Proceedings

Impact of the stabilized sewage sludge-based granulated fertilizer on *Sinapis alba* growth and biomass chemical characteristics †

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Abstract: Municipal sewage sludge is a problematic waste that needs to be managed. Modern wastewater treatment plants (WWTPs) generate stabilized sewage sludges with good chemical and biological parameters. The Central Mining Institute (CMI, Poland) has developed a proprietary technology (patent PL233754) for production of a granulated organo-mineral fertilizer from the stabilized sewage sludge. It is a mixture of municipal WWTP-collected, dewatered sewage sludge, dolomite, lime, gypsum, ammonium carbonate and microcrystalline cellulose. The sewage sludge contained heavy metals at levels lower than: Cr, 100 mg; Cd, 5 mg; Ni, 60 mg; Pb, 140 mg; Hg, 2 mg and was free from live eggs of intestinal parasites of the genera *Ascaria*, *Trichuris*, and *Toxacara* as well as from *Salmonella* bacteria. Micro-field tests were conducted at WWTP in Żory (Poland) on five 5m² fields. The effectiveness of plant growth was evaluated based on drone photos showing field coverage upon vegetation, and post-harvest determination of the plant dry mass. The analyses showed significant changes in biomass chemical composition: the N concentration was 289,6% of the control and 98,2% of commercial fertilizer, whereas the respective P content was 145,1% and 300%. The results prove that the innovative fertilizer is highly competitive with other available commercial products.

Keywords: organo-mineral fertilizer; municipal sewage sludge; micro-field test

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1. Introduction

In Poland, due to the dynamic development of sewerage systems it was necessary to build new sewage treatment plants within the last ten years [1]. The total number of wastewater treatment plants (WWTPs) increased from 2417 in 2000 to 3278 in 2019 [2]. The number of Polish sewage treatment plants categorized by type are presented in Table 1.

Table 1. Number of sewage treatment plants by type in Poland in 2000-2019

		Number of Plants			
Wastewater Treatment Plants	**Mechanical**	**Mechanical-chemical**	**Biological**	**With increased removal of biogenic elements**	**Total**
2000	135	17	1 844	421	2417
2010	59	-	2 263	814	3136
2015	20	-	2 427	826	3273
2019	7	-	2 454	817	3278

The growing numbers of municipal WWTPs lead to the formation of large amounts of sewage sludge. The Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment is the major legal act that regulates activities in sewage management [3]. The objective of the Directive is to protect the environment from adverse effects of the abovementioned waste water discharges.

In the light of the Polish law, and in accordance with the EU regulations [4], the municipal sewage sludge is defined as waste which according to the classification of waste was included in the group 19 with the code 19 08 05. Thus, all the activities regarding the sewage sludge management are regulated mainly by regulations relevant to the waste management sector, with particular emphasis on the Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, so-called the Waste Framework Directive [5]. The management of municipal sewage sludge was discussed in detail and related to the EU and Polish legal regulations by Rosiek and Zgórska & Głodniok [6,7]. Furthermore, the problem was presented by Rosiek as well as by Kaszycki et al. in the context of circular economy [8, 9].

The Directive 2008/98/EC [5] discusses the issues of sewage sludge generation in terms of waste, while the Council Directive 86/278/EEC of 12 June 1986 [10] ("Directive … on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture", commonly known as the "sludge directive"), brings regulations related to the sewage sludge management, conditioning and effectively limiting the possibilities of its agricultural and natural use. The overriding aim of the latter Directive is to promote the use of sewage sludge in agriculture, while preventing and minimizing its negative impact on humans and the natural environment. Moreover, it indicates both the conditions to be met while using sewage sludges in agriculture, and the quality of soils to which they are to be applied.

For the above reasons, creating conditions and environmentally-safe methods of municipal sewage sludge utilization appears as an urgent need. On the other hand, the global population growth causes increasing demand for developing agricultural food production, which can be strongly promoted by efficient fertilizer inputs [11].

The possibility of using sewage sludge as a fertilizer depends on the content of organic matter and nutrients (carbon, nitrogen and phosphorus), the presence of hazardous substances as well as technology of their treatment. The properly prepared sludge may become a valuable source of organic ingredients for crops (phosphorus and nitrogen), as well as a rich source of macro- and microelements [12, 13].

The organo-mineral granulated fertilizer developed by the Central Mining Institute (CMI, GIG Research Institute) in Katowice, Poland, is a product fully complying with the Polish law requirements, protected as an invention by the Polish Patent Office [14]. It is a mixture of municipal dewatered sewage sludge collected from municipal WWTP , dolomite (50% $CaCO_3$ and 40% MgCO3), lime (96% CaO), gypsum, ammonium carbonate and microcrystalline cellulose. According to our analyses, the sewage sludges for fertilizer production contain heavy metals at levels lower than: chromium (Cr) 100 mg, cadmium (Cd) 5 mg, nickel (Ni) 60 mg, lead (Pb) 140 mg, mercury (Hg) 2 mg. They are also free from live eggs of the intestinal parasites *Ascaria* sp. *Trichuris* sp., *Toxacara* sp. as well as of bacteria of the genus *Salmonella*. Typically, the sewage sludge after dewatering in centrifuges containes 19-20% of dry mass. The final product appears as irregular shape non-dusting granulate with diameter 1-6 mm. Granulation of materials is one of the most significant unit operations applied in complex manufacturing processes. It enables forming of grains or granules from a powdery or solid substance of appropriate physicochemical properties, shape and dimensions. To obtain the granular organic fertilizer from dewatered sewage sludge, admixed with the above-mentioned additives, a technology of dynamic counter rotating mixing is applied. This is a unique process that can mechanically disperse sewage sludge pulp into small (2-6 mm diameter) particles by high rotation power (1000 rpm) followed by lowering the rotating power of turbine to initiate the granulation process. Elaboration of the above method was a technological challenge due to the hard-to-process physical form of sewage sludge [15].

The process of granulate production is presented as a block scheme in Fig. 2.

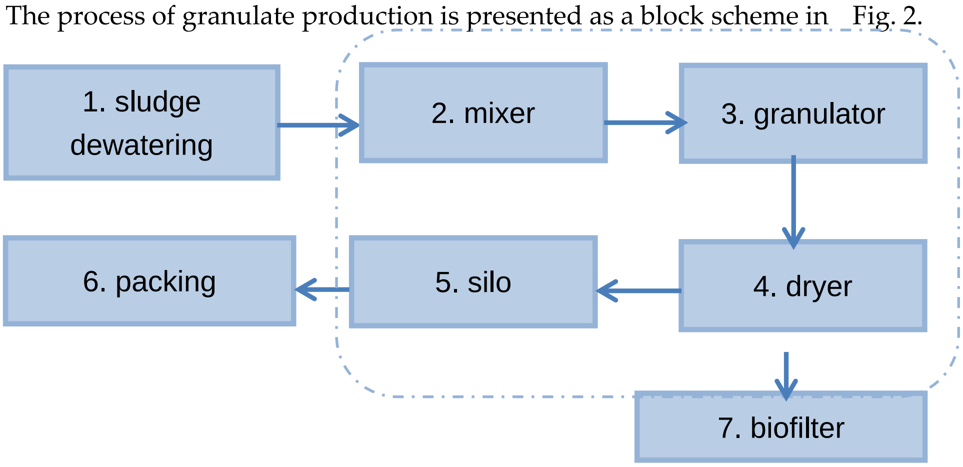

Figure 1 Block scheme of granulated fertilizer production

Granule forming from the stabilized and physically dewatered municipal sewage sludge (1) requires mechanical transport of the sludge to the dynamic counter rotating mixer containing all the necessary components (2). Simultaneously, screw conveyors transport proper doses of other granulate components: lime, microcrystalline cellulose and dolomite from three separate silos directly to the same mixer. The components are transported to the silos pneumatically from road tankers equipped with compressors.

When all the components are mixed, a chemical reaction between sewage sludge and lime occurs. From the mixer, the product is gravitationally fed into the disc granulator (3). After granulating, granules contain approximately 40-45% dry mass and are further transported to the dryer (4), where, at the temperature of 50-80°C they become desiccated until reaching dry matter content of approximately 75-80%. As the result of this reaction, ammonia is released, which, together with odors, is exhausted to the biofilter (7). The granules, after desiccation in the dryer, are taken to the silo (5) to cool them before bagger packaging (6) [16].

The use of sewage sludge as a substrate for the production of innovative fertilizing products can be regarded as an alternative way to improve soil fertility and support the effect of mineral fertilization. The production of fertilizing products is an eco-efficient way of sewage sludge management, while ensuring the greatest benefits at the lowest costs, and reducing the environmental nuisances of the sewage treatment plant.

2. Materials and Methods

2.1. Site Description and Experimental Design

Four different types of fertilizer were used in the test field. Three of them (GIG I, II, III) were prepared by the GIG Institute from the stabilized sewage sludge, while the fourth one was a commercial organic-mineral fertilizer with a chemical composition similar to the developed fertilizers (Table 2)

Table 2 Chemical composition of the tested fertilizers and the soil from test fields

	Soil from test fields	GIG Fertilizer I (I)	Commercial fertilizer (N COM)	GIG Fertilizer II (II)	GIG Fertilizer III (III)
	[%]				
N	0,44	1,35	9,00	1,30	1,05
P	0,30	0,93	4,80	0,89	0,72
K	0,81	0,09	9,13	0,09	0,06
S	0,09	0,32	10,00	5,12	0,66
Mg	0,17	7,25	3,32	0,47	8,15

The field experiment was conducted at the experimental site of the water and sewer company Przedsiębiorstwo Wodociągów i Kanalizacji w Żorach, in Żory, Southern Poland, Silesian Voivodeship (50″052 N, 18″695 E, 240 m above sea level). The soil particle size composition was as follows: silt 66.8%, clay 21.2%, and sand 12%.

Prior to the establishment of field experiment, the field was managed with chisel plowing and a rotary power system. In order to study the effect of fertilization using white mustard (*Sinapis alba* L.), the experimental field was split into five replicate plots for each of the treatments: 1) Control (C); 2) GIG fertilizer I (I) 3) Commercial fertilizer (N COM); 4) GIG fertilizer II (II); 5) GIG fertilizer III (III). The dimensions of each plot were 5 m x 5m (Figure 1).

Figure 2 Experimental site in Żory (Poland)

For each plot, 40 g of *Sinapis alba* (L.) were sown and a fertilizer (Table 3) was applied at an amount of 5Mg/ha.

Table 3 Composition of fertilizer mixtures in each experimental plot

	Experimental plot	**1**	**2**	**3**	**4**	**5**
		CONTROL (C)	GIG Fertilizer I (I)	Commercial fertilizer (N COM)	GIG Fertilizer II (II)	GIG Fertilizer III (III)
Composition (% w/w)	Sewage sludge	x	74	x	74	64
	Calcium oxide/quicklime	x	5	x	x	5
	Dolomite flour	x	20	x	x	30
	Gypsum	x	x	x	25	x
	Cellulose fibers	x	1	x	1	1

To ensure even and precise watering conditions appropriate for the plant growth, the experimental plots were systematically irrigated with sprinklers adjusted to changeable weather conditions.

2.2. Sample collection and analyzes

Sinapis alba plants were collected on day 52 (July, 2019). Two samples were randomized in each of the five replicate plots for every treatment. The samples were collected by extracting soil cores with plants of 15 cm x 15 cm from a 15 cm depth (Figure 3).

Figure 3 Sampling of the *Sinapis alba* plant material

Plant numbers were counted in each sample, and then the stems, roots, and the whole plant lengths were measured. The number of side shoots was also assessed. The aboveground structures of plant samples (collected within 52 and 71 days after sowing) were dried at 65 °C for 3 days and then ground into a fine powder for further analyses. Determination of water and dry matter in biomass was carried out by weight method according to PN-EN ISO 18134-3:2015-11. The organic matter content was calculated with a weight method as a result of burnout of the sample according to PN-EN 15935:2013-02.

Determination of the total sulfur content was performed by high temperature combustion and Infrared (IR) detection according to PN-EN ISO 16994:2016-10. Nitrogen content was determined by a titration method, and mercury by atomic absorption spectrometry with cold vapor generation (CVAAS according to the internal CMI procedure. The assays of Cd, Cr, Cu, Mn, Mo, Ni, Pb, Zn, Fe, Al, B, P, K, Na, Ca and Mg were performed employing the inductively coupled plasma optical emission spectrometry (ICP-OES) method according to the internal procedure.

3. Results and discussion

Sinapis alba dry mass was analyzed to establish the concentrations pf N, P, K, S, Mg and Ca, as well as of heavy metals. The main goal of the analyses was to indicate changes in N and P concentration in plant dry mass upon investigating differences between bioavailability of nutrients from different fertilizer sources. The second aim was also to verify whether the fertilizers based on municipal wastes, typically containing lower N, P, K levels, can still be competitive with other commercial products.

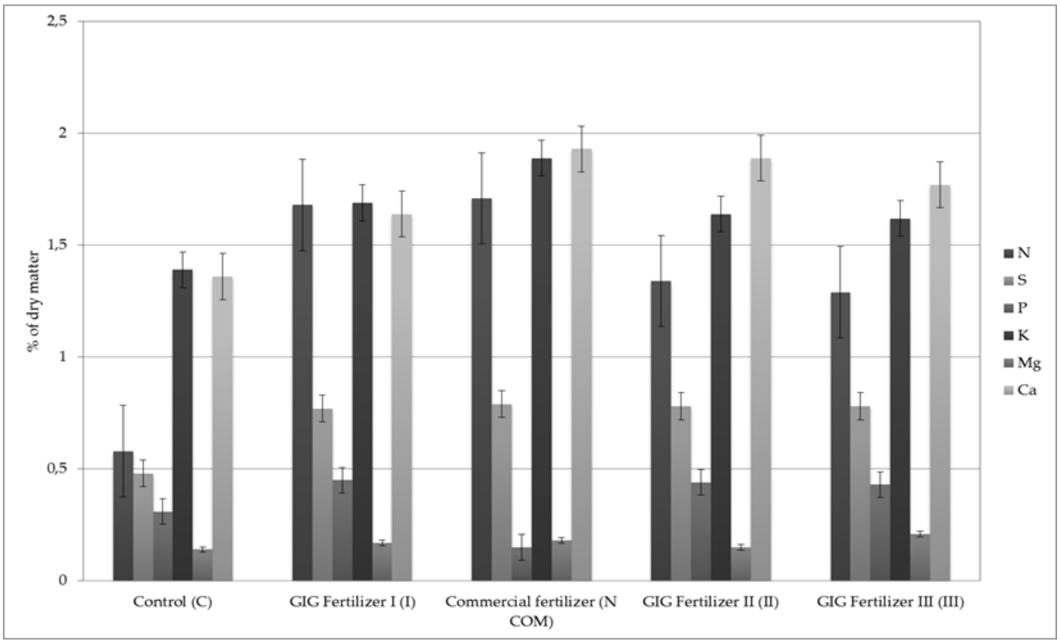

Figure 4 Results of the chemical analyses of the tested fertilizers

Dry mass analyses showed significant changes in biomass chemical composition: the N concentration was 289,6% of the control and 98,2% of the commercial fertilizer, whereas the respective P content was 145,1% and 300% for GIG fertilizer I. For GIG fertilizer II the N concentration was 231,1% of control and 78,4% of commercial fertilizer, whereas the P concentration was 141,9% of control and 293,3 of commercial fertilizer. For GIG fertilizer III the N concentration was 231,0% of control and 78,3% of commercial fertilizer, whereas the P concentration was 138,7 of control and 286,6% of commercial fertilizer. The results prove that the GIG fertilizer produced from municipal sewage sludge is highly competitive with other available commercial products.

The nitrogen and phosphorus concentrations in the commercial fertilizer (N COM) were several-fold higher than in all the tested GIG fertilizers composed of municipal sewage sludge. For N, the determined levels were 6,6, 6,9, and 8,6 times higher relative to GIG fertilizers I, II and III, respectively and for Phosphorus, the respective fold values were 5,2 5,4 and 6,6. It has to be emphasized here that the field test results with either of the fertilizer product show equal concentration of N in dry mass of plants as well as similar plant growth, which clearly proves that the N absorption from organic waste was much more effective than that obtained for the commercial product (Fig 4). Therefore, considerably higher N bioavailability can be inferred for the GIG innovative fertilizer. Furthermore, the phosphorus concentration in plants grown on the GIG sewage-based fertilizer was higher than in plants fertilized with the commercial product (Fig.4). The observed high bioavailability of key biogenic elements is of particular importance in terms of implementing the concept of Green Deal and idea of Circular Economy.

The use of all GIG-elaborated fertilizers, that is GIG I, GIG II and GIG III products, as well as the commercial fertilizer resulted in comparable plant growth stimulation. The highest rate of stimulation was obtained for plants fertilized with the GIG II (51,2%) and I fertilizer (49%). In plants fertilized with the commercial fertilizer together with other plant cultivation agents, a slight inhibition of root growth was identified in relation to the control plants. In the case of plants fertilized with the GIG I fertilizer, the root growth was stimulated by 8,4% (Figure 5).

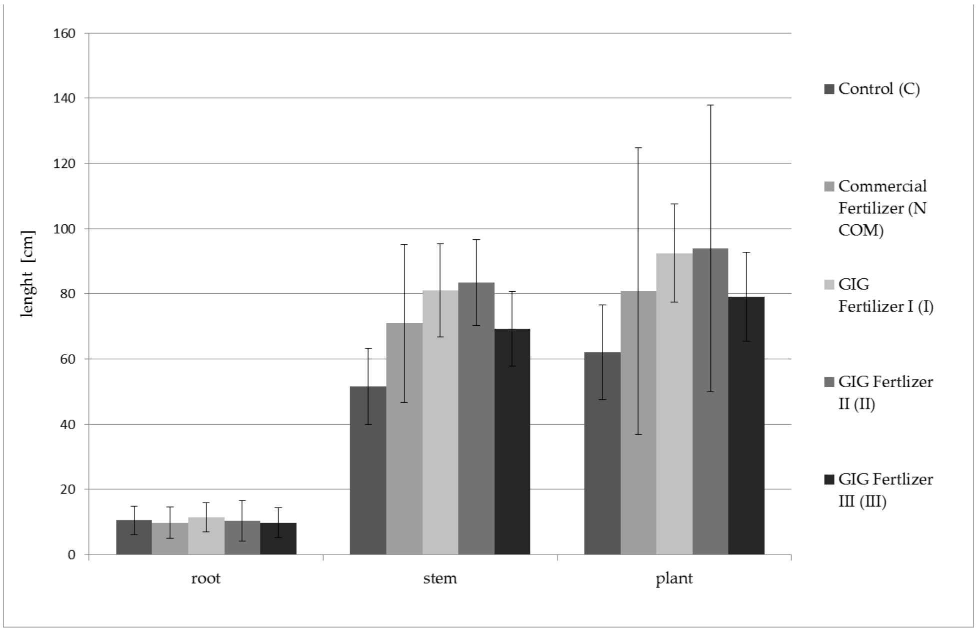

Figure 5 *Sinapis alba* growth of plant organs upon fertilizing with the GIG fertilizers I, II, and III as compared to the application of the commercial product N COM.

Rates of stimulation/inhibition of *Sinapis alba* plant organ growth upon fertilizing with the GIG fertilizers I, II, and III as compared to the commercial product N COM. The data replotted from Figure 5.It should be noted here that the results obtained by Wolloman *et al* showed that bioavailability of phosphorus from sewage sludge-based fertilizers depended on its form and the sludge processing technology. Accordingly, the products obtained with thermal processes had lower bioavailability than the ones generated upon mechanical processing [17]. In our case, the stabilized municipal sewage sludge was treated with mineral additives thus it may result in higher bioavailability of phosphorus and other nutrients.

In turn, the research of Gonzaga *at al* [18] revealed significant changes in N and P bioavailabilities due to biochar presence in sewage sludge which raised concerns about the management and effectivness of biochar coming from sewage sludges as a soil amendment. The mentioned study showed that biochar improved plant growth during the first 60 days of cultivation and the concentration of N in plants was increased by 17-40% [18]. Also research conducted by Dubis et al show great potential in sewage sludge based fertilizers as in result their research proved that sewage sludge and mineral fertilizers exerted similar yield-forming effects for miscanthus growth [19].

5. Conclusions

The presented preliminary studies show a great potential for developing advanced technologies of mechanical sewage sludge processing into added-value products. As for the safety regulations regarding heavy metal levels, the analyses showed that the concentrations of these elements in plant dry mass were similar and at remained at the acceptable level, both for our newly-developed sewage-sludge based fertilizer and for a commercial product.

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