COMPARISON OF PHYSICAL MECHANICAL PROPERTIES OF GRANULATED FERTILIZER PRODUCED FROM COMPOSTED CATTLE AND DRIED COW, PIG AND POULTRY MANURE

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Abstract. The advantages of granular organic fertilizers are more convenient handling, storage, transportation, compared to traditional management of manure with litter. Manure granulation can increase the bulk density, improve storability, reduce transportation costs, and make these materials easier to handle using traditional existing handling and storage equipment. There were prepared four experimental samples of various manure mill and granules in laboratory conditions. For granule production a 7.5 kW granulator, with a horizontal 6 mm matrix was used. During the research, the physical-mechanical characteristics were estimated: biometric properties (dimensions, mass), raw material and granule volume and density, humidity, and granule strength of various composition cattle, cow, pig, and poultry manure material. Cattle manure compost contained the most material (65%) of the mass fraction, up to 0.25 mm. In dried cow, pig, and poultry manure, the amount of fraction material was mostly from 1 to 2 mm. The obtained results show that the highest bulk density of the prepared mill was from cow manure and the lowest bulk density was from poultry manure. The highest moisture content was also for cow manure, and the lowest determined moisture content was for poultry manure samples. The highest density was determined for cattle manure compost granules. The highest compressive strength, in the horizontal plane, was determined for hen manure granules, the force required to crush them reached 657 N. The aim of this work is to compare the main physical and mechanical properties of the studied manure material and produced experimental granules.

Keywords: manure, organic granular fertilizer, physical mechanical properties, density, granule strength.

Introduction

The problem of soil degradation encourages a closer look at the possibilities of applying organic fertilizers in agriculture. To improve these possibilities, manure granulation is increasingly used, it helps make organic fertilizers convenient for transport and mechanized fertilization using fertilizer spreaders [1]. When fertilizing only with mineral fertilizers, the soil is at risk of degradation. Due to improper fertilization, the amount of humus in the soil may begin to decrease; the amount of other substances needed by plants also decreases.

Fertilizing with manure not only improves the condition of the soil, but also achieves the goal of obtaining a better crop yield. Properly used manure of various animals and birds can become a valuable raw material for the production of fertilizers. Granulation of manure is becoming especially popular, which makes it possible not to lose useful substances during fertilization.

The advantages of granular organic fertilizers are more convenient handling, storage, and transportation, compared to the traditional handling of manure with litter. According to Papandrea and other authors the purposes of compost pelletizing are to produce pellets that are the densified form of compost or other mixtures, simplifying handling, transport, and storage operations [2]. Mostafa and others' studies showed that the effect of the biomass type, its composition, densification process, particle size, pellet size and the way they behave under testing conditions is obvious [3; 4]. It was found that higher density and durability could be achieved with a moisture content in the range of 40-43%, the hammer mill screen size of about 0.5 mm for cattle manure raw material [5].

The aim of this work is to compare the main physical and mechanical properties of the studied manure material and produced experimental granules, paying special attention to the strength of the granules.

Materials and methods

The following physical-mechanical characteristics of composted cattle and dried cow, pig and poultry manure were investigated: fractional composition of the milled material, the moisture content and bulk density of raw material mass; biometric parameters of produced granules (measurements, mass, density); strength of granules. This research has been performed using standard methodologies for evaluation of granular biofuel and modified methods.

Raw material preparation. In farms located in the Marijampole district (Lithuania) manure from cows, pigs and laying hens (approximately 10 kg each) was collected. Straw is used for litter in the farms for all kinds of animals. Manure samples dried naturally to 50% humidity in an open place. To achieve a moisture content of about 15%, the samples were artificially dried in a ventilation canal with a slow flow of heated air. After that, the prepared material is placed in a hammer mill GMM-1 (Lithuania), where the manure is ground to a fine fraction (2 mm sieve in the hammer mill was used). Cattle manure samples were purchased from a manure composting company in the Kaisiadoriai district (Lithuania). Cattle manure compost was not further dried or milled, because this is done at the compost distribution company.

Fractional composition. Fractional composition of milled manure was determined using the sieve shaker Retsch AS 200 (Germany), 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, the set of sieves in the horizontal surface turned in semicircle for 1 min. The mass remaining on the sieves was weighted, and sample part of every fraction in percentage was calculated. Each test was repeated 3 times like in the previous research [6; 7].

Material bulk density. The bulk density was determined according to the standard methodology (LST EN 1237:2002). The prepared milled material is filled in a 6 dm^3 cylinder till the upper edge. The empty vessel and vessel with the milled material are weighted and the mass of the mill is calculated. The bulk density is calculated by dividing the mass by the container volume. Each test was repeated 3 times.

Moisture content was determined according to the standard methodology (EN 12048:1999). The samples were weighted and dried for 24 hours in a laboratory-drying chamber in the temperature of 105 ºC.

Granule producing. There were produced four variants of manure granules in laboratory conditions (Table 1). For granule production a 7.5 kW granulator ZLSP200B (Poland), with a horizontal granulator matrix with 6 mm diameter holes was used.

Table 1

Produced and investigated organic raw material for granulation

Sample codes	Manure raw material used for experimental granule production
GA	Cattle manure compost
KA	Cow manure dried
S	Pig manure dried
VI	Laying hen manure dried

The granule parameters. The granule parameters were determined by measuring their height and diameter using the Vernier caliper LIMIT 150 mm (accuracy to 0.01 mm). Granule weight was determined using the Kern ABJ (Germany) scales (accuracy to 0.01 g). The height, diameter and weight were calculated for each type of manure samples using 10 granules to obtain the average error. The granule volume was calculated using the granule diameter and length. The density of all investigated granule samples was calculated according to standard methods [7].

Granule strength determination. Granule strength tests were performed in the test machine "Instron 5960" (USA) and parameter registration system "Bluehill". The diameter and height of each cylindrical granule were measured before testing and granules with the height to diameter ratio greater than 2:1 selected for testing. The granules were placed horizontally on the plate and individually compressed until breakage achieved. Granule compressive strength (N) was determined as the maximum force recorded when compressing the granule at fracture. A semi-static load with a constant displacement of 20 mm·min^{-1} was used. The tests were repeated 5 times for each type of granules.

During all data processing using the appropriate number of repetitions, average values and their confidence intervals (CI) under the 95% probability level were found.

Results and discussion

Experimental investigations of manure preparation and conversion into granular fertilizers were carried out in 2017-2022, in a laboratory based at the department of Agricultural Engineering and Safety of the Vytautas Magnus University Agriculture Academy in Lithuania. Investigations were carried out with various types of manure and additives. This paper summarizes the results of several years.

Cattle manure compost contained the most material (65%) in the mass fraction up to 0.25 mm. Cow manure mill contained mostly 1 to 2 mm of material (22%). Pig manure contained mostly up to 0.25 mm fraction material and the mass amount reached up to 23%. In hen manure, the amount of material from 1 to 2 mm fraction reached 33% (Table 2). The fractional composition of all types of manure was in most cases up to 2 mm, so it can be said that the dried or composted (in cattle manure case) material of all studied types was suitable for granulation.

Table 2

Fraction composition of cattle, cow, pig, poultry manure milled material (percent)

Type of manure material	Range of diameter of sieve holes, mm							
	0-0.25	0.25-0.50	0.50-0.63	0.63-1.00	1.00-2.00	2.00-3.15	3.15-4.00	4.00-5.00
Cattle (GA)	65.2±2.30	17.4±1.75	3.87±0.76	4.3±0.64	4.63±0.28	2.07±0.11	1.03±0.46	1.5±1.12
Cow (KA)	17.60±0.92	19.83±1.93	13.00±0.84	19.77±0.28	22.17±1.60	4.60±1.12	1.27±0.46	1.77±0.56
Pig (S)	23.20±1.81	21.50±049	12.13±0.53	18.23±0.76	16.53±0.56	3.70±0.49	1.47±0.46	3.23±0.28
Hen (VI)	14.33±6.72	17.10±2.62	11.60±2.11	18.91±1.05	33.53±5.29	4.05±1.85	0.29±0.13	0.18±0.13

From the obtained results, we can see that the highest bulk density of the prepared mill was for cow manure material – 620 kg·m^{-3}, and the lowest bulk density of laying hens' manure – 445.3 kg·m^{-3}. Moisture content is one of the dominant factors affecting the granule quality. Average moisture content of the prepared mill after artificially drying in the ventilation canal was from 13.98±0.26 in the hen manure case until 22.53±1.91 in the cow manure case (Table 3).

Table 3

Moisture content and density of experimental granules

Parameters	Cattle (GA) compost	Cow (KA) manure dried	Pig (S) manure dried	Hen (VI) manure dried
Bulk density, kg·m^{-3}	556.4±5.81	620±7.04	525.3±4.05	445.3±4.31
Mill moisture content before granulation, %	16.90±0.46	22.53±1.91	21.39±0.32	13.98±0.26

It has been determined that the produced granulated fertilizers were in the range of the granule diameter up to 6 mm. Granule average length was not more than 15.7±1.25 mm (in Hen (VI) samples case). The highest density was determined for cattle manure compost granules – 1497.32±70.58 kg·m^{-3}, and the lowest for hen (VI) manure granules – 1234.15±42.25 kg·m^{-3} (Table 4). The milled material of cattle and pig manure had finer fractions, so it is likely that the density of the above-mentioned granules was the highest. According to other authors the density values of swine manure granules produced from dried swine manure by adding 10% of water was 1407.23 kg·m^{-3} and produced from dried swine manure by adding 20% of water 1363.04 kg·m^{-3}, respectively [8].

Table 4

Determination of density of different types of granules

Type of granules	Granule parameters		
	Diameter *d*, mm	Length, *l*, mm	Density, kg·m^{-3}
Cattle (GA)	5.56±0.8	15.03±1.4	1497.32±70.58
Cow (KA)	5.55±0.9	13.9±1.6	1256.93±81.28
Pig (S)	5.57±0.9	13.2±5.6	1461.66±105.75
Hen (VI)	5.83±0.11	15.7±1.2	1234.15±42.25

General view of the produced cattle (GA), cow (KA), pig (S) and hen (VI) manure granules is presented in Figures 1 – 4. Since the same technology is used for the production of granules, it was monitored that visually the granules did not differ, except for the colour intensity. It could be noted that all tested granule types have not the characterizing smell of manure.

Fig. 1. **Cattle (GA) manure compost granules**

Fig. 2. **Cow (KA) manure granules**

Fig. 3. **Pig (S) manure granules**

Fig. 4. **Hen (VI) manure granules**

The granule crushing strength test of granular manure fertilizers is shown in Figures 5-6. Cattle manure compost granules (GA series) deformed at a maximum compressive force more than of 600 N, with deformation ranging from 0.1 mm to 0.5 mm until the granules completely disintegrated. The cow manure granules deformed at a maximum compression force of more than 700 N, the compression deformation was from 0.2 mm to 0.6 mm. Pig manure granules deformed at a maximum compressive force of 650 N, the deformation was from 0.1 mm to 0.5 mm. The hen granules deformed at a maximum compressive force of more than 700 N, the compression deformation was from 0.1 mm to 0.5 mm before the granules disintegrated. Analyzing the deformation curves of all manure samples, we observed that the maximum crushing force in horizontal direction achieved at more 720 N and deformation was in the range from 0.1 until 0.6 mm. Most of deformation begins at 0.2 mm and continues until 0.5 mm in all sample cases. The weaker granules were in cattle manure (GA) and cow manure (KA) samples in some cases, in such cases the minimum granule strength was a little bit more than 400 N.

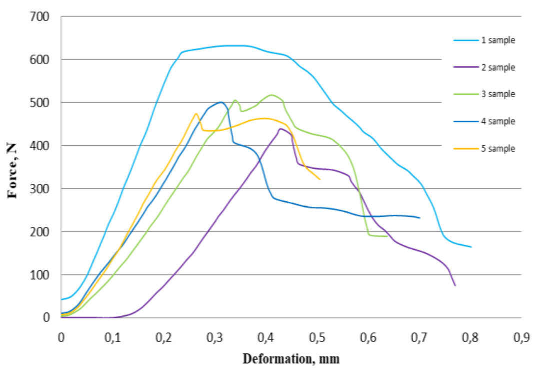

Fig. 5. **Curves of cattle manure compost (GA) granule strength test**

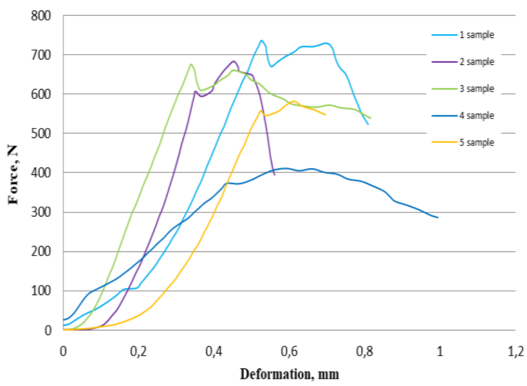

Fig. 6. **Curves of cow (KA) manure granule strength test**

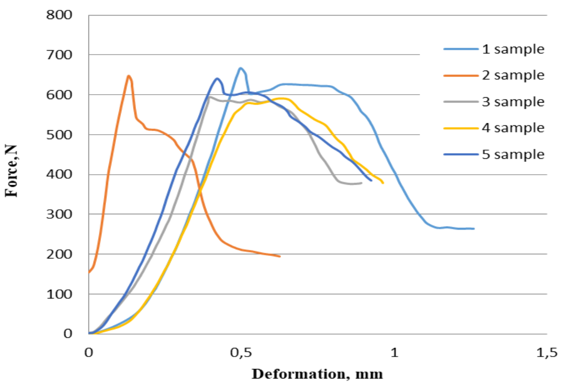

Fig. 7. **Curves of pig manure (S) granule strength test**

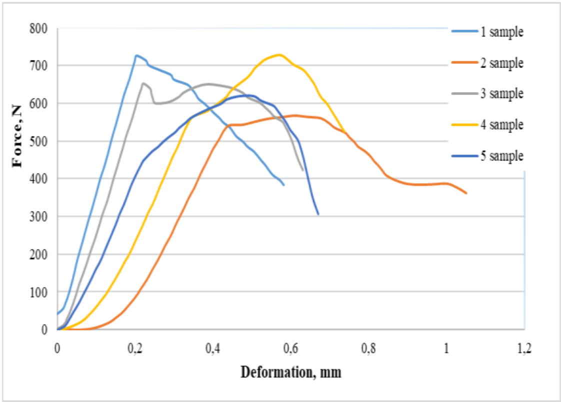

Fig. 8. **Curves of hen manure (VI) granule strength test**

Maximum crushing load test results from all series granule samples and the average values and their confidence intervals (CI) are shown in Figure 9. Maximum crushing loud force meanings are collected from Instron Bluehill program test control data. It was determined that all experimental granule samples showed a high compressive strength that exceeded 500 N in horizontal direction. Granule sample VI and granule samples with a semi-static stability of 657 N, were found to be the most mechanically stable, but there is no obvious significant difference comparing VI, S and KA series granules (Fig. 9).

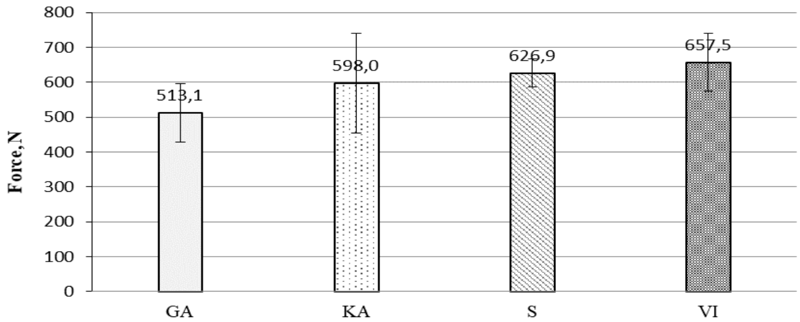

Fig. 9. **Comparison of compressive strength of produced cattle (GA), cow (KA), pig (S), hen (VI) manure granules**

It could be argued that all tested granules were sufficiently strong. The highest compressive strength, in the horizontal plane, was determined for hen manure granules, the force required to crush them reached 657.5±82.32 N. For comparison, according to a scientist from Poland, the hardness of granulate significantly increases together with greater contents of chicken manure and smaller contents of straw. With 80% poultry dropping granules the strength achieved 465 N [9]. In our research, straw litter percentage was not estimated. Although the cattle manure compost granules had the lowest compressive strength, it required 513.1±84.22 N of force to crush the granules. All types of investigated manure with litter granular fertilizer should be strong enough for storage, transportation and pass through a fertilizer disc spreader without braking.

Conclusions

1. From cattle, cow, pig and hen manure, using granulation technologies, it is possible to produce high-quality fertilizers that do not have the pungent smell characteristic of manure, are easily transported, and can be used for fertilizing crops of various sizes. Granular manure fertilizers increase the yield and quality of plants and the amount of humus in the soil. The use of manure granules corresponds to the ideas of sustainable, environmentally friendly farming.
2. Cattle manure compost contained the most material (65%) in the mass fraction up to 0.25 mm. Cow manure mill contained mostly 1 to 2 mm of material (22%). Pig manure contained mostly up to 0.25 mm fraction material and the mass amount reached up to 23%. In hen manure, the amount of material from 1 to 2 mm fraction reached 33%. The fractional composition of all types of manure

was in most cases up to 2 mm. Average moisture content of the prepared mill after artificially drying in the ventilation canal was from 13.98±0.26% in the hen manure case until 22.53±1.91% in the cow manure case. The dried or composted manure material of all studied types was suitable for granulation.

3. It has been determined that the produced granulated fertilizers were in the range of the granule diameter up to 6 mm. Granule average length was not more than 15.7±1.25 mm (in hen (VI) samples case). The highest density was determined for cattle manure compost granules – 1497.32±70.58 kg·m^{-3}, and the lowest for hen (VI) manure granules – 1234.15±42.25 kg·m^{-3}.
4. It can be argued that all tested granules were sufficiently strong. The highest compressive strength, in the horizontal plane, was determined for hen manure granules, the force required to crush them reached 657.5±82.32 N. Although the cattle manure compost granules had the lowest compressive strength, it required 513.1±84.22 N of force to crush the granules. All types of investigated manure with litter granular fertilizer should be strong enough for storage, transportation and pass through a fertilizer disc spreader without braking.

Author contributions

Conceptualization, E.J., A.G. and R.M.; methodology, R.M. and A.J.; software, R.M.; validation. E.J., A.G., R.M. and A.J; formal analysis, E.J., R.M. and A.G.; investigation, E.J., R.M., A.G. and A.J; data curation, E.J., R.M., A.G. and A.J.; writing – original draft preparation, R.M.; writing – review and editing, E.J. and A.J.; visualization, R.M.; project administration, E.J.; funding acquisition, A. G. All authors have read and agreed to the published version of the manuscript.

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