MANURE PROCESSING INTO GRANULAR FERTILIZERS USING ADDITIONAL ADDITIVES

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Abstract. According to the project of the EU Commission (Circular Economy Package Document) currently only 5 % of bio-waste in the European Union is recycled. The EU imports around 6 million per year tons of phosphates, but up to 30 % of this amount could be replaced by substances received from organic waste (manure and others). Organic fertilizers are the only alternative for organic farms. The additional value is received by replacing mineral fertilizers with organic ones: reduced energy consumption for fertilizer production and transportation, less environment pollution, improved soil properties. In addition to this, recycled biomass is more homogeneous and more even spread in the fields. The aim of the work is to determine the possibilities of processing of manure compost and other waste into granular organic fertilizers, the physical – mechanical properties of granules. The physical mechanical properties of raw material for granular organic fertilizers with various additives molasses, defecate (lime sludge), which have a significant influence on the quality of granules, are discussed in the article. The fertilizer granules must be sufficiently resistant for transporting, storing and spreading in the soil. Properties such as the raw material fractional composition, material and granules moisture, strength of the granules and others were investigated. It has been determined that compaction of milled manure without additives requires 42.6 $kJ \cdot t^{-1}$ of energy, the mass with molasses additive 44.8 $kJ \cdot t^{-1}$ and with defecate additive 53.0 $kJ \cdot t^{-1}$ energy, while estimating the pressure function parameters and the density of the required granules.

Keywords: manure, compost, granulation, energy consumption, mechanical properties.

Introduction

With reference to Lithuania, according to official statistics, from 2015 to 2019 a total of pig 572,012 heads were reared [1]. The number of the most popular animals at the beginning of the year is presented in Table 1. The number of animals tends to decline, but such concentration of livestock farming activity makes it critical from the environmental and the economical points of view, setting up technologies for proper management of both manures in compliance with the required lowering of livestock farming environmental pressure [2].

Table 1

Number of animals at the beginning of 2015–2019 [1]

Animal kind	2015	2016	2017	2018	2019
Pig	714157	687822	663915	611931	572012
Cattle	736612	722602	694752	676893	653513

One of the manure management trends is to process manure into valuable granular fertilizing products. Granule manufacturing is an energy intensive process. Tumuluru et al. reviewed that the power consumption of commercial pellet mills falls within the range of 48.9-130.7 $kJ \cdot t^{-1}$, the 37-40 % of which is required to compress the material, while the remaining energy is required to overcome friction during compression. Specific energy consumption is ranging 59-268.2 $kJ \cdot t^{-1}$ for pellet mills [3]. At a given densification system, the moisture content and other biomass properties (e.g., particle size distribution, biochemical composition) can significantly affect the specific energy requirements of the process [3-5]. Anyway, the high energy input required makes it uneconomical and not practical for farmers to directly purchase and use a pellet mill. In the granulation process water and particulate binders or additives are used, such as molasses, oils and others, to improve the granulation process and the granule quality parameters [6].

The aim of the investigation is to determine the possibilities of processing pig litter manure compost and other waste into granular organic fertilizers and the physical – mechanical properties of the granules.

Materials and methods

The following physical-mechanical characteristics of pig compost manure fertilizers were investigated and determined: the moisture of raw material and granules; biometric parameters of granules: measurements, mass, density; bulk density of raw material and granules; strength of granules and others. This research has been performed using the standard and modified methods.

Raw material preparation. Pig (swine) manure compost samples were dried naturally till about 40 % humidity. To achieve about 20 % humidity the compost samples were dried artificially in the ventilation canal with slow heated air flow. After heating the material was placed in the hammer mill, where it was grinded in fine powder form. Fractional composition of the milled manure was determined using a set of 200 mm diameter sieves. The sieve diameter range was: 0 mm, 0.25 mm, 0.5 mm, 0.63 mm, 1 mm, 2 mm, 3.15 mm, 4 mm and 5 mm. When sieving a 100 g mass sample with a special sieve shaker RETSCH AS 200, a set of sieves in horizontal surface is turned in semicircle for 1 min. The mass remaining on the sieves is weighted, and the sample part of every fraction in percentage is calculated. Each test is repeated 3 times.

Raw material and granule bulk density. An empty 6 dm^3 cylinder is weighted. The prepared mill is filled in the cylinder till the upper edge. The vessel with mill is weighted and the mass of mill is calculated. Bulk density of granules was determined according to DIN EN 1237. Bulk density was calculated by dividing the mass by the container volume.

Milled raw material and granule moisture content. Moisture content is determined according to the standard methodology. The samples were weighted and dried for 24 hours in the temperature of 105 ºC. Granules moisture content was determined analogous to mill, in a laboratory drying chamber oven according to the standard method DIN EN 13040.

Raw material compression test. For raw material pressure test 3 types of milled pig litter compost samples were made. The first one was without any supplements and named S1. The second was named S4 + Mel1, which consists of 4 parts of pig manure and 1 part of molasses. The third sample was named S4 + Def1 and it consists of 4 parts of pig manure and 1 part of defecate (lime sludge). A cylindrical chamber (12.2 mm diameter) with a piston device was filled with milled pig manure compost till 120 mm. The piston stroke was set to 60 mm. When the chamber was filled with milled manure, the compression force dependence on the deformation of the pressed mass was determined. The resulting curves were used to calculate the characteristics of the mechanical properties of the granulated raw material. The dependence of the pressure force F required for the granulation process on deformation of the material to be pressed is determined experimentally using the test machine “Instron 5960” and command and parameter registration computer system “Bluehill”.

It is known that the biomass pressure process is usually described by indicator functions [7]. In calculating the technological and technical parameters of the granulation process, it is necessary to know the required granule density and pressure, which are described by the following dependency:

$$p = C \cdot \rho^{a}, \tag{1}$$

where p – required pressure, MPa;
C – coefficient describing the mechanical properties of the granulated material;
a – coefficient of density variation;
ρ – density required to compress the raw material, $kg \cdot m^{-3}$.

The energy required for the granulation process is calculated as a function of density by dependency [8]:

$$E = \frac{C}{a-1}(\rho^{a-1} - \rho_0^{a-1}), \tag{2}$$

where E – energy, $kJ \cdot t^{-1}$;
ρ_0 – bulk density of the raw material, $kg \cdot m^{-3}$.

Granule producing. There were produced 2 variants of pig litter manure compost granules in laboratory conditions. The samples were wetted by sprinkling water on them. The first sample was wetted with water without any supplement named S1. Other samples were wetted by sprinkling water with molasses additional material (supplement). Mixing ratio among the raw material with water and molasses emulsion rate 1:1 named S2. For granule production a small capacity granulator 7.5 kW was used, with a horizontal granulator matrix with 6 mm diameter holes.

The granule parameters. The granule parameters were determined by measuring their height and diameter (digital calliper, accuracy to 0.01 mm). The granule weight was assessed by KERN ABJ scales (accuracy to 0.001 g). The height, diameter and weights were calculated for each type of samples using 10 of the granules to obtain the average error. The granules volume was calculated using the granule size (diameter and length).

Density of granules. Unit density of the granules was determined by calculating the weight and volume of 10 granules individually [9]. Knowing the moisture of the granules, the density of dry material (DM) of each sort of organic fertilizers and the data spread reliable interval (error) were calculated.

Granule strength measuring. Granule strength tests were made in the test machine "Instron 5960" and command and parameter registration by the computer system "Bluehill". The tests were performed by placing granules on plane with horizontal and vertical loads. Pig manure compost granules S1 tested in horizontal direction named S1 (HOR) and in vertical direction S1 (VERT). Analogically are named S2 granules series (S2 (HOR) and S2 (VERT)). Tests were made for 5 times for each sample. For compressive tests granules were selected of the height to diameter ratio greater than 2:1 (height – 12 mm; diameter – 6 mm). The test results were registered every 0.1 second until the granule completely crushed. The pressing speed (20 mm·min^{-1}) was the same for all samples. The measuring error was 0.02 %. During data processing, average values and their confidence intervals (CI) under the 0.95 probability level were found and the figures were made using MS Office program Excel 2010.

Results and discussion

Fractional composition of granulated compost fertilizers depends on the particle diameter. After evaluating the pig manure compost mill fractional composition (Fig. 1), the maximum of mill fraction accumulated on the range 0-0.25 mm holes sieve (23.20 ± 1.81 %). A smaller quantity of flour fraction accumulated on the sieves ranging with 0.25-0.50 mm holes (21.50 ± 0.49 %) and with 0.63-1.00 mm holes (18.23 ± 0.76 %). The compost mill particle size distribution was quite big. Comparing it with cattle manure compost mill for industrial production, the biggest part of mass accumulated in the fraction range of 0-0.25 mm.

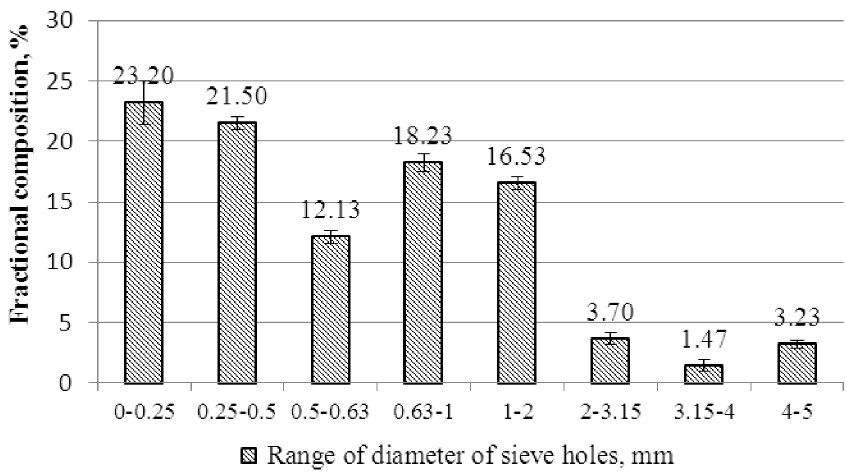

Fig. 1. **Raw material fractional composition**

Bulk density of composted pig manure raw material was 525.8 ± 56.06 kg·m^{-3}. It is quite similar to the cattle manure compost raw material bulk density (556.4 ± 5.81 kg·m^{-3}) [9]. Raw material moisture content was 21.39 ± 0.32 %.

Compression force is very important for granule mechanical characteristics. Dependence of pig manure density on compression is presented in Figure 2. The desired compression can be selected, according to which we obtain the corresponding granule density.

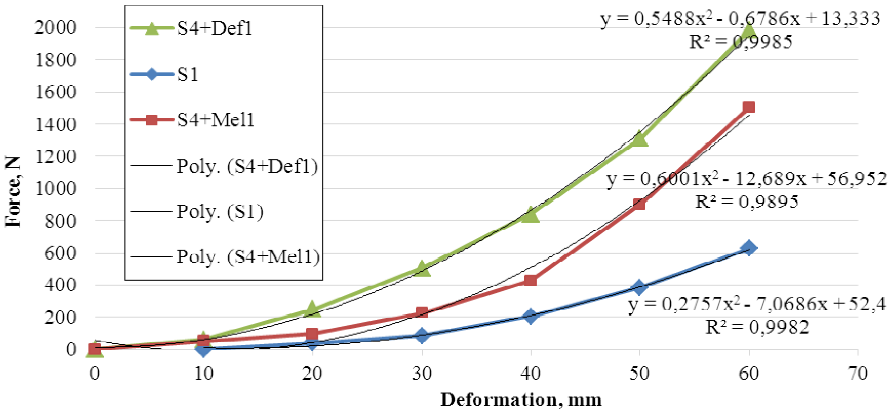

Fig. 2. **Raw material deformation dependence on compression**

During the experiment the cylindrical chamber was filled with milled manure and pressed. According to the obtained curves (Fig. 2) the changing mass density and pressure (Equation 1), and the density change coefficient *a* have been calculated. In the final stage, the coefficients describing the mechanical properties of the pressurized mass and the required energy *E* (Equation 2) were calculated. The calculation results are listed in Table 2. Using molasses and defecate additives, the final manure density was from 1212 to 1418 kg·m^{-3}, and the pressure from 9.8 to 16.5 MPa. Comparing the pressures of milled pig manure without additives, molasses adds up to 21 % of the required pressure and defecate up to 24 %. Compressive energy with molasses additive increased from 42.6 to 44.8 kJ·t^{-1} and with the defecate additive up to 53 kJ·t·$^{-1}$.

Table 2

Physical parameters of composted pig manure raw material

Manure type	Bulk density ρ_0, kg·m^{-3}	Compres-sion, Mpa	Sample density, kg·m^{-3}	Coefficient *C*	Coefficient *a*	Energy *E*, kJ·t^{-1}
S1	481	9.8	1212	1.68 x10^{-7}	2.52	42.6
S4 + 1Mel	511	12.5	1353	0.676 x10^{-7}	2.64	44.8
S4 + 1Def	615	16.5	1498	2.94 x10^{-7}	2.44	53.0

The density of the raw material and the granular material varies as shown in Figure 3. According to the researches, the density of the granulated material increases more than 3 times (from 482 to 1354 kg·m^{-3}).

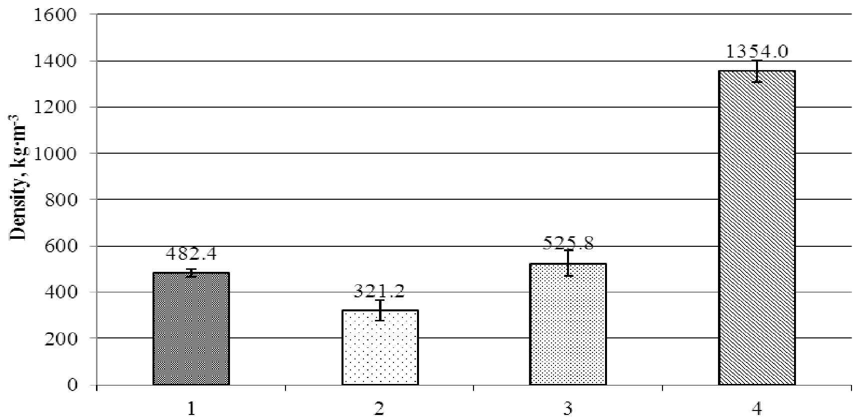

Fig. 3. **Raw material and granule density comparison:** 1 – naturally dried material bulk density, kg·m^{-3}; 2 – artificially dried material bulk density, kg·m^{-3}; 3 – milled material bulk density, kg·m^{-3}; 4 – granule density, kg·m^{-3}

It has been determined that the produced granulated fertilizers were in the range of the granule diameter from 5.76 ± 0.1 mm. Average granules weight was about 0.48 ± 0.03 g. Granule average length 12.6 ± 0.08 mm. Granulating raw material with such kind of traditional granulator, with a horizontal granulator matrix, we got big granule length scattering. Average density of S1 granules (without additives) was 1374.81 ± 44.78 kg·m^{-3} and 1242.01 ± 44.78 kg·m^{-3} D.M. S2 granules (with water to molasses emulsion rate 1:1) 1349.55 ± 159.76 kg·m^{-3} and 1219.30 ± 159.76 kg·m^{-3} D.M. Granule bulk density was 647.1 ± 4.05 kg·m^{-3}. Average granule humidity was 9.66 ± 1.20 %.

The crushing strength test of pig manure compost curves is shown in Figure 4. There was picked one average inherent curve from 5 samples on purpose to show the character of the force variation in the granule crushing strength test. Maximum crushing load test results from 5 samples on each granule series and the average values and their confidence intervals (CI) are shown in Figure 5. Maximum crushing loud force meanings were collected from the Instron Bluehill test control software data. There were picked the points, from which the force started to decrease for each sample.

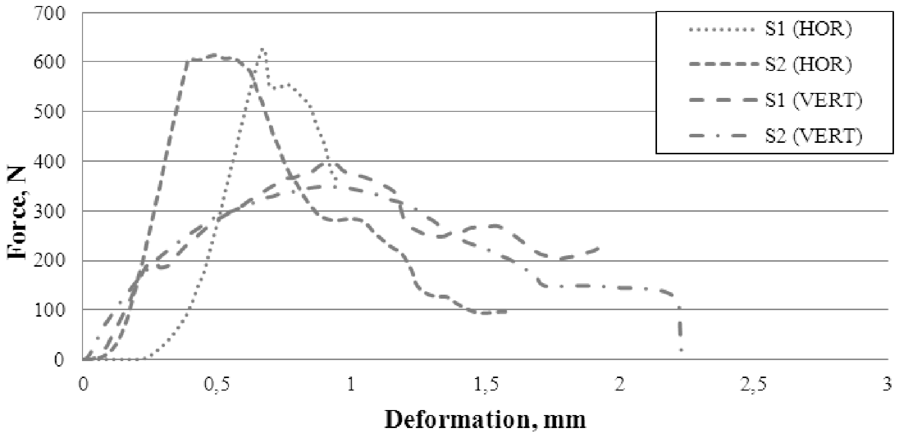

Fig. 4. **Granule strength test typical curves**

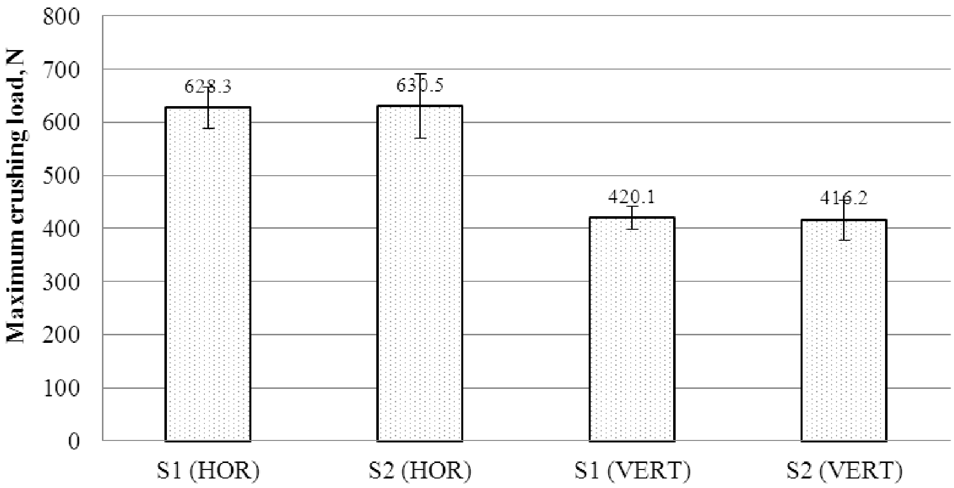

Fig. 5. **Strength test of organic fertilizer granules**

Analysing the deformation curves, it can be observed that at the maximum crushing force in horizontal direction achieved at more than 671.8 N, deformation was in the range from 0.23 mm in S2 (HOR) granule case (Fig 4). These granules series showed the greatest resistance to mechanical load. Average S1 series granule crushing strength was 628.3 ± 38.90 N, but there is no significant difference comparing to S2 series granules 630.5 ± 60.32 N (Fig. 5). A similar situation with the strength test was in vertical direction. Compared to previous studies of cattle manure compost granules, it may be seen that granules under the force of 425 N in horizontal compression and 228 N in vertical compression disintegrated totally. Granules with molasses supplement reached 491 N in horizontal direction and 451 N in vertical direction [9]. Pig manure granules have shown better results. Organic granular fertilizer should be firm enough to pass through a disc spreader without grinding to powder, also for transportation and storage.

Conclusions

1. The use of additives increased the initial density of the milled manure compost from 481 to 511 kg·m^{-3} with the addition of molasses and up to 615 kg·m^{-3} with defecate.
2. The use of molasses supplements is estimated to require 21 %, and with the use of additives for defecate 24 % higher pressures compared to milled pig manure pressures without additives.
3. Using the experimental pressure dependence on mass deformation, the index pressure function coefficients characterizing mechanical properties of milled pig manure were calculated.
4. It has been determined that the compaction of milled manure without additives requires 42.6 kJ·t^{-1} of energy, the mass with molasses additive 44.8 kJ·t^{-1} and with defecate additive 53.0 kJ·t^{-1} energy while estimating the pressure function parameters and the density of the required granules.
5. Granules produced from pig manure raw material were in the range of the diameter from 5.76 ± 0.1 mm and average length 12,6 ± 0,08 mm. Average density of S1 granules (without additives) was 1374.81 ± 44.78 kg·m^{-3} and 1349.55 ± 159.76 kg·m^{-3} of S2 granules (with water to molasses emulsion rate 1:1).
6. Molasses addictive (mixing ratio among the raw material with water and molasses emulsion rate 1:1) in pig manure compost had not significant influence in the vertical and horizontal directions for granule strength.

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