OPTIMIZATION OF ORGANIC FERTILIZER DISTRIBUTION USING EDEM SIMULATION ANALYSIS
/
OPTIMIZAREA DISTRIBUȚIEI ÎNGRĂȘĂMINTELOR ORGANICE UTILIZÂND ANALIZA PRIN SIMULARE EDEM

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ABSTRACT
This study investigates the distribution performance of solid organic fertilizers using vertical helical rotor equipment, focusing on the optimization of spreading uniformity. EDEM simulations were employed to analyse the particle flow and distribution patterns under varying rotor speeds (360, 440, and 540 rpm) and inclination angles (75°, 80°, and 85°). The results indicate that the most uniform distribution is achieved at 540 rpm with a 75° rotor inclination. The study was extended to a configuration with four rotors, simulating field-like conditions. Although a good lateral and longitudinal spread was observed, material concentration along the machine's central axis suggests a second pass is needed for complete field coverage. These findings contribute to the design optimization of fertilizer spreading equipment to improve efficiency and application precision.

REZUMAT
Această lucrare investighează performanța de distribuire a îngrășămintelor organice solide utilizând echipamente cu rotoare verticale elicoidale, cu accent pe optimizarea uniformității de împrăștiere. Simulările realizate în EDEM au permis analiza fluxului de particule și a modelului de distribuție în funcție de viteza rotorului (360, 440 și 540 rpm) și unghiul de înclinare (75°, 80° și 85°). Rezultatele au indicat că distribuția cea mai uniformă se obține la 540 rpm și un unghi de 75°. Studiul a fost extins la o configurație cu patru rotoare, simulând condiții reale de lucru. Deși s-a observat o bună extindere a împrăștierii pe direcțiile transversală și longitudinală, concentrarea materialului pe axa centrală a echipamentului sugerează necesitatea unei a doua treceri pentru acoperire completă. Concluziile contribuie la optimizarea proiectării echipamentelor de împrăștiere a îngrășămintelor pentru creșterea eficienței și a preciziei aplicării.

INTRODUCTION
In recent years, there has been a growing recognition of the critical role that solid organic fertilizers play in sustainable agriculture. These fertilizers not only enhance soil fertility and structure but also promote biodiversity and improve water retention, ultimately leading to increased crop yields. Effective distribution of organic fertilizers across soil surfaces is vital for ensuring uniform application, which maximizes their benefits while minimizing environmental impacts *(Dang et al., 2022; Ramadan, 2023; Katchali et al., 2025; Sánchez-Monedero et al., 2019).*

Traditionally, the design of equipment for distributing solid organic fertilizers relied on empirical methods and hands-on experience. However, as agricultural technology advances, the need for precision and efficiency has led to the integration of computational tools in the design process. Software platforms such as EDEM, which utilize discrete element modelling (DEM), allow engineers to simulate and analyse the behaviour of granular materials under various conditions. This parametric modelling provides insights into the dynamics of fertilizer distribution, enabling the optimization of equipment design through precise calculations (*Ou et al, 2025; Xu et al, 2023; Zinkevičienė et. al, 2021).*

By comparing classical design approaches with modern computational methods, one can observe a significant improvement in both the precision and efficiency of fertilizer application. The parametric modelling offered by EDEM facilitates the identification of optimal parameters for equipment operation, such as flow rates, distribution patterns, and contact forces, which are critical for achieving consistent application rates across varying soil types and terrain *(Debska et al, 2022).*

The integration of advanced modelling software into the design of organic fertilizer distribution systems represents a significant advancement over traditional methods. This synergy of technology and agriculture not only enhances the effectiveness of fertilizer application but also supports sustainable agricultural practices by improving soil health and productivity.

Traditionally, organic manure was distributed manually, which was labour-intensive and time-consuming. To improve efficiency, various types of fertilizer spreaders have been developed across the world, that reduce labour requirements while ensuring uniform application rates. The primary performance criterion for these spreaders is the uniformity of distribution across diverse conditions, which is influenced by the design and functionality of the metering devices used *(Thirion et al., 1997, Liu et al., 2022).*

EDEM software, powered by the Discrete Element Method (DEM), has been effectively utilized in agricultural applications to enhance the distribution of fertilizers and seeds, sowing precision, parameter calibration (*Wenzheng et al., 2018; Du et al.,* 2019; *Yang et al, 2018, Walunj et al, 2023).* Some notable examples are presented below.

According to *Yang et. al,2008,* spreading uniformity is a key factor in evaluating the performance of a fertilizer spreader. The varying size parameters of different fertilizers available on the market - such as average particle mass, particle diameter, and surface roughness - directly influence the uniformity of distribution. Given these differences, achieving optimal design for a variable-rate fertilizer machine equipped with crop sensing, data analysis, and a fertilizer controller is crucial. Using the laboratory's existing disc variable fertilizer applicator as a prototype, their study employs EDEM simulations to model the fertilization process of various commercially available fertilizers and analyses their distribution patterns. This study simulates the spread of potassium chloride, potassium sulphate, and urea using EDEM in a centrifugal disc variable-rate fertilizer applicator. The lateral homogeneity variation coefficients are 43.34%, 26.26%, and 39.21%, respectively. Results indicate that the spreading uniformity does not meet the standard, highlighting the need for further research to enhance machine performance.

Hai Ding et.al (2017) designed a new fertilizer guide device to improve the uniformity of base fertilizer application (Figs. 1, 2). Using EDEM simulations, they analysed factors such as the installation angle of the fertilizer guide groove and the opening angle of shunt components. The simulation results provided valuable insights for optimizing the design parameters, leading to improved fertilizer distribution uniformity.

The fertilizer particles were modelled as spheres. The material density of the fertilizer particles was determined using the following equation.

$$\rho_f = \frac{m_f}{V_f} = \frac{m_f}{\frac{4}{3}\pi\left(\frac{D_f}{2}\right)^3} = \frac{6m_f}{\pi D_f{}^3} \tag{1}$$

where:

ρ_f is the particle density, g/cm^3 ; m_f - particle mass, g; V_f - particle volume, mm^3;

D_f - average particle diameter, mm;

Average particle density ρ_f=1.861 g/cm^3; bulk density of fertilizer particle was 0.982 g/cm^3

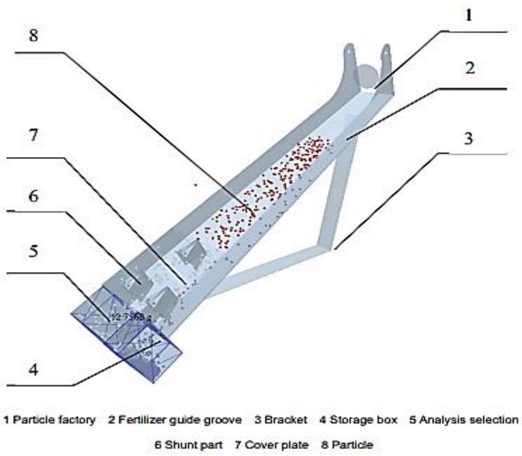


Fig. 1 - EDEM simulation model of fertilizer application

Item	Property	Value
particles	Poisson ratio	0.25
	Shear modulus/ Pa	1.0×107
	density/(kg·m^{-3})	1861
Grooved wheel, housing	Poisson ratio	0.394
	Shear modulus	3.189×10^8
	density/(kg·m^{-3})	1335
particle-particle	Coefficient of restitution	0.6
	Coefficient of static friction	0.4
	Coefficient of kinetic friction	0.01
Particle-grooved wheel, housing	Coefficient of restitution	0.5
	Coefficient of static friction	0.5
	Coefficient of kinetic friction	0.01

Fig. 2 - Pre-treatment parameter setting

Shan et al, (2024), designed a soil compaction mechanism suitable for rice seedbeds and simulated its performance using EDEM - RecurDyn software (Figs. 3, 4). The study verified that integrating an eccentric vibration mechanism with spring support into seedbed levelling machines enhances soil compaction effectiveness. This design ensures compliance with agronomic standards while improving operational performance in modern rice seedling greenhouse systems. Field trials confirmed the model's accuracy, with a relative error of less than 5% between simulated and measured results, thereby demonstrating the effectiveness of the optimized compaction mechanism.

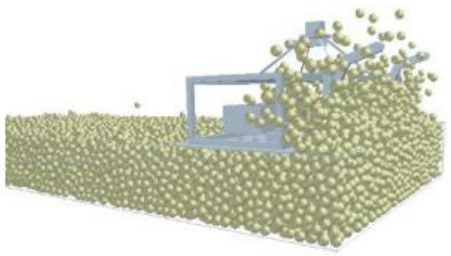


Fig. 3 - Effect of machine forward speed on seedbed

Main Parameters of the Soil Particle Model

Parameter name	Value
Soil particles density [kg/m^3]	2740
Soil particle shear modulus [Pa]	1.55e+08
Soil particle Poisson's ratio	0.29
Coefficient of restitution between soil particles	0.4
Static friction coefficient between soil particles	0.4
Dynamic friction coefficient between soil particles	0.11
Surface energy between soil particles [J/m^2]	0.159
Static friction coefficient between soil and leveling machine	0.5
Soil-Separate Rubbing coefficient between the leveling machines	0.48
Dynamic friction coefficient between soil and leveling machine	0.21

Fig. 4 - Main Parameters of the Soil Particle Model
Shan et al, (2024)

Wang et al., (2022), conducted a study on the seed-filling process in a sugarcane seed-metering device using EDEM simulation. A geometric model of the device, a particle model, and a contact model were established to analyse billet movement and interactions. In their EDEM model, a single-bud billet, originally cylindrical in shape, was approximated using three overlapping spheres to represent its geometry and mass distribution. This particle clustering method effectively maintained the mechanical behaviour of the billet while allowing the simulation to remain computationally feasible. Experimental validation showed a 6.67% relative error in the angle of repose, confirming the accuracy of material parameters. The seed-filling experiment yielded linear correlation coefficients of 0.762 for qualification filling rate S_q and 0.869 for the missed filling rate S_e, verifying the simulation's reliability. Analysis of particle velocity and force revealed two circulation circles in the seed box, with larger circles facilitating billet entry into the rake bar. The findings provide a theoretical basis for optimizing sugarcane billet planter design (Figs. 5-7).

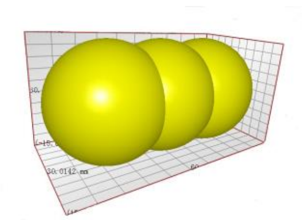


Fig. 5 - Model diagram of single-bud billet

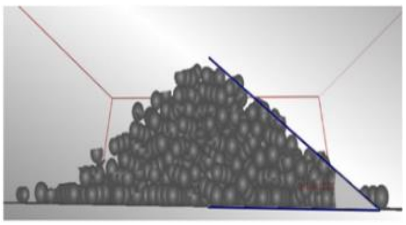


Fig. 6 - Generation of a pile of single-bud billet models for simulation

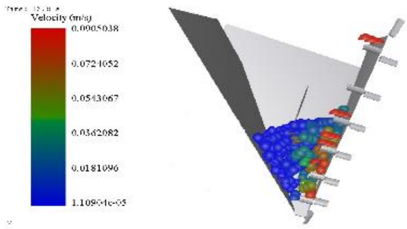


Fig. 7 - Motion simulation results

Dumitru et al. (2024) used EDEM software in order to design and simulate the processes to develop an efficient seed distributor. Using SolidWorks modelling software, the spreader was designed to ensure uniform seed distribution by considering factors such as seed size, distribution speed, and soil type (Fig. 8-9). SolidWorks enabled precise structural analysis and performance evaluation of the distributor components. To validate its efficiency, EDEM software, based on the discrete element method (DEM), was employed to simulate seed movement and interaction with the soil. The simulation provided detailed insights into seed trajectory, fall speed, and distribution patterns. Based on these results, iterative modifications were made in SolidWorks and re-tested in EDEM, allowing for continuous optimization. This iterative approach ensured the distributor met the efficiency and reliability requirements for real-world agricultural applications.

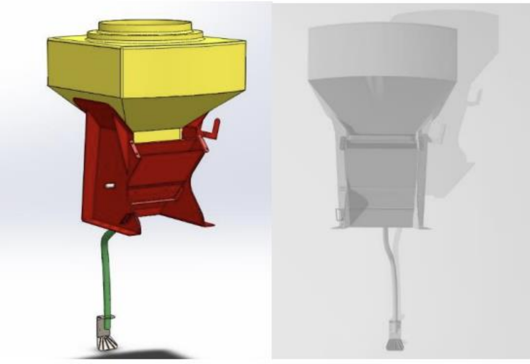


Fig. 8 - Seed distributor with SolidWorks Software

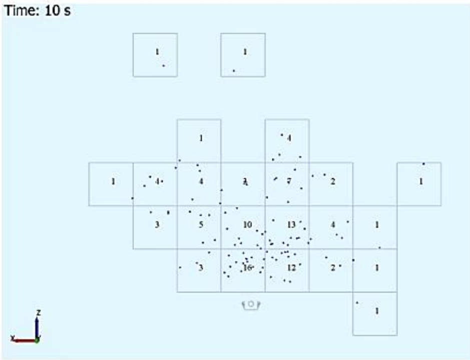


Fig. 9 - 3D Scatter plot for the seeds

MATERIALS AND METHODS

Equipment for distributing solid organic fertilizers with vertical rotors (helical) is among the most widespread and commonly used in agriculture due to their efficiency and versatility. These machines are essential for the effective management of fertilizers, particularly manure and compost, as they allow for uniform and rapid distribution over large areas of land.

The vertical rotor distribution units work by utilizing rotors equipped with helical spirals or blades, which are mounted on a frame and powered by the tractor's power take-off (PTO). These rotors are usually arranged in pairs (two or four), and each rotor rotates in opposite directions - typically one rotor in a counterclockwise direction and the other in a clockwise direction (Fig. 10). This setup helps to fragment and distribute the material over a wide area. At the base of the rotors, there are discs with blades that pick up any material not processed by the helical spirals or that falls from the conveyor.

One of the main characteristics that make these machines so popular is their large working width and ability to distribute material over considerable distances. For example, rotors tilted away from the vertical plane can significantly increase the distribution range, thereby providing wider coverage and reducing the working time. Furthermore, this technology minimizes the risk of clogging or overloading the transmission system, a common issue with other types of fertilizer distributors *(Popa L., 2009; Ștefan et al., 2019).*

a) two vertical rotors HR 250 Model
(https://www.pikrite.com/spreaders/vertical-beaters/#)

b) 4 vertical rotors MG 5 Experimental model
(Popa L, 2009; Ștefan, 2023)

Fig. 10 - Types of machines that use vertical rotors for distributing fertilizers

The rotors work by fragmenting the material and throwing it onto the soil in an even layer, which is crucial for ensuring proper fertilization. Additionally, modern systems allow for the adjustment of the throwing angle, the distribution width, and the distance between the rotors, offering precise control over the distribution process.

Another significant advantage is that the machine's own volume does not significantly affect the usable space on the platform, thus allowing for greater loading capacity. The tilted rotor arrangement also contributes to more efficient fertilizer distribution.

EDEM allows for the simulation of the material flow within the fertilizer spreader. By modelling the behaviour of solid organic fertilizers (which are often irregularly shaped and have different sizes, densities, and moisture contents), it is possible to optimize the distribution pattern. This ensures a uniform spread across the field, which is crucial for effective fertilization, preventing over- or under-application in different areas of the land.

EDEM was employed to conduct a series of simulations aimed at optimizing the uniformity of material distribution on the ground. By utilizing advanced simulation software, the behaviour of particles under varying conditions can be modelled, enabling fine-tuning of the distribution process. Simulations were first conducted using a single distribution rotor, after which the results were scaled up by incorporating four identical rotors across the full width of the machine's hopper. This approach allowed performance assessment of a single rotor before extending the findings to a multi-rotor system, thereby providing a more accurate representation of material distribution across the entire equipment width. In this way, optimal efficiency and uniformity of the distribution process can be ensured under full operational conditions.

For the study of fertilizer distribution on the soil surface by a helical rotor (Fig. 11) arranged in the vertical plane, the following initial data were considered:

- Rotor speed n = 360, 440 and 540 rpm;
- Outer diameter of the helical spiral D_{out}= 0.345 m;
- Inner diameter of the helical spiral d_{in} =0.115 m;
- Pitch of the helical spiral p = 0.3 m;
- Rotor length l = 0.9 m;
- Distance between rotor and soil: h = 1.2 m
- Rotor inclination relative to the vertical axis α = 85°, 80°, and 75°;
- Coefficient of friction with the metal surface μ = 0.5;
- Fertilizer type: compost;
- Simulation time, t=25 s.

The simulations will be conducted in a stationary position and will focus on the quantitative distribution on the soil, under different working conditions, to determine the optimal distribution variant, with distribution uniformity as the main indicator.

Distribution uniformity illustrates how the material is spread across the working width of the machine and along the direction of travel.

Transversal uniformity represents the percentage at which the amount of material reaching the soil remains constant along the direction perpendicular to the machine's travel direction. If the material amounts deposited on the soil per square meter vary significantly from the central area, it is necessary to overlap the boundary zones during adjacent passes of the machine in order to maintain this uniformity.

$$U = \left[1 - \frac{\sqrt{\frac{\sum_{i=1}^{j}(\sigma_i - \sigma_m)^2}{j-1}}}{\sigma_m}\right] \cdot 100 \tag{2}$$

where: U is the distribution uniformity degree across the effective working width, [%];

σ_m– is the average amount of manure falling into a collector along the effective working width, [kg];

σ_i – is the actual amount falling into each collector along the effective working width, [kg];

n – is the number of collectors in each row, placed across the effective working width.

Effective working width is the width where the spreader actually applies fertilizer uniformly to the soil. This is often smaller than the total working width because uniform distribution depends on factors like machine adjustment, operational condition, and field conditions. In many cases, to achieve uniform application, overlapping of adjacent passes is required, which reduces the effective working width compared to the total working width.

In our previous study, a mathematical model was developed to describe the motion of organic fertilizers (manure) during the distribution process, using equations derived from force equilibrium and based on classical mechanics principles *(Ștefan et al., 2018; Ștefan et al., 2019)* The particle trajectory was divided into two distinct phases: movement along the helical rotor surface and subsequent parabolic flight through the air. The model incorporated the relationships between the machine's design parameters and the material properties, providing explicit equations for calculating the time required for the material to reach the soil.

Building upon this theoretical foundation, the current paper advances the analysis by employing discrete element method (DEM) simulations using EDEM software. This approach enables a more detailed and realistic representation of the distribution process, taking into account particle interactions and the variability in particle size, shape, and moisture content.

Fig. 11 shows the model of the organic fertilizer spreader rotor designed in SolidWorks, similar with its version in STL format, ready to be imported into the EDEM by Altair simulation software. For the simulation, a type of material (compost) was selected to be imported into the software. The rotor dimensions were proposed based on research into existing market solutions for distribution equipment.

Table 1 contains the values of the physical parameters necessary for DEM (Discrete Element Method) simulations in the EDEM software taken from literature for similar material type *(Han et. al, 2023; Yu et al., 2020)*. These parameters define the behaviour of the materials involved - especially steel and particles - within the simulations, including the interactions between particles and between particles and steel surfaces. The material selected for simulations is compost, with the properties mentioned above. The particles are spherical in shape, with a diameter ranging between 5 and 10 mm. The EDEM software was configured to randomly distribute particles within this range, meaning that the initial positions of the particles were assigned without a predefined pattern, adhering only to the imposed boundaries (Fig. 12).

In the present simulation, organic fertilizer particles were approximated as spheres, primarily due to computational limitations and the current capabilities of EDEM software. This method is commonly used in preliminary design studies *(Yang et al., 2018; Wang et al., 2022),* with the aim of identifying trends rather than achieving precise replication of physical experiments. This simplification is a widely accepted approach in discrete element modelling (DEM), particularly for simulations requiring large particle counts and efficient computation.

To simulate the cohesive behaviour of moist organic fertilizer (compost), the default contact model in EDEM was replaced with the Hertz-Mindlin with JKR contact model. This advanced model accounts for particle adhesion through surface energy, allowing particles to stick together and form clusters, which more accurately represents the real flow behaviour of compost.

Mathematically, the normal force F_n includes both elastic deformation and adhesive pull-off forces:

$$F_n = \frac{4}{3}E^*\sqrt{R^*}\delta^{3/2} - 3\pi\gamma R^* \qquad (3)$$

where:

E^* is the equivalent Young's modulus;

R^* is the effective radius;

δ is the overlap;

γ is the surface energy.

The tangential force F_t is limited by friction:

$$F_t \leq \mu F_n \qquad (4)$$

In the simulation, this model allowed the particles to behave more like wet compost, leading to more realistic spreading patterns, better cluster formation, and improved correlation with observed field behaviour. By adjusting parameters such as surface energy, Poisson's ratio, and shear modulus, the simulation was calibrated to match the expected compost flow characteristics.

The horizontal axis *(X)* represents the particle diameter, ranging from 0 to 10 cm, indicating that the simulated particles were generated with sizes distributed within this interval.

The vertical axis *(Y)* represents the number of particles corresponding to each diameter range.

The graph shows a decreasing distribution, suggesting that smaller particles are more numerous, while larger particles are less frequent. This type of distribution is commonly observed in granular material handling processes, where finer particles tend to be present in greater numbers compared to coarser ones.

Such a distribution can significantly influence material behaviour in the simulation, affecting phenomena such as granular flow, compaction, or particle segregation.

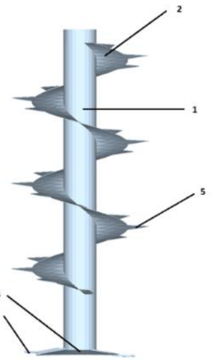
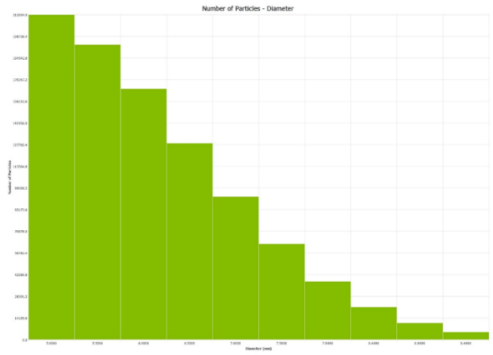
	

Fig. 11 - Rotor vertical helicoidal (SolidWorks) *1. shaft, 2. helical spiral, 3. disc, 4. spreader blade, 5. cutting knife*	**Fig. 12 – Particle size distribution**

Table 1

Parameters required for EDEM simulation

EDEM Parameters	Materials	Value	Materials	Value
Density (kg·m^{-3})	Steel	7850 *(Han et al., 2023; You et al, 2020)*	Compost	550 *(You et al, 2020)*
Poisson's ratio	Steel	0.3 *(Han et al., 2023; You et al, 2020)*	Compost	0.5 *(Yu et al, 2020)*
Shear modulus (Pa)	Steel	7.9×10^{10} *(Han et al., 2023; You et al, 2020)*	Compost	1×10^{6} *(Yu et al, 2020)*
Coefficient of restitution	Compost-Steel	0.1 *(Yu et al, 2020)*	Compost - Compost	0.1 *(Yu et al, 2020)*
Coefficient of static friction	Compost - Steel	0.59 *(Yu et al, 2020)*	Compost - Compost	0.2 *(Yu et al, 2020)*
Coefficient of rolling friction	Compost - Steel	0.04 *(Yu et al, 2020)*	Compost - Compost	0.5 *(Yu et al, 2020)*
Surface energy (J m^{-2})			Compost - Compost	3.5 *(Yu et al, 2020)*

In the creator tree presented in Fig.13, a *15 x 15 m* polygon is used to model the soil which serves as the primary environment where the fertilizer will be dispersed. This polygon outlines the boundaries of the soil area, providing a clear visual representation of the terrain in which the simulation occurs.

For modelling the compost factory, a box is created (Fig.14). The box dimension is *L x l x h* = 2.3 x 0.5 x 1.15 m. The box is then filled with material (particles) for a more realistic and accurate representation (Fig.15).

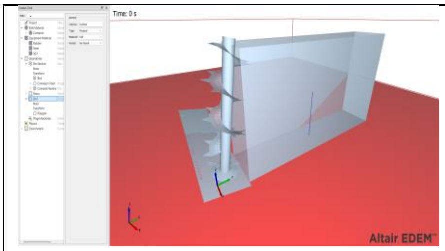
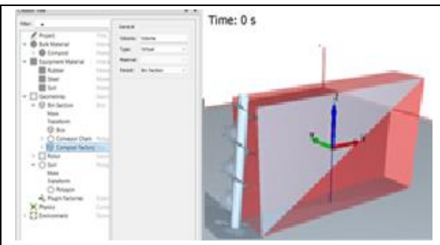
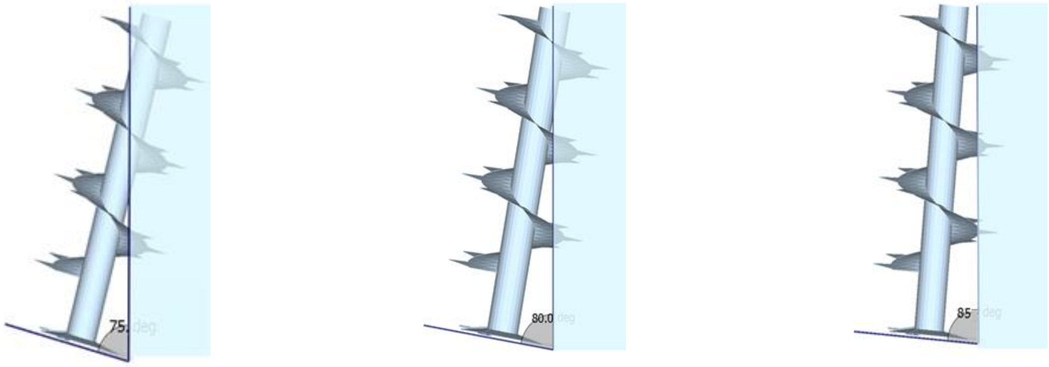
	

Fig. 13 - Soil area representation	**Fig. 14 - Compost factory (box)**	**Fig. 15 – Box filled with compost particles**

Additionally, another polygon is created to represent the conveyor chain inside the trailer. To enhance realism, a sinusoidal translation is applied to this polygon, simulating the movement of the conveyor system. These polygons are essential for defining the spatial elements of the simulation and ensuring a more accurate representation of material distribution. Once these components are in place, the simulation is initiated, allowing for a detailed visualization of the material flow and its dispersion over the soil. For the simulations, the chain speed is considered 0.006 m/s.

The rotor is positioned at different angles between vertical axis and rotor base (Fig. 16), which plays a critical role in directing the material as it makes contact with the rotor blade. This angle helps ensure that the manure is efficiently distributed across the soil surface by optimizing their trajectory after collision, promoting a more uniform spread. The 75º, 80º and 85º inclinations are specifically chosen to balance the forces acting on the particles during impact, minimizing bounce or clumping and enhancing overall spreading efficiency.



a) 75° inclination angle *b) 80° inclination angle* *c) 85° inclination angle*

Fig. 16 – Rotor inclination relative to the vertical axis

RESULTS

In this section, the results of a 3D scatter plot representing the spatial distribution of material within the defined area are presented. A detailed quantitative analysis has been conducted, focusing on several key aspects: density analysis, variance in material distribution, hotspot identification, and standard deviation.

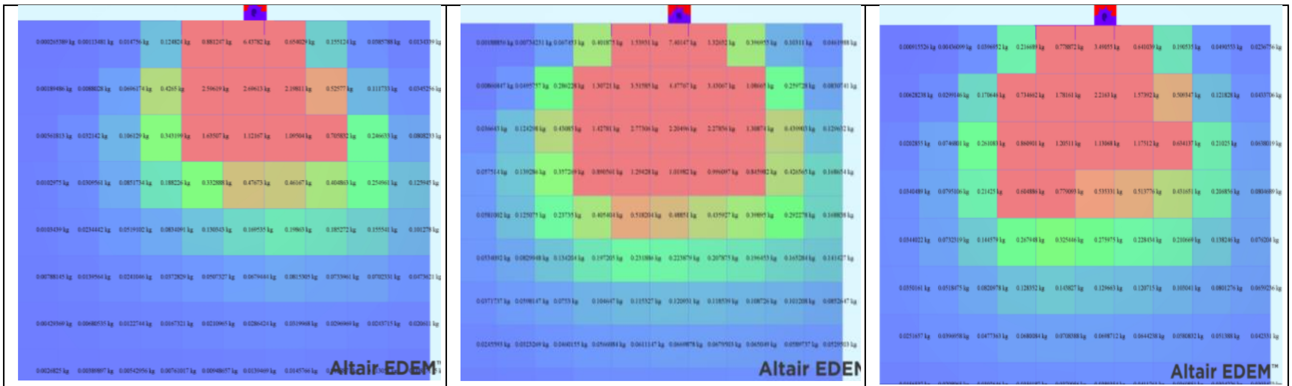
The scatter plot is divided in sections of *1 x 1 m* for an easier interpretation.

A quantitative analysis was performed using a 3D scatter plot of material distribution, generated with EDEM software. The 3D material deposition data was converted into a simplified 2D grid format, as shown, where each cell represents the amount of manure deposited in the corresponding area. This visualization helps assess the uniformity of the spreading process and identify potential areas of over- or under-application.

Figure 17 c) presents a grid-based visualization of material distribution, where each square represents a specific area and the amount of material deposited within it. The colour gradient transitions from red (high accumulation) to blue (low accumulation), illustrating the spreading efficiency. The central region remains the most concentrated, while the periphery shows a sparser distribution, meanwhile material accumulation on the soil happens further from the release point.

In Fig. 17 (a) and (b), the highest material concentration appears in the central region of the distribution area, the colour gradient shifts from red (high accumulation) to blue (low accumulation), which signifies the greatest deposited mass per grid cell. The distribution pattern suggests a localized accumulation near the release point, gradually decreasing outward.

Compared to Figs. 17 (a) and (b), which show significant material buildup near the release point, fig. 17 (c) represents a more favourable distribution. Large accumulations near the rotor are reduced, and the material is spread more evenly over a greater distance. This improved dispersion enhances uniformity and minimizes excessive deposition in the immediate vicinity of the rotor.



a) inclination 80° for 360 rpm *b) inclination 80° for 440 rpm* *c) inclination 80° for 540 rpm*

Fig. 17 - Material distribution patterns

The images provided depict the manure distribution results using a spreading system with rotors set at an 80-degree angle while operating at three different rotational speeds: 360 rpm, 440 rpm, and 540 rpm. Each image represents the distribution pattern through a color-coded grid, where higher concentrations of manure appear in red, while lower deposition areas transition into green and blue shades. By analysing these patterns, it can be determined how effectively each rotational speed disperses the manure across the field.

At 360 RPM, the first image shows a highly concentrated manure distribution in the central region, with a significant buildup of material in the middle of the spread area. The outer sections receive considerably less manure, indicating a less uniform spreading pattern. The deposition appears asymmetrical, with much of the material failing to disperse widely, suggesting that at this lower speed, the spreading system struggles to distribute manure effectively across a larger surface area. This results in an uneven application, which could lead to over-fertilization in some areas while leaving others under-treated.

Increasing the speed to 440 rpm, as shown in the second image, results in a more balanced distribution compared to the 360 rpm setting. The accumulation in the centre is still present but appears less pronounced, with the spread extending further outward. The manure is dispersed more evenly, covering a broader area with a smoother transition in concentration. While there is still some central buildup, the overall pattern suggests improved field coverage, reducing the risk of excessive material being deposited in one location while ensuring more consistent application across the spread zone.

The final image, representing the highest speed of 540 rpm, demonstrates the most effective manure distribution. The central accumulation is significantly reduced, and the material is spread much more uniformly across the field. The colour gradient transitions more gradually, indicating that manure is distributed more consistently rather than being concentrated in a single area. The spread reaches its widest extent in this scenario, covering a larger portion of the field and achieving a more optimal application. This suggests that operating at a higher rotational speed allows for better manure dispersion, minimizing uneven patches and promoting a more efficient fertilization process.

Although the simulation was carried out under stationary conditions, the results can be used to estimate the distribution in dynamic operation, assuming that the material is discharged uniformly over time and that the machine's movement merely shifts this distribution spatially. Thus, by temporally overlapping the values along the direction of travel, a realistic estimation of the field spreading pattern is obtained.

In each case (for each rotor speed), the behaviour of the particles was simulated in a setup where the machine remained stationary while the rotors were active. The space around the machine was divided into transverse sectors, and the mass of particles collected in each sector was recorded.

The collected data were summed column-wise (along the longitudinal axis) to simulate the equivalent behaviour of the machine moving at a constant speed of 1 m/s. This approach allows the transformation of the stationary distribution into a distributed band model, similar to what would be observed in actual field conditions.

The resulting distribution for each simulation was represented in Fig. 18, where:

- the *X*-axis corresponds to the lateral distance from the machine's central axis,
- the *Y*-axis indicates the relative amount of material distributed across each transverse band.

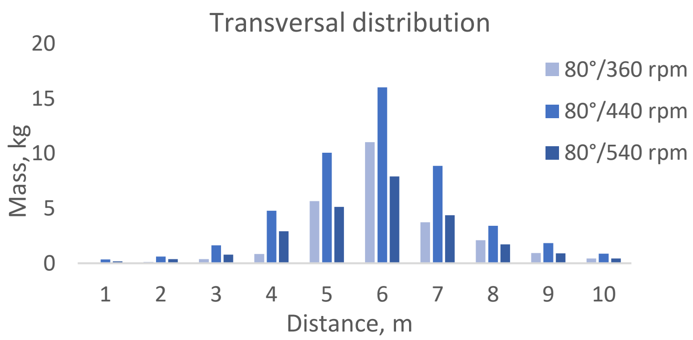


Fig. 18 - Transversal distribution at different rotational speeds

From these results, it is evident that 540 rpm offers the best overall distribution, as it reduces central buildup while increasing uniformity across the entire spread area. In contrast, 360 rpm leads to a highly concentrated and inefficient distribution, while 440 rpm shows some improvement but still does not achieve the same level of coverage as the highest speed. Therefore, for optimal manure spreading with rotors set at an angle of 80°, using 540 rpm is the most effective choice, ensuring a more even and efficient application across the field.

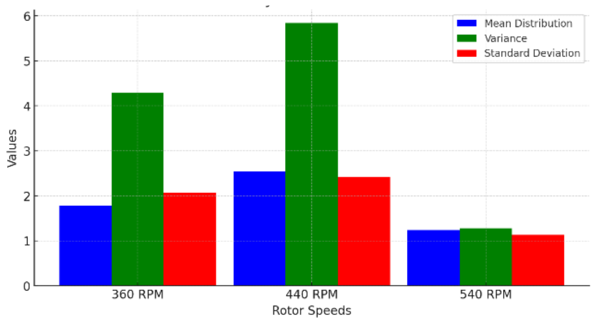
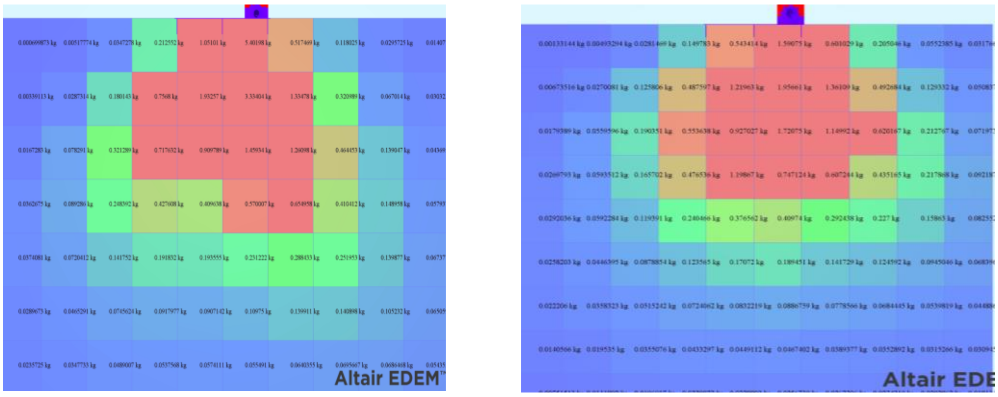


Fig. 19 – Statistical analysis of compost distribution

A statistical analysis of manure distribution at different rotor speeds (360 rpm, 440 rpm, and 540 rpm) is given in Fig. 19. The blue bars indicate the mean distribution, showing the average spread of manure at each speed. The green bars represent variance, which measures how much the distribution varies from the mean. The red bars depict the standard deviation, illustrating the extent of deviation from the average spread. The data suggests that at 440 rpm, there is the highest variance and standard deviation, indicating an uneven spread. In contrast, 540 rpm achieves a more uniform spread, making it the best choice for consistency.

Given that 540 rpm provided the most consistent material distribution with the lowest variance and standard deviation, two additional simulations were conducted where the rotor angle was modified to assess its impact on spreading performance. Adjusting the rotor angle was intended to further optimize both the coverage and uniformity of manure distribution. The simulations enabled analysis of whether slight variations in rotor inclination could improve efficiency or introduce new variations in the spreading pattern. The results from these additional tests, shown in Fig. 20 a) and b), help determine the optimal combination of speed and angle for the most effective manure distribution.



a) 75-degree, 540 RPM *b) 85-degree ,540 RPM*

Fig. 20 - Compost distribution at 540 RPM

The conclusion drawn from the additional simulations highlighted the significant impact of the rotor angle on manure distribution. By comparing the different angle settings, it was observed that minor adjustments in rotor inclination had notable effects on coverage and uniformity. However, the 75° angle setting demonstrated the best balance between coverage and uniformity, providing a more even distribution and broader coverage compared to the other angles tested. In conclusion, choosing a 75° angle in combination with a speed of 540 RPM represents the optimal solution for ensuring an efficient and uniform manure distribution, maximizing equipment performance in terms of both coverage and variability.

Following the stationary simulations, the results were extrapolated to estimate the distribution in dynamic operation at a speed of 1 m/s. It was found that at 75° inclination, the distribution was the most uniform, with no significant peaks in the central area, ensuring a more consistent spread of material during dynamic operation. This adjustment helped reduce the central concentration of particles, which is commonly observed at lower inclination angles.

The obtained results of the distributions at different rotor inclination angles are shown in Fig. 21, confirming that the 75° provided the most optimal spreading pattern.

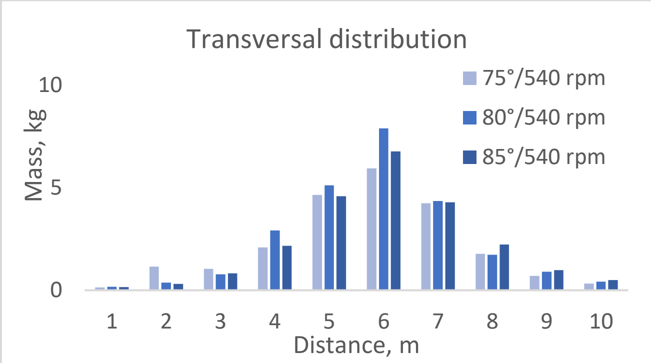


Fig. 21 - Transversal distribution at different inclination angles

The simulations were performed over a period of 25 seconds under stationary conditions. However, in reality, the material flow rate is much lower when the machine is in motion. The simulations primarily provide insight into the profile of the distribution curve but do not necessarily represent the actual quantities of material being spread.

The quantities of fertilizer distributed on the soil can be adjusted based on the machine's working speed. Specifically, as the machine moves slower, a greater quantity of fertilizer is deposited per unit area, since the material has more time to spread across the field. Conversely, when the machine moves at a higher speed, the amount of solid fertilizer reaching the soil decreases, as the material is spread over a larger area in a shorter time.

This relationship between the machine speed and the quantity of material distributed is essential for real-world applications. By controlling the working speed of the machine, it is possible to achieve the desired amount of fertilizer applied to the field, optimizing the application rate for different soil types and conditions.

After determining the optimal parameters for a single rotor, the performance of a fertilizer distributor equipped with four vertical rotors, spaced 0.5 m apart, was simulated. The width of the hopper in this design is 2 meters, which corresponds to the average width of an agricultural trailer. The direction of rotation of the four rotors, each inclined at 75° relative to the horizontal axis, directed towards the interior of the machine, is shown in Fig. 22 (two rotors rotate to the left and two to the right).

The optimal distribution identified previously should have a uniform profile, with a smooth transition between areas of high and low particle concentration.

For the machine with four rotors, a high concentration of particles is observed along the central axis of the equipment, indicating an overlap of the material flow streams.

A noticeable expansion of the particle distribution occurs both transversely and longitudinally, which is beneficial as it results in wider coverage of the area (Figs. 23, 24). The area covered by the machine is increased. Transversely, the coverage extends from 7 meters to 15 meters, and longitudinally, it ranges from 10 meters to 15 meters. This expansion of the covered area further enhances the uniformity of fertilizer distribution across the field. Even the maximum spreading width increases very much, the actual effective working width is about 5 m. The transversal spreading uniformity reported to the effective width, is about 88%.

To further uniformize the lateral zones, a second pass is necessary to achieve an overlap of the material deposited on the ground, ensuring a more even spread of fertilizer.

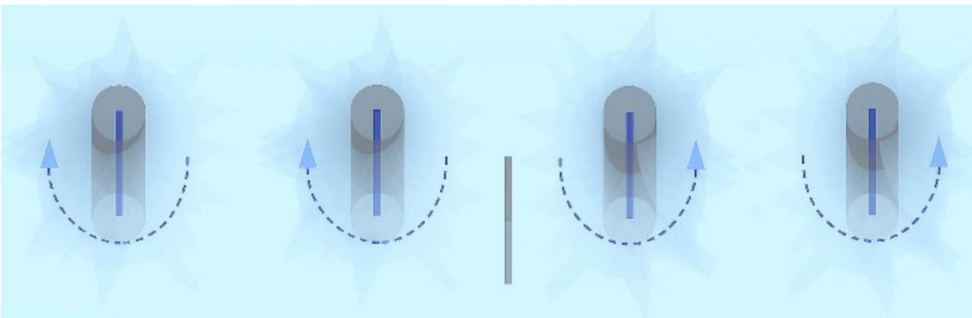


Fig. 22 – Direction of rotor rotational speed

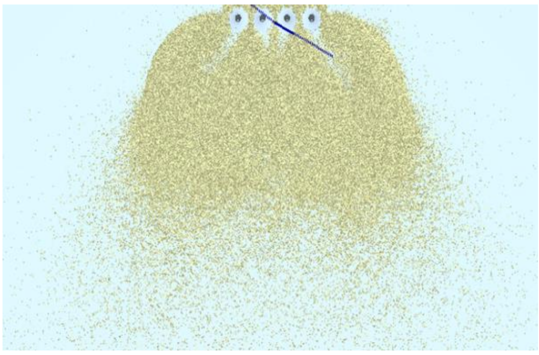


Fig. 23 - Particle distribution – top view

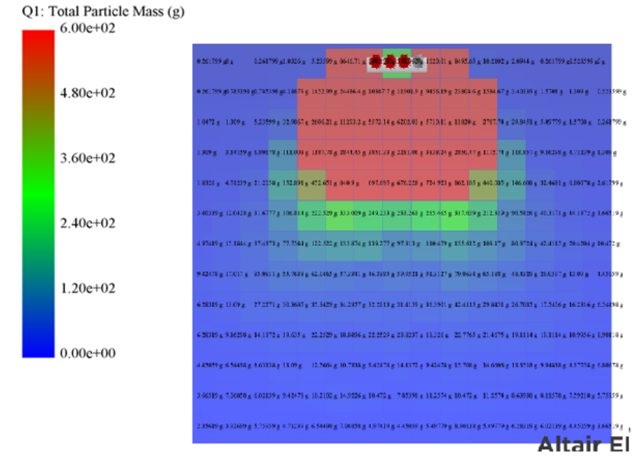


Fig. 24 - Particle's mass distribution

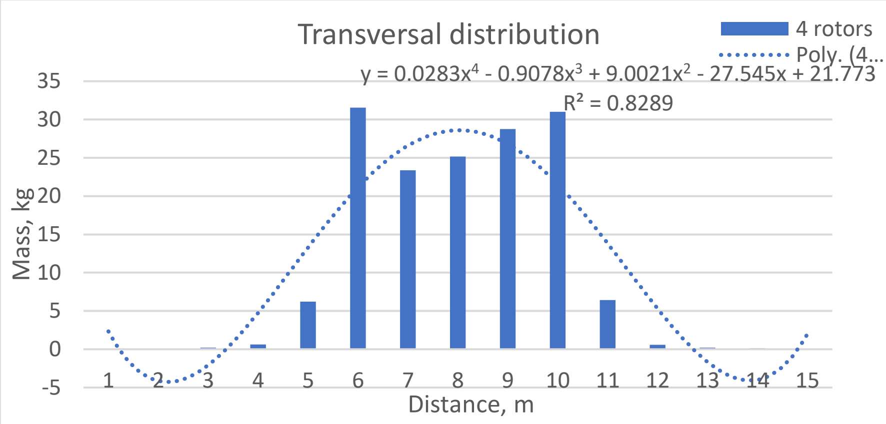


Fig. 25 – Simulated transversal distribution

It is important to emphasize that a four-rotor system not only ensures a wider working width and a more uniform coverage (Fig. 25) but also offers a significant advantage in fragmenting the organic fertilizer (manure). With four rotors, the material is broken down more effectively, allowing for better dispersion and finer fragmentation, which is crucial for proper incorporation into the soil. Therefore, using four rotors is recommended not just for achieving an even distribution but also for improving the quality of material processing, which enhances fertilizer efficiency.

To further uniformize the lateral zones, a second pass is necessary to achieve an overlap of the material deposited on the ground, ensuring a more even spread of fertilizer.

CONCLUSIONS

The integration of EDEM software into the design process of fertilizer spreaders demonstrated a significant improvement in application precision and efficiency, with parametric modelling facilitating the identification of optimal operating parameters. Detailed analysis of fertilizer distribution at different rotor rotation speeds showed that while 360 rpm resulted in a highly concentrated and inefficient distribution, and 440 rpm showed some improvement but with suboptimal uniformity, 540 rpm offered the most efficient and uniform distribution, significantly reducing central accumulation and ensuring a more consistent spread over a larger area.

At 540 rpm, additional simulations revealed that a 75° angle provided the best balance between coverage and uniformity, minimizing excessive concentrations in the central area.

Although simulations were performed under stationary conditions, the results can be extrapolated to estimate distribution in dynamic operation (at a speed of 1 m/s), indicating that a 75° inclination ensures the most uniform distribution during movement. It was also confirmed that the machine's working speed directly influences the quantity of fertilizer deposited per unit area: a lower speed allows for the deposition of a larger quantity, while a higher speed reduces the quantity per unit area. Simulating a distribution system with four vertical rotors (inclined at 75°, spaced 0.5 meters apart) indicated a significant increase in working width and more uniform coverage (extension from 7 to 15 meters transversely and 10 to 15 meters longitudinally).

Furthermore, a four-rotor system contributes to more efficient fragmentation of organic fertilizer, ensuring finer dispersion and optimal incorporation into the soil, thereby maximizing fertilization efficiency. To further uniformize the lateral zones and ensure a more consistent spread of fertilizer on the ground, a second pass of the machine is necessary to achieve an overlap of the deposited material.

In conclusion, the use of EDEM simulations allowed for the optimization of key parameters for the design and operation of organic fertilizer distribution equipment. It was established that a rotation speed of 540 rpm and a rotor inclination angle of 75°, combined with a four-rotor system, represent the optimal configuration for efficient, uniform distribution and superior material fragmentation, essential for improving soil health and agricultural productivity.

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