SIMULATION RESEARCH ON PROPERTIES OF SPHERICAL MANURE GRANULES

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Abstract. To increase the effectiveness of fertilizers, fertilization technologies are constantly being improved, the quality of fertilizers is improved, and optimal application rates are selected. To protect the soil and the surrounding environment, even organic fertilizers must be spread on the soil following agro-technical requirements. The uniform distribution of organic granular fertilizers in the soil is complicated due to their different physical-mechanical properties and the shape of the granules, compared to mineral fertilizers. Experimental studies are constantly being conducted to determine the properties of granular organic manure fertilizers, but these studies are time-consuming and some require special, expensive equipment. Modern engineering modelling programs simulate the properties of granular fertilizers and allow significantly expand the limits of experiments. The simulation of their properties can be done faster, and the results are sufficiently accurate, having an experimentally verified digital model of organic fertilizers. The purpose of this research is to investigate the effect of properties of spherical granular organic fertilizers in poultry manure spreading using the discrete element Altair EDEM simulation program. Simulation studies were carried out on spherical organic fertilizer bulk density, static and dynamic collapse angles, and static and dynamic friction coefficients of granules. The obtained results showed that the bulk density of the sphere-shaped organic manure granules was higher, the angles of collapse and the pile were slightly smaller and the coefficients of friction were higher, compared to the cylindrical organic fertilizers made from the same manure. These properties have the greatest effect on the uniform spreading of these fertilizers when using centrifugal fertilizer spreaders, so when using spherical fertilizers, they are spread more evenly when spreading sufficiently high rates of fertilizer.

Keywords: manure granules, spherical shape, DEM simulation, mechanical properties**.**

Introduction

Sustainable soil and environmental management [1] is based on the use of organic fertilizers, which have a significant impact on maintaining soil quality and protecting the environment. Organic fertilizers increase the soil organic matter, which improves water retention and cation exchange, increases crop yields, and reduces greenhouse gas emissions. In addition, organic nutrient management helps sequester carbon in the soil, which improves overall soil quality [1; 2].

All organic fertilizers are usually spread with mineral fertilizer spreaders or manure shakers, so the fertilizer is often spread unevenly and the required effect is not achieved. The uniform distribution of organic granular fertilizers in the soil is difficult due to the different physical-mechanical properties and the shape of the granules compared to mineral fertilizers [3].

Scientists mainly use experimental studies that determine the uniformity of spreading both mineral and organic fertilizers on the soil surface [4]. However, such research takes a lot of time and requires special, expensive equipment such as agricultural machinery, fertilizers, fuel and a farmer's field. In addition, fertilization is carried out in a certain period of the year, it is impossible to carry out research all year round. During the research, an attempt is made to analyse the influence of the physical-mechanical properties of fertilizers on their distribution, but this requires many additional resources [5].

In addition to the experimental research, theoretical numerical-mathematical models are used, which analyse the interaction of fertilizer particles with the disk, the interaction of particles with other fertilizer particles, and their physical-mechanical properties [6; 7]. Researchers validate theoretical models with experimental results to understand the influence of fertilizer characteristics and dosage rates on spreading efficiency. Researchers simulate field conditions by adapting spreaders to operate on a typical field surface. It helps detect irregular flow and evaluate the accuracy of propagation [7; 8]. They also study the physical properties of fertilizers that affect the quality of spreading. In the studies are also carried out fertilizer application simulations using the discrete element modelling program EDEM. The results of these studies show that certain dosage rates and more accurate determination of fertilizer properties allow expanding the limits of research dissemination using simulation.

In order to expand the solutions to these scientific problems, the aim of our study is to investigate the influence of the physical properties of spherical granular organic fertilizers made from poultry manure on the field surface, using Discrete element Altair EDEM simulation software.

Materials and methods

Calibration studies of granular fertilizer properties were carried out using the software Altair EDEM 2023 of the Discrete element method (DEM). To verify the numerical values of the granule properties three research methods were used: 1) bulk density, 2) static disintegration, and 3) angle of dynamic disintegration determination studies. In order to determine the effect of the granule shape on the main characteristics of granules, DEM modelling studies of granule behaviour were performed for 1) cylindrical and 2) spherical granules. Organic fertilizer granules were made from poultry manure and its composition [9] is presented in Table 1.

Table 1

Composition of granulated chicken manure fertiliser

Composition	Value
Nitrogen N total (organic), %	4.0 (3.6)
Ammonia NH_4, %	0.4
Phosphorus pentoxide P_2O_5, %	3.0
Potassium oxide K_2O, %	2.5
Calcium oxide CaO, %	9.0
Magnesium oxide MgO, %	1.0
Sulphur SO_3, %	1.5

The material properties of fertilizer granules [8-10] are presented in Table 2. The properties of high-density polyethylene HDPE [11] are also presented in Table 2, as the equipment used in the studies exposed to granules made from this polymer.

Table 2

Material properties of particles and equipment

Properties	Granules	HDPE
Solid density, $kg \cdot m^{-3}$	1297.21	950.00
Poured bulk density, $kg \cdot m^{-3}$	709.99	-
Poisson's ratio	0.25	0.45
Young's modulus, MPa	75.00	600.00

In addition to the material properties, DEM modelling studies use properties of interactions between particles and between particles and surfaces of the research equipment. The values of these properties were taken from the references [8; 10], and during the simulation studies of behaviour of the granules, they were changed, and those values were selected, using which the best simulation results were obtained. The properties of interaction between particles and surfaces were verified in the study presented in Table 3.

Table 3

Interaction properties of particles and equipment material

Interaction	Particle-particle	Particle-equipment
Coefficient of restitution	0.60	0.45
Coefficient of static friction	0.50	0.30
Coefficient of rolling friction	0.20	0.10

The properties presented in Table 2 and 3 are used for modelling the behaviour of both cylindrical and spherical granules. The cylindrical granules had an average diameter of 5.49 mm and an average length of 9.60 mm, with a range of 16.76 mm in the granule length. The histogram of the length distribution of cylindrical granules is presented in Figure 1. As it is seen from this histogram, the distribution of the length of the granules is symmetrical and close to the shape of the curve of the Normal Distribution. The average of the diameter of the spherical granules was 3.80 mm; standard deviation of the diameter was 0.54 mm, the range of the granule diameter was 1.60 mm. The histogram of diameter distribution of spherical granules is presented in Figure 1. As it is seen from this histogram, the distribution of the diameter of the granules is symmetrical. It is close to the curve of the Normal Distribution visually judging by the shape.

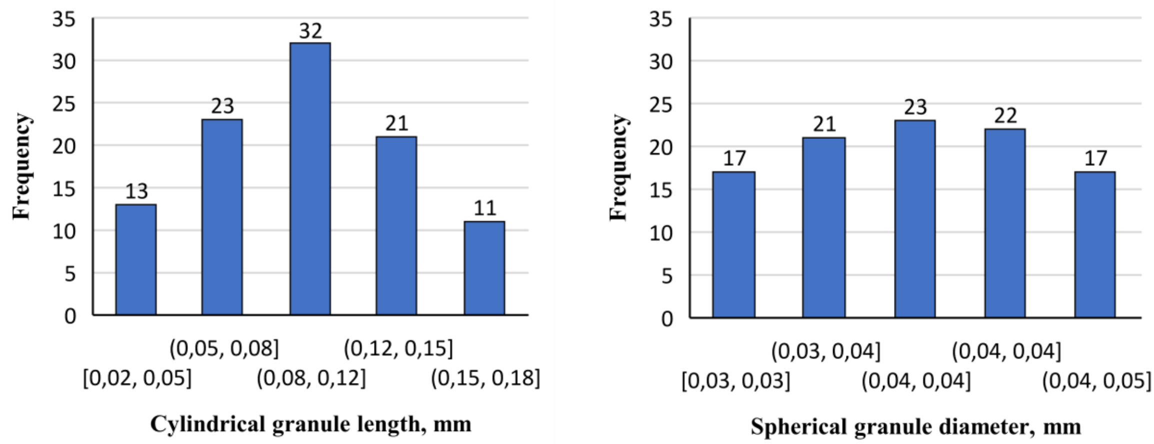
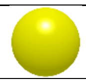
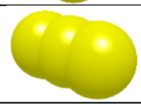
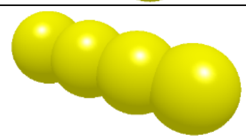


Fig. 1. **Granule size distribution histograms**

Five models of granular particles of different sizes and shapes were used in the simulation studies of the behaviour of cylindrical granules. The diameter, length, percentage composition and shape of these particles are presented in Table 4.

Table 4

Geometry and shape of cylindrical particles

No.	Particle diameter, mm	Particle length, mm	Fraction, %	Particle shape	Shape view
1	3.18	-	13.00	Single sphere	
2	5.49	-	23.00	Single sphere	
3	5.49	9.88	32.00	Three-sphere	
4	5.49	13.24	21.00	Straight four spheres	
5	5.49	16.59	11.00	Straight four spheres	

During the calibration studies of the behaviour of spherical granules and their properties, the model of a cylindrical granule was used. The diameter distribution was according to the Normal Distribution. The average diameter was 3.80 mm, the standard deviation was 0.54 mm, the minimum diameter was 3.00 mm, and the maximum was 4.60 mm, the diameter range was 1.60 mm.

The free-fall bulk density of both forms of granules was determined using a cylindrical container with an inner diameter of 103.39 mm, wall thickness of 3 mm, container height of 170.00 mm, and a container capacity of 1.43 l, respectively. All vessels used in the research were made of HDPE polymer. The main properties of these vessels are presented in Table 2. The images of the vessel filled with both types of granules are shown in Figure 2. The duration of the simulation of the bulk density was 12 s, the granule flow rate was 0.10 $kg \cdot s^{-1}$, and total mass of granules in the model was 1.10 kg. During the tests, the bulk density of the granules poured freely into the vessel and the density of the granule material were determined.

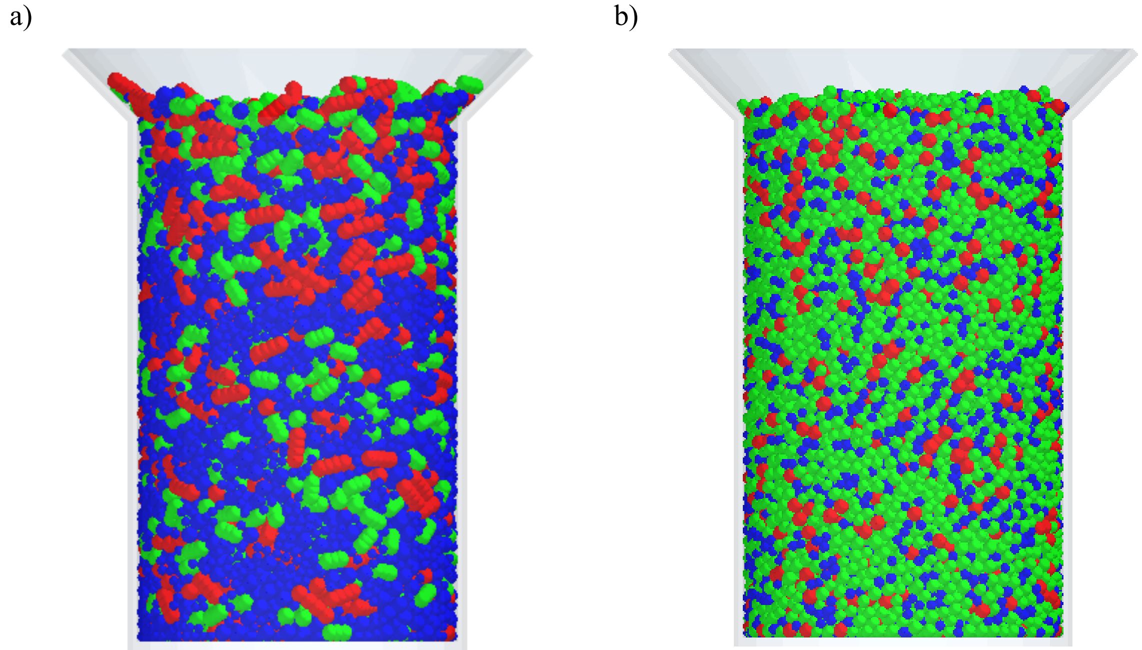
The studies of static determination of the natural angle of disintegration of granules were carried out using a cylindrical container with an inner diameter of 103.39 mm, wall thickness of 3.00 mm, and a container height of 18.00 mm. The duration of the simulation of the decay angle was 23 s, the flow of granules was 0.04 $kg \cdot s^{-1}$, and total mass of granules in the model was 0.80 kg. During these studies, in order to form a real pile of granules, part of the simulated granules had to fall outside the used container. The natural angle of disintegration of the granules was determined.

The dynamic angle of collapse of the granules and the height of the pile of granules were determined using a cylindrical drum with an inner diameter of 103.39 mm, wall thickness of 3.00 mm, and a drum depth of 75.00 mm. The volume of the drum was 0.63 l, 36.42% of its volume filled with granules. The drum rotates clockwise at a speed of 1.89 rad s^{-1}. The duration of the simulation of the dynamic angle of collapse was 30 s, the granule flow rate was 0.0167 $kg \cdot s^{-1}$, and the total mass of the model granules was 0.167 kg. During the research, the dynamic angle of collapse and the height of the formed pile of granules were determined.

All 3D models of the equipment used in the simulation were created using the SOLIDWORKS 2024 EDU software package. In the simulation, the Hertz-Mindlin model of particles between particles and particles with contacting surfaces was used, during which it was assumed that there was no adhesion between particles, i.e. they did not stick to each other and to the surface of the equipment.

Results and discussion

The bulk density results for cylinder and sphere-shaped granules are presented in Figure 2. The red colour represents the largest volume, whereas the green colour represents the smallest volume.



Bulk density: 745.99 $kg \cdot m^{-3}$
Solid density: 1300 $kg \cdot m^{-3}$

Bulk density: 749.46 $kg \cdot m^{-3}$
Solid density: 1300 $kg \cdot m^{-3}$

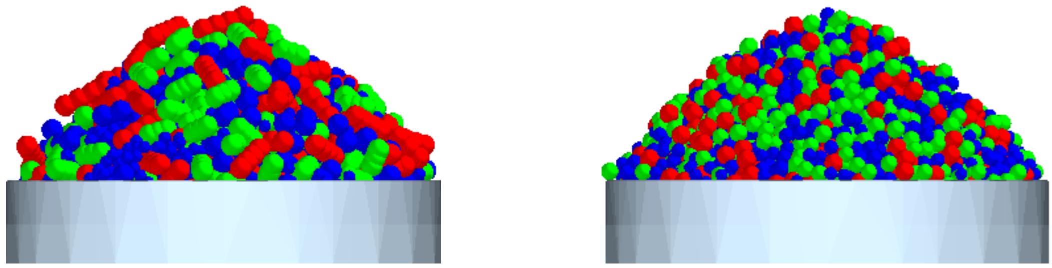
Fig. 2. **Poured bulk density:** a – cylindrical-shaped granules; b – spherical-shaped granules

The simulation results have shown that the bulk density of cylindrical and spherical granules was 745.99 and 749.46 $kg \cdot m^{-3}$, and the difference between the freely poured bulk densities of different-shaped granules was 0.46%. In the research of the authors [10], the bulk density of similar cylindrical granules was experimentally determined to be 709.99 $kg \cdot m^{-3}$; the difference between the simulation and experimental results was 4.83%.

During these studies, it was accepted that the accuracy of the simulation results achieved is adequate. After carrying out modelling studies of the bulk density of granules, the density of the material of both types of granules was determined and it was 1300 $kg \cdot m^{-3}$, i.e. only 0.22% higher than the material density of similar cylindrical granules determined in the researchers' works [10].

Figure 3 presents the results of the free-pour angle of collapse tests for both types of granules.

a) b)



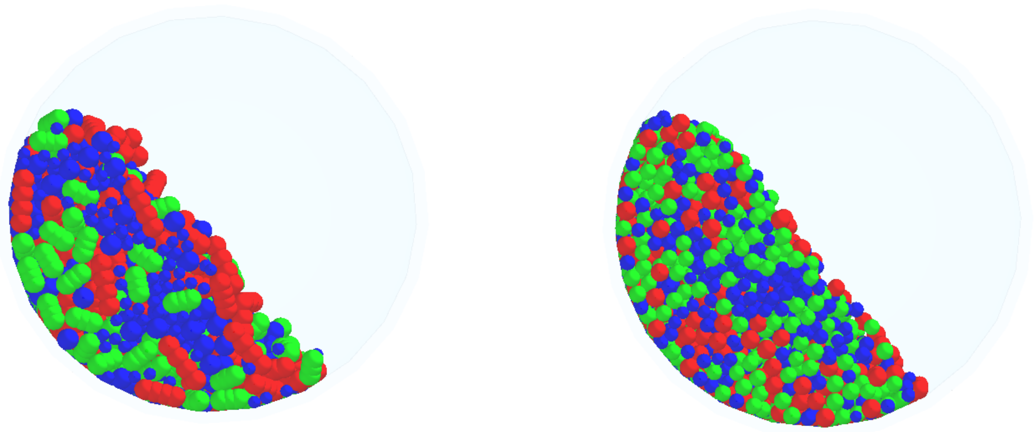
Static repose angle: 35.76º Static repose angle: 36.35º

Fig. 3. **Static repose angle:** a – cylindrical-shaped granules; b – spherical-shaped granules

The static angle of disintegration of the cylinder-shaped granules was 35.76º, and 36.35º was obtained for the sphere-shaped granules; the difference was 1.67%. Studies on determining the angle of collapse of granules with similar properties using one cylindrical ring were not carried out, but in the researchers' works [10], the static angle of collapse of similar granules determined by another method was about 33.00º. If these results of the static angle of collapse of the cylindrical granules were compared with the obtained results during the simulation, the difference was 7.71% and in this case, this resulting difference is too big. For a more precise verification of the properties of the granules and for the verification of the results of the modelling of the static angle of disintegration, additional experimental studies should be performed.

Figure 4 shows the results of the dynamic angle of collapse of granules and the height of the formed granule pit site.

a) b)



Dynamic response angle: 53.60º
Height of pellet bed H: 78.20 mm

Dynamic response angle: 50.25º
Height of pellet bed H 78.94 mm

Fig. 4. **Dynamic angle of repose:** a – cylindrical-shaped granules; b – spherical-shaped granules

It was found that the dynamic angle of disintegration of cylindrical granules was 53.60º, while that of spherical granules was 50.25º. The difference between both granule types was 6.67%. The difference between the heights of the formed granule hopper site was only 0.93%. As any research was not found in which studies of dynamic disintegration of granules with similar properties and shape were performed, so it is not possible to compare the research results obtained during modelling with experimental ones. In order to verify the results of the simulation studies, it is necessary to perform experimental studies of the dynamic angle of disintegration of granules.

When carrying out the accurate modelling of the behaviour of granules (e.g. their spreading by a centrifugal disc spreader, their transportation by a screw conveyor, etc.) using the DEM method, it is necessary to know many of their properties, and some of them (e.g. coefficient of restitution, coefficient of rolling friction) during experiments are quite difficult to determine directly. It is likely that using these three above-mentioned tests for determining the behaviour of granules will be sufficient for verifying the properties of granules. It should be noted that experimentally conducting research on determining the bulk density of granules and static and dynamic disintegration angle will be technically simple and the research will be carried out quickly due to the simplicity of the equipment and simple comparison of the results.

Conclusions

1. The obtained results showed that the difference between the bulk density of the sphere and cylindrical organic granules was 0.46%. The difference between the static angle of disintegration of the cylindrical granules and sphere granules was 1.67%. The difference between the dynamic angle of disintegration of the sphere and cylindrical organic granules was 6.67%.
2. As these properties of fertilizers have the greatest effect on uniform spreading of the fertilizers, accurate simulating of granule spreading and determination of granule properties are very important.

Author contributions

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

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