential for the key metabolic processes. Proteins containing iron in their active centers are involved in the transport of electrons in the respiratory chain, transport and storage of oxygen, regulation of gene expression, as well as in the synthesis of DNA and RNA. Zinc and manganese, also present in the basalt flour, are equally important as far as physiology is concerned.

5. CONCLUSION

Based on the preliminary physicochemical properties of basalt flour as a mining waste from the Męcinka mine processing plant, it was proved that it meets the safety criteria for substances introduced into the soil. The use of basalt dust as a soil remineralizer increases the pH-value of acid soils and can be a source of microelements important for plant development. Nevertheless, it is necessary to regrind or adjust the dedusting devices to achieve a higher content of the grain fraction with a diameter of 0.063 mm, that is the most accessible to plants. The respiratory parameters determined in this study characterize the proper life functions of soil microorganisms after introducing various doses of the tested basalt flour into the soil. It seems that the use of basalt dust as a soil remineralizer should be monitored by respirometric activity of soil microorganisms in response to the agro-technical introduction of too high doses of rock material. The obtained data contradict the former suggestions that over-fertilisation with the rock material is impossible (Zagożdżon 2008).

The basalt flour must be granulated to avoid dusting during transport and sowing into fields. The method of granulating basalt dust should be solved by chemical technology. The most economically effective application of a basalt-based soil remineralizer can be expected in southern Poland, where the transport routes from the place of production to the recipient are the shortest (Blachowski, Buczyńska 2020). The large-scale management of basalt flour in agriculture can significantly reduce the amount of deposited mining waste and is in line with the principles of the Circular Economy and the European Parliament Resolution on Soil Protection (2021/2548 (RSP)) with a low carbon footprint.

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