STUDY ON THE EFFICIENCY OF A STONE-COLLECTING MACHINE USING DISCRETE SIMULATION METHODS (DEM)
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STUDIU ASUPRA EFICIENȚEI UNEI MAȘINI DE ADUNAT PIETRE PRIN METODE DE SIMULARE DISCRETĂ (DEM)

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ABSTRACT
This study presents a digital simulation of a stone-picking machine using the Discrete Element Method (DEM) to analyze its interaction with heterogeneous soil and scattered stones. A detailed 3D model of the machine was developed in SolidWorks and imported into EDEM software to replicate the mechanical operation and material flow during field use. The simulation aims to evaluate the machine's performance in terms of stone collection efficiency, component interaction with granular material, and potential clogging scenarios. By accurately modeling the geometry and motion of key parts, such as the collection system and conveyor belt, the study provides insight into operational dynamics that are difficult to capture through physical prototypes alone. This workflow demonstrates how integrating CAD-based design with DEM simulation can contribute to optimizing agricultural machinery for improved field reliability and performance. Additionally, the stone-picking machine can be effectively used in field preparation prior to soil work for establishing vineyards and orchards, helping to create a clean and suitable seedbed that supports sustainable crop development.

REZUMAT
Acest studiu prezintă o simulare digitală a unei mașini de cules pietre folosind metoda elementelor discrete (DEM) pentru a analiza interacțiunea acesteia cu solul eterogen și pietrele împrăștiate. Un model 3D detaliat al mașinii a fost dezvoltat în SolidWorks și importat în software-ul EDEM pentru a reproduce funcționarea mecanică și fluxul de materiale în timpul utilizării pe teren. Simularea urmărește să evalueze performanța mașinii în ceea ce privește eficiența colectării pietrelor, interacțiunea componentelor cu materialul granular și scenariile potențiale de înfundare. Prin modelarea precisă a geometriei și mișcării pieselor cheie ale mașinii, cum ar fi sistemul de colectare și banda transportoare, studiul oferă o perspectivă asupra dinamicii operaționale care este dificil de captat doar prin prototipuri fizice. Acest flux de lucru demonstrează modul în care integrarea proiectării bazate pe CAD cu simularea DEM poate contribui la optimizarea utilajelor agricole pentru îmbunătățirea fiabilității și a performanțelor pe teren. În plus, mașina de cules pietre poate fi utilizată eficient în pregătirea terenului înainte de lucrările solului destinate înființării plantațiilor de viță de vie și pomi fructiferi, contribuind la crearea unui pat germinativ curat și adecvat dezvoltării durabile a acestora.

INTRODUCTION
In modern agriculture, removing stones from farmland is a crucial step in soil preparation, particularly in regions with rocky terrain that can hinder planting, harvesting, and crop development. Stones and debris can damage machinery, slow down operations, and reduce yields. Stone-picking machines address these challenges by cleaning the soil prior to cultivation. However, designing machines that can efficiently handle stones of varying sizes, shapes, and materials under different field conditions remains a major technical challenge (*Csikós et al., 2023*).

Setting up a vineyard or orchard starts with preparing the soil so that plants can develop strong roots, make the best use of water, and stay productive for years to come *(Nguyen et al., 2025)*. A crucial part of this preparation is clearing the field of rocks and stones, which can get in the way of machinery used for plowing, planting, or installing irrigation systems *(Griesser et al., 2022)*.

Stone-picking machines are essential for preparing land, efficiently removing stones and creating a clean, level seedbed - critical for precise planting in vineyards and orchards *(Leonel et al., 2025)*. They also reduce soil compaction and improve root zones, supporting stronger, healthier crops *(Giffard et al., 2022)*.
Advances in digital design and simulation tools have made agricultural machinery design faster and more efficient. Engineers can now use predictive methods instead of trial and error, with programs like SolidWorks and Altair's EDEM helping turn ideas into accurate, reliable designs *(Zhou et al., 2025; Zhao et al., 2022)*.

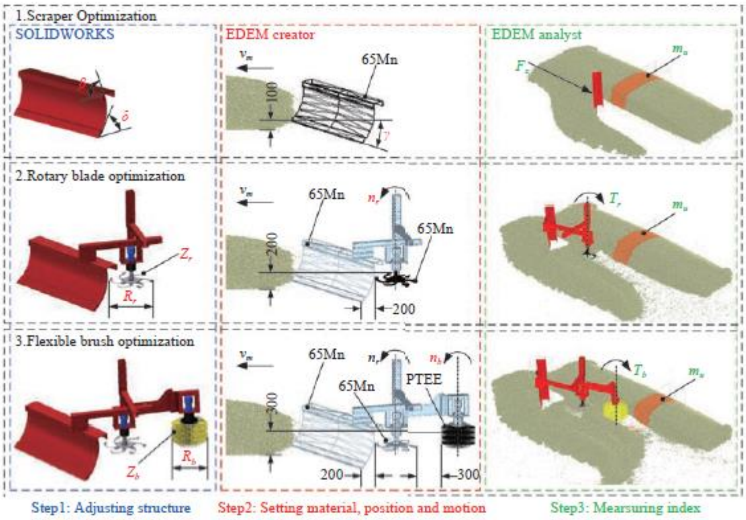


Fig. 1 - Process Chart for Model Optimization and Simplification in Simulation
(Yang, et. al. 2024)

Figure 1 shows the EDEM simulation workflow for a rotary blade, including geometry setup, material and motion settings, and performance analysis using force vectors (T_x, T_Y). EDEM models granular materials like soil, rocks, sand, and seeds, allowing engineers to test machinery interactions with mixed particles, including collisions, friction, and flow *(Tong et al., 2022; Weimo et al., 2025)*.
By combining SolidWorks and EDEM, researchers can simulate real field conditions, evaluate designs, and track key factors like stone collection rate, material flow, component wear, and force distribution (*Jelinek et al., 2025*). This approach speeds up design, reduces prototyping costs, and helps detect potential issues early *(Lu et al., 2022).*
Stone collection efficiency depends on machine design, speed, soil, stone density, and environment. Conventional testing often misses complex interactions, while EDEM simulations provide detailed insights, even on uneven soils or with varied stone sizes *(Gage et al., 2014; Geng et al., 2022)*.
This article presents a simulation-based study of a stone-collecting machine, using a SolidWorks model integrated into EDEM by Altair. The research investigates the machine's performance at different operating speeds to evaluate its efficiency in collecting stones. The study contributes to sustainable agricultural design through digital prototyping and simulation-driven development.

Equipment and System Design

Kose U. et al. (2025) developed a tractor-powered stone-collecting machine to improve soil quality and reduce manual labor in rocky areas like Saurashtra, Gujarat. Equipped with a digging blade, soil-separating conveyor, and rear collection trolley, it uses the tractor's PTO to efficiently lift, separate, and gather stones. Field tests under real conditions measured its key performance metrics.

Table 1

Performance parameters field test

Depth of cut	10 cm
Wheel slip	7.58%
Draft force	2107 N
Fuel consumption	4.01 liters per hour
Field efficiency	76.05%

These results confirmed the machine's capability to remove stones effectively while maintaining fuel efficiency and minimizing operational strain on the tractor.

A digital model of the machine was created in SolidWorks and imported into Altair EDEM for DEM simulation. This allowed engineers to study interactions between soil, stones, and moving parts, visualize stone paths, and identify stress points, offering key insights into the machine's performance under different conditions.

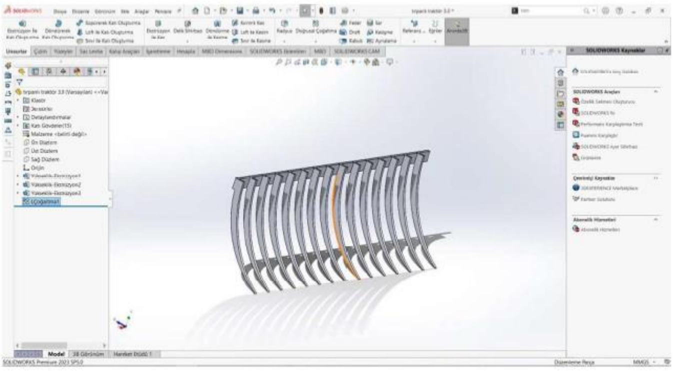
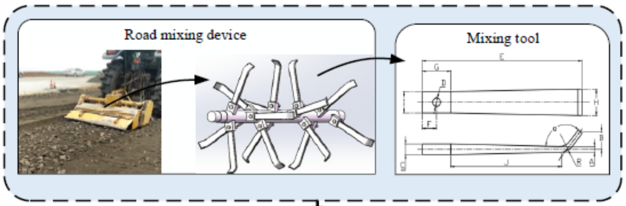


Fig. 2 - 3D model of the rake assembly
(Kose, U.et. al. 2025)

Figure 2 shows how the rakes are mounted onto the UPN 160 steel profile in the design of the stone-collecting machine. Made from S355 steel, this profile provides a durable and sturdy support for the machine. The rakes, which gather stones during operation, are attached to the UPN 160 profile at 150 mm intervals. Each rake has 10 mm slots that make it easy to secure firmly to the frame.

System Configuration and Parameter Optimization

Zhan et al. (2020) used EDEM simulations to find the optimal rotational speed for road-mixing equipment with cement-stabilized crushed stone. Testing speeds from 65 to 150 r/min, they found mixing quality improved up to 120 r/min and then levelled off, identifying 120 r/min as the best balance of efficiency, energy use, and tool wear.



Name	A	B	C	D	E	F	G	H	I	J	R	α
Size (mm)	10	35	15	16	340	30	60	50	40	230	30	130°

- Angle of tool axis is between 54°and 85°
- Angle of tools in the same section is between 130° and 180°
- The distance of each section is between 40mm and 80mm

Fig. 3 - Specifications and structural configuration of the mixing device
(Zhan, Z. et. al. 2020)

Figure 3 shows the mixing device's structure and key dimensions for large-sized cement-stabilized crushed stone. Designed with precise geometry, the device features tool angles between 54°–85°, angular spacing of 130°–180°, and axial distances of 40–80 mm. Based on a cutlass design and following a multi-helix principle, it ensures uniform material distribution and efficient mixing.

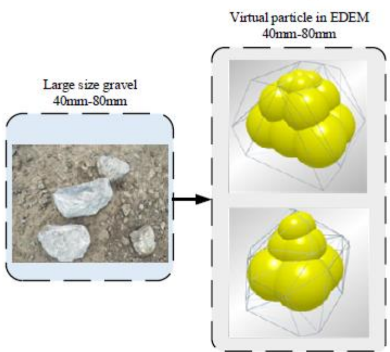


Fig. 4 - EDEM Simulation Model of Water-Stabilized Macadam Particles
(Zhan, Z. et. al. 2020)

Figure 4 shows an EDEM simulation of water-stabilized macadam, representing cement-stabilized crushed stone. Particle sizes are simplified to 4–19 mm and modelled as spheres, while the Hertz-Mindlin with JKR contact model accounts for moisture and surface energy to simulate particle interactions under construction conditions.

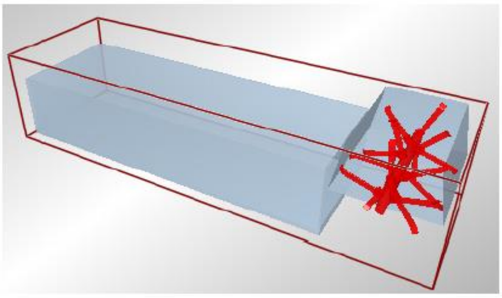


Fig. 5 - EDEM Simulation Model of the Mixing Device
(Zhan, Z. et. al. 2020)

Figure 5 shows the EDEM-simulated mixing system, with a stone container, cover shell, and mixing tools. Two particle types are mixed using the Hertz-Mindlin (No Slip) model to capture interactions accurately.
Rudani et al. (2018) designed a tractor-powered stone-collecting machine with a digging blade, conveyor, collection trolley, and power unit. Field tests showed it removed stones efficiently (76.05%) with low fuel use (4.01 L/h), outperforming manual methods.

Fig. 8 a) Design schematic of the stone collector; b) Assembled stone collector
(Rudani, M.R. et. al. 2018)

MATERIALS AND METHODS

A workflow combining design and simulation was created to evaluate a stone-collecting machine in realistic field conditions. A detailed 3D model was built in SolidWorks to optimize the machine's structure and performance, taking into account stone size, soil resistance, and operating speed. While SolidWorks provided precise modeling, EDEM simulations using the Discrete Element Method (DEM) allowed engineers to study how soil, stones, and machine components interact in action.

The machine features a ground-guided reel with spring-loaded tines that lift stones onto a conveyor, letting the soil fall back. The stones are then gathered in a bucket with a grated bottom, which separates and removes loose soil via a hydraulic system. EDEM simulations helped visualize stone movement, track contact forces, and pinpoint design issues. Through iterative refinements, the machine's efficiency was improved, highlighting the benefits of combining CAD and DEM tools for optimizing agricultural equipment.

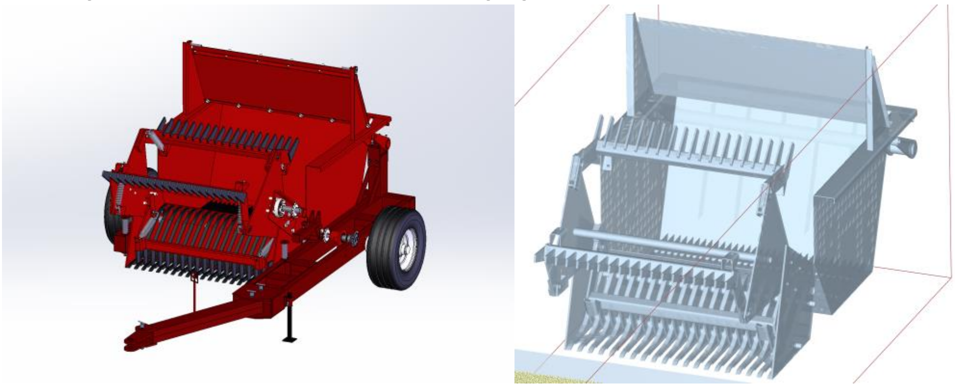
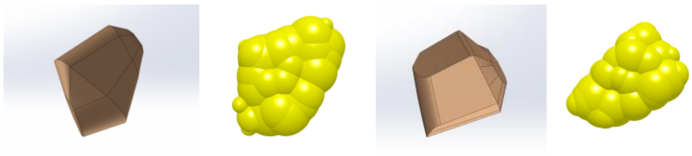
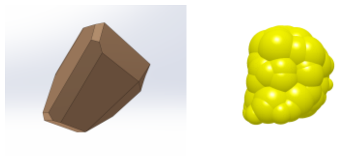


Fig.11 - Stone-collecting machine modelled in SolidWorks and imported into EDEM as an STL file

Figure 11 shows the 3D model of the stone-collecting machine created in SolidWorks, along with its simplified STL version prepared for import into Altair's EDEM, which uses the Discrete Element Method (DEM). To simulate real operating conditions, a controlled test environment was set up, consisting of a prepared soil bed and a variety of stones differing in size, shape, and mass. These stones were modeled with high-resolution CAD geometry to capture detailed physical and mechanical properties, closely resembling natural stones. This realistic setup provided a reliable basis for evaluating the machine's performance under operational conditions. Figure 12 illustrates the geometrical representation of the stones, with the parameter L indicating the longitudinal dimension of each modeled stone.



a) b)



c)

Fig.12 – Geometry of stones used in the simulation

a) L= 270 mmm b) L = 70 mm c) L = 60 mm

For the simulation environment setup in Figure 13, two main components were created using polygon-based geometries: the soil layer, representing the ground surface, and the rock bed, simulating randomly distributed stones on top of the soil layer. These components defined the spatial and mechanical boundaries within which the collection process would be evaluated. The stones were placed with randomized coordinates using the EDEM's built-in random positioning method, to replicate natural field conditions and irregular stone dispersion.

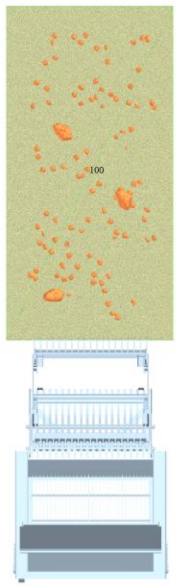


Fig. 13 - Simulation environment (Soil Layer, Rock Bed, Stone Collecting Machine)

The interaction between the machine's collection system - specifically the rotary pick-up mechanism and conveyor system - and the stones was then simulated.

In the EDEM simulation, the soil was modelled as a granular material composed of spherical particles with physical parameters assigned based on typical clayey soil properties found in literature. These included a particle density of 1250 kg/m^3, a shear modulus of 1×10^6 Pa, and a Poisson's ratio of 0.4; and for steel, a density of 7850 kg/m^3, a shear modulus of 7×10^7 Pa, and a Poisson's ratio of 0.3. Contact interactions between soil particles were defined using the Hertz-Mindlin JKR contact model, with a coefficient of restitution of 0.57, static friction coefficient of 0.85, rolling friction of 0.15, and surface energy of 1.05 J/m^2.

Interactions between the soil and machine surfaces were modelled with appropriate coefficients of restitution, static and rolling friction, set to 0.09, 0.5, and 0.09, respectively, based on specific literature data *(Chen et al., 2022).*

The rock particles were assigned a density of 2700 kg/m³, a shear modulus of 3.85 × 10^8 Pa, and a Poisson's ratio of 0.3. Interactions between rocks and equipment were modelled using the Hertz–Mindlin (no-slip) contact model, with a coefficient of restitution of 0.27, a static friction coefficient of 0.31, and a rolling friction coefficient of 0.37 *(Boikov et al., 2021).*

The collection efficiency (η) quantifies the proportion of stones successfully harvested relative to the total stones encountered during the operation and is mathematically expressed according to:

$$\eta = \frac{N_c}{N_c+N_l} \times 100 \tag{1}$$

where: N_c is the number of stones collected and N_l the number of stones lost.

Additionally, the collection and loss rates (stones per second) were evaluated as:

$$R_c = \frac{N_c}{t_c} \; R_l = \frac{N_l}{t_c} \tag{2}$$

where t_c represents the collection time in seconds;
R_c – collection rate;
R_l – loss rate.

As shown in Figure 14, the machine moves over the terrain, and the rotary teeth engage with the stones, lifting and propelling them toward the rear conveyor. This system then transfers the stones to the bunker compartment, located at the rear of the machine. The simulation tracked key dynamics such as the stone's pickup trajectory, contact forces during impact with mechanical components, potential bouncing or ricochet behavior, and final deposition within the storage area.

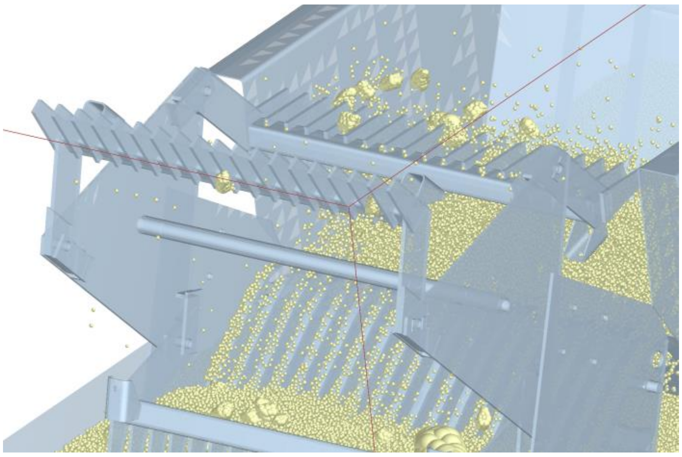
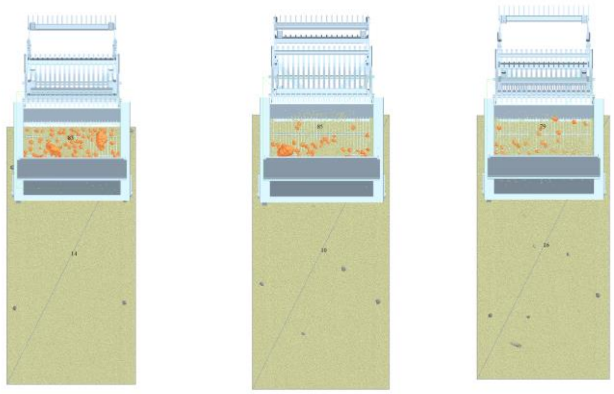


Fig. 14 - Interaction between stone collecting machine and rocks in EDEM

Throughout the simulation, EDEM allowed for detailed tracking of each stone's motion, contact forces, velocities, and distribution patterns, thereby enabling assessment of the machine's operational efficiency. Based on the observed particle behavior, iterative adjustments to the geometry and positioning of the collection elements were made in SolidWorks, followed by repeated DEM simulations to refine performance.

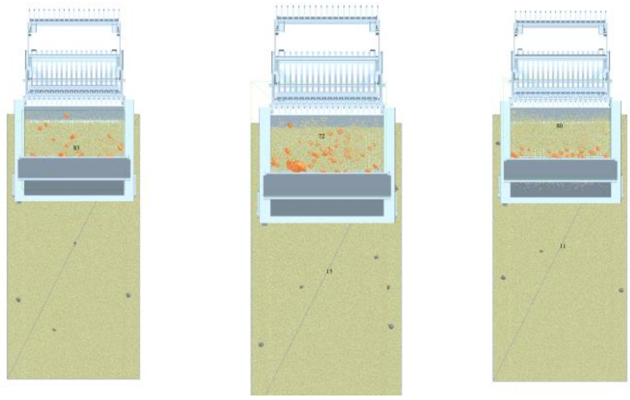
RESULTS

Figures 15, 16, and 17 present the simulation results for the stone-collecting machine operating at three different forward velocities: v = 4 km/h, v = 5 km/h, and v = 6 km/h, respectively. For each velocity, simulations were conducted at three rotational speeds of the pickup mechanism: 25 rpm, 35 rpm, and 45 rpm. The machine's motion was modelled with linear forward movement combined with linear rotational motion of the fork system, designed to lift stones from the terrain. The simulations captured key dynamics, including the pickup trajectory of stones, contact forces upon impact with mechanical components, possible bouncing or ricochet behavior, and the final deposition position within the storage area. These results offer insight into the machine's operational efficiency under varying speed and rotational parameters.



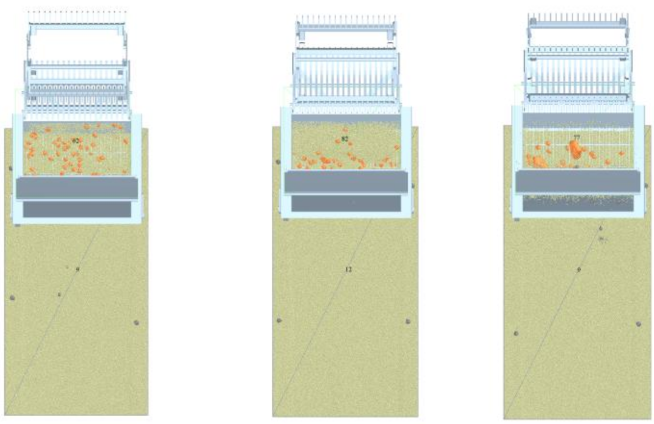
a) b) c)

Fig. 15 – v = 4 km/h a) 25 rpm b) 35 rpm c) 45 rpm



a) b) c)

Fig. 16 – v = 5 km/h a) 25 rpm b) 35 rpm c) 45 rpm



a) b) c)

Fig. 17 – V= 6 km/h a) 25 rpm b) 35 rpm c) 45 rpm

Based on the simulation results illustrated in Figures 15, 16, and 17, which correspond to three different forward velocities of the stone-collecting machine — v = 4 km/h, v = 5 km/h, and v = 6 km/ha detailed analysis of the system's behavior was performed. To further evaluate the machine's efficiency in collecting stones, number of particles vs. time analysis will be generated in EDEM for each velocity and rotational speed combination. This analysis will help quantify the rate and consistency of particle collection over time, offering deeper insight into the influence of machine speed and pickup mechanism rotation on operational performance.

Figures 18, 19, and 20 illustrate the progression of stone removal by the stone-collecting machine operating at forward speeds of 4 km/h, 5 km/h, and 6 km/h. Each figure illustrates the particle collection behavior over time for the three rotational speeds of the pickup mechanism: 25 rpm, 35 rpm, and 45 rpm. This analysis highlights how changes in forward speed and rotation rate influence the stone pickup rate and overall collection efficiency, providing a clearer understanding of the dynamic performance of the system under varying operational conditions.

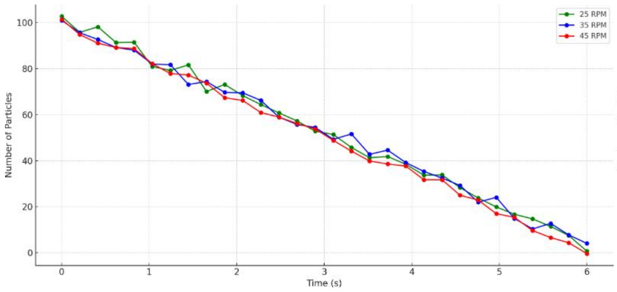


Fig. 18 - Evaluation of Stone Removal Progression Over Time at 4 km/h

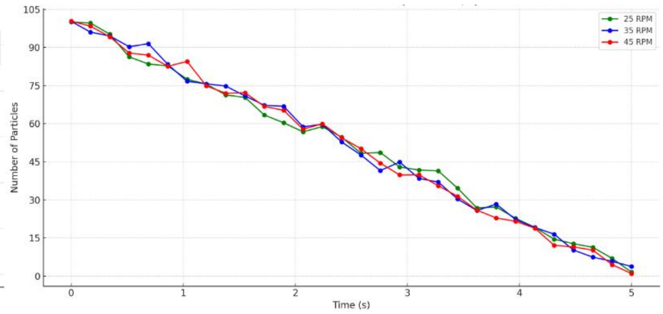


Fig.19 - Evaluation of Stone Removal Progression Over Time at 5 km/h

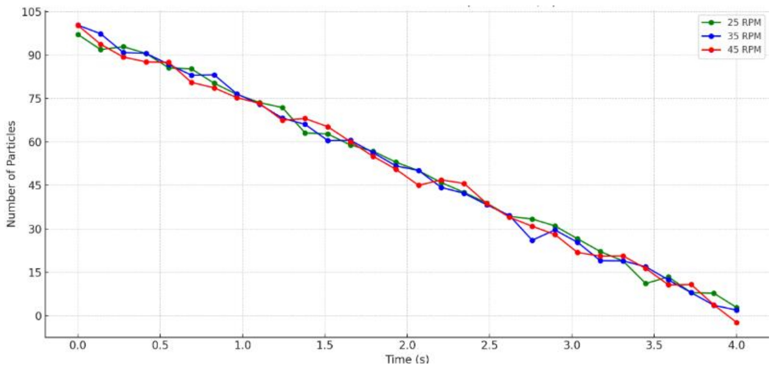


Fig. 20 - Evaluation of Stone Removal Progression Over Time at 6 km/h

To simplify the interpretation of the simulation results presented in Figures 18, 19, and 20, the data from the Number of Particles vs. Time graphs were consolidated into a summary table. This table represents a 2D parameter grid that maps the different combinations of forward velocity and rotational speed to the corresponding particle collection outcomes. By organizing the results in this way, the complex 3D simulation outputs are presented in a more accessible format, enabling easier comparison and evaluation of the machine's performance across varying operational conditions.

Table 2

2D Parameter Grid for 3D Simulation Outputs

Speed (km/h)	Rpm	Stones Collected	Stones Lost	Collection time (s)
4	25	83	17	3,8
4	35	85	15	3,8
4	45	79	21	3,8
5	25	72	28	3,2
5	35	83	17	3,19
5	45	80	20	3,5
6	25	62	38	2,6
6	35	82	18	2,6
6	45	77	23	2,7

In this study, the performance of a stone-collecting machine was evaluated under various operational speeds and rotational speeds using simulation data represented in Table 2. Key performance indicators including collection efficiency, collection rate, and loss rate were calculated to assess the machine's effectiveness.

Based on the equations (1) and (2), the raw data presented in Table 2 were quantitatively processed to evaluate the operational performance of the stone-collecting system. The analysis yielded key performance indicators - namely, collection efficiency (η), collection rate (R_c), and loss rate (R_l) - which are critical for assessing the functional reliability and throughput capacity of the machine under varying kinematic conditions. These parameters were computed for each experimental configuration, combining different forward velocities (4, 5, and 6 km/h) with rotational speeds of the collection mechanism (25, 35, and 45 rpm). The results are consolidated in Table 3, offering comparative performance results that facilitates the identification of optimal operational regimes. This parametric evaluation provides valuable insights into the trade-offs between collection speed and material losses, serving as a basis for informed design refinements and future field implementation.

Table 3

2D Parameter Grid for Performance Results

Working Speed (km/h)	Rotational speed (rpm)	Collection efficiency (η) %	Collection rate (R_c) stones/s	Loss Rate (R_l) stones/s
4	25	83	21,84	4,47
4	35	85	22,37	3,95
4	45	79	20,79	5,53
5	25	72	22,50	8,75
5	35	83	26,02	5,33
5	45	80	22,86	5,71
6	25	62	23,85	14,62
6	35	82	31,54	6,92
6	45	77	28,52	8,52

Among the tested configurations, the 5 km/h and 35 rpm setting offer an optimal balance between performance and efficiency. With a high collection efficiency of 83%, a strong collection rate of 26.02 stones/s, and a relatively low loss rate of 5.33 stones/s, this configuration ensures effective stone removal while minimizing resource waste. Additionally, its favorable fuel consumption per collected stone indicates it is well-suited for long-term field operations where both productivity and energy efficiency are critical.

The results indicate strong performance in dynamic field conditions, contributing to improved soil preparation and reduced machine downtime. The performance outcomes are illustrated in Figure 21.

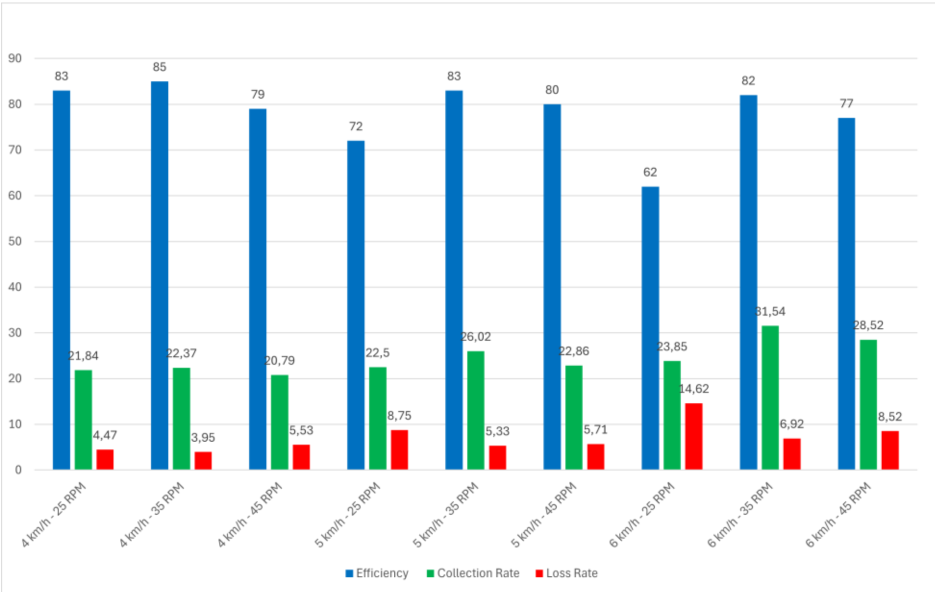


Fig. 21 - Performance Metrics vs. Operating Conditions

CONCLUSIONS

In conclusion, the use of discrete element method (DEM) simulation through EDEM software proved to be a valuable approach for evaluating the efficiency and design performance of the stone-collecting machine. By enabling detailed analysis of particle interactions and material flow, DEM allowed for accurate prediction of system behavior under varying operating conditions critically for optimizing component design and reducing mechanical resistance during operation. The ability to simulate and refine the process virtually offers significant advantages in improving design decisions and minimizing the need for repeated physical prototyping.

Nonetheless, simulation results must be validated through experimental testing to ensure real-world accuracy. Therefore, upcoming physical trials with the developed machine will provide essential data to compare against simulation outputs. This comparison will serve to validate the model, identify potential deviations, and further calibrate the simulation parameters. The integration of DEM simulation with practical experimentation is expected to strengthen the reliability of virtual modeling for agricultural machinery and support its application in future development and optimization efforts.

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