DESIGN AND EXPERIMENT OF A PEANUT SEEDING DEVICE FOR SYNCHRONOUS HOLE FERTILIZATION AND DIRECTLY-ABOVE SEEDING
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花生穴施肥同步正位播种装置设计与试验

Yi LIU[1)], Massoudibrahim SALEM[2)],Haipeng YAN[2)], Peng GUO[2)], Chao XIA[2)], Guangbao XIA[3)], Ahmed F. El-Shafie[2,4)], Dongwei WANG[3,*)]

[1)]College of Mechanical and Electrical Engineering, Qingdao Agricultural University, Qingdao/China
[2)]Yellow River Delta Intelligent Agricultural Machinery Equipment Industry Academy, Dongying/China
[3)]Industrial Research Institute of Saline and Alkaline High-Efficiency Agricultural Technology, Qingdao Agricultural University, Dongying/China
[4)] Water Relations and Field Irrigation Department, National Research Centre, Cairo/ Egypt.
Tel: +86-459-13012532108; E-mail: w88030661@163.com
Corresponding author: Dongwei Wang
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ABSTRACT
To improve the utilization rate of fertilizers by peanut seeds, this study presents the synchronous hole fertilization and directly-above seeding of peanuts and designs a pneumatic horizontal disc hole fertilization device. A theoretical analysis of the ditching process of the fertilization furrow opener was carried out, and the height of the hole fertilization device from the ground was determined to be 40 mm. Through the analysis of the hole fertilization and directly-above seeding operation process, the time difference between seed metering and fertilizer metering was determined. Combining with theoretical analysis, EDEM-FLUENT coupling simulation tests and field tests were carried out on the device. The field test results showed that the error of the fertilization hole spacing ranges between 2.3-4.5%, the error of the hole fertilization depth is 3.2-5.1%, the seed - fertilizer distance is 64.8-67.2 mm, and the fertilizer distribution length is 99.3-107.5 mm. The test results meet the requirements specified in the sowing and fertilization standards.

摘要
为了提高花生种子对肥料的利用率，本文以花生穴施肥同步正位播种为研究目标，设计了这一种气吹式水平圆盘穴施肥装置。对施肥开沟器开沟过程进行了理论分析，确定了穴施肥装置距离地面的高度为 40mm。通过对穴施肥及正位播种作业过程的分析，确定了排种与排肥的时间差。结合理论分析对该装置进行了 EDEM-FLUENT 耦合仿真试验及田间试验，田间试验结果表明施肥穴距误差为 2.3%-4.5%，穴施肥深度误差为 3.2%-5.1%，种肥间距为 64.8 mm-67.2 mm，肥料分布长度为 99.3 mm-107.5 mm。试验结果满足播种施肥标准中规定的要求。

INTRODUCTION
Peanuts, an important oil crop and economic crop in China, play a crucial role in ensuring food security and supporting the agricultural economy *(Tang et al., 2019; Shi et al., 2016)*. With the improvement of agricultural mechanization, peanut seeding technology is gradually evolving toward high efficiency and precision *(Timilsena et al., 2015; Shang et al., 2016)*. Currently, traditional seeding operations still rely primarily on strip fertilization, which faces challenges such as low efficiency and poor fertilizer utilization *(Liu., 2017;)*. Excessive use of chemical fertilizers is likely to lead to problems such as soil compaction, degradation, and environmental pollution *(Parent et al., 2020)*. However, precision fertilization serves as an effective means of supporting the goals of sustainable agricultural development *(Gyamf et al., 2019)*. The peanut hole fertilization technique involves applying a fixed quantity of fertilizer in a hole-like pattern at a specific distance beside or directly beneath peanut seeds or plants. Studies have shown that this method enables quantitative and precise fertilization, thereby enhancing fertilizer use efficiency *(Luo et al., 2016; Wang et al., 2016)*.

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[1] *Yi Liu, master degree; Massoudibrahim Salem, Prof. Ph.D.; Haipeng Yan, master degree; Peng Guo, Ph.D.; Chao Xia, Ph.D.; Guangbao Xia, Ph.D.; Ahmed El-Shafie, Prof. Ph.D.; Dongwei Wang, Prof. Ph.D.*

Da Silva et al. designed a perforating and injecting device for liquid fertilizer, which combines soil perforation with liquid fertilizer injection to reduce disturbance to roots, crop residues, and soil, thereby improving plant fertilizer utilization *(Da Silva et al., 2019)*; Martins et al. proposed a method for variable rate nitrogen fertilization in corn using optical sensors, providing data reference for variable rate fertilization decisions through a portable chlorophyll detector *(Martins et al., 2020)*. Du Xin et al. designed an inclined trapezoidal hole-type hole fertilization distributor *(Wang et al., 2018; Du et al., 2021)* which achieves precision fertilizer filling through inclined trapezoidal holes with fixed volume and uses airflow assistance at the fertilizer discharge port to rapidly discharge fertilizers into holes. However, the distributor has a complex structure and requires replacing the fertilizer discharge adjustment plug to regulate the fertilization amount. Liu et al. designed an automatic seed-aligned fertilization system for corn based on a planetary gear system, which uses a rotary cavity disc hole fertilization device, which can detect in real-time the falling information of seeds and fertilizers, calculate their relative positions, and make real-time adjustments via a control motor *(Liu et al., 2023)*.

To enhance fertilizer utilization rate and the yield per unit area of peanuts, this study focuses on the designed pneumatic horizontal disc hole fertilization device. By analysing the motion trajectories of seeds and clustered fertilizers, the phase difference between the seed metering disc and the fertilizer metering disc was determined. Moreover, field tests were carried out to evaluate the performance of hole fertilization and directly - above seeding performance of the synchronous hole fertilization and directly - above seeding device. The results are expected to provide both theoretical insights and practical references on the equipment for the advancement of precision fertilization technology in peanut cultivation.

MATERIALS AND METHODS

Overall structure and working principle of the synchronous hole fertilization and directly-above seeding device for peanuts

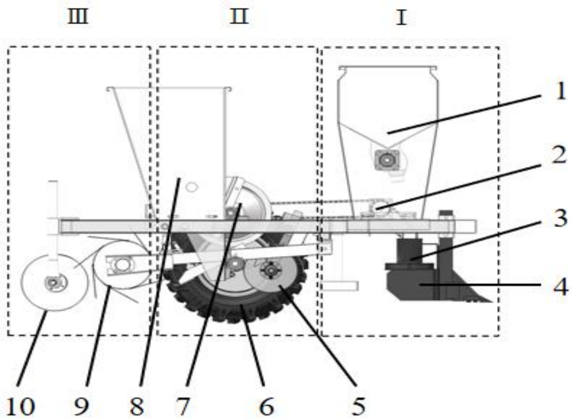

Fig. 1 - Overall structure of the synchronous hole fertilization and directly-above seeding device for peanuts

Ⅰ-Fertilization unit; Ⅱ-Seeding unit; Ⅲ-Soil covering unit;1-Main fertilizer tank; 2-Transmission device; 3-Hole fertilization device; 4-Fertilization furrow opener; 5-Seeding opener; 6-Ground wheel; 7-Seed metering device;8-Seed box; 9-Press wheel; 10-Soil covering wheel.

The synchronous hole fertilization and directly-above seeding device for peanut planters is mainly composed of a seeding unit, a hole fertilization unit, and a motor control unit. The hole fertilization unit mainly includes a fertilization furrow opener, a hole fertilization device, a commutator, etc. During seeding operations, the hole fertilization device extracts fertilizer particles from the fertilizer box and forms clusters in the fertilizer cavity. These particles are transported by the fertilizer metering disc to the fertilizer discharge port, where they are discharged into the fertilization furrow in holes under the action of air flow. The seeding unit consists of a seed metering device, a disc-type furrow opener, a press wheel, a soil covering disc, etc., and uses a spoon-wheel precision seed metering device to achieve precise peanut seeding. The motor control unit is mainly composed of a microprocessor, a speed measurement device, a stepper motor, and a transmission system.

A speed sensor is installed on the ground wheel axle to detect in real-time and to calculate the travel speed, and regulate the motor rotation speed, ensuring that fertilizer particles are applied in holes along the fertilization furrow according to the peanut hole spacing. Meanwhile, the fertilizer metering disc shaft and the seed metering disc shaft maintain a fixed transmission ratio.

By analysing the motion relationship between seeds and hole-applied fertilizers, the phase difference between the seed metering disc and the fertilizer metering disc is determined to ensure that seeds are accurately placed directly above the fertilizers.

Design of hole fertilization device

The horizontal disc hole fertilization device is mainly composed of a fixed plate, housing, fertilizer metering disc, fertilizer quantity adjustment disc, fertilizer tank, motor, coupling, air inlet pipe, etc. According to the fertilizer metering workflow, the fertilizer metering disc can be divided into a fertilizer filling zone Ⅰ, fertilizer transport zone Ⅱ, fertilizer discharge zone Ⅲ, transition zone Ⅳ, as shown in Figure 2.

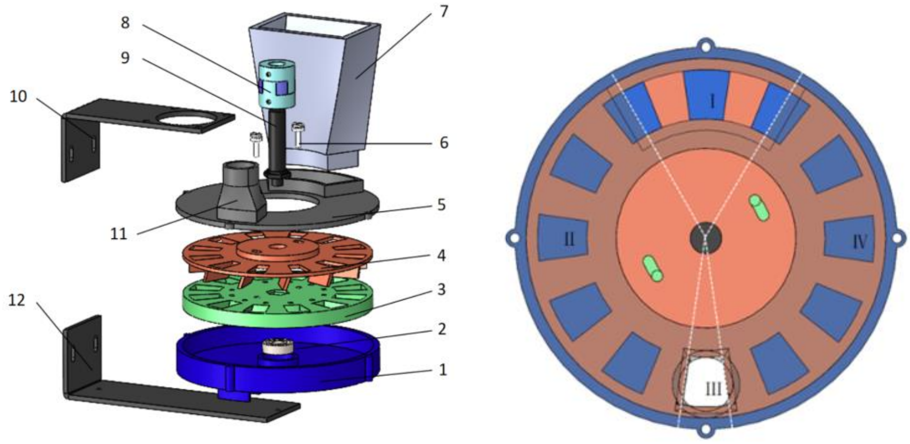

Fig. 2 - Structure of hole fertilization device and fertilizer metering disc zoning

1-Lower housing; 2-Bearing; 3-Fertilizer metering disc; 4-Fertilizer quantity adjustment disc; 5-Upper housing; 6- Fertilizer quantity adjustment bolt; 7-Fertilizer distributor tank; 8-Coupling; 9-Shaft; 10-Upper mounting plate;11-Air inlet pipe; 12-Lower mounting plate; Ⅰ-Fertilizer filling zone; Ⅱ-Fertilizer transport zone; Ⅲ-Fertilizer discharge zone; Ⅳ-Transition zone.

During fertilization, fertilizer particles fall from the planter's fertilizer box into the fertilizer distributor tank through the fertilizer discharge pipe, forming a fertilizer layer of a certain thickness. The fertilizer metering disc and the fertilizer quantity adjustment disc are fixed by fertilizer quantity adjustment bolts. By loosening these bolts and rotating the adjustment disc, the volume of the fertilizer cavities can be changed to regulate the filling amount. The fertilizer metering disc has multiple fertilizer cavities evenly distributed along its central axis. Driven by the shaft, the fertilizer metering disc and adjustment disc rotate counterclockwise in synchronization. As they pass through the fertilizer filling zone at a certain speed, fertilizer particles fill the cavities under gravity and the disturbance of the metering disc. Protected by the upper and lower housings and pushed by the metering disc, the clustered fertilizers travel through the fertilizer transport zone to the fertilizer discharge zone. An air inlet pipe is installed directly above the fertilizer discharge port, connected to a fan above. Under the action of positive pressure airflow and gravity, the fertilizer particles are rapidly discharged, forming holes in the field for application.

Analysis of the installation position of the hole fertilization device

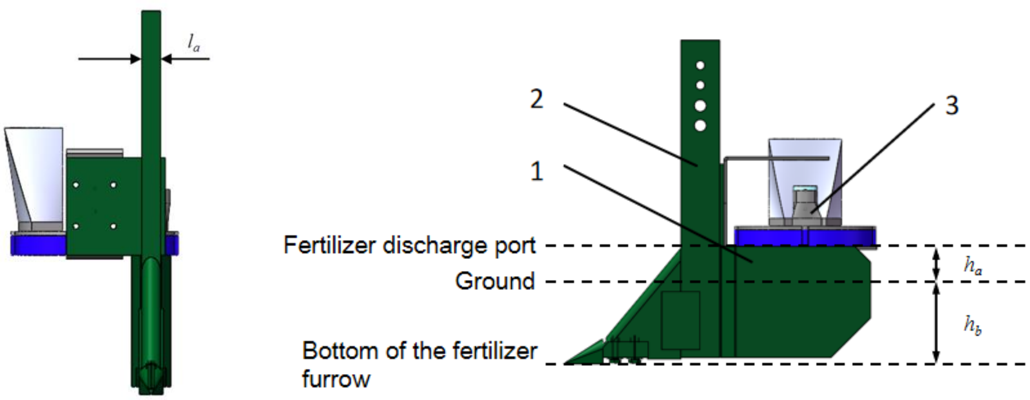

Fig. 3 - Schematic diagram of hole fertilization device installation position

1-Furrow opener wing;2-Shovel column;3-Hole fertilization device.

The hole fertilization device is fixed above the furrow opener wings, with the fertilizer discharge port located between the two wings, as shown in Figure 3. During fertilization operations, the furrow opener creates a fertilizer furrow in the soil. Hole-applied fertilizers are discharged from the fertilizer discharge port, fall into the furrow through the wings, and the extended wings on both sides prevent soil from collapsing on the sides of the furrow, maintaining a complete furrow shape.

To reduce the falling time of hole-applied fertilizers and to minimize bouncing and scattering caused by collisions with soil, the installation height of the fertilizer metering disc should be minimized to ensure low-position fertilization. The relative positions of the fertilizer distributor of the hole fertilization device with respect to the ground and the bottom of the fertilizer furrow are shown in Figure 3. During fertilization, the furrow opener lifts and throws part of the soil in the furrow to both sides, forming soil mounds on the edges of the furrow. To prevent excessive soil mounds from squeezing the fertilizer distributor, the installation height of the fertilizer discharge port must be analyzed and calculated. Assuming no soil compaction during furrowing and conservation of soil volume, the height *h* between the fertilizer discharge port and the ground satisfies the following condition:

$$l_a \cdot h_b \le \frac{1}{2} h_a \frac{2h_a}{\tan\theta_t} \tag{1}$$

where: l_a is the width of the furrow opener shovel column, [m]; h_b is the height from the ground to the bottom of the fertilizer furrow, [m]; h_a is the height from the fertilizer discharge port of the fertilization device to the ground, [m]; θ_t is the soil angle of repose, [°].

The relational expression for the height from the fertilizer discharge port to the ground can be derived as:

$$h_a \ge \sqrt{l_a \cdot h_b \cdot \tan\theta_t} \tag{2}$$

The width of the furrow opener shovel column used in this study is 30 mm. According to relevant literature, the distance from the ground to the bottom of the fertilizer furrow is generally 90–110 mm, and the soil angle of repose is 31°. Calculations using Equation (2) show that the minimum height from the fertilizer discharge port of the fertilization device to the ground is 40 mm.

Motion analysis of clustered fertilizers

The synchronous direct-position seeding device for peanut hole fertilization first applies fertilizer particles in clustered form into the fertilizer furrow at the hole spacing required by peanut seeding agronomy, then places seeds directly above the fertilizers while maintaining a certain distance. The relative position between seeds and fertilizers directly affects peanut yield and fertilizer utilization efficiency. Here, h_j represents the vertical distance between seeds and fertilizers after seeding and fertilization, and the distribution of seeds and fertilizers is shown in Figure 4.

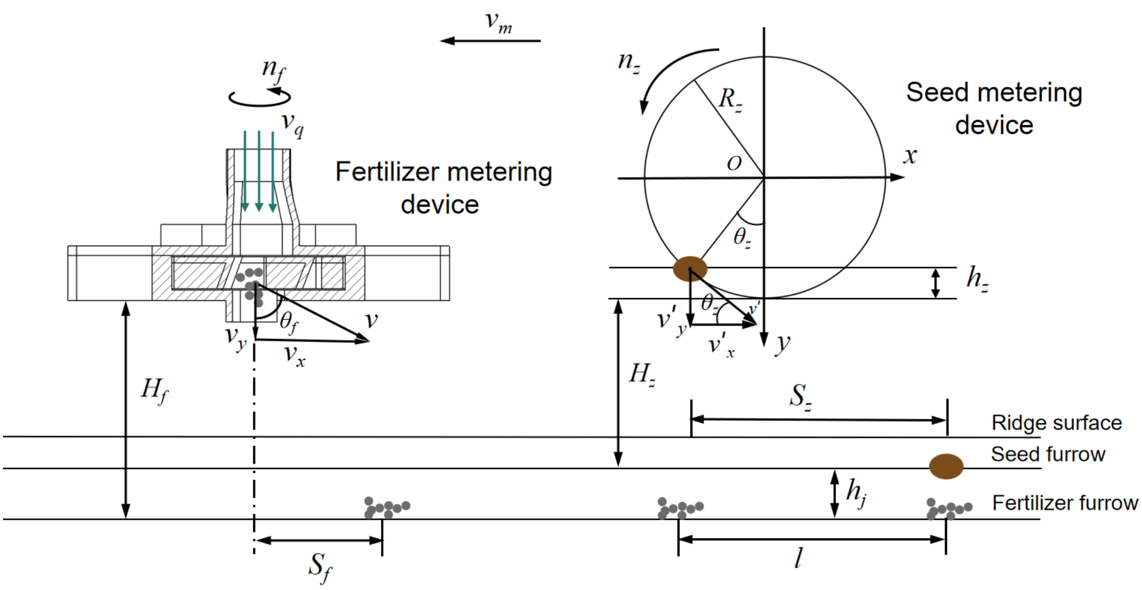

Fig. 4 - Analysis of motion trajectories of seeds and fertilizers

During fertilization, the fertilizer metering disc transports clustered fertilizer particles to the fertilizer discharge port. The fertilizers are discharged backward under the combined action of wind force and gravity, where v_m is the machine travel speed in the direction of machine movement. When the fertilizer distributor starts discharging at the fertilizer discharge port, the horizontal and vertical velocities of the clustered fertilizers when they leave the fertilizer cavities are:

$$\begin{cases} v_x = -v_m + v \cdot \sin\theta_f \\ v_y = v \cdot \cos\theta_f \end{cases} \tag{3}$$

where: v_x is the horizontal component velocity of hole-applied fertilizers when leaving the fertilizer cavity, [m/s]; v_y is the vertical component velocity of hole-applied fertilizers when leaving the fertilizer cavity, [m/s]; v_m is the machine travel speed, [m/s]; v is the resultant velocity of hole-applied fertilizers when leaving the fertilizer cavity, [m/s]; θ_f is the angle between the resultant velocity of hole-applied fertilizers and the vertical direction, [°].

When the hole-applied fertilizers leave the fertilizer cavity and fall into the fertilizer furrow, the distance they move in the vertical direction is:

$$H_f = v_y \cdot t_1 + \frac{1}{2} g t_1^{\,2} \tag{4}$$

where: H_f is the distance from the fertilizer discharge port to the bottom of the fertilizer furrow, [m]; t_1 is the time for hole-applied fertilizers to fall from the fertilizer cavity to the furrow bottom, [s]; g is the gravitational acceleration, [m/s^2].

From Equations (3) and (4), it results:

$$t_1 = \frac{-v \cdot \cos\theta_f + \sqrt{v^2 \cdot \cos^2\theta_f - 2gH_f}}{g} \tag{5}$$

The horizontal displacement of hole-applied fertilizers when leaving the fertilizer cavity and falling into the fertilizer furrow is:

$$S_f = v_x \cdot t_1 \tag{6}$$

where: S_f is the horizontal moving distance of the fertilizer when it falls from the fertilizer cavity to the fertilizer trench during hole - application fertilization, [m].

Seed motion analysis

Peanut seeds start to detach from the seed metering disc at the position shown in Figure 4 and fall into the seed furrow under the action of gravity. The horizontal and vertical velocities of peanut seeds when detaching from the seed metering disc are:

$$\begin{cases} v'_x = -v_m + v' \cdot \cos\theta_z \\ v'_y = v' \cdot \sin\theta_z \end{cases} \tag{7}$$

where: v_x' is the horizontal component velocity of seeds when detaching from the seed metering disc, [m/s]; v_y' is the vertical component velocity of seeds when detaching from the seed metering disc, [m/s]; v_m is the machine travel speed, [m/s]; v' is the resultant velocity of the peanut seed when it detaches from the seed - discharging disc, [m/s]; θ_z is the seed dropping angle, [°].

The distance travelled by peanut seeds in the vertical direction after detaching from the seed metering disc is:

$$H_z + h_z = v'_y \, t_2 + \frac{1}{2} g t_2^{\,2} \tag{8}$$

where: H_z is the vertical distance from the bottom of the seed metering disc to the bottom of the seed furrow, [m]; h_z is the distance from the seed detachment position on the seed metering disc to the bottom of the seed metering disc, [m]; t_2 is the time for peanut seeds to detach from the seed metering disc and reach the seed furrow, [s].

Among these distances, distance h_2 from the position where peanut seeds detach from the seed metering disc to the bottom of the seed metering disc is:

$$h_z = R_z\left(1-\cos\theta_z\right) \tag{9}$$

where: *Rz* is the radius of the seed metering disc, [m].

From Equations (7), (8), and (9), it results:

$$t_2 = \frac{-v'\cdot\sin\theta_z + \sqrt{\left(v'\cdot\cos\theta_z\right)^2 + 2g\left[H_z + R_z\left(1-\cos\theta_z\right)\right]}}{g} \tag{10}$$

The horizontal displacement of seeds, S_z, [m], when detaching from the seed metering disc and falling into the seed furrow is:

$$S_z = v'_x \cdot t_2 \tag{11}$$

The time difference between the falling of peanut seeds and fertilizers, Δ*t* [s] is:

$$\Delta t = t_1 - t_2 \tag{12}$$

On the premise of ensuring the normal operation of the fertilizer metering device, its installation position should be as low as possible to reduce the scattering of hole-applied fertilizers and improve the hole-forming performance of the fertilizer metering device. According to the previous design, the installation height h_1 of the fertilizer metering device is 130 mm, which is lower than that of the seed metering device. Therefore, the falling time of seeds is longer than that of fertilizers, and the time difference between their descent must be considered to ensure that the seeds land directly above the hole-applied fertilizers.

Simulation model construction

The device model was established using SolidWorks software. To improve simulation efficiency and reduce simulation time, components without direct contact with fertilizer particles were simplified. A conveyor belt was added 130 mm below the fertilizer metering device to simulate the bottom of the fertilizer furrow for intuitive and quantitative analysis of the hole-fertilizing performance of the fertilizer metering device. The completed 3D model was saved in .STP format and imported into EDEM simulation software. A plane was added 40 mm below the seed discharge port to simulate the bottom of the seed furrow. Fertilizer particles were spherical with an equivalent diameter of 3.3 mm. Since there is no adhesive force between particles or between particles and the fertilizer metering device, the Hertz-Mindlin no-slip contact model was selected (*Zhu et al., 2020*). The simulation models of the fertilizer metering device and fertilizer particles are shown in Figure 5, with model parameters listed in Table 1 and Table 2 *(Ding et al., 2019; Liu et al., 2018; Ding et al., 2018)*.

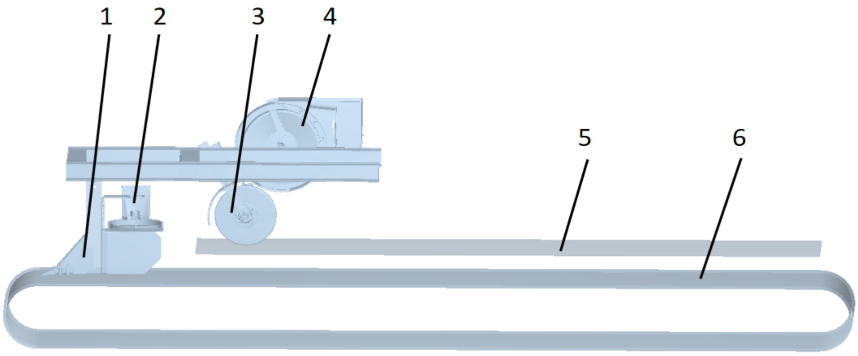

Fig. 5 - EDEM simulation model for synchronous hole fertilization and directly-above seeding device
1-Fertilizer opener; 2-Hole fertilization device; 3-Seeding opener; 4-Seed metering device; 5-Seed furrow plane; 6-Conveyor belt.

Table 1

EDEM simulation parameters for fertilizer metering process

Item	Fertilizer particles	Fertilizer metering device	Soil	Peanut	Seed metering device
Poisson's ratio	0.25	0.41	0.31	0.30	0.35
Shear modulus/Pa	1.13×10^8	1.71×10^8	7.27×10^8	5.72×10^7	1.22×10^8
Density/kg·m^{-3}	1625	1150	2210	1300	1455

Table 2

Contact parameters between materials

Item	Fertilizer-fertilizer	Fertilizer-fertilizer metering device	Fertilizer-soil	Peanut-seed metering device	Peanut-soil
Coefficient of restitution	0.31	0.35	0.05	0.6	0.11
Static friction coefficient	0.33	0.26	1.27	0.34	1.17
Kinetic friction coefficient	0.13	0.21	1.21	0.04	0.92

The 3D model of the fertilizer metering device was imported into the Fluent module of Workbench in .STP format. The fluid domain model was extracted using the DesignModeler tool, and adjusted into three regions—air inlet pipe, fertilizer chamber, and fertilizer outlet—in SpaceClaim software. The adjusted fluid model was then imported into the Meshing module of Fluent for mesh generation *(Sun et al., 2024)*. Polyhedral meshes were selected as the grid type, with interfaces set between the air inlet pipe and fertilizer chamber, as well as between the fertilizer chamber and fertilizer outlet. The air inlet and fertilizer outlet were set as pressure inlet and pressure outlet, respectively, as shown in Figure 6. In EDEM software, the time step was set to 3×10^{-6} s, while in Fluent software, the time step was 3×10^{-4} s. The total simulation duration was the time required for fertilizing 15 holes.

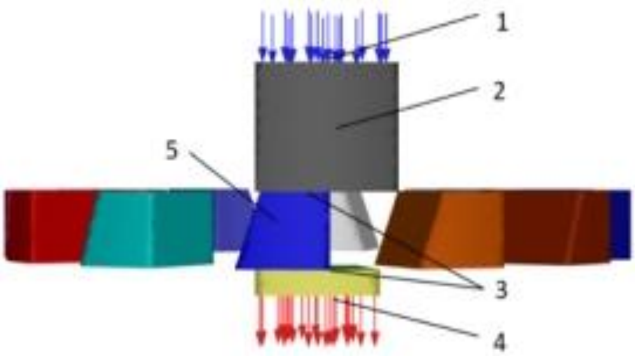

Fig. 6 - Airflow field simulation model

1-Pressure inlet; 2-Air inlet pipe; 3-Interface; 4-Pressure outlet; 5-Fertilizer chamber.

Simulation of experimental design

The magnitude of airflow speed affects the fertilizer metering performance of the hole fertilization device. To obtain optimal airflow speed parameters and reduce the number of subsequent test combinations, a preliminary pre-experiment was first conducted. Specifically, when the machine's traveling speed was 4 km/h, the airflow speed was set from 0 to 16 m/s, and a single-factor test was carried out using the test indicators of fertilizer distribution length and accuracy of hole fertilization amount.

In the EDEM post-processing interface, Grid Bin Groups were added at the fertilizer metering disc and conveyor belt respectively *(Liu et al., 2022)*, as shown in Figure 7.

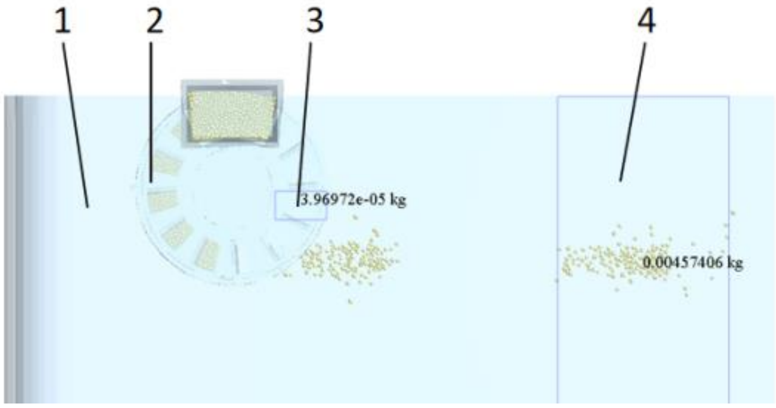

Fig. 7 - Grid cell group position

1-Conveyor belt; 2- Hole fertilization device; 3- Grid cell group 1; 4- Grid cell group 2

The grid cell group on the fertilizer metering disc is located at two fertilizer chambers behind the fertilizer outlet, with a height of 30 mm and the same length and width as a single fertilizer chamber, used to count the mass of residual fertilizer in the chamber after metering. The grid cell group on the conveyor belt has its bottom on the same plane as the conveyor belt bottom, with a height of 40 mm and a width of 300 mm, used to count the mass of discharged fertilizer and the fertilizer distribution length. By adjusting the length of the grid cell group to match the fertilizer's distribution length, the desired fertilizer distribution length can be obtained.

Data for 15 fertilized holes were collected each time, and their average value was calculated to analyze the accuracy of hole fertilization amount and fertilizer distribution length. The calculation formula for the accuracy of hole fertilization amount is:

$$Y_1 = \frac{\sum_{i=1}^{j} \frac{m_i}{m}}{j} \times 100\% \tag{13}$$

where: Y_1 is the accuracy of hole fertilization amount, [%]; m is the standard fertilization mass per hole, [g]; m_i is the actual fertilization mass per hole, [g]; j is the number of fertilizer holes passing through the grid cell group.

The influence of airflow speed on the accuracy of hole fertilization amount and fertilizer distribution length is shown in Figure 8.

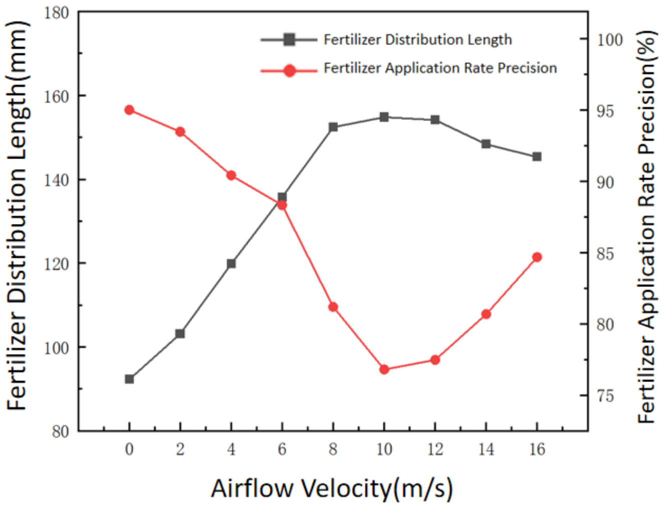

Fig. 8 - Effects of airflow speed on test indicators

When the airflow speed ranges from 0 m/s to 16 m/s, the accuracy of hole fertilization amount first increases and then decreases with the increase of airflow speed, though the decreasing trend is relatively slow. The fertilizer distribution length initially decreases and then increases, with both test indicators—fertilization amount accuracy and distribution length—reaching their optimal values at an airflow speed of 10 m/s. Under the conditions of a machine traveling speed of 4 km/h and a wall inclination angle of 70°, the hole fertilization performance of the fertilizer metering device is relatively stable when the airflow speed is approximately 10 m/s. The test results indicate that when the airflow speed is too low, the fertilizer metering device cannot discharge fertilizer from the chamber in time, reducing the accuracy of hole fertilization amount. When the speed is too high, although the fertilizer clearing rate of the metering device increases, the excessive velocity of fertilizer particles leaving the chamber causes splashing when they contact the conveyor belt, increasing the fertilizer distribution length. Therefore, the inlet airflow speed should be controlled between 8 m/s and 12 m/s.

RESULTS

Hole fertilization synchronous positioning seeding simulation test

Combining the results of single-factor tests, the airflow speed was designed to range from 8 m/s to 12 m/s, the machine traveling speed from 2 km/h to 6 km/h, and the hole spacing was set at 200 mm. Simulation tests were conducted with the longitudinal spacing between seeds and fertilizer, fertilizer distribution length, and hole spacing error in fertilization as test indicators.

The longitudinal spacing between seeds and fertilizer is defined as the distance between peanut seeds and the fertilizer distribution center in the machine's forward direction. The hole spacing in fertilization is taken as the distance between the centers of two adjacent fertilizer accumulations after fertilization, and the calculation formula for the hole spacing error is:

$$W = \frac{\sum_{i=1}^{j} \frac{|S - S_i|}{S}}{j} \times 100\% \tag{14}$$

where: W is the hole spacing error in fertilization, [%]; S is the designed hole spacing for fertilization, [m]; S_i is the actual hole spacing at the i-th position during operation, [m]; j is is the number of fertilizer holes passing through the grid cell group.

The results of the simulation test are shown in Figure 9, and the test results are presented in Table 3.

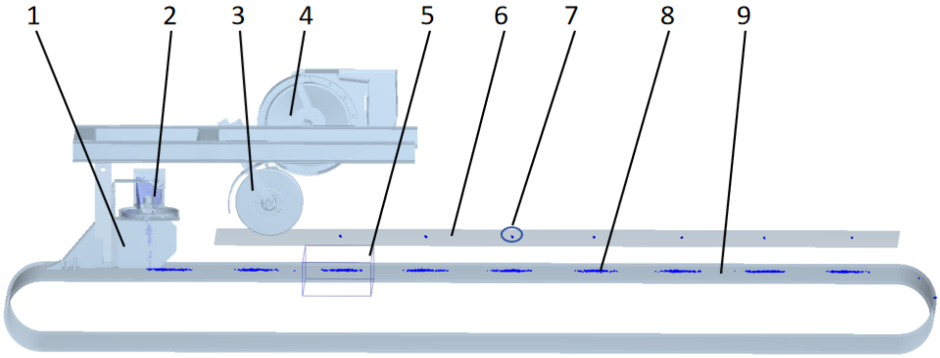

Fig. 9 - Synchronous positioning seeding simulation test for hole fertilization
1-Fertilizer opener; 2-Hole fertilization device; 3-Seeding opener; 4-Seed metering disc; 5-Grid cell group; 6-Seed furrow plane; ; 7-Peanut seeds; 8-Clumped fertilizer; 9-Conveyor belt.

Table 3

Test results of synchronous positioning seeding for hole fertilization

Machine traveling speed [km·h⁻¹]	Airflow speed [m·s⁻¹]	Longitudinal spacing between seed and fertilizer [mm]	Fertilizer distribution length [mm]	Hole spacing error in fertilization [%]
2	8	6.8	93.3	3.6
	10	6.1	91.2	3.3
	12	7.7	92.9	3.9
4	8	7.3	91.7	4.9
	10	8.1	84.2	4.8
	12	8.7	85.6	5.1
6	8	10.2	98.5	5.2
	10	10.9	94.2	5.7
	12	11.7	95.7	6.0
Mean		8.6	91.9	4.7
Standard deviation		1.82	12.87	2.64

Data in Table 3 show that when the airflow speed is constant, the longitudinal spacing between seeds and fertilizer and the hole spacing error in fertilization show an increasing trend with the increase in machine traveling speed, with a mean longitudinal spacing between seeds and fertilizer of 8.6 mm and a mean hole spacing error of 4.7%. When the machine traveling speed is constant, the fertilizer distribution length shows a trend of first increasing and then decreasing, with a mean distribution length of 91.9 mm, and the minimum distribution length occurs at an airflow speed of 10 m/s. Considering the test data comprehensively, the airflow speed is determined to be 10 m/s.

Field experiment

The field experiment was conducted in Guangrao County, Dongying City, Shandong Province. The peanut variety used was Yuhua 18 and Luhua 10, and the fertilizer was granular slow-release compound fertilizer produced by Liuguo Chemical Industry Co., Ltd. Before the experiment, the soil was rototilled, leveled, and loosened to ensure that it meets the sowing conditions for peanuts.

Fig. 10 - Hole fertilization device and field experiment

Based on the widely used peanut fertilization amount in the region, we evaluated the hole fertilization performance and positioning seed metering performance of the device with reference to the *Technical Specifications for Quality Evaluation of Fertilizer Machinery* (NY/T 1003-2006) and *Operation Quality of Mulching Hole Seeding Machines* (NY/T 987-2006) *(Hu et al., 2016; Geng et al., 2018)*. A 10 m operation length was selected as a test area, and field test data were analyzed using hole spacing error in fertilization, fertilization depth error, seed-fertilizer spacing, and fertilizer distribution length as test indicators. The test results are shown in Figure 11.

Fig. 11 - Field experiment data collection

Table 4 presents the field trial results for Yuhua 18 peanut seeds. When the machine travel speed ranges from 2 km/h to 6 km/h, the hole spacing accuracy rate can reach over 94.5%. The vertical distance between seeds and fertilizer is between 64.8 mm and 67.2 mm, and the fertilizer distribution length ranges from 95.7 mm to 107.5 mm.

Table 4

Field trial results of Yuhua 18 peanut seeds

Machine traveling speed [km·h⁻¹]	Hole spacing error [%]	Vertical spacing between seed and fertilizer [mm]	Fertilizer distribution length [mm]	Longitudinal spacing between seed and fertilizer [mm]
2	3.3	67.2	99.3	5.4
4	4.9	66.4	95.7	6.2
6	5.5	64.8	107.5	7.1

Table 5 presents the field trial results for Luhua 10 peanut seeds. The hole spacing accuracy rate can reach over 94.1%, the vertical distance between seeds and fertilizer ranges from 65.4 mm to 71.1 mm, and the fertilizer distribution length is between 91.1 mm and 105.8 mm.

Table 5

Field trial results of Luhua 10 peanut seeds

Machine traveling speed [km·h⁻¹]	Hole spacing error [%]	Vertical spacing between seed and fertilizer [mm]	Fertilizer distribution length [mm]	Longitudinal spacing between seed and fertilizer [mm]
2	3.7	71.1	101.3	6.2
4	4.6	68.7	91.1	7.7
6	5.9	65.4	105.8	10.1

Both sets of trials meet the requirements for simultaneous and correctly positioned hole fertilization and sowing.

CONCLUSIONS

(1) A hole fertilization device was designed, and its installation position was analysed to determine that the minimum distance between the fertilizer discharge port and the ground is 40 mm. The movement trajectories of seeds and fertilizer during the sowing and fertilization process were analysed to obtain the time difference between seed metering and fertilizer metering. Based on theoretical analysis, simulation tests were designed. The results of single-factor tests showed that the optimal hole fertilization performance occurs when the airflow speed is 8 m/s to 12 m/s. The two-factor test results indicated that the average values of the test indicators for the designed synchronous positioning seeding device with hole fertilization are as follows: longitudinal spacing between seeds and fertilizer of 8.6 mm, fertilizer distribution length of 91.9 mm, and hole spacing error in fertilization of 4.7%.

(2) A field experiment of the synchronous positioning seeding device with hole fertilization was carried out. The hole fertilization device was installed on a peanut seeding and fertilizing machine for two rows per ridge, and the transmission mode was changed simultaneously. The theoretical fertilization depth was set at 100 mm, the seeding depth at 30 mm, the theoretical hole spacing at 200 mm, and the machine traveling speed at 2 km/h to 6 km/h. The field trial results for Yuhua 18 peanuts showed a hole spacing error of 3.3% to 5.5%, a seed-fertilizer spacing of 64.8 mm to 67.2 mm, and a fertilizer distribution length of 99.3 mm to 107.5 mm. For Luhua 10 peanuts, the corresponding results were: 3.7% to 5.9% (hole spacing error), 65.4 mm to 71.1 mm (seed-fertilizer spacing), and 91.1 mm to 105.8 mm (fertilizer distribution length). The experimental results meet the requirements specified in the seeding and fertilization standards.

(3) Compared to the traditional strip fertilization, where the minimum fertilizer application rate is 450 kg/ha, the hole fertilization device used in this study achieves a minimum fertilizer application rate of 375 kg kg/ha, saving approximately 16.7% of fertilizer/ha and improving fertilizer utilization efficiency.

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