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Review
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APPLICATION OF THE DISCRETE ELEMENT METHOD IN AGRICULTURAL ENGINEERING: ADVANCES AND INSIGHTS

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Abstract: Discrete Element Methods (DEM) are a new numerical approach that can be used to model the behavior of granular media. In agriculture, DEM has been increasingly employed as a means of optimizing a variety of agricultural operations such as soil tillage, seeding, harvesting, as well as post-harvesting activities. This review article seeks to offer a thorough analysis of the use of DEM in agriculture as well as the prospects of this new approach. This article will address the basic theory of DEM, its applications in agricultural operations, as well as various difficulties that can arise as a result of the use of DEM in agricultural practices.

Keywords: Simulation, Numerical modeling, Agricultural materials, Mechanical behavior

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1. Introduction

Because agriculture is the most important source of income and relevant to economic evolution, it is continuously evolving (Erbay, 2013). As agricultural systems develop complex systems, there is an increasing need to grasp and optimize processes (Khan et al., 2021). Each system's core components have the greatest influence on sustainability. These components are soil, seed, fertilizer and crop residues. Unable to efficiently analyze, most researchers have bypassed interactions with the most value. Research indicates the Discrete Element Method (DEM) could alleviate this issue (Chen et al., 2022).

In various branches of engineering, the Discrete Element Method has been highlighted as an efficient numerical instrument for solving scientific and technological problems. The first applications were reported by Cundall and Strack in 1979 and involved simulating granular materials. Unlike continuum approaches, DEM treats particulate materials as discrete parts. It uses a Lagrangian method in which dynamic parameters of particles are followed throughout the simulation (Kačianauskas et al., 2007). By simulating motion and rotation of particles, as well as contact forces, DEM captures important aspects of granular matter systems, particularly in agriculture, where granular materials are used throughout the process (Tijskens et al., 2003).

One of the primary strengths of DEM is the flexibility it offers concerning material properties, particle shapes, and size distributions. This flexibility helps solve problems in agriculture and facilitates modeling of intricate scenarios (Barbhuiya et al., 2023). Improvements in computer technology and algorithms have made DEM simulations more efficient and easier to use, increasing its use in agriculture. DEM provides a framework and practical tool for optimizing agricultural machinery, soil management, and crop production (Zhao et al., 2021).

There are different kinds of DEM software such as EDEM, PFC, Pasimodo, Agridem, Yade-DEM, and DEMeter++ (Fleissner 2010; Shmulevich 2010). This software has enabled reliable simulation studies for agricultural material models focused on machine-material interactions (Coetzee and Els 2009). Understanding soil-tool interactions is important to design equipment that is energy efficient and effective (Ahmad et al., 2023). Traditional experimental methods are unsuitable for measuring certain forces in complex soil-tool interfaces. DEM has overcome this challenge. Soil-tool interactions can be simulated with parameters such as particle shape, size distribution, and material properties, allowing tool optimization for specific conditions (Chen et al., 2013).

The use of DEM also applies to seed-soil interaction when planting. For germination and yield, seed placement and soil cover are important. This is influenced by soil compaction, particle size and seed morphology. Regarding soil-seed contact, Zhou et al. (2014) discussed its implications for engineering and agronomy. He created numerical models to forecast contact properties and examined hardness, particle size and the press wheel rule.

The applicability of DEM goes beyond soil-seed

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interactions to simulating furrow opening, measuring seeds, and fertilizers (Wang et al., 2019; Xiaolong et al., 2020; Zha et al., 2021). Optimizing equipment design and reducing losses is a result of simulating material movements. DEM focuses on managing crop residues and assists farmers in choosing methods of integrating organic matter that preserve soil structure and nutrient balance (Zhang et al., 2025).

The evaluation of soil compaction is another use of DEM. This results from heavy machinery and frequent passes as mentioned by Pásthy et al. (2024) and Li et al. (2025). Soil compaction hinders productivity by limiting water infiltration and root growth (Zhang et al., 2024). Using DEM, combinations of tire pressure, wheel load, and soil moisture can be studied to simulate compaction and analyze soil types and strategies to mitigate it (Acquah and Chen, 2021).

DEM applications are limited by computational costs for large-scale systems, though they remain complex and expensive. Agricultural practices involve millions of particles, making field-scale modeling costly. Nevertheless, parallel computing, cloud-based simulations, and hybrid techniques enable more efficient and extensive uses of DEM (Huang and Keppler, 2023; Guo and Xia, 2023; Tian et al., 2024)."

Various strategies have been put forward to solve DEM limitations. Productivity can be gained by assembling databases of pre-calibrated micromechanical properties, streamlining calibration to save time and cost. Precise simulation of machine-material interactions benefits from integrating DEM with approaches such as the Finite Element Method (FEM). High-performance parallel processing and other computing aids have reduced computational intensity and created a foundation for efficient large-scale simulations (Yan et al., 2022; Guo and Xia, 2023).

Consequently, DEM stands as a remarkable achievement in agricultural research and engineering. By enabling detailed modeling of granular material behavior, it improves efficiency in machinery design, operational refinements, and innovative approaches to soil management and crop production. DEM has great potential to expand within agriculture, enhancing efficient, sustainable, and productive systems, especially as processing power increases and algorithms advance.

1.1. Historical Background

The first generation of Discrete Element Method (DEM) applications focused on simulating granular materials and particle systems. As shown in Figure 1, these applications date back to the 1970s. Over the years, DEM use has significantly increased and is now applied in areas such as agricultural engineering.

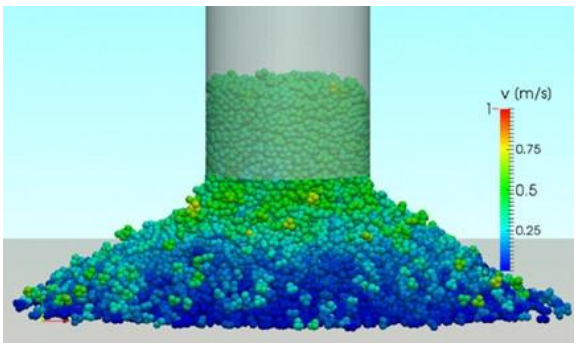


Figure 1. DEM simulation of granular materials (Al-Hashemi et al., 2018).

The pioneering work laid the foundation for later uses in soil mechanics and plant-soil interactions in agriculture (Walunj et al., 2023; Tian et al., 2024). As research progressed, the ability of Discrete Element Modelling (DEM) to characterize complex interactions in agricultural systems gained attention. The simulation of tillage, seeding, and crop harvest has been documented. Combining DEM with techniques like Computational Fluid Dynamics (CFD) and Multi-Body Dynamics (MBD) has deepened assessment of agricultural machinery for shifting and seeding (Zhiwei et al., 2021; Yan et al., 2022). Difficulties in modelling saturated soils and capturing mechanical characteristics at different moisture levels, essential for farming, persist (Tian et al., 2024). The growth of the agricultural DEM community comes mainly from improvements in computational power and algorithms. Increased power and refined calibration methods have allowed researchers to exploit DEM as a tool for designing, constructing, and fine-tuning agricultural processes and machinery (Zhiwei et al., 2021) (Figure 2).



Figure 2. Design of agricultural equipment with DEM simulation.

Tian et al. (2024) indicate that the continuous merging of novel methods, for example, Smoothed Particle Hydrodynamics (SPH), is a significant step forward in the application of DEM, especially in studies of seed germination, and thus imparts a bright future to such research.

2. Fundamental Principles of Discrete Element Method (DEM)

The Discrete Element Method (DEM) is a popular computer modelling approach for simulating granular materials and is useful in agricultural engineering. DEM integrates Newton's equations of motion for each particle, allowing thorough exploration of particle dynamics. This includes translations, rotations, and interactions such as contact forces, friction, and cohesion (Figure 3).

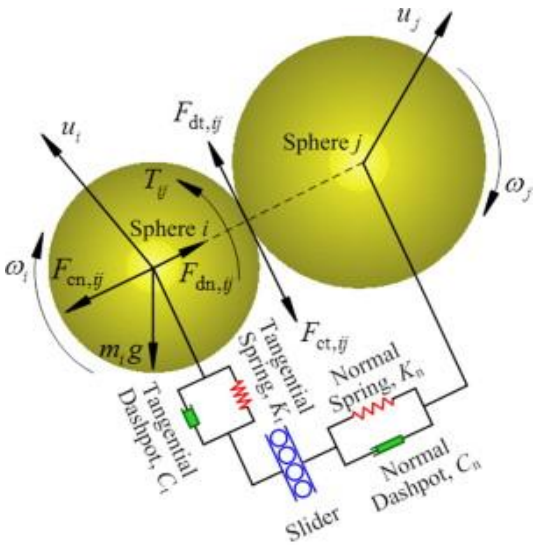


Figure 3. Model of the interaction forces between two particles (Zhang et al., 2014).

This method is beneficial as it handles complex particle shapes, polydisperse size distributions, and interaction mechanisms—elastic, plastic, and viscoelastic. Accordingly, DEM is instrumental in studying agricultural phenomena such as soil-particle dynamics during tillage, granular flow in grain storage, and interactions between machinery and particle environments. DEM supports reengineering agricultural processes by enabling in-depth understanding of material behavior under different mechanical and environmental conditions (Zhu et al., 2008) (Figure 4).

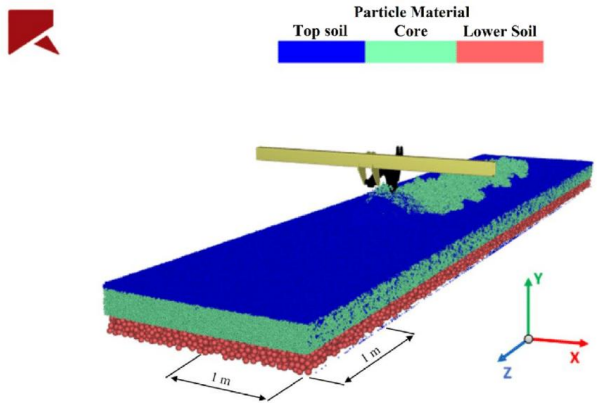


Figure 4. Application of DEM in optimization of agricultural processes (Kesner et al., 2021).

2.1. Particle Interaction and Contact Models

DEM relies on contact models that explain how particles interact with each other. Such models take into account variables like the normal and the tangential forces during the particle contact, which may be influenced by parameters like particle shape and material properties. Usually, the Hertz-Mindlin contact model (HMCM) is employed for this, but it might not be able to efficiently forecast vertical soil forces all the time (Figure 5).

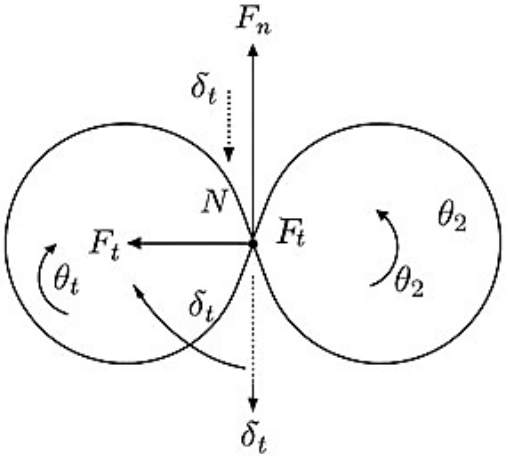


Figure 5. The Hertz-Mindlin contact model (HMCM).

There are cases where the Hysteretic Spring contact model (HSCM) was demonstrined to give more accurate estimations of soil behavior and particle movement, specifically in soil-related scenarios. (Aikins et al., 2023; Walunj et al., 2023) (Figure 6).

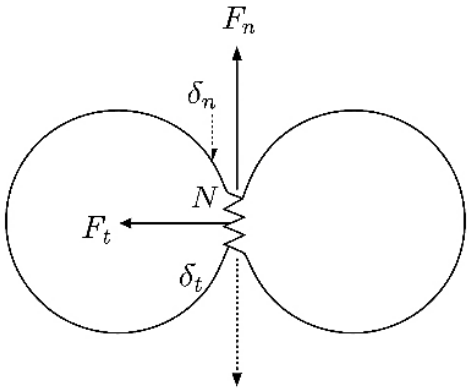


Figure 6. The Hysteretic Spring contact model (HSCM).

2.2. Simulation of Agricultural Processes

As demonstrated in multiple studies, DEM can be applied to various agricultural simulations. To illustrate, DEM can be used to analyze the interactions between soil and agricultural tools and machinery during tillage. This has yielded substantial insights into the parameters of soil disturbance and movement (Zhiwei et al., 2021; Yan et al., 2022) (Figure 7).

Being able to simulate granular flows, for example, the movement of seeds during planting or the flow of grains after harvest, allows the designing and making of farm machines as well as their (Thielke et al., 2015) optimization (Figure 8).

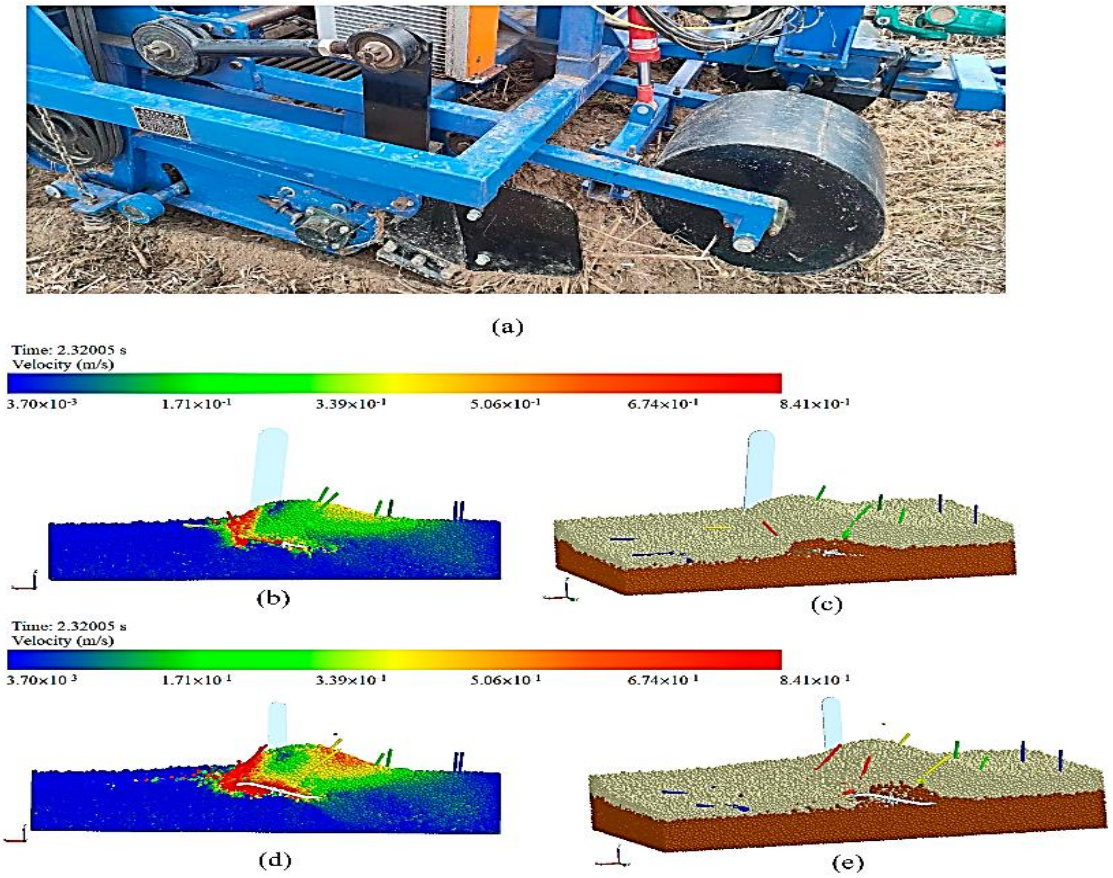


Figure 7. Soil–crop mass translocation properties of the tools evaluated in sandy loam soil: (a) field experiment result, (b,c) DEM result for the fork-shaped shovel, and (d,e) DEM result for the S-shaped shovel (Awuah et al., 2023).

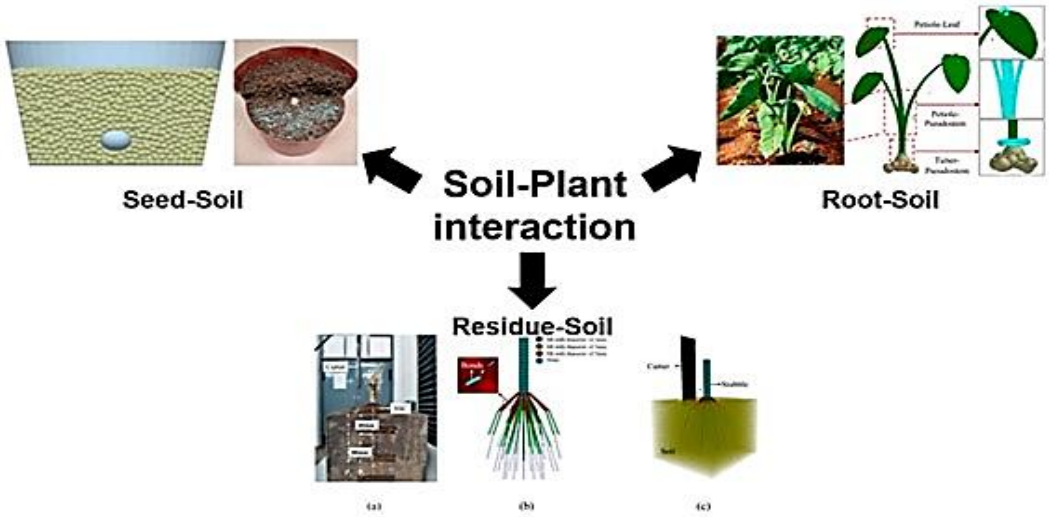


Figure 8. Soil-plant interaction systems simulated with the discrete element method (DEM) (Tian et al., 2024).

2.3. Calibration of Simulation Parameters

Accurate parameter settings in Discrete Element Method (DEM) simulations are essential for accurate results. Scientists perform laboratory experiments to discover physical characteristics of agricultural products like grains, seeds, and soil. For example, studies determined how seeds rebound after being dropped, a detail that must be simulated to predict seed movement during processing or handling (Wu et al., 2021; Yan et al., 2022; Aikins et al., 2023) (Figure 9). Nevertheless, it is not merely a matter of bounce; in the case of cohesive substances, such as damp soil, researchers rely on sophisticated techniques, including stress tests and specially designed shear experiments, to adjust their models accurately. The integration of these methods can significantly enhance the credibility of their simulations, thus enabling them to forecast changes in grain movement through the equipment as well as soil stability in the agricultural sector (Thielke et al. 2015; Coetzee and Scheffler 2022; Walunj et al. 2023).

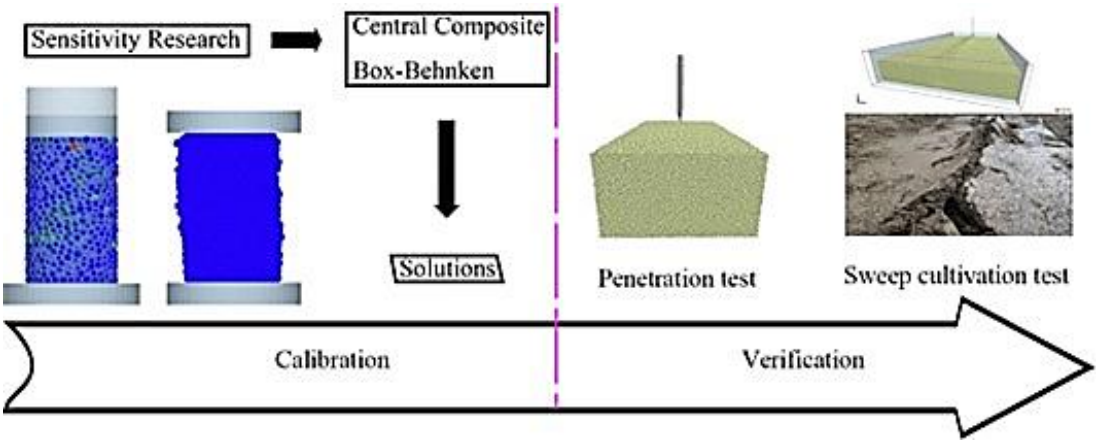


Figure 9. Calibration of discrete element parameters for modeling of subsurface soils (Wu et al., 2021).

3. Applications of DEM in Agriculture

3.1. Soil Tillage

Tillage is an essential farm operation including soil preparation, crop residue management, weed control, mixing nutrients, and improving soil structure. The Discrete Element Method has been implemented to portray interactions of tillage machines with soil. Ucgul et al. (2014) examined forces on the implement and soil displacement patterns using DEM to depict tillage-soil interaction. Their research showed DEM is a viable tool for determining traction forces and soil disturbance necessary for efficient tillage (Figure 10).

Further studies have broadened the use of DEM in tillage. Shmulevich et al. (2007) investigated the optimization of tillage methods by means of DEM to study how tillage speed influences soil fragmentation and clod formation. In the same way, Acquah and Chen (2021) employed DEM to examine how the change of soil compaction with increasing tillage depth and emphasized that controlling the depth is extremely helpful in reducing the soil damage (Figure 11).

3.2 Seed Planting

To achieve uniform crop output and maximize yield, correct seed placement is important. The Discrete Element Method (DEM) has been used to represent seed meters distributing seeds one by one. Coetzee and Els (2009) employed DEM to imitate seed movement inside a seed meter and identify elements influencing seed selection and distribution. Their research emphasized DEM as an instrument for developing efficient seed measurement systems. Recent experiments show DEM can be used in seed techniques more effectively (Figure 12). Li et al. (2025) designed a seed guide device for a pneumatic rapeseed meter, optimized by CFD-DEM, which improved seed guidance performance. Lei et al. (2021) studied seed movement and sowing performance of a centralized seed measurement system for rapeseed using DEM simulation and bench testing.

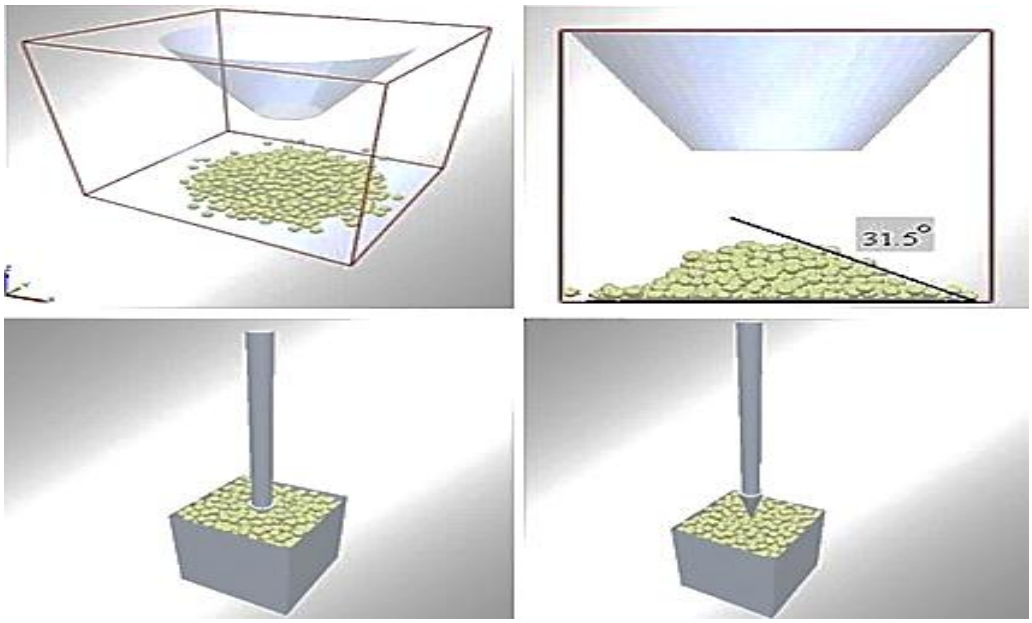


Figure 10. Simulation of angle of repose and penetration test (Ucgul et al., 2014).

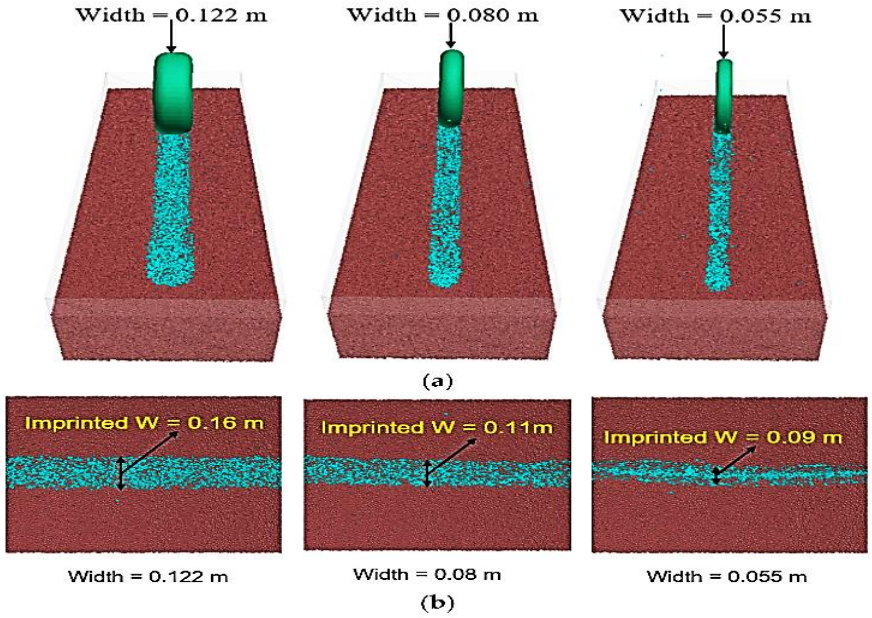


Figure 11. (a) Simulation of press-wheel under different widths (W); (b) imprinted widths for 0.122 m, 0.08 m and 0.055 m press-wheels after passage on soil with medium moisture content level.

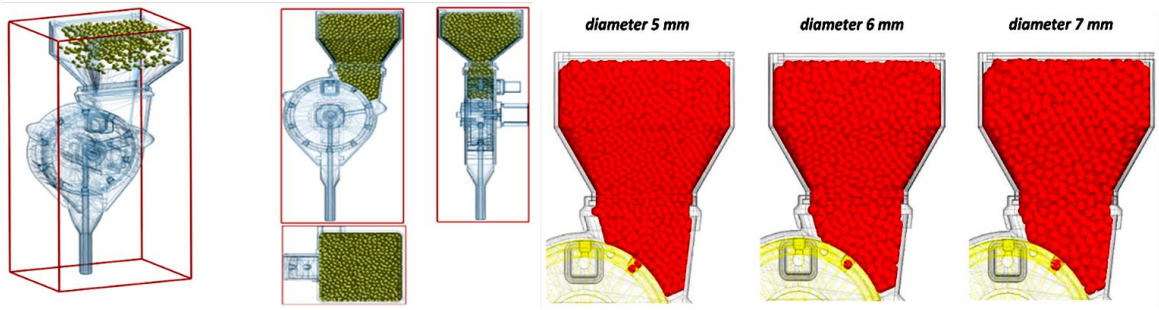


Figure 12. Simulation of the seed sowing device and the process of loading the seed hopper (Lysych et al., 2021).

3.3 Harvesting

Harvesting operations are agricultural processes that require the use of mechanical equipment such as combine harvesters. To explain how cutting and threshing are done in the machine where the plants are cut and the grains separated from the rest, a digital model has been developed (Figure 13). In their paper released, Li et al. 2023 devised a method to build a threshing drum with the help of a discrete element method, a "crop-machine" interaction system model" and the kinematic equation of the corn kernel during the threshing process was obtained. The research confirmed that DEM could serve as a tool to the designing of the harvesting machinery and therefore be an instrument of achieving high harvesting efficiency.

Additional improvements in DEM have allowed very detailed simulations of harvesting operations. Miu and Kutzbach (2008) utilized DEM to simulate the movement of grain in a combine harvester, isolating the variables that cause grain loss and breakage. In the same way, Qingqiu et al., (2024) conducted a study on the identification of cutting tests and the mechanical properties of *Caragana korshinskii* Kom. stems by the use of discrete element modeling.

3.4 Post-Harvest Operations

Various postharvest operations like grain handling and storage are indispensable processes that involve the movement and interaction of granular materials. DEM has been successfully implemented to simulate the movement of grains in silos, hoppers, and conveyors (Figure 15). González-Montellano et al. (2012) employed DEM to simulate the discharge of grain from a silo in order to ascertain the flow patterns and the factors that influence segregation. Their investigation pointed out that DEM is a tool that can be used to plan the layout of grain handling systems in an efficient way and to lower the losses in postharvest operations.

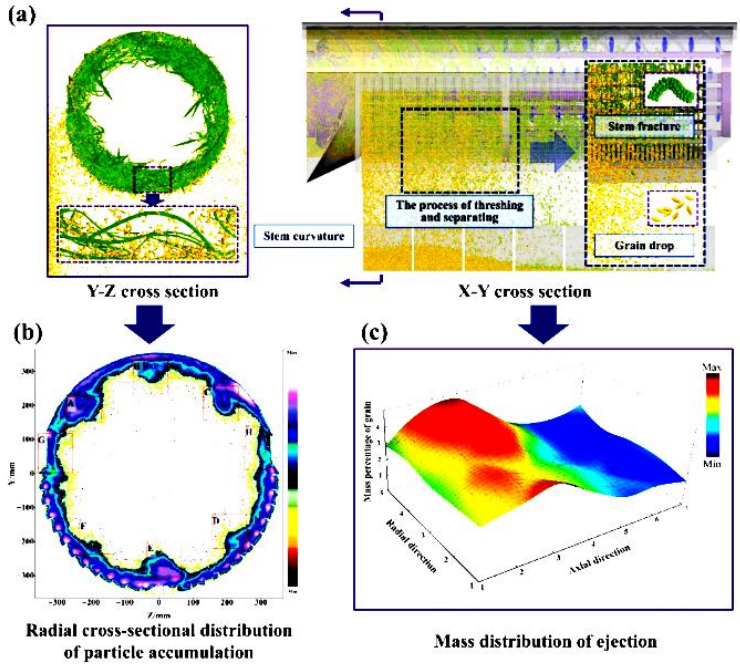


Figure 13. Simulation process. (a) Threshing and separation process. (b) Material bulk density during threshing (c) Response surface of mass distribution of collected materials in the aggregate box (Yang et al., 2025).

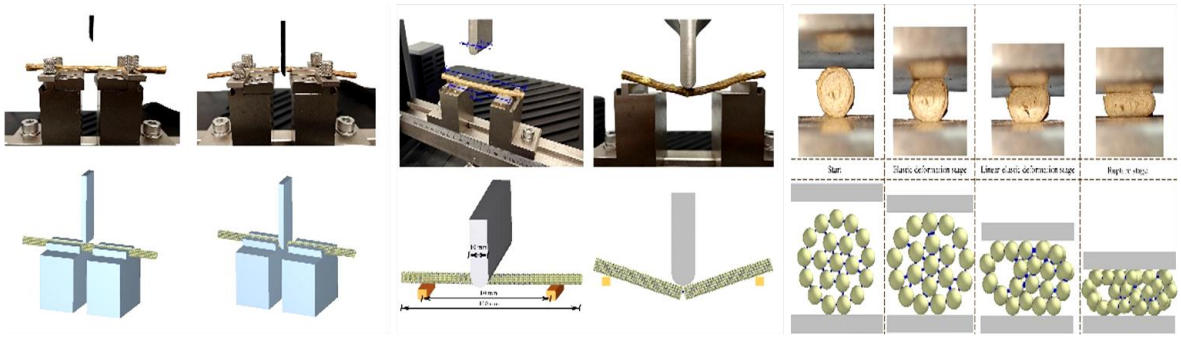


Figure 14. Simulation of shear fracture, three-point bending and compression experiments (Qingqiu et al., 2024).

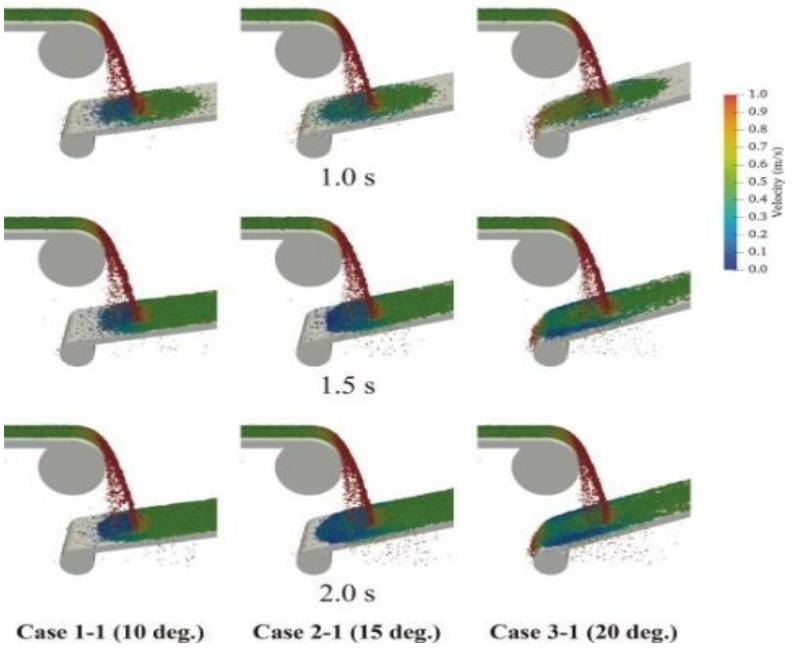


Figure 15. Simulation of particle transport progress under different tilt angle conditions with DEM (Tsunazawa et al., 2024).

Recent research pointed out that DEM is still a technology that can be applied in postharvest operations. Anand et al. (2019) employed DEM to simulate grain movement in a conveyor system to identify variables that influence grain damage and energy consumption. In the same way, Markauskas et al. (2015) researched segregation of grains during storage with DEM, thus, giving the potential to storage optimization.

4. Challenges and Limitations

Usage of DEM in farming has several advantages, but at the same time, it also has some drawbacks. The main restrictions are:

- Computational Cost: DEM simulations may require a significant amount of computational resources for sizeable systems with many particles. The computational cost goes up with the complexity of the particle shapes and the interaction models. Cleary (2010) dealt with the difficulties of scaling-up DEM simulations, pointing out the necessity for efficient algorithms and parallel processing methods.
- Parameter Calibration: For simulations with DEM to be correct, it is necessary to set the material parameters properly. These include things like the stiffness of particles, the coefficients of friction, and the cohesion. In many cases, these parameters are very challenging to obtain through direct experiments and can change depending on the material and the state of the sample. Coetzee (2017) reviewed in detail the methods of parameter calibration, and he emphasized that getting the parameters right is the key to the simulation being trustworthy.
- Scalability: Due to computational limitations, DEM simulations are usually confined to small-scale systems. It is still challenging to scale up DEM simulations to actual agricultural systems. Guo et al. (2013) explored the applicability of coarse-grained methods for enhancing the scalability of DEM simulations and proved that they could be used for large-scale applications.
- Particle Shape Representation: In general, DEM simulations consider spherical particles, which might not be a true representation of the shape of natural agri-food materials like seeds and soil aggregates. To get precise simulation results, there is a necessity for advanced DEM models that take into account the shape of non-spherical particles. Ferellec and McDowell (2010) came up with a way of depicting non-spherical particles in DEM and proved its efficiency by simulating complex granular systems.

5. Future of DEM

The Discrete Element Method (DEM) has become one of the most essential computational tools in agricultural engineering, which enables detailed simulations of granular materials and soil-machine interactions at both macro and micro levels (Aikins et al., 2023). With the advent of precision agriculture and sustainable farming systems, DEM is set to experience a revolutionary change that will not only enhance its capabilities but also extend its applications significantly. The future development of the DEM will be marked by the implementation of advanced computational techniques, mainly the coupling of DEM with other complementary simulation methods like computational fluid dynamics (CFD) and multi-body dynamics (MBD) (Zhao et al., 2021). These multi-physics coupling strategies overcome the existing challenges of the simulation of complex agricultural processes where particle-fluid interactions, e.g., airflow in seed metering devices or slurry behavior in processing equipment, organ the most significant parts, are involved (Tian et al., 2024). Besides, the integration of machine learning and artificial intelligence in the DEM flowchart is a complete revolution in the calibration and optimization of the contact parameters (Wang et al., 2025). Machine learning algorithms are capable of drastically cutting down the parameter estimation which is a very time-consuming process by learning from experimental data and allowing the discrete element models to be calibrated adaptively and in real-time (Kabas et al., 2024). The large-scale simulations with millions of particles will become a reality due to the high-speed computing systems such as GPU acceleration, thus it will be possible to model the whole field operations or processing plants instead of the isolated parts (Pogulis and Servin, 2025).

Future integration of DEM with digital twin technologies and precision agriculture platforms is very far-sighted when thinking about how it will change agricultural decision-making and system optimization (Kim and Heo 2024). Digital twins—virtual replicas of physical agricultural systems that continuously update based on real-time sensor data—can use DEM models to foresee the performance of the equipment, to figure out the best operational parameters and to evaluate the impact of design changes without really doing it (Kim and Heo 2024; Bali and Singh 2024). This fusion will empower the agricultural machinery systems to become adaptive which means that they will be capable of changing automatically the operating parameters depending on the variable soil conditions, crop properties or environmental factors (Cutini et al., 2023). Nevertheless, there are still considerable obstacles such as the necessity of having standardized parameter databases for a variety of agricultural materials, better representations of the complicated shapes of particles and the behaviors that depend on moisture as well as the enhanced integration of the simulation results with the experiments done in the field (Haikang et al., 2025). It will be crucial to have the development of multi-scale

modeling frameworks which are capable of changing smoothly from the interaction of single particles to phenomena on a field scale together with the collaboration which is cross-disciplinary and involves agricultural engineers, computer scientists, and agronomists in order to unlock the full potential of DEM as a tool for the implementation of sustainable, efficient, and technologically advanced agricultural systems (Haikang et al., 2025).

6. Conclusion

The Discrete Element Method (DEM) is now a major computational means to study the complex mechanical behavior of granular materials in agriculture. The ability to simulate soil deformation, seed-soil interactions, and crop processing dynamics has created a lot of new knowledge for the optimisation of agricultural mechanisation and processes. In the case of soil processing, DEM helps through a detailed soil-tool-machine interaction analysis to the designing of efficient tools that achieve soil fragmentation and aeration at a low energy consumption level. Likewise, in seed planting, DEM simulations facilitate the investigation of seed distribution mechanisms, thus giving the optimum planting depth and spacing to increase crop yields. What is more, in harvesting and postharvest operations, DEM is instrumental in the study of material flow, thus the mechanical damage to grains and fruits can be minimized and the efficiency of conveyors, separators and storage systems can be improved.

Though the method is widely applicable, the high computational cost of DEM simulation is a major obstacle to the approach which, therefore, requires considerable computing power especially for large-scale operations with millions of particles involved. Furthermore, accurate parameter calibration- for instance, contact properties and particle size distributions- is necessary for the trustworthiness of DEM models in the field.

To unlock the full power of DEM in agricultural engineering, subsequent research should mainly focus on the creation of sophisticated particle models that realistically depict complex material properties, e.g., moisture-dependent cohesion, organic matter heterogeneity, and root-soil interactions. The coupling of DEM with other numerical methods like Finite Element Method (FEM) and Computational Fluid Dynamics (CFD) can help realize more comprehensive Multiphysics simulations by considering the interactions of granular materials, plant structures, and fluid flows. Moreover, employing high-performance computing (HPC) and artificial intelligence (AI) means, such as machine learning-based surrogate models, can drastically lower computational costs and speed up simulations.

The implementation of GPU-based parallel computing and cloud-based simulation platforms can thus extend the DEM scalability for vast agricultural applications. By turning these issues around and improving DEM methods, scholars and engineers will be able to make more accurate and predictive models which, in turn, will help to the optimization of farming, sustainability, and the rise of food production in the face of global challenges.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	Ö.K
C	100
D	100
S	100
L	100
W	100
CR	100
SR	100

C= concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

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