INVESTIGATION OF PHYSICAL-MECHANICAL PROPERTIES OF EXPERIMENTAL ORGANIC GRANULAR FERTILIZERS

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Abstract. Injection into the soil organic fertilizers, which consist of the main chemical elements (nitrogen, phosphorus, potassium), improves the soil dynamics of biological processes. The best effect is achieved when the fertilizer is placed locally, i.e. during the seeding process in the plant root system development zone. For that reason, it is economically expedient to create and use a granular organic fertilizer (cattle, poultry manure, organic compost) with relevant physical-mechanical properties, which influence the product warehousing (storage), transport, straggling spreading in the soil and localized insertion. The physical-mechanical properties were determined (bulk density 770-680 kg·m^{-3}, natural slope 30.5-34.4º and the inrush failure angles 43-47º, mechanical durability of pellets more then 86 %, etc.) of experimental granulated organic fertilizer produced by different technologies, because the physical-mechanical properties have a significant influence on the technological product parameters.

Keywords: granulation, organic fertilizer, pellets, physical-mechanical properties.

Introduction

Organic waste is a secondary raw material generated as a result of the production process in agricultural, municipal, recycling, and a number of other companies. This type of secondary raw materials includes livestock and poultry manure, crop production and feed waste, vegetable and fruit processing waste, catering waste, etc. Utilization of such materials that contain valuable chemical components (nitrogen, phosphorus, potassium) allows processing them into valuable products such as organic fertilizers, food and feed additives, etc. at the same time reducing production losses.

To preserve the environment and its resources, to achieve the maximum economic effect and produce a competitive product, there have been constant efforts to find ways how to utilize all production waste and secondary raw materials generated as a result of various types of human activity. One of the organic waste treatment methods involves processing of such secondary raw material into organic products by means of granulation. [1-3] Organic waste processing is an entire ecological process with the final stage being granulation. Organic-processed manure-based granular fertilizer does not contain pathogenic microflora, weed seeds, pathogen egg cells or larvae s. In a granulated form, the majority of processed materials acquire better physical-mechanical properties: increased density, mechanical strength, pourability, etc. Such products are easier to transport, and use in various technological processes. Granulated products remain pourable longer, are dust-free, easy to sieve, and will remain in soil longer and less likely to leach. In turn, one of the main advantages of granulated organic fertilizers is significantly lower consumption volumes compared to traditional compost and biohumus. The reason is that pellets can be incorporated into the soil together with seeds during sowing using serial sowing machines thus making granulated fertilizer more efficient. Thus, the main task in granulation of bulk materials is increasing the quality of granules.

Production of high-quality organic granulated fertilizer is a complex task as the process is subject to various factors: variety and quality of raw materials, composition and compatibility of material formulation, moisture content and its variation during the granulation process, quality and degree of abrasion of the operating parts of the grinder and the granulator used, correct selection and setting of equipment operating modes, etc. This means that producers of organic granulated fertilizers need to take into account all the elements and stages of the technological process of granulation. In a competitive market, this cannot be overlooked or ignored. In the granulation process, there are several factors affecting the quality of the final (new) product. Some authors claim the quality of granulated product is mostly affected by the composition of granules (20 %), pressing quality 15 %, material shredding parameters up to 20 %, additional processing approximately 40 %, as well as the drying-cooling process [4].

The quality of granulated product (pellet strength and shape) is highly affected by the perforation of the granulator's matrix, i.e. measurements and the shape of the channel [2; 5; 7]. There is a certain relation between the pellet diameter and the length of the matrix channel, the pressing length, affecting the desirable pellet strength. However, the cross-sectional area of the matrix channel affects the efficiency of the granulation process. Matrix force depends on its thickness, which should be 10 times larger than the diameter of the channel. In any case, it is necessary to find the optimum working conditions under which the pellets retain their given measurements (volume), shape, and integrity. Elasticity of pellets allows for change in measurements and shape after coming out of the matrix channel. Cracks in pellets along the perimeter demonstrate that the product was insufficiently compressed or remained too short in the matrix channel when subject to pressure. There is a linear relationship observed between the performance of the granulator and the diameter of the matrix channels, the number of channels by matrix parameter and width as well as the quality of the channel internal surface. A similar relationship is observed between the matric channel configuration, i.e. the structural and geometric shape, and component composition of the raw material [5; 7]

The reasons for insufficient control of such newly produced product quality may lie in the lack of technical means to assess the parameters of specific physical-mechanical properties of pellets, high production volumes and variety of technical equipment, composition and formulation of the original product (raw material). Selection of the organic fertilizer granulation method depends on the physical-mechanical properties, compatibility and material plasticity of the components of the material being granulated. Mechanical durability (strength) or pellet strength index is a parameter of the resistance of pellets towards mechanical impacts/abrasion of other pellets as a consequence of handling and transportation, spreading in soil by means of the centrifugal fertilizer spreader, or incorporating locally into soil during sowing. For example, in production of granular compound feed, the strength index of pellets varies from 92 to 94, and indexes below 88 are considered inacceptable. [8; 9] Pellet hardness, or static strength is a parameter of the resistance of pellets towards certain load (pressure). It should be noted that when the number of the measured pellets is less than 15 pellets, the accuracy of the results of measuring this parameter will be insufficient [2; 5; 9]. Pellet hardness and mechanical durability are interrelated: based on the values of these parameters, the correct parameters of the granulation process can be determined. The analysis of physical and mechanical characteristics allows identifying the reasons of poor pellet quality. Production of consistent, high-quality pellets remains a complex task for producers of granulated organic fertilizers. In the long term, organic fertilizer pellets must meet the relevant regulations and standard requirements with respect to the composition and amounts of nutrients (chemical elements) as well as the physical and mechanical properties. Management and implementation of the granulation process of organic secondary raw materials and waste is a complex scientific-practical problem. In such case, it would be economically reasonable to develop and use a granulated organic fertilizer having certain physical-mechanical properties, which affect the product storage, transportation, scattered distribution in soil, or local incorporation.

The aim of this paper is to identify the influence of certain granulation factors (origin and composition of the original product (raw material), granulometric composition of the raw material, moisture content in the mixture, and the method of granulation) on the properties of bulk organic fertilizers.

Materials and methods

Responding to the problems of handling organic materials in agriculture, the beef cattle manure granulation technology and the necessary equipment were developed. With the help of this technology new types of organic fertilizers were developed, i.e. ground pourable beef cattle compost and granulated compost fertilizer.

Production of these innovative fertilizers involves composting of manure from *Angus* and *Angus-Simental* beef cattle using a special technology (Fig. 1).

Analysis of the physical properties of granulated organic fertilizers is the first and most affordable way to determine the production method and the quality of the product. The analysis of physical test results provides information on the quality of pellets, which may be used to adjust the production process and improve the quality of the product. Quality of pellets may be assessed on the basis of several physical-mechanical properties: length, average mass (weight), bulk density, pourability, static and mechanical strength, etc.

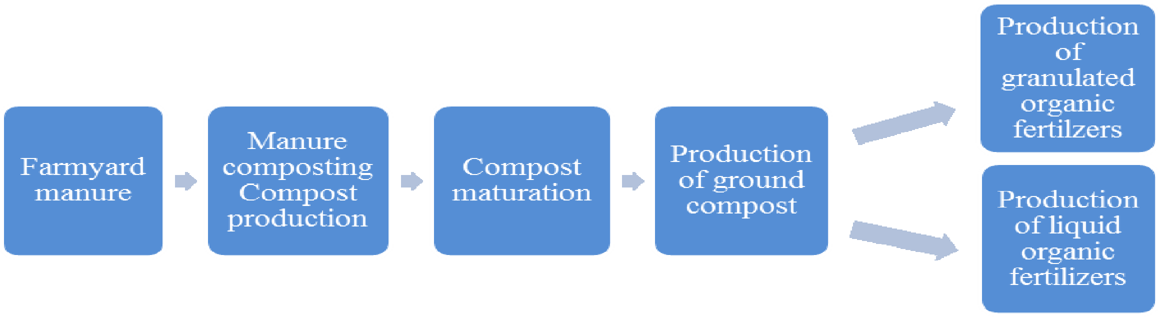

Fig. 1. **Organic granulated fertilizer production scheme**

Average mass of pellets should be seen by the producer as a significant property as it relates to the pellet length and density, which is an indicator of the bulk density of the pellets. Optimal pellet density should not exceed its diameter 2.5 times. Pellets with the length exceeding the optimal value are more difficult to transport, and cause problems when scattering on soil or using locally during sowing. The majority of modern methods and technologies used for granulation of agricultural organic materials may seem insufficiently effective because of incomplete assessment of the characteristics and structural-deformation properties of the original product. Granular fertilizers were produced using different material components (beef cattle manure-based shredded compost and fermented poultry manure) and different technological process conditions (using matrixes of channel diameters 6.0 mm, 4.0 mm, and 5.0 mm). Granulated organic fertilizer notation: GM-6; GM-4 and FPM-5. Physical parameters of the studied granulated fertilizers are presented in Table 1.

Table 1

Physical parameters of tested pellets

Parameter	**Pellets**			**Testing methods**
	GM-6	**GM-4**	**PMF-5**	
Moisture content, %	18.61 ± 0.32	14.97 ± 0.57	16.36 ± 0.54	LST EN 14774: 2010
Bulk density, kg·m^{-3}	769.96 ± 4.74	788.37 ± 5.81	685.35 ± 4.28	LST EN 15103: 2010

Granulometric composition of granulated fertilizers was determined using the sieve shaker Retsch AS 200. Set of sieves used with the sieve shaker: 7.1 mm; 5.6 mm; 5.0 mm; 4.0 mm; 3.15 mm; 2.0 mm; 1.0 mm; 0.50 mm; 0.25 mm, and less than 0.25 mm [5]. Fertilizer pellet sliding angle and the angle of natural repose were determined applying the method of pellets sliding down freely from a container, and measured with the accuracy of ± 1.0 degree. The measurements were repeated 5 times.

Mechanical durability was determined in accordance with the standard LST EN 15210-1:2010. The assessment was performed based on the granulometric composition of the product. First, the sample was cleaned from fine particles by sieving gently through the sieve Ø 3.15 mm. The sample volume mass (500 ± 10 g) was poured into the test chamber that rotates at the speed of 50 ± 2 rev·min^{-1}. After 500 revolutions, the drum was emptied and the material was sieved [6]. Pellet mechanical durability is calculated:

$$DU = \frac{m_A}{m_E} \cdot 100\,\%\,, \tag{1}$$

where DU – mechanical durability, %;
m_A – mass of pellets after the test, g;
m_E – mass of pellets before the test, g.

To determine static durability of the pellets, the testing machine *Instron 5960* and parameter control and recording system *Bluehill* were used The rate of compressive load applied to the pellets was 1.0; 10.0; 20.0; and 30.0 mm·min^{-1}. Such load may be considered as semi static as the effect of the inertia force was not significant. Computer software records the force at which pellet breakage occurs. Crushing tests were carried out in two directions: pallet position vertical to the crushing surface, and pallet position horizontal to the crushing surface (Fig. 2). The experimental tests with the pellets were repeated 10 times.

a)

b)

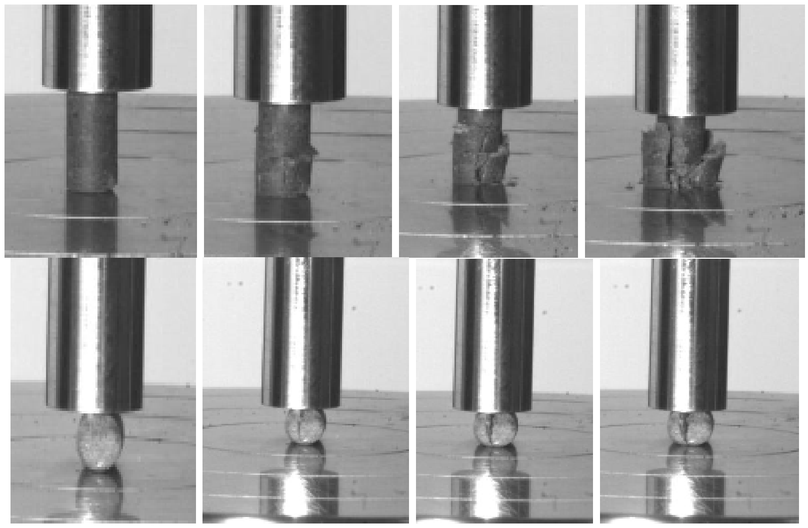

Fig. 2. **Crushing test schemes:** a – vertical crushing; b – horizontal crushing

Research data were processed using mathematical-statistical methods assessing the average values and their confidence intervals given a 95 % probability [7].

Results and discussion

Produced granulated fertilizers are rich in key nutrients and microelements. The chemical composition of the fertilizers showed that they contain the following elements: N – 2.56 %; K_2O – 6.0 %; P_2O_5 – 1.51 %; Ca – 2.93 %; Cu – 19.0 mg·kg^{-1}; Zn – 130 mg·kg$^{-1;}$ Mn – 190.0 mg·kg^{-1} ; B – 42.0 mg·kg^{-1} ; Se – 0.63 mg·kg^{-1} etc.

In production of granulated fertilizers, the granulometric (fractional) composition is of extreme importance. It affects the evenness of distribution on soil both by fertilizer spreaders and locally during sowing. Granulometric composition of granulated compost fertilizers depends on the pellet diameter. It has been determined that the produced 6.0 mm granulated fertilizers were dominated (80.95 %) by fraction in the range of the pellet diameter from 5.6 mm to 7.1 mm. Pellet fraction between 5.0 mm and 5.59 mm amounted 8.31 %, and fraction between 4.0 mm and 4.99 mm – 6.63 %. The remaining percentage of the fertilizer particle composition consisted of smaller fractions of pellets. Granulated 4.0 mm fertilizers were dominated (40.6 %) by pellet fraction from 4.0 mm to 4.99 mm. Respectively, pellet fractions from 3.15 mm to 3.99 mm amounted to 39.6 %.

The results of the measurements of the organic fertilizer pellets' angle of repose and sliding angles as indicators characterising pourability of bulk materials are presented in Figure 3. The angle of repose for the pellets PMF – 5 was by 4.0-6.0 % higher compared to the pellets produced from cattle manure. Mechanical properties of the granulated product indicate the pellet resistance to the effects of external mechanical factors.

Pellet static strength characterizes decomposition stress of a separate single pellet under single-direction load. The study has revealed that the speed of this load variation in the given interval does not significantly affect the load size itself (up to 50 %).

The results of the studies on static stability of the tested pellets up to the highest static load or the highest normal stress at which the pellet decomposes have revealed that when pellets are compressed vertically and horizontally their static strengths differ from 10 % to 20 %. It was found that the most mechanically stable were the pellets GM-6 with static stability limit 430 N when subject to vertical compression, and deformation level up to 1.2-1.3 mm. For the pellets GM-4 and PMF-5, the decomposition limit value was 120-145 N, and deformation was respectively 0.45-0.55 and 0.75-0.85 mm. The calculated modulus of elasticity (E) for these materials has revealed

$E = 3.5 \cdot 10^2$ -$4.0 \cdot 10^2$ MPa for granulated fertilizer GM-6, $E = 2.0 \cdot 10^2$-$2.4 \cdot 10^2$ MPa for fertilizer GM-4, and $E = 1.8 \cdot 10^2$-$2.3 \cdot 10^2$ MPa for fertilizer PMF-5. The obtained results show that the plasticity of the studied granulated organic fertilizers is different. The testing results of mechanical durability of organic fertilizer pellets (Fig. 4) have revealed that the pellets PMF-5 have the biggest resistance to mechanical impact and the pellets GM-4 have the lowest resistance to mechanical impact.

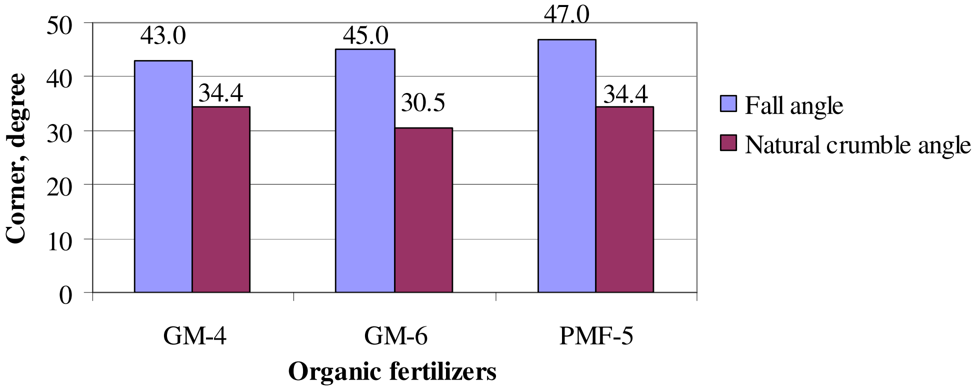

Fig. 3. **Fall angle and natural crumble angle of pellet**

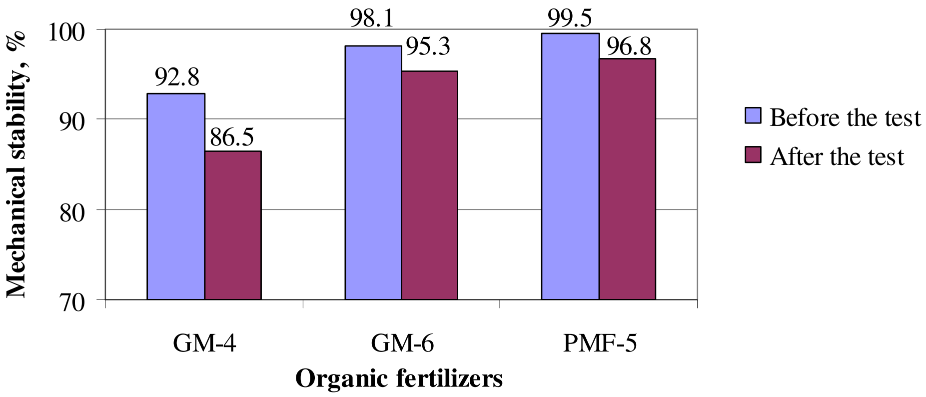

Fig. 4. **Mechanical stability of organic fertilizers**

The results of fractional distribution of mechanically damaged fertilizer pellets (Fig. 5) have revealed that the dominant particle fraction was less than 1.0 mm. The percentage of pellets showed that the pellets GM-4 have more tend to decompose (larger fraction amounts to 3.2-4.9 %) in all studied fraction groups.

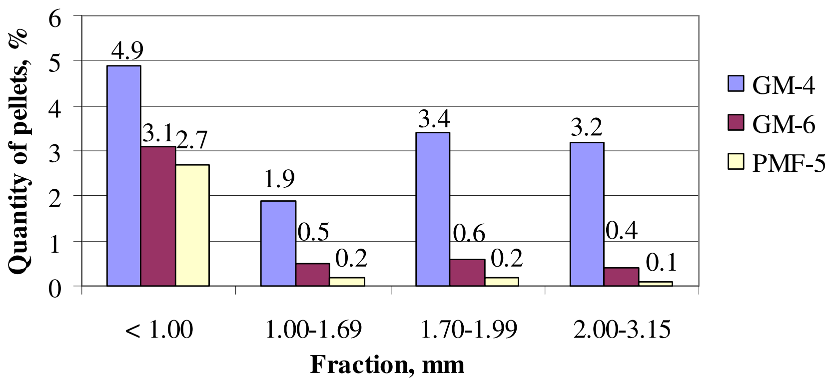

Fig. 5. **Dependence of quantity of pellets on fraction part**

The study of mechanical durability of fertilizer PMF – 5 showed that the major part of the mass of mechanically affected pellets consisted of the finest fraction of 1.0 mm. This shows that the pellets of these fertilizers are more sensitive to abrasive effect of other pellets in the total pellet mass.

Conclusions

It was found that the results of organic pellets that were formatted using the matrixes of different channel diameters depend on the kinetics and rheological properties. The elasticity module of pellets was different and it was found to be the highest for GM-6 fertilizer pellets ($E = 3.5 \cdot 10^2$- $4.0 \cdot 10^2$ MPa). This indicator characterising material plasticity needs to be taken into account during the further stages of the produced product lifecycle.

Pellets of organic fertilizer GM-4 have less mechanical resistance. Under impact of dynamic load these pellets were more tend to break, whereas the pellets PMF-5 were more sensitive to abrasion (the volume of the fine fraction was larger approximately 12 times compared to other pellets).

The designed technological scheme of organic granulated fertilizer production allowed designing and producing organic fertilizer with physical-mechanical properties serving the purpose of the product and meeting the technical as well as quality requirements.

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