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Chemical stability and sanitary properties of pelletized organo-mineral waste-derived fertilizer

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Abstract: Different types of organic waste can be used as fertilizers or soil improvers, but such materials are susceptible to chemical and biochemical decomposition, and their storage can entail a deterioration in their quality. Evaluation of the influence of water content and ambient temperature on the chemical and microbiological properties of pelletized organo-mineral fertilizer produced on the basis of digestate from biogas plant and ashes from biomass combustion was the aim of the study. The results of the short (one month's storage in the – laboratory silo) and long-term (one year's storage in – unheated compartment) studies showed that the quality of the fertilizer depends on the temperature, fertilizer humidity, and air accessibility. The growth in the temperature from 20 to 30°C decreased the content of total and ammonium nitrogen, while the increase in water content stimulated the development of the fungi in fertilizer stored at 20 and 30°C. The access of the ambient air resulted in the increase of moisture and volatile solids content in the fertilizer. It was stated that fertilizer should be stored without access to the atmospheric air, at the temperature below 20°C to ensure their long-term chemical stability and microbial safety.

Introduction

The land application of residues is one of the most preferred methods of sustainable waste management. Such action allows to utilize the waste and improve the soil properties, but it also helps to reduce the financial and environmental costs related to waste management and usage of mineral fertilizers (Walsh et al. 2012). The aim of the study was to determine the effect of storage conditions on the chemical and microbial properties of the pelletized organo-mineral fertilizer produced on the basis of digestate from agricultural biogas plant and ashes from biomass combustion process.

Providing the nutrients for plants is a key requirement for maintaining long-term soil productivity, especially in places, where the nutrients are systematically discharged with the biomass. Nutrients can be supplied in form of inorganic or organic fertilizers. The short and long-term field studies showed that the best effects in plant productivity were obtained when the integrated organo-mineral fertilization was used (Zhong et al. 2010, Lazcano et al. 2013). Commonly used inorganic fertilizers allow to partially meet the nutritional needs of the plants, namely to cover the demand for nitrogen, phosphorus, potassium, calcium, magnesium or sulfur. However, they do not supply the trace elements that are necessary for normal activity of plant cells and do not improve the physical and adsorption properties of the soil. The use of organic fertilizers leads to multifaceted improvement of the soil quality, not only by providing nutrients, but also affecting the physical, chemical and physicochemical properties of the soil. Thus, many experts recommend application of organic or organo-mineral fertilizers that supply not only the basic biogens, but also the microelements and humigenic substances (Chen et al. 2007).

Many different types of waste, e.g. organic fraction of municipal waste, wood ashes, sewage sludge, agricultural waste, such as post-harvest residues, poultry, pig, cow and rabbit manure were tested as components of organic or organo-mineral fertilizers (Zhong et al. 2010, Lazcano et al. 2013, Baran et al. 2015, Iżewska and Wołoszyk 2014, Kominko et al. 2017, Küçük and Tekgül 2017). The waste has to be free of harmful microorganisms, parasites and toxic chemicals to avoid environmental risks, such as leaching of heavy metal or contamination of the soils with enteric bacteria (Nkoa 2014). Different types of digestates from biogas plants meet these requirements. However, their fertilizing properties are determined by the composition of digested feedstock, which

influences the organic matter content, nutrient concentrations and sanitary conditions (Wiśniewski et al. 2015, Nkoa 2014,Tambone et al. 2010, Alburquerque et al. 2012). Low concentration of nutrients, compared to inorganic fertilizers, is the main disadvantage of a liquid manure, sludge or digestate, and it makes the amendment effects visible only at high fertilizer dosages (Iakimenko et al. 1996). Thus, large amount of digestate has to be applied in order to meet the plant demand for nutrients. Effective dewatering is needed to avoid the high cost of fertilizer transport. It leads to a significant decrease in volume, simplifies its handling and application into the soil. Highly-effective dewatering enhances the chemical and biochemical stability of the fertilizer components, which makes its storage easier. However, dry digestate may cause troubles during transport and application to the soil because of its low density and loose structure. The pelleting process solves this problem. The process involves bonding of fine particles of the material together into pellets in an extruder under the high pressure conditions (Dinel 2003). The pelletized organic fertilizer can be distributed more accurately, directly into the desired place. Additionally, the nutrients are released slowly, protecting the environment against their uncontrolled runoff (Bradbury 2015).

The quality of pelletized fertilizer is influenced by the transport and storage conditions (Marlair and Kordek 2005). The studies on different types of biomass containing pellets showed that changes in their structure and composition depend on the kind of stored material, its density, moisture content, physical and chemical composition. These changes are induced by the external factors, including temperature, air humidity, or pressure on the silo walls (Zhong et al. 2001, Xu et al. 2010). Daily or seasonal variations in the temperature and humidity may lead to changes of physical, chemical and microbiological parameters of the pellets.

The caking of fertilizer during a long-term storage caused by biological and chemical processes taking place in the material is the most common problem encountered by farmers. When improperly protected, fertilizers absorb ambient moisture, which leads to an aggregation of the material and hinders the land application thereof. Caking is influenced by the temperature. Its increases may lead to overheating which results in a complete aggregation of the fertilizer deposit.

Microorganisms are another relevant factor that influences a quality of the pellets. Bacteria and fungi are common microorganisms that colonise the pellets produced from different types of organic materials (Xu et al. 2010, Kymäläinen et al. 2015). A mass appearance of the microorganisms causes a rapid biodegradation of the organic matter and leads to deterioration in the physical stability and chemical parameters of the pellets.

Materials and methods

Examined material

Pelletized fertilizer produced in the pilot-scale installation was the subject of the studies. The pellets consist mainly of organic and inorganic residual substrates. Basic parameters of two main components of the fertilizer are shown in Table 1. The digestate produced in biogas plant in Siedliszczki near Lublin (eastern Poland, 51°08'14.9"N 22°52'07.5"E) during anaerobic co-digestion of corn silage, waste from fruit and vegetable industry, and whey were the basic substrates for the production of pellets, constituting the organic component of the fertilizer. Additionally, the bottom ashes from biomass combustion and mineral additives (zeolite, dolomite and bentonite) were used in order to supplement the microelements in a final product and to obtain better mechanical parameters. The digested material was dewatered to the moisture content of *ca.* 70% and mixed with powdered natural zeolite, dolomite and bentonite (<2 mm in diameter) in total dose 6 kg of mineral additives/100 dm^3 of digestate). The mixture was subsequently homogenized, and bottom ashes from biomass combustion and calcium oxide were added (in mass ratio 3.5:1.75:1). The reaction of lime and water caused an increase in the temperature, which led to the hygienization of the sludge. After cooling the mixture in the air stream to the temperature of 45°C, the pelletizing process was carried out. The length of the pellets ranged from 10 to 24 mm, and their diameter was 4 mm.

The initial water content of the fertilized pellets used in the laboratory and field experiments was 11.85%±0.14. All the experiments were carried out on the same batch of the pellets produced in 2014.

Storage of the pelletized fertilizer under laboratory conditions

Laboratory experiments were conducted in 2014 on the pellets taken from the production line. The special pressure chambers (approved by the Office of Technical Inspection) were used for

Table 1. Characteristics of basic components of the fertilizer

	Digestate	Bottom ash
pH	7.5±0.28	11.28±0.17
TS [%]	3.95±0.55	n.a
TVS [% TS]	54.26±04.5	n.a
N [% w.w]	0.39±0.18	n.a
P [%]	0.05±0.01	5.53±0.06
K [%]	0.37±0.03	12.6±4.3
Mg [%]	0.03±0.01	2.38±0.2
Ca [%]	0.31±0.02	11.12±0.76

n.a – not analysed

simulation of the fertilizer storage conditions in a laboratory scale. The construction of the pressure chambers ensured the control of the temperature, moisture, and load of the stored material. Therefore, it was possible to simulate the conditions of industrial silos. The experimental setup allows for carrying out the examinations under the pressure of up to 0.2±0.01 MPa in a controlled temperature ranging from 4 to 40°C. Two chambers had the temperature control in the range from 20 to 40°C, while in the third chamber the lower temperature could be set, using a cooling unit. The active volume of the chamber was 0.25 m^3. The technical data of the pressure chambers were following: pressure = 0.2 MPa, maximum temperature = 313.16 K (10°C), actual capacity = 244 dm^3, the diameter of tank = 508 mm, the height of the tank = 1725 mm. In order to examine the influence of temperature and moisture content on the properties of stored fertilizer the samples of the examined materials with different moisture content (13, 18 and 25% of weight) were placed in three chambers, at the temperatures of 7, 20 and 30°C. The examinations were carried out in thee repetitions.

To obtain the assumed moisture content the fertilizer samples were sprinkled with the relevant amount of distilled water), which was calculated according to the equation:

$$\Delta \mathrm{mw} = m\frac{W_1 - W_0}{100 - W_1}$$

where: m – mass of the sample (g), W_1 and W_0 – assumed and initial water content water content (% of weight).

Next, the samples were packed in polyethylene bags and stored at 5°C in the refrigerator for 24 h. The moisture content was re-controlled prior to the experiment.

Before placing inside the laboratory chamber, each sample of the fertilizer (0.5 kg of wet weight) was put into a PVC bag, which in turn was placed in latex rubber balloons. The PVC was used to avoid the reaction of the fertilizer with latex. The isolation of the samples, which were different in terms of moisture content, was applied in order to eliminate the effect of the changes in moisture of particular samples due to water evaporation of the more humid material and water vapour adsorption by the drier material, and also to obtain the more reliable results of the research on fungi growing, because of their potential migration from one sample to another. Additionally, the oxygen diffusion to the fertilizer from air contained in the chamber was limited. A 30-day storage time was selected according to the results of previous study (Kasprzycka et al. 2010). After this period, an adequate number of samples was taken from each silo and immediately subjected to analysis.

Long-term storage of the pelletized fertilizer under field conditions

The study on the influence of long-term storage was carried out on the pellet samples stored under different field conditions, provided by the producer. The study involved the pellets produced in 2014 and stored for one year in an unheated cell under varied atmospheric pressure, air humidity and temperature. The average annual ambient temperature in the Lublin region is *ca* 9.0°C (WIOŚ 2016) and the average relative humidity is *ca.* 80% (Siłuch 2005). One part of the pellets was stored in a pile (80 cm of height) under the air access (open-air conditions) and the second one was tightly closed in a plastic bag (air-tight conditions). The results of examinations carried out on the pellets produced in 2014 (control sample) were used as the reference.

Analytical methods

The analyses involved the determination of the parameters which govern the agronomic value of the fertilizers and environmental safety related to their land application.

The moisture content and total solids content (TS) were determined gravimetrically on the basis of the loss of weight during drying at 105°C in a laboratory dryer in accordance with the standard EN 14774-3:2009 (EN 14774-3:2009). The content of total volatile solids (TVS) expressed as the percentage of total solids was calculated on the basis of remaining residues determined after incineration at 550°C in a muffle furnace. The pH value was measured using a pH-meter (CyberScan pH 1500, EUTECH Instruments). The measurements were conducted in water suspension (fertilizer with distilled water mixed in volumetric ratio 1:5) one hour after the mixing stopped. The content of total nitrogen (N_{tot}), expressed as a percentage of dry weight, was determined with the Kjeldahl distillation method (Kieltec System 1026, Tecator, Denmark). The content of ammonium nitrogen N-NH_4^+ was measured with the Kjeldahl distillation method. An ICP OES-iCAP 6500Duo spectrophotometer was used for determination of the micro- and macroelement content (Ca, K, Mg, P, S and Al, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Sr, Sc, Sr). Prior to the analysis, the samples were mineralized using HNO_3 and HCl in Microwave 3000 solv (Anton Paar).

Microbiological analysis

Microbiological analyses consisted of: quantification of microorganisms (fungi and bacteria) on Petri dishes, inoculation of grown colonies of fungi onto agar slants in order to obtain the microcultures, and identification of fungi under an optical microscope (OLYMPUS, CKX41). The quantification on Petri dishes was carried out in accordance with Polish Standards (PN-ISO 6887-1, PN-R-64791, and PN-ISO 21527-2:2009). The conditions for the incubation of the fungi and bacteria colonies on Petri dishes are given in Table 2. The studies were carried out in triplicate for each dilution and growth medium.

The identification of the fungal colonies growing on pellets was performed for the fertilizer samples stored in a pressured chambers during the laboratory experiment.

For this purpose, the inoculum from the Petri dishes was transferred onto the agar slants placed in tubes. The number of agar slant tubes corresponded to the number of colonies being grown. When the slants were overgrown by the fungi, hyphae were collected and transferred in sterile conditions on plates with potato medium prepared beforehand in order to obtain the microcultures. They were used for microscopic observations of the morphological forms of fungal hyphae, e.g. sporulation. The microscopic findings were used for identification of fungi in accordance with Barnett's key (1962).

Statistical analysis

A three-way analysis of variance was performed by using STATISTICA 12 software to determine the effect of the temperature, water content, and access of the ambient air to the

pellets on the composition, chemical and microbial properties of the stored fertilizers.

Results and discussion

Effect of short-term storage in laboratory silo on the chemical properties of the pellets

In order to determine the impact of the storage conditions on agronomic quality of the pelletized fertilizer, the content of total and volatile solids, the pH value, and the concentration of the main nutrients: N, P, K as well as selected micro-and macroelements were analysed. The results of the studies are presented in Table 3.

Changes in temperature and moisture content did not influence the content of total volatile solids. The average values of this parameter ranged from 25.60 (in the sample with 13% of moisture stored at 7°C) to 25.93% of dry weight (in the sample with 18% of moisture stored at 30°C), and the differences were not statistically significant (Table 3). Although the increase in the temperature to 30°C caused a slight increase in pH over the average value of 12.7, in comparison to the average pH of the samples stored at 7 and 20°C (12.67 and 12.65, respectively), the variations cannot be regarded as significant. Moreover, there were no significant differences in pH measured in the samples with different moistures, stored in particular temperatures.

The analysed fertilizer was characterised by low nitrogen content, ca 0.6% of TS (Table 3, data for control sample). Moreover, the 1-month period of storage of fertilizer at 30°C caused a slight decrease in the content of this element of about 7–10%, to the values of 0.57–0.55% of TS (Table 3). The decrease in the contents of N_{tot} and $N\text{-}NH_4^+$ averaged over the samples with different levels of moisture was influenced by the increase in the temperature inside the silo from 20 to 30°C. The growth in the temperature from 7 to 20°C did not decrease

Table 2. Incubation conditions for culturing of microorganisms

Group of microorganisms	Medium of the growth	Temperature of incubation [°C]	Incubation time [d]
Total number of bacteria	PCA	30	2
Salmonella sp.	SS	37	24
Total number of fungi	*Sabouraud agar*[1]	28	7–10
	Potato dextrose agar (PDA, Martin)[2]	22	10–15

[1)] used in the long-term storage experiment
[2)] used in the laboratory experiment

Table 3. Physicochemical and biochemical properties of the fertilizer with different moisture content stored at different temperatures under laboratory conditions (average values and standard deviations)

Storage parameters		pH	TVS [% d.w]	Ash [% d.w]	N_{tot} [% w.w]	$N\text{-}NH_4^+$ [mg·L^{-1}]
Temperature [°C]	Moisture [%]					
30	13%	12.70 ±0.01	25.83 ±2.30	74.17 ±5.40	0.57 ±0.10	0.73 ±0.10
	18%	12.73 ±0.01	25.93 ±2.10	74.07 ±4.80	0.57 ±0.10	0.73 ±0.10
	25%	12.78 ±0.02	25.88 ±1.80	74.12 ±4.50	0.55 ±0.03	0.70 ±0.12
20	13%	12.65 ±0.10	25.66 ±3.10	74.34 ±2.80	0.62 ±0.02	0.79 ±0.11
	18%	12.67 ±0.01	25.67 ±2.8	74.42 ±2.90	0.60 ±0.01	0.77 ±0.10
	25%	12.67 ±0.03	25.70 ±1.87	74.40 ±3.30	0.60 ±0.01	0.77 ±0.10
7	13%	12.67 ±0.10	25.60 ±1.7	74.40 ±2.40	0.63 ±0.10	0.81 ±0.11
	18%	12.67 ±0.02	25.67 ±1.20	74.33 ±4.3	0.63 ±0.05	0.81 ±0.10
	25%	12.67 ±0.01	25.68 ±1.50	74.37 ±3.8	0.62 ±0.1	0.80 ±0.02
Control (before storage)		12.66 ±0.02	25.66 ±2.75	74.34 ±3.1	0.61 ±0.02	0.79 ±0.10

the content of both parameters significantly. In the temperature range of 20 to 30°C, the increase in temperature by 1°C was accompanied by the decrease of N_{tot} by 0.07%, while in the range of 7 to 20°C it was only by 0.02. It was found that increase in moisture content of the fertilizer from 13 to 25% did not influence the nitrogen content (Table 3).

The phosphorus content in fertilizer was low, ca. 0.5% (Table 4). The content of available phosphorus is strictly dependent on the soil pH. The element is available for the plant as $H_2PO_4^-$ ion that is formed in acid soils, but such conditions favour the immobilization of the phosphorus by binding or precipitation. On the other hand, low available ions of phosphates are formed in the alkaline reaction. Thus, the slight acidic or neutral soil reaction is the most suitable for providing the proper conditions for P sorption by the plants. For this reason, the examined fertilizer that is characterized by high content of calcium (11.12 to 11.52% d.w.) is recommended for application in acid soils. Calcium is a key element for plant growth that regulates the absorption of other elements influencing the chemical properties of the soil. The contents of phosphorus, potassium, and calcium during the storage did not change significantly, similarly to the concentrations of the examined microelements (Table 4).

Effect of long-term storage under field conditions on the chemical properties of the pellets

Contrary to the results of the laboratory study, significant differences in TS and TVS values were observed in pellets examined after the long-term storage under field conditions (Table 5). The average values of TS ranged from 82.85 to 88.28%, and lower values were measured in samples stored under open-air conditions. The latter were characterized by the values *ca*. 5% lower than in the control samples and in the samples stored under air-tight conditions. The decrease in TS can be attributed to the hygroscopic ability of the fertilizer components. Statistically significant differences were also observed in the case of TVS values, which ranged from 28.7 to 33.86% of d.w. The highest content of organic substances was found in the fertilizer stored under open-air conditions, while the lowest one in the fertilizer examined directly after production (Table 5). The increase of TVS can be explained by an increment in the biomass of the microorganisms growing on the pellets.

Different storage conditions in the long-term study did not cause significant changes in pH value of the fertilizers. The average pH of the examined samples ranged from 12.46 to 12.5 (Table 5).

Important changes in nutrients concentration during the long-term storage were stated. The concentration of ammonium in the fertilizers decreased both under the air-tight and open--air conditions (Table 4). A drastic drop in this parameter was observed during the storage of the fertilizer in a plastic bag. Average concentration of $N\text{-}NH_4^+$ in these samples was ca. 10-fold lower than before the storage. At the same time, the decrease in N_{tot} was not evident. While the concentration of $N\text{-}NH_4^+$ decreased over 80% due to storing under the air-tight conditions, the concentration of N_{tot} decreased only ca. 21%. It suggests that the release of nitrogen in the form of NH_3, favoured by high pH value and stimulated by low moisture content of the fertilizer, was the main reason of the decrease in N_{tot} content in the fertilizer stored in plastic bags. Significant, but lower loss in the ammonium concentration (of about 38%) was observed also in the samples stored under open-air conditions.

According to the data given in Table 5 the examined fertilizers were characterized by high content of potassium (ca. 3.5% wet weight as K_2O) and lower content of phosphorus (ca. 1% wet weight as P_2O_5). Both these parameters exceeded the minimum value given for fertilizers designated as organo--mineral PK fertilizers, which are 0.5% of wet weight for $P\text{-}P_2O_5$ and 1.0% of wet weight for $K\text{-}K_2O$, according to Polish standards (Dz.U. 2008, No 119, item 765). One year storage

Table 4. The content of the selected elements in the fertilizer with 25% of moisture, before and after storage under the laboratory conditions (the values marked by the superscript letter (a) given in the column did not differ significantly at $p<0.05$; standard deviation of less than 5%)

Element / Concentration	Ca	P	K	Mg	S	Pb	Cu	Fe	Hg	Mn	Sr	Sc	Ni	Cr	Cd
	[%]					[mg kg^{-1}]									
BEFORE STORAGE															
	11.50 a	0.45 a	3.25 a	0.70 a	0.71 a	25 a	45 a	5080 a	< 0.1 a	770 a	170 a	0.77 a	16.10 a	41 a	2.20 a
AFTER STORAGE															
at temperature 7°C															
	11.50 a	0.66 a	3.40 a	0.70 a	0.70 a	22 a	41 a	5083 a	< 0.10 a	768 a	170 a	0.82 a	16.15 a	41 a	2.20 a
at temperature 20°C															
	11.03 a	0.50 a	3.13 a	0.55 a	0.80 a	24 a	48 a	5078 a	< 0.10 a	773 a	168 a	0.74 a	16.22 a	41 a	2.20 a
at temperature 30°C															
	11.12 a	0.60 a	3.12 a	0.42 a	0.70 a	26 a	45 a	5084 a	< 0.10 a	772 a	167 a	0.77 a	15.85 a	42 a	2.20 a

did not significantly influence the concentrations of P and K in the fertilizers. Thus, due to the concentration of nitrogen, phosphorous, potassium and low content of heavy metals the pelletized fertilizer obtained by mixing of waste-derived organic matrixes with several inorganic materials can be designated as organo-mineral P and K fertilizer. On the other hand, high pH resulting mainly from the application of CaO as fertilizer component, can act as an agent limiting the long-term use of the fertilizer. Excessive saturation of the soil sorption system with Ca and raising pH over neutral value may lead to impairment of the intake of biogenic elements, e.g. phosphorus.

Effect of short-term storage in laboratory silo on microbial properties of the pellets

Evaluation of the risk of mould fungi and bacteria growth in the examined fertilizer was the aim of the microbial study. The growth of the fungi was influenced by temperature and the moisture content of the substrate. No growth of filamentous fungi was noted in fertilizer samples stored at a temperature of 7°C while insignificant growth of fungal colonies was observed at a temperature of 20°C (Fig. 1a). At this temperature, the highest abundance of fungi, equal to 1.5×10^4 CFU g^{-1} was noted in the samples with the highest moisture content (25%). The influence of moisture on the abundance of fungi was also observed in the case of the samples stored at 30°C (Fig. 1b). The average number of colonies of filamentous fungi in the samples with the moisture of 13% and 18% did not exceed 1.3×10^4 CFU g^{-1}, while an increase of moisture to 25% induced the development of fungal colonies. Their quantity grew to 2.3×10^4 CFU g^{-1}, which was the highest value found during the laboratory study. The important role of the moisture content for the development of fungal colonies in different types of stored organic materials has been emphasised by many authors (Weinberg et al. 2008, Chico-Santamarta 2011).

Table 5. Parameters of the fertilizer stored under field conditions in long-term study (average value and confidence intervals, α=0.05)

Parameter	Before storage	After storage	
		Air-tight conditions	Open-air conditions
TS [%]	88.1±0.10	88.3±0.12	82.85±0.09
Moisture content [%]	11.9±0.10	11.7±0.12	17.15±0.09
TVS [% TS]	28.7±0.12	30.8±0.27	33.86±0.37
pH	12.5±0.08	12.46±0.08	12.40±0.04
N_{tot} [% w.w.]	0.6±0.01	0.53±0.01	0.60±0.01
N_{tot} [mg/kg d.w.]	7544±91	5945±80	7203±85
N-NH_4 [mg/kg d.w.]	36.1±1.37	3.56±0.09	22.30±0.25
P-P_2O_5 [% w.w.]	1.01±0.01	1.02±0.02	1.02±0.02
K-K_2O [% w.w.]	3.49±0.56	3.82±0.53	3.73±0.55
Abundance of fungi [CFU g^{-1} d.w.]	10	<10	$9.5\cdot10^4$

w.w – wet weight
d.w. – dry weight

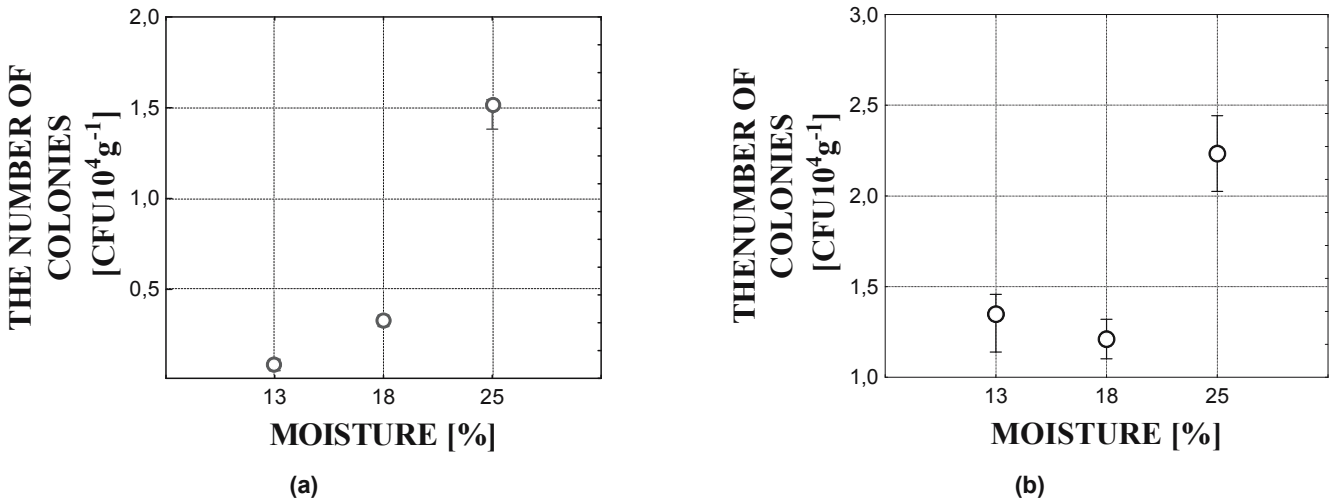

Fig. 1. The average number of filamentous fungi in fertilizer examined under laboratory conditions, stored at (a) 20°C and (b) 30°C, depending on the moisture content

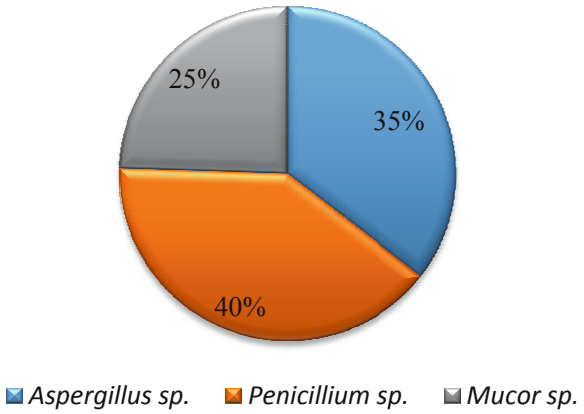

Fig. 2. The percentage of particular genera of the fungi found in fertilizer stored at 30°C in the laboratory experiment

The filamentous fungi belonging to the genera *Aspergillus, Penicillium*, and *Fusarium* were found on the fertilizer samples stored in the laboratory silo. The species belonging to *Penicillium* were the most numerous populations of the fungi in fertilizer with moisture content of 25% stored at 30°C (Fig. 2).

Effect of long-term storage of the fertilizer on microbial properties of the pellets

The storage conditions influenced the number of fungi in the fertilizer examined in the long-term study. The raw fertilizer was inhabited only by the single colonies (*ca.* 10 CFU g^{-1} d.w.) in spite of a high moisture content of the material. The samples stored in a plastic bag were characterized by even smaller quantity of fungi. However, storage of the fertilizers under open-air conditions stimulated the growth of fungi. Their quantity increased to 9.5×10^4 CFU g^{-1}d.w. The number of fungi in this material was similar to the highest values found by Chico-Santamarta et al. (2011) in pellets produced from rape (canola) straw, which were stored for one year in plastic bags exposed to shifts in atmospheric conditions. Taking into account the higher organic matter content in canola straw than in the organo-mineral fertilizer, the more favourable conditions for the growth of fungal colonies would be expected. But, low moisture content (below 11%) inhibited the development of microorganisms.

Contrary to the changes in the fungal colonies, the abundance of the bacteria community inhabiting fertilizers was not influenced by the long-term storage conditions. The quantity of the bacteria in all analyzed samples was so low that the determination of their total quantity on PCA medium was impossible. Single colonies of bacteria were observed only on the medium that contained the material isolated from the samples stored in a plastic bag. No rods of Salmonella were found in any of the examined pellet samples.

Conclusions

The results of a 1-month study carried out in laboratory silos under controlled temperature (7, 20 and 30°C) and moisture content (13, 18 and 25% of weight), and 1 year study carried under air-tight and open-air conditions showed that the quality of the organo-mineral fertilizer obtained by mixing of waste-derived organic matrixes with several inorganic materials depended on their storage conditions. Although, the short-term experiment showed that the content of neither total solids nor volatile solids was influenced by the changes in the storage conditions, the unfavorable changes were observed in the nitrogen content. It decreased with the increase of storage temperature, and this drop was more efficient in the range of the temperature growth from 20 to 30°C than from 7 to 20°C. The increase in temperature was accompanied by the growth in pH value, but this phenomenon was significant only in the range of 20–30°C. Additionally, in this range of temperature, the increase in pH value was influenced by the increase in moisture content. The moisture content of the fertilizer did not affect the nitrogen concentration. However, the increase in water content stimulated the development of the fungi in the fertilizer stored at 20 and 30°C, which manifested in the growth of their abundance. The storage of the fertilizers for 1 year under air-tight and open-air conditions and at the seasonal changes in the temperature caused more significant variations in the properties of the fertilizers. Except for the more evident decrease in nitrogen content, especially in the fertilizers stored in an air-tight bag, the changes in contents of total solids and organic matter were observed. The fertilizer stored in an open-air pile had significantly higher moisture and content of volatile solids, compared to the raw material and pellets stored under air-tight conditions. Additionally, it was characterized by the highest abundance of fungi, equal to 9.5×10^4 CFU g^{-1} d.w.

To summarize, despite of the potential loss in the nitrogen content, the storage of the pelletized organo-mineral fertilizer under air-tight conditions is recommended because of detrimental changes in water content of the material and microbial properties of the pellets exposed to atmospheric air. The temperature inside the storage area should not exceed 20°C. Increase of the temperature over this value increases the risk of enhanced development of the communities of filamentous fungi.

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Stabilność chemiczna i właściwości sanitarne peletyzowanego nawozu organiczno-mineralnego wytworzonego z odpadów

Streszczenie: Celem pracy jest ocena wpływu wilgotności, temperatury i dostępu powietrza na właściwości chemiczne i mikrobiologiczne granulowanego nawozu wytworzonego na bazie pofermentu z biogazowni i popiołów ze spalania biomasy. Wyniki badań krótkoterminowych i długoterminowych wykazały, że jakość nawozu zależy od temperatury, wilgotności nawozu i dostępności powietrza. Wzrost temperatury od 20 do 30°C znacząco obniżył zawartość azotu, a wzrost wilgotności stymulował rozwój grzybów. Dostęp powietrza powodował wzrost wilgotności i zawartości substancji organicznej w nawozie. Stwierdzono, że w celu zapewnienia długoterminowej stabilności chemicznej i bezpieczeństwa mikrobiologicznego nawóz należy przechowywać bez dostępu powietrza, w temperaturze poniżej 20°C.