

Article

Design and Testing of a Rotary Tiller-Type No-Till Cotton Planter with Seeding Belt

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Abstract

To address issues such as plastic film residue and poor seed depth stability during cotton sowing operations in Xinjiang, a new type of no-till cotton seeder has been proposed and designed. The seeder is mainly composed of a rotary tillage device, a furrow opener and fertilizing device, a sowing mechanism, a compaction mechanism, and mechanical transmission parts. The structure and working principle of the cotton seeder are expounded on; the key parts, such as the rotary tillage mechanism, furrow opener, and compaction system are analyzed; and the key factors of the best size of each part are determined. The single-factor simulation design was carried out using the EDEM discrete element simulation technology, with the machine's forward speed, rotary tillage speed, furrow opening depth, and compaction depth as the test conditions and the sowing quality as the evaluation standard. The corresponding mechanical model was established and determined the optimal combination of simulation parameters. To evaluate the performance of the cotton no-tillage seeder, field tests were conducted on its rotary tillage, tape laying, and seed press performance. The field experiment's results indicate that under the optimal simulated parameter combination, the actual planting depth was approximately 28 mm with a coefficient of variation of 12.26%, achieving a compliance rate of 93.3%; the average planting spacing was 64.05 mm with a coefficient of variation of 12.46%; the soil disturbance rate was 32.9%; the germination rate was 96%; and the seed drying rate was below 2%. These results comply with industry standards and agronomic requirements, providing technical support for ensuring the quality of no-till cotton cultivation.

Keywords: no-till cotton planting; rotary tiller type; compaction; conservation tillage

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1. Introduction

Cotton, as a crucial strategic material and cash crop, is widely used in textiles, medicine, food (processing cottonseed into edible oil), aerospace, and other fields. China's cotton production accounts for about 24% of the global total. As the core cotton production area of China, Xinjiang's cotton planting area reached 2.369 million hm² and 2.448 million hm², respectively, in the 2023/2024 season, accounting for over 90% of China's total sown area, playing a key role in the global cotton textile supply chain. Therefore, ensuring stable

and high cotton production is of great significance to China's economic security and the stability of its industrial supply chain [1].

In Xinjiang, cotton cultivation predominantly uses a system of tillage followed by mulching. By integrating mulching cultivation with drip irrigation, farmers can achieve the dual benefits of maintaining soil temperature and moisture while conserving water and fertilizer [2]. However, prolonged use of this method leads to annual accumulation of residual mulch in the plow layer, which diminishes the soil's water retention and nutrient storage capacity. This ultimately compromises cotton seedlings' emergence, growth, and development [3–5].

No-tillage cotton cultivation plays a vital role in combating farmland dust and soil erosion and in water retention, soil fertility enhancement, cost reduction, and efficiency improvement in cotton production [6,7]. It also strengthens the industry's competitiveness and promotes sustainable agricultural development [8]. This technique minimizes soil disturbance and preserves the soil's structure and organic matter content, thereby boosting fertility [9,10]. The core principle is "reducing soil disturbance," achieved through reduced tillage or complete no-tillage practices. By increasing straw mulching, enhancing the soil's erosion resistance, and minimizing runoff and eroded material loss, it effectively controls soil erosion. Long-term studies have demonstrated that straw mulching significantly reduces surface runoff by 60% and soil water loss by approximately 80%, enhances water use efficiency by 15–17%, and increases soil water retention capacity by 14–15% [11]. Compared with conventional farming practices, long-term conservation tillage markedly improves the organic carbon content in the 0–5 cm and >5–10 cm soil layers (by 29.54% and 22.38%, respectively; $p < 0.05$), carbon storage (by 31.11% and 27.34%, $p < 0.05$), and total nitrogen content (by 53.74% and 37.60, $p < 0.05$) and significantly elevates the carbon-to-nitrogen ratio in the surface soil ($p < 0.05$) [12]. Under higher temperatures, soils subjected to continuous tillage exhibit elevated soil temperatures, whereas no-till cultivation and no-till with straw incorporation show lower surface temperatures compared with conventional methods. These findings indicate that conservation tillage techniques are more effective than continuous tillage in reducing soil temperature and exerting a temperature-regulating effect [13].

Sowing quality is pivotal to cotton growth. Current cotton cultivation faces challenges like inconsistent planting depth and suboptimal seedbed structure, where compaction plays a key role [14,15]. This process involves compacting soil after the seeds are sown into furrows to improve structure and create a firm, favorable environment. There are two types: pre-sowing compaction and post-covering compaction. Proper compaction enhances seed–soil contact, boosting germination rates [16,17]. Moderate compaction not only optimizes seedbed conditions but also improves water retention and reduces soil erosion [18,19].

To address the aforementioned challenges, this study developed a rotary cultivating cotton no-till seeder tailored to agricultural practices, with detailed designs for its rotary components, fertilization system, drip tape deployment mechanism, compaction unit, and sowing mechanism. Through single-factor experiments, we analyzed the stress distribution and motion dynamics of these critical components. A discrete element model was established to simulate soil–straw interactions, while the compaction device's operational process was digitally modeled. By evaluating the impact of various factors on sowing performance, we identified the optimal parameter configuration. Field trials validated the simulation results, effectively resolving the issues of uneven sowing depth and spacing, thereby enhancing the stability and reliability of the cotton no-till seeder.

2. Materials and Methods

2.1. Overall Structure and Working Principle

2.1.1. The Overall Structure

The overall structure of the no-till cotton seeder is shown in Figure 1. It primarily consists of a rotary tillage unit, a packer and leveling unit, a double-disc furrow opener, a furrow fertilizer application assembly, a drip tape laying device, a contour adjustment mechanism, and a main frame. This configuration enables operations including rotary tillage and soil fragmentation, fertilizer application, furrow opening, seed planting, and soil compaction. The rotary tillage and fertilization unit primarily comprises rotary tillage blades, sliding blade furrow openers with fertilizer tubes, and a fertilizer hopper. The seed distribution mechanism primarily consists of a row sowing distributor and a chain-driven differential mechanism for adjusting the ground wheels' speed, allowing the sowing rate to be modified according to the working conditions by changing the gear ratio. The press-down and shaping unit mainly consists of a front press-down roller, a rear press-down wheel mechanism, and chain drive components. The drip tape laying assembly primarily includes a drip tape frame and ground wheels. The depth contouring control device adjusts the maximum depth of the furrow opening and seeding assembly by altering the positions of various bolt holes. Specific parameters are shown in Table 1.

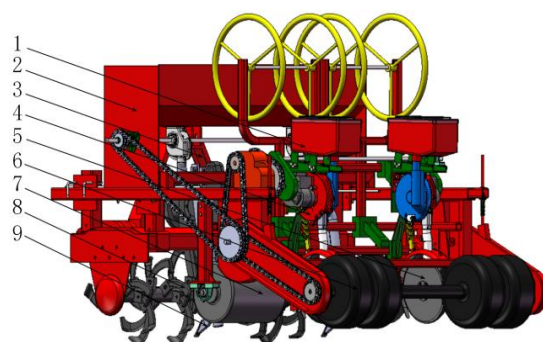


Figure 1. Schematic diagram of the no-till cotton seeder. 1. Seed box. 2. Fertilizer box. 3. Three-point suspension. 4. Seed dispenser. 5. Double-disc furrow opener. 6. Compaction wheel. 7. Pressure roller. 8. Rotary tiller blade group. 9. Fertilizer opener.

Table 1. Technical parameters of the no-till cotton seeder.

Parameters Attended Mode	Numerical Value/Form Suspension Type
Overall dimension (length × width × height)/(mm × mm × mm)	2100 × 1650 × 1370
Number of working lines	2
Line spacing/mm	400~760
Stubble crushing and cleaning component types	Seedling belt with rotary tillage
Furrow opener type	Double disc
Pre-pressing device	Pressure roller
Post-compression device	Compaction wheel
Forward speed/(km/h)	1.2~4.5
Rotary tillage depth/mm	80~150
Rotary tiller blade speed/(r·min ⁻¹)	280~400
Working width/mm	1500
Matching power/kW	>60
Quality of the whole machine/kg	1450

2.1.2. Working Principle

The seeds are finely chopped to form a seedbed. As the tractor advances, the slotted fertilizer opener creates a furrow, while the rotary tiller blade group returns and covers the soil, filling in the furrows. The front roller advances with the machine, compacting the tilled soil surface to level it before sowing, ensuring optimal conditions for furrowing. The double-disc furrow opener works on compacted soil, with the roller further pressuring the sown soil to enhance seed coverage, improve soil compaction, maintain moisture, and boost germination rates. As shown in Figure 2, the rotary tiller blade group, slotted furrow, fertilizer opener, pressure roller, double-disc furrow opener, and compaction wheel are aligned in a straight line to achieve synchronized fertilization and sowing across the seedbed.

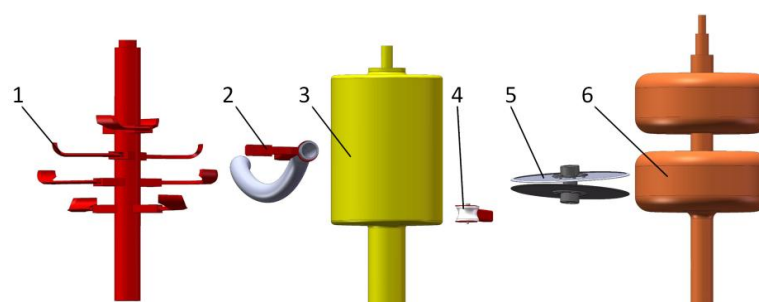


Figure 2. 1. Rotary tiller blade group. 2. Fertilizer opener. 3. Pressure roller. 4. Drip tape reel. 5. double-disc furrow opener. 6. Compaction wheel.

2.2. Design and Parameter Analysis of Key Components

2.2.1. Cotton Planting Patterns in Xinjiang

Currently, cotton cultivation in Xinjiang primarily adopts the wide–narrow row planting model of 1 film and 6 rows (660 mm + 100 mm), as shown in Figure 3. The narrow-row area serves as the cotton planting zone, with a sowing spacing of 100 mm and a drip irrigation belt laid in the middle; the wide-row spacing is 660 mm; and the planting is simultaneously covered with plastic film measuring 2050 mm in width, thereby achieving the effects of heat and moisture retention, as well as water and fertilizer conservation.

To facilitate cotton sowing under straw coverage conditions, this paper proposes an equal-row no-tillage cotton cultivation model as shown in Figure 4. The standard row spacing is 760 mm; post-sowing, no plastic film mulching is applied. Rotating tillage components are used solely for cultivating the cotton planting area, while the non-sown areas remain covered with straw to maximize straw utilization and minimize soil disturbance, thereby reducing soil erosion, enhancing water retention and moisture conservation, improving soil fertility, and ensuring stable and abundant cotton yields.

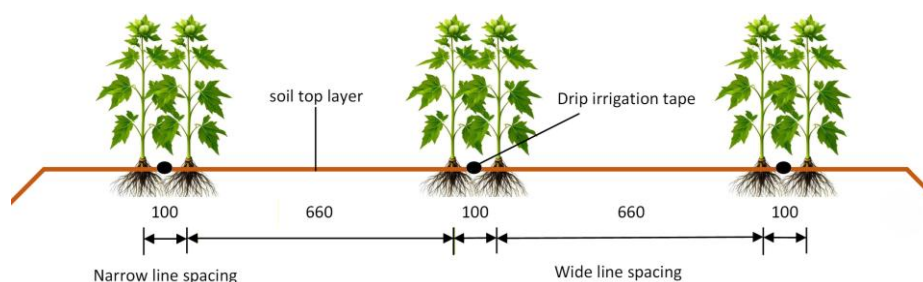


Figure 3. Schematic diagram of traditional cotton cultivation practices.

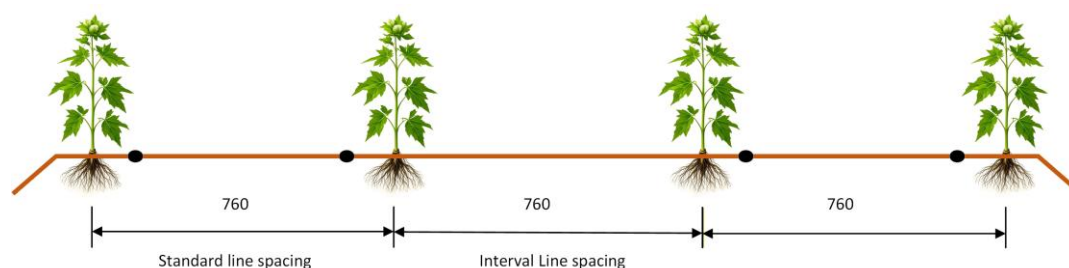


Figure 4. Schematic diagram of cotton cultivation pattern on stubble fields.

2.2.2. Design of the Rotary Tiller Blade Group

The rotary tiller blade operates in two modes, forward rotation and reverse rotation. To minimize soil disturbance and ensure optimal seedbed conditions, the forward rotation method is preferred. This mode features a shorter cutting interval. During operation, surface straw is first compressed into the soil by the blades, then mixed with the plowed layer and returned to the surface, creating a finely fragmented seedbed structure while maintaining adequate straw coverage. The design combines spiral and directional arrangements, with the blades symmetrically oriented inward, as shown in Figure 5. This configuration precisely directs the soil deposition inward, forming well-defined furrows [20].

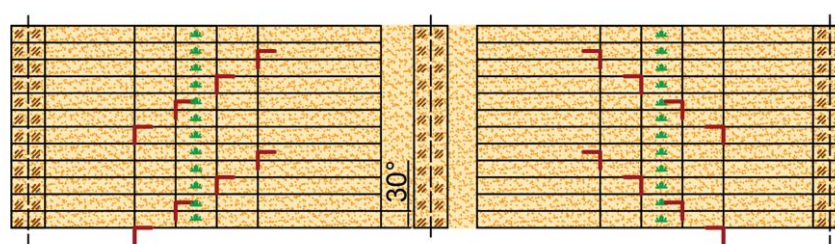


Figure 5. Rotary tiller blade arrangement. Note: The dashed line is the center line;  indicates cotton plants;  indicates the root stubble of the previous cotton crop.

According to the motion characteristics of the rotary tiller blade in forward rotation, the motion equation of the blade tip at time t is [21]:

$$\begin{cases} x = V_m t + R \cos(\omega t) \\ y = R \sin(\omega t) \end{cases} \quad (1)$$

In the formula, ω is the angular velocity of the rotary tiller blade, in ($^\circ$); R is the rotation radius of the rotary tiller blade, in mm.

The seedling strip rotary tiller blade group primarily consists of a rotary tiller blade assembly, a soil-retaining plate, and a gearbox operating at 300 rpm. Its power consumption is mainly allocated to three functions: soil cutting by the blades, soil clod throwing, and transmission. Notably, soil cutting and clod throwing account for over 80% of total power consumption, while that of the other components are negligible. The power consumption calculation formula is as follows:

$$N = \frac{100K_r B H V_m}{102} \approx K_r B H V_m \quad (2)$$

In the formula, K_r denotes the specific resistance of rotary tillage soil (unit: kg/cm^2). Its value is related to soil and tillage depth, with higher tillage depth resulting in higher values, as the cultivation environment is dry land with abundant crop straw and weeds. Take $K_r = 1.2$. B is the working width (unit: m); take $B = 1.5$ m. H is the tillage depth (unit: mm); take $H = 100$ mm. V_m is the seeding machine speed (unit: m/s); take $V_m = 1.2$ m/s.

Substitute all parameters into Equation (2) to derive the consumption of the seedling cleaning device: $N = 21.6$ kW. The tractor's rated power is to be used in conjunction with 66.2 kW. The power consumption is 32.62% of the power supply, so the whole rotary tiller blade group meets the design requirements.

To ensure optimal stubble and soil fragmentation, the rotary tiller blade should follow a cycloid trajectory, with the blades' rotational speed set at 10 times the machine's forward speed. The sliding blade furrower fertilizes directly after tillage, using the ejected soil to cover the fertilizer. This process requires high-quality soil fragmentation. With a 100 mm soil-cutting pitch, the number of rotary tiller blades per soil-cutting zone is determined as follows

$$L = \frac{60,000v_m}{nS} \quad (3)$$

Where v_m is the rotational speed of the rotary tiller blade, in r/min.

The formula indicates that when the machine's forward speed is 1.2 m/s and the rotary tiller blade shaft rotates at 300 r/min, the number of rotary tiller blades L in the same soil-cutting zone is 2. This means that each cutter disc is equipped with two rotary tiller blades, with adjacent blades spaced at 180 degrees. The rotary tiller blades use a central drive mechanism, and the blade shafts are made of 70 mm hollow steel pipes. To ensure balanced force distribution on both sides of the rotary tiller, a symmetrical spiral arrangement is adopted [21,22], centered around the gearbox to guarantee operational stability. Eight rotary tiller blades are installed on each left and right roller. To prevent missed cultivation during furrow opening, the maximum axial spacing between blade seats can be set at 75 mm. The width of a single grid is 30 mm, and the initial installation angle difference ψ is 22.5°, as calculated by Equation (4).

$$\psi = \frac{180^\circ}{L} \quad (4)$$

2.2.3. Design of the Compaction Wheel

The compaction wheel operation ensures soil firmness after rotary tillage. The width of the compaction wheel determines the quality of the compaction process. Under a constant load, an excessively narrow wheel width may cause seedling bands to sink and furrow bottoms to become uneven. Conversely, an overly wide wheel increases the contact area between the wheel and soil, reducing compaction efficiency. According to the requirements in the *Agricultural Machinery Manual*, the compaction wheel width $B = 80$ mm is recommended. Thin steel plates are used for the wheels, and smooth cylindrical wheels feature a wider compaction surface with even pressure distribution, enhancing soil compaction after rotary tillage [22].

When maintaining a constant working speed and unit area pressure, the compaction effect is closely related to the diameter of the compaction wheel. A larger wheel diameter and longer compaction time result in tighter soil compaction. Conversely, an excessively small wheel diameter or a short compaction time leads to insufficient compaction and severe soil dragging and bulging. Therefore, the compaction wheel's diameter should be within a reasonable range (200–500 mm). Under the premise of ensuring operational stability and performance, a compaction wheel diameter of 360 mm is selected. According to the *Agricultural Machinery Design Manual*, the normal rotation of the compaction wheel must meet the following requirements (5):

$$R \geq \frac{\omega_r}{Qf} \quad (5)$$

In the formula, R denotes the radius of the compaction wheel, in m; ω_r represents the friction torque within the sleeve, in N·m; Q is the weight of the compaction wheel and its

attached load, in N; and f is the soil's friction coefficient with the compaction wheel. The sleeve's friction torque can be disregarded.

The stress analysis of the longitudinal section of the compaction wheel is shown in Figure 6.

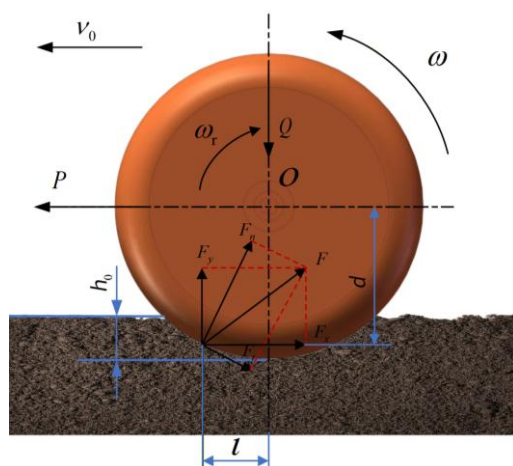


Figure 6. Force analysis of the compaction wheel.

In Figure 6, V_0 denotes the wheel's motion direction, which aligns with the tractor's movement; ω indicates the direction of the press roller's movement; P represents the tractor traction force, in N; F_n represents the resultant force of the soil's reaction force on the wheel in the normal direction, in N; F_t represents the resultant tangential frictional force of the soil on the wheel, in N; F denotes the resultant force of F_x and F_y , with F_x and F_y representing the horizontal and vertical components of F , in N; l indicates the horizontal distance between the action point A and the wheel's center, mm; d signifies the vertical distance between the action point A and the wheel's center, mm; and h_0 denotes the seeding rows' compaction depth, in mm.

2.2.4. Design of the Double-Disc Furrow Opener

As shown in Figure 7, the double-disc furrow opener primarily consists of a furrow opener, a spring-loaded profiling mechanism, and a depth adjustment mechanism.

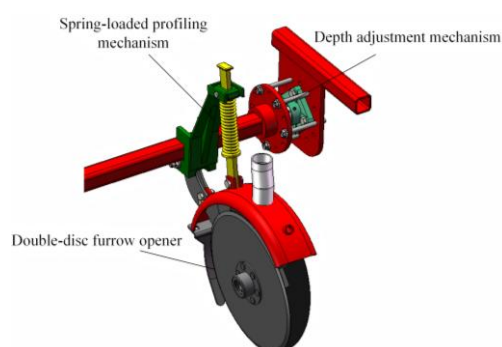


Figure 7. Schematic diagram of the double-disc furrow opener.

The double-disc furrow opener operates effectively in both no-till fields and high-moisture conditions, resisting soil adhesion and clogging. Therefore, the double-disc opener has been selected as the seed furrow opener [23,24]. The cutting edges of the double-disc opener converge at a point forward and downward, forming an angle. During seeding, the double-disc opener first enters the soil with its front discs to create a narrow furrow, loosening the soil. The 12° discs, which also function to widen the furrow, expand

this narrow channel into a complete seed furrow. Seeds are guided directly to the bottom of the furrow through the seed guide tube, ensuring that the seed depth aligns precisely with the seeding depth. The double-disc cutter diameter is selected as 320 mm. To ensure width, enhance soil return and seed coverage, and reduce seed exposure, the disc angle and convergence point angle are designed according to the relationship [11] among the disc angle, convergence point angle, and diameter. Subsequently, the compaction wheel compacts the seed furrow to enhance soil–seed contact density. Seeding depth is adjusted by manipulating the limit bolt and rotating the support crossbeam. Furrow stability is regulated via springs according to the soil conditions and the crop’s compaction requirements.

$$b = D_p (1 - \cos \beta_1) \sin \frac{\alpha_1}{2} \quad (6)$$

In the formula, b represents the furrow width, in mm; D_p represents the diameter of the double-disc opener, in mm; α_1 represents the angle between the discs of the double-disc opener, in ($^\circ$); β_1 represents the angle of the convergence point position of the double-disc opener, in ($^\circ$); and ε_0 is the intersection point where the lower edges of the two discs converge at the front end.

As shown in Figure 8, based on the seeding requirements of the integrated machine, the target furrow width is 30 mm [25]. To accommodate the seed delivery tube, the angle between the discs of the furrow opener is designed as 12. Substituting the known parameters into Equation (6) yields a convergence point position angle of 75.4 $^\circ$.

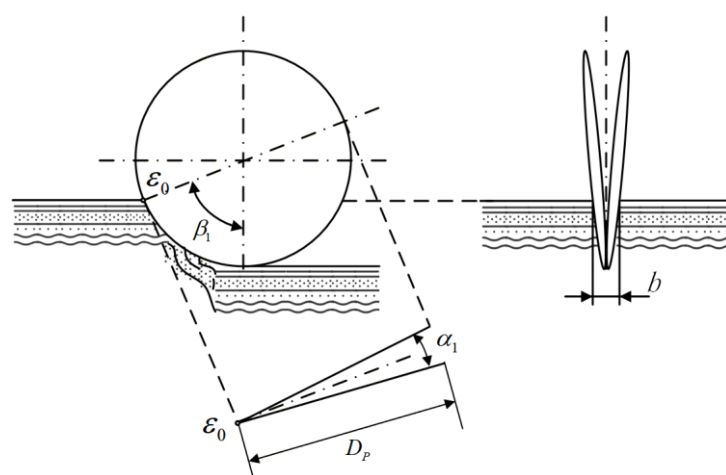


Figure 8. Intersection point and angle of two discs.

2.3. Simulation of Rotary and Compaction

To validate the influence patterns of the combined action between the rotary tiller blade group and the compaction wheels on the seedbed seeding depth’s stability, a simulation model was constructed using the discrete element analysis software EDEM 2023. This model incorporates the rotary tiller blade group, double-disc furrow opener, and compaction wheels to investigate the influencing patterns on the seedbed’s levelness.

2.3.1. Simulate Settings and Parameters

The soil parameter contact model is based on a typical arid experimental field in Xinjiang. This field features a silt loam soil type derived from loess parent material, exhibiting heavy loam characteristics. The soil composition includes 5.03% clay, 77.7% silt, and 17.27% sand, with a density of 1600 kg/m³ and a pH value of 8.243. Soil particle diameters range from 20 to 50 μ m [26,27]. Considering computational capacity and simulation efficiency, spherical particles with a 4 mm radius were selected to represent soil particles. The Hertz–

Mindlin model with bonding was used for soil–soil particle contact, while the Hertz–Mindlin (no slip) model was used for soil–working part contact.

A soil trench model measuring 3000 mm (length) $\times$ 600 mm (width) $\times$ 200 mm (height) was established, with a soil layer thickness of 200 mm and a cotton stalk layer thickness of 10 mm. The 3D model constructed in SolidWorks 2024 was imported into EDEM 2023. Relevant simulation parameters were obtained from the literature. Post-harvest crop residues were represented by straw particle models. The straw particles were combined using the Meta-Particle function to create various types of slender straw models. Specific parameters are shown in Table 2.

Table 2. Geometric model parameters for residual crop residue particles on the soil surface.

Parameters	Long Cotton Stalk	Medium Cotton Stalk	Short Cotton Stalks
Particle radius/mm	4	3	2
Ball center distance/mm	4	3	2
Number of particles/grains	19	19	19
Straw length/mm	80	60	40

The material for soil-contacting components such as the rotary tiller blades and furrow opener is specified as 65 Mn steel. The Poisson ratios for soil, cotton stalks, and steel are 0.36, 0.35, and 0.30, respectively; their densities are 1600, 1080, and 7850 kg/m³; and their shear moduli are 1.0×10^6 , 0.69×10^6 , and 7.94×10^{10} Pa [28–30]. Specific contact parameters for the model are shown in Table 3.

Table 3. Contact parameters of the model.

Parameter	Value
Soil–soil recovery coefficient	0.48
Soil–soil static friction coefficient	0.695
Soil–soil dynamic friction coefficient	0.24
Soil–straw recovery coefficient	0.314
Soil–straw static friction coefficient	0.512
Soil–straw dynamic friction coefficient	0.15
Soil–steel recovery coefficient	0.55
Soil–steel static friction coefficient	0.44
Soil–steel dynamic friction coefficient	0.078
Straw–steel recovery coefficient	0.46
Straw–steel static friction coefficient	0.37
Straw–steel dynamic friction coefficient	0.064
Straw–straw recovery coefficient	0.5
Straw–straw static friction coefficient	0.41
Straw–straw dynamic friction coefficient	0.06
Normal stiffness coefficient/(N·m ⁻³)	2.40×10^7
Tangential stiffness coefficient/(N·m ⁻³)	1.70×10^7
Normal critical stress/Pa	2.35×10^5
Tangential critical stress/Pa	1.86×10^5
Bonding radius/mm	4.5

This study examined 100 seeds of the Xinluzhong 65 (middle-early maturing upland cotton variety) cotton variety, measuring their three-axis dimensions. The results are presented in Table 4. Table 4 indicates that the length dimension of Xinluzhong 65 cotton seeds is greater than both the width and thickness dimensions. Variability in thickness is

higher than that in length and width. A KS test conducted on the three-axis dimensions revealed that the significance values for length, width, and thickness all exceeded 0.05. Therefore, the three-axis dimensions of the cotton seeds can be considered to approximate a normal distribution [31,32].

Table 4. Contact parameters of model.

Index	Minimum/mm	Maximum/mm	Mean Value/mm
Length	8.56	10.25	9.41
Width	5.09	5.56	5.33
Thickness	4.65	5.31	4.98

We used the Creator module in EDEM software to create a cotton seed model (as shown in Figure 9, and the spherical aggregation method to merge seven spheres into a single cotton seed.

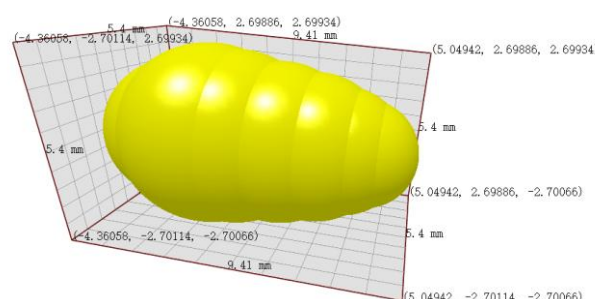


Figure 9. Parameters of the cotton seed geometry model.

2.3.2. Simulation Operation Process and Test Design

The grid size was set to three times the minimum particle radius, generating a total of 473.76 kg of soil particles and 19.44 kg of straw. The simulation model is shown in Figure 10.

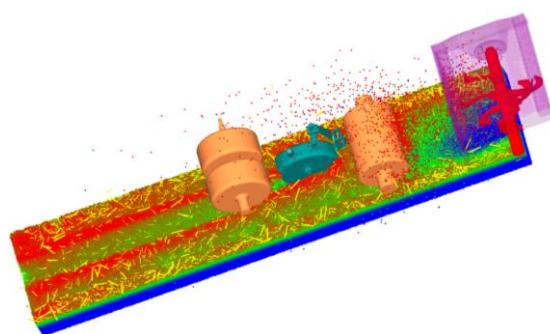


Figure 10. Simulation experiment model.

In the simulation experiment, the variation ranges for each factor were set as follows: rotary tiller blade speed from 150 to 450 r/min, working speed from 1.2 to 4.5 m/s, and tillage depth from 60 to 100 mm. The entire rotary tillage process was divided into two stages. During the 0–2.0 s interval, soil particles were statically generated by the particle factory. Under gravitational force, these particles fell into the soil channel, forming a particle model composed of spherical and clumpy aggregates until the entire channel space was filled. From 2.0 to 2.4 s, compaction occurred on the soil trough plane. From 2.4 to 3.2 s, straw particles were statically generated by the particle factory. The simulation con-

cluded when the maximum velocity of all straw particles fell below 0.001 m/s. Subsequently, using the model export function in EDEM's post-processing tools, the stabilized soil trough model was exported as a fixed template. The simulation initial time was set to 0 s. Finally, this soil trough model was imported as the initial conditions into the corresponding 3D model for the experiment phase. During the 0–5.6 s time interval, seedbed preparation operations (rotary tillage, furrow opening, and compaction) were performed. To prevent bond breakage due to excessive time steps and ensure complete tillage of the soil channel, simulation data were saved every 0.01 s.

On the basis of the theoretical analysis and single-factor preliminary test validation, the following factors were selected for experimentation: forward speed, rotary tiller blade speed, rotary tiller blade depth, pressure roller depth, and compaction wheel depth. Single-factor experimental analysis was conducted using seeding operation quality as the evaluation metric. Specific experimental factors and their codes are listed in Table 5.

Table 5. Test factor coding.

Encode	Rotational Speed of Rotary Tiller Blade, $n/(\text{r}\cdot\text{min}^{-1})$	Forward Speed, $v/(\text{m}\cdot\text{s}^{-1})$	Depth of Cultivation, h/mm	Pressure Roller Depth, h_1/mm	Compaction Wheel Depth, h_0/mm
1	150	2.85	80	15	15
2	300	2.85	80	15	15
3	450	2.85	80	15	15
4	300	2.85	60	15	15
5	300	2.85	100	15	15
6	300	1.2	80	15	15
7	300	4.5	80	15	15
8	300	2.85	80	10	15
9	300	2.85	80	20	15
10	300	2.85	80	15	20
11	300	2.85	80	15	10

3. Simulation Experimental Results and Analysis

3.1. Seed Distribution Under Double Compaction Effects

Figure 11 illustrates the seed distribution when the rotary tiller blade rotates at 300 r/min, advances at 2.85 km/h, operates at a working depth of 100 mm, and uses a roller working depth and wheel depth of 15 mm each. The cross-section of the worked area indicates that after rotary tillage, only a small portion of the straw remains within the 3–8 cm soil depth range, with the majority distributed above the top 3 cm of soil. Four discrete datasets, each comprising ten seed records, were analyzed. Calculations yielded an average sowing depth of 2.539 cm, with a coefficient of variation of 16.5% and a sample standard deviation of 4.19. The mean sowing uniformity was 59 mm, exhibiting a coefficient of variation of 24.37% and a sample standard deviation of 14.38. Both the seeding depth and spacing met the agricultural technical requirements for cotton production.

3.2. Analysis of Soil Particle Movement Patterns

To more clearly observe the effects of the rotary tillage double compaction furrowing unit on soil particles' motion during operation, as well as the interaction mechanism between the soil-contacting components and the soil, a velocity map analysis of the soil particles was conducted. Figure 12 shows the soil particle velocity contour map during 3.0 s of stable operation. The color variations represent differences in soil particles' velocity, while the depth of color indicates the proportion of particles at a specific velocity in that

region. The contour map reveals that as the rotary tiller blades move through the soil, they exert cutting and squeezing forces on the soil particles. According to the soil particle color display, particles with higher velocities are primarily concentrated at the front of the blade, with speeds increasing toward the blade tip. This occurs because surface soil particles possess greater freedom of movement, enabling easier upward and lateral displacement under compression and shear forces. Following the rotary tiller's cutting action, the compactor rollers immediately perform soil particle compaction. Soil particles possess relatively high velocities prior to compaction, which subsequently reduces their relative velocities. Following furrow opening operations by the opener, soil particles on both the inner and outer sides of the dual discs exhibit noticeable velocity changes, initiating downward and lateral movement. This occurs as soil particles settle back into the opened furrows, generating relatively high velocities. Simultaneously, it is evident that the width range of the double discs corresponds to the trench width, exerting a substantial velocity influence on the soil on both sides. During compaction, the wheel primarily acts on soil particles immediately adjacent to its outer surface. Post-operation, the soil particles remain stable without exhibiting bouncing fluctuations, indicating effective compaction.

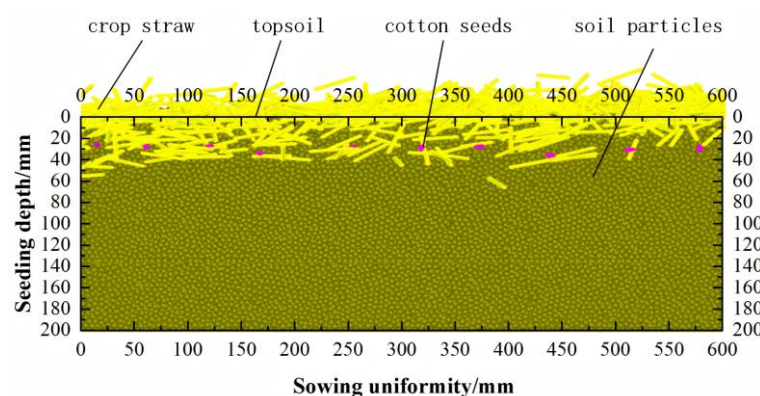


Figure 11. Seed distribution map.

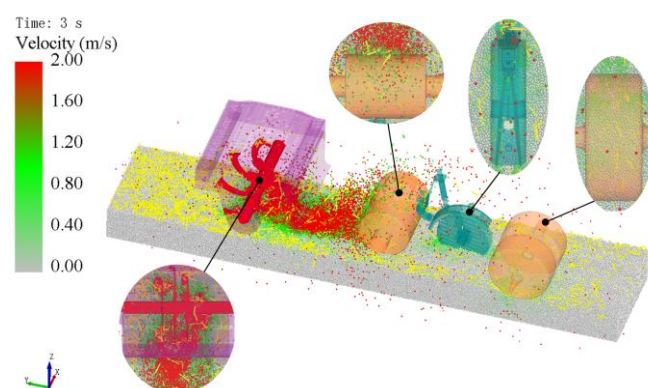


Figure 12. Velocity cloud map of soil particles.

The lateral cross-section of the soil particle model and the contour lines of the upper surface of the soil particles after each component completes its operation are shown in Figure 13 (the black dashed line represents the soil contour line). It can be observed that after the rotary tiller blade operates, the soil particles move toward both sides and the rear, subsequently scattering unevenly across the seedbed (I). During wheel compaction, the soil is preliminarily leveled and compacted. Topsoil particles shift laterally, creating initial conditions for subsequent double-disc coulter operation (II). After the double-disc opener operation, topsoil particles further move laterally, while the second layer of soil particles

breaks up, loses compaction, and shifts laterally upward. At this stage, significant upward disturbance occurs within the soil layers. Measuring the disturbance height of soil particles in each layer reveals that the first layer's particles are disturbed upward by 15 mm (III). Finally, the wheel performs the final compaction and shaping of soil particles in the seedling band area (IV), ensuring moderate soil firmness in the seed furrows. This allows seeds to lie in close contact with the soil, facilitating cotton seeds' germination and ultimately achieving the desired objectives.

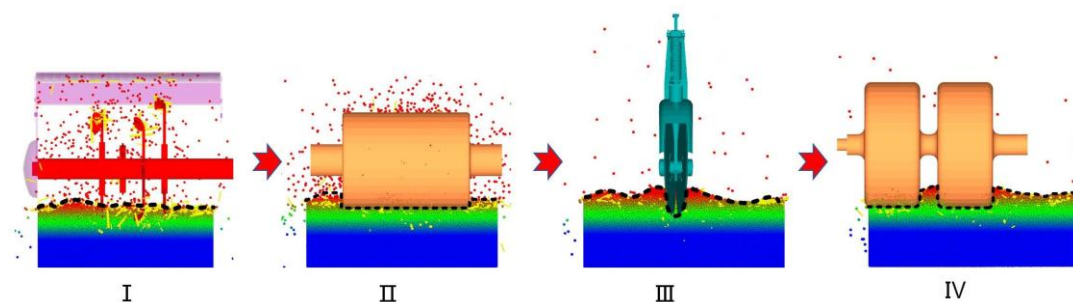


Figure 13. Schematic diagram for measuring the operations' resistance. (I) After rotary tillage; (II) after roller compaction; (III) after the double-disc furrow opener's operation; (IV) after compaction.

3.3. Seed Planting Depth Analysis

The average seeding depth and coefficient of variation serve as primary indicators for evaluating seeding quality, with significant differences observed. Figure 14 illustrates how seeding depth varies under the influence of different factors.

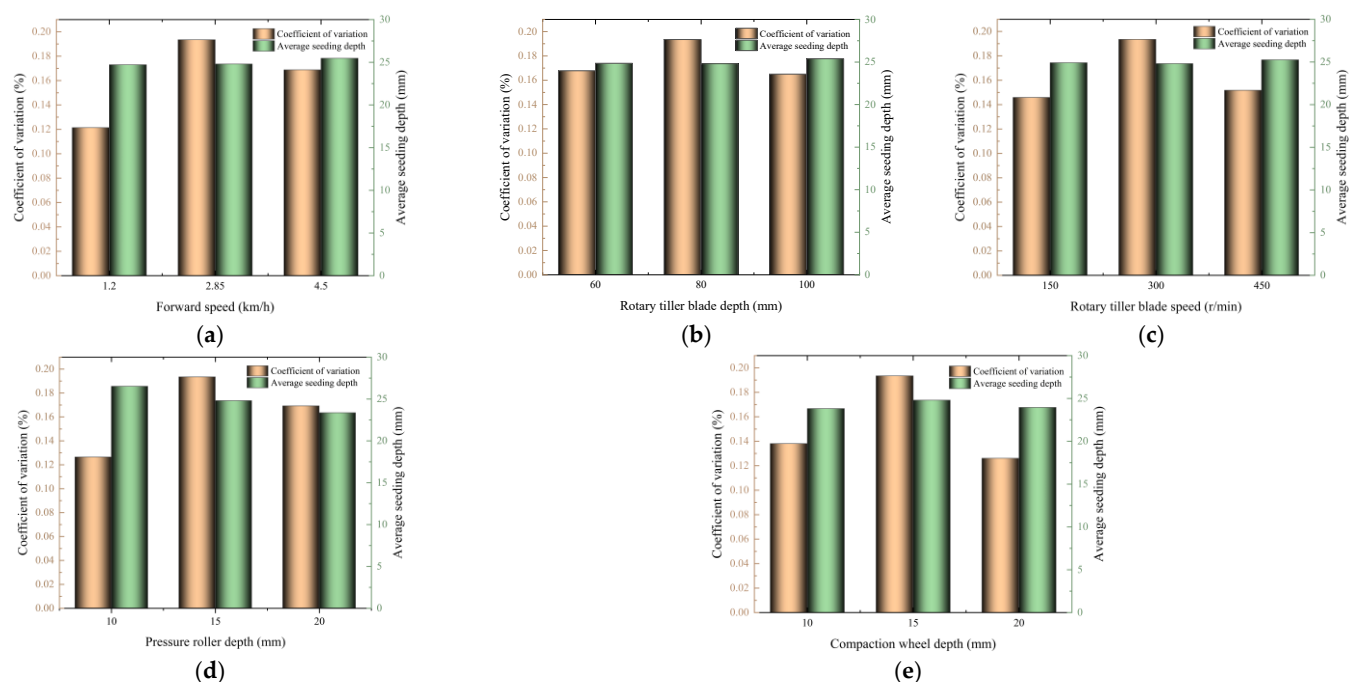


Figure 14. Results of single-factor simulation experiments on sowing. (a) Forward speed; (b) rotary tiller blade depth; (c) rotary tiller blade speed; (d) pressure roller depth; (e) compaction wheel depth.

Figure 14a indicates that forward speed has almost no effect on the average seeding depth. However, when the forward speed increases from 1.2 km/h to 4.5 km/h, the unevenness of seeding depth significantly rises. At 2.85 km/h, the coefficient of variation for seeding depth increases by 59.39% compared with 1.2 km/h.

Figure 14b demonstrates that under constant conditions of forward speed, compaction wheel depth, pressure roller depth, and the rotary tiller blade's rotational speed, the working depth of the rotary tiller blade has a minor effect on seeding depth. The coefficient of variation for seeding depth reaches its minimum at a rotary tiller blade working depth of 100 mm, being only 16.50%. This may be attributed to the soil being sufficiently tilled, resulting in more uniform soil return during seed placement.

Figure 14c indicates that the operating speed of the rotary tiller significantly affects the uniformity of seeding depth. As the operating speed increases, the unevenness in both the amount and height of soil scattered onto the seedbed by the rotary tiller worsens. Sowing depth is susceptible to soil height irregularities. When the rotary tiller speed exceeded 300 rad/min, the coefficient of variation for sowing depth decreased from 19.35% to 15.17%. This reduction may result from the enhanced soil particle fragmentation at high speeds, producing finer soil particles that facilitate furrow formation and uniform seed distribution.

Figure 14d shows that seeding depth decreases with increasing roller compaction depth. Specifically, at a 20 mm compaction depth, the seeding depth reached 88.07% of the 10 mm depth, equivalent to a reduction of 3.16 mm, indicating a significant influence of roller depth on seeding depth. The coefficient of variation for seeding depth increases with greater roller compaction depth. Specifically, at a 15 mm compaction depth, the coefficient of variation for seeding depth increased by 53.08% compared with 10 mm.

Figure 14e indicates that the coefficient of variation for seeding depth first increases and then decreases with increasing wheel compaction depth. At higher speeds, the increased contact area between the packer wheel and the soil surface enhances soil compaction, leading to more uniform seed distribution. In simulations, the coefficient of variation for seeding depth at 20 mm was 6.74% lower than at 15 mm (only 65.16% of the coefficient at 15 mm), indicating that the compaction wheel's penetration depth significantly influences the coefficient of variation in seeding depth.

According to the analysis above, a clear correlation exists between the machine's forward speed and seeding depth stability. When speed increased to 2.85 km/h, the coefficient of variation in seeding depth rose significantly from 12.14% to 19.35%. However, at 4.5 km/h, the negative effect of increased speed diminished, indicating that higher forward speeds have a smaller impact on sowing depth variability. When the press wheel penetration depth increased to 20 mm, the sowing depth decreased significantly, from 26.51 mm to 23.35 mm. This demonstrates that increased press depth has a greater influence on sowing depth variability.

3.4. Force Analysis of the Compaction Component

To more clearly observe the influence of dual compaction components on the soil particle stress states during operation, this experiment captured a stress state contour map of the soil at the 3 s mark, along with the stress mechanism of the soil-contacting components under soil interaction, enabling a comprehensive analysis of the compaction components' stress process. Figure 15 shows that the force curve changes throughout the entire operation process of the dual compaction components under the following conditions: a rotary tiller blade speed of 300 r/min, a forward speed of 2.85 km/h, a rotary tiller blade working depth of 100 mm, and the working depths of both the compaction roller and compaction wheel at 15 mm. The roller began contacting the soil at 1 s, rapidly rising to peak load at 1.4 s. During stable operation, the applied pressure gradually decreased, and the roller began disengaging from the soil at 4 s. The force analysis segment for this experiment spans 1.4 s to 4.0 s. The compaction wheel began contacting the soil at 2.1 s,

rapidly ascended to its peak at 2.4 s, exhibited a force variation pattern similar to the compaction roller during stable operation, and began leaving the soil environment at 5.2 s. Therefore, the force data from 2.4 s to 5.2 s were selected for analysis.

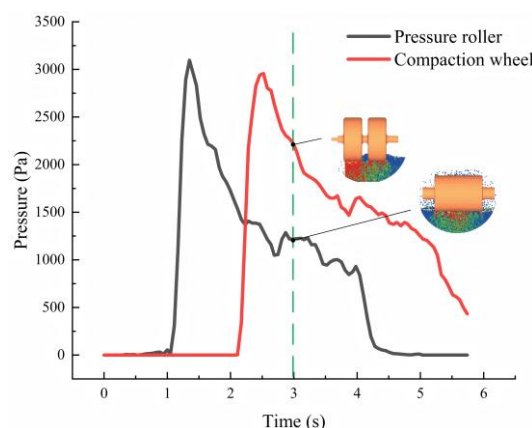


Figure 15. Pressure diagram for the dual suppression device.

The average force and coefficient of variation of the compacted components are key indicators reflecting compaction quality. Significant differences exist in the effects of various experimental factors on these indicators. Figure 16 illustrates variations in compaction force under different factor conditions.

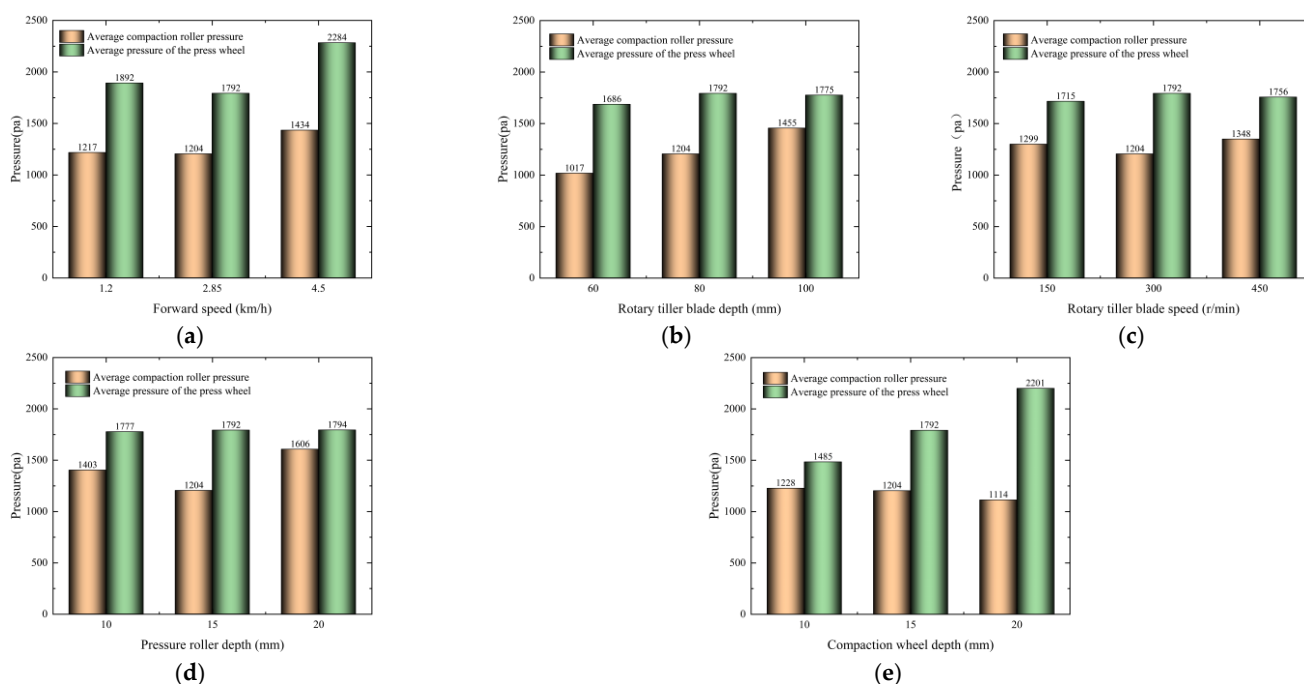


Figure 16. Results of single-factor simulation experiment for suppression. (a) Forward speed; (b) rotary tiller blade depth; (c) rotary tiller blade speed; (d) pressure roller depth; (e) compaction wheel depth.

As can be seen from Figure 16a, forward speed significantly affects the compaction force. When forward speed increases from 2.85 km/h to 4.5 km/h, the force on the press roller increases by 19.1%, while the force on the compaction wheel rises by 27.4%, adding 492 Pa.

As is evident from Figure 16b, when the forward speed, compaction wheel depth, press roller depth, and rotary tiller depth remain constant, the rotational speed of the rotary tiller has a minor effect on the force exerted on the compaction device. Only at 450 r/min, possibly due to significant unevenness caused by soil thrown from tilling into the seed furrow, did the force on the compaction roller increase by 144 Pa.

It can be observed from Figure 16c that the working depth of the rotary tiller significantly affects the force exerted on the pressure roller. As the tilling depth increases, the amount of soil scattered onto the seedbed and its height irregularity also increase, correspondingly enlarging the soil surface area contacted by the packer roller. When the working depth of the rotary tiller blades increased from 60 mm to 100 mm, the pressure on the roller increased by 43.06%.

As indicated in Figure 16d, the pressure exerted on the compaction wheel is not directly correlated with the working depth of the press roller. As shown in Figure 16e, the pressure exerted on the press roller is not directly correlated with the increase in working depth of the press wheel. Instead, the working load of the compaction wheel gradually increases with increasing working depth. As the working depth of the compaction wheel increased from 10 mm to 20 mm, the force exerted by the compaction wheel rose by 48.2%, corresponding to an increase of 716 Pa.

According to the analysis above, a clear correlation exists between the machine's forward speed and compaction intensity. When operating speeds reached 2.85 km/h and 4.5 km/h, the average compaction pressure of the roller increased from 1204 Pa to 1434 Pa, indicating that higher operating speeds increase the pressure exerted by the roller on the seedbed. This trade-off highlights the need to optimize agricultural machinery operations by finding the optimal balance between working speed and compaction capability. The depth of the compaction wheel's penetration significantly impacts the average compaction pressure. As compaction depth increases, the load on the compaction wheel rises to 2201 Pa, indicating that deeper compaction ultimately enhances compaction effectiveness, ensuring thorough compaction of the seedbed. Additionally, at a rotary tillage depth of 100 mm, the average compaction pressure of the roller and the compaction wheel reached peak values of 1455 Pa and 1775 Pa, respectively. This demonstrates that the working depth of the rotary tillage blades enhances the compaction effect.

4. Field Experiment

4.1. Test Conditions

To validate the accuracy of EDEM simulation results and assess the actual field performance of no-till cotton seeders, field performance tests were conducted at the Yuli Cotton Experimental Field in Xinjiang (ambient temperature: 5.45–12.67 °C). Comparative tests were simultaneously performed with plastic-covered cotton seeders. The test site is the cotton stubble land harvested by a cotton picker in autumn 2024. Straw was not shredded, with a straw coverage of 0.21 kg/m². Straw lengths primarily ranged from 40 mm to 120 mm, and the diameter of straw fragments ranged from 2 mm to 15 mm, achieving 84% straw coverage at a moisture content of 6.6%. The soil firmness was 1683.3 kPa, and the absolute soil moisture content of the test plot was 20.1%. The pre-sowing field conditions are shown in Figure 17a. Experimental equipment included a Dong fang Hong LX-904 tractor, a no-till cotton planter, a soil firmness meter (Spectrum SC-900, Spectrum Technologies Inc., Haltom City, Texas 76117, USA), a soil moisture meter (Zhejiang Top-Cloud Agricultural Technology Co., Ltd, accuracy ±3%, Hangzhou 310000, China), a measuring tape (100 m), a steel ruler (300 mm), and cotton seeds (Xinluzhong No.65 Cotton Seed, seed moisture content: 8.7%, 1000-seed weight: 82.2 g). Figure 17b shows the field trial site for the planter.

4.2. Test Indicators and Methods

4.2.1. Uniformity of Sowing

Six sowing strips were randomly selected within the operational section. Within each strip, five 1000-mm-long test segments were sequentially extracted, and the number of seeds within each segment was recorded. The total seed count across all sampling areas was denoted as T , and the total number of sampling areas was denoted as U . The uniformity index was calculated using the coefficient of variation; a lower coefficient indicates better uniformity [33].

$$D = \sum_i^3 D_i \quad (7)$$

$$X = \frac{1}{3} \sum_{i=1}^3 X_i \quad (8)$$

$$G = \sqrt{\frac{1}{D} \sum (x - X)^2} \quad (9)$$

$$V = \frac{G}{X} \times 100\% \quad (10)$$

In the formulas, D is the total number of measurement sections, D_i is the number of measurement sections in each plot, X is the average number of seeds per section, X_i is the average number of seeds per section in each plot, x is the number of seeds in each section, G is the total standard deviation, n is the number of measurement rows, and V is the coefficient of variation for sowing uniformity.



Figure 17. (a) Surface straw before operation. (b) Field verification test.

4.2.2. Seeding Depth Qualification Rate

Six sowing bands were randomly selected within the operational zone. Within each band, five 1000-mm-long test sections were extracted. After normal seeding and soil covering by the no-till seeder, the soil layer was scraped open to measure the thickness of the soil covering the seeds. The soil covering depth was calculated as $(h \pm 1)$ cm. When the seeding depth is less than 3 cm, the soil coverage depth is $(h \pm 0.5)$ cm. The percentage of measurement points within this range, where h represents the seeding depth adjusted according to agronomic requirements. Other calculation methods are consistent with the seeding depth pass rate (D_1) calculation method used in the simulation experiments.

$$D_1 = \frac{N'}{N} \times 100\% \quad (11)$$

In the formula, D_1 denotes the seed depth pass rate, in %; N' denotes the number of seeds passing the depth requirement; and N denotes the total number of seeds.

4.2.3. Groundbreaking Rate

On the basis of the method for determining the disturbance rate, we measured the disturbance width across two working widths within the survey area. Five random points were selected within each width for measurement. We calculated the percentage of disturbance width relative to the survey area width using Equation (12). The average of the five survey areas represents the disturbance rate.

$$D_2 = \frac{\sum \kappa_i}{6\omega} \times 100\% \quad (12)$$

In the formula, D_2 is the soil disturbance rate, in %; κ_i is the measured soil disturbance width per location, in mm; and ω is the working width, mm.

According to the optimized simulation results, when operating at a speed of 4.5 km/h, with the rotary tiller blades rotating at 450 rpm and a soil penetration depth of 100 mm, the straw exhibits good longitudinal flowability. The implement operates smoothly without clogging, demonstrating excellent passability. The straw clearance effect in the seedbed is satisfactory. The soil disturbance rate test results are shown in Figure 18.

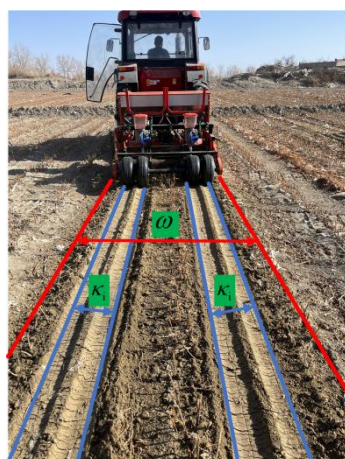


Figure 18. Field test.

The working width ω of the no-till cotton cultivator is 1520 mm. The single-side rotary tillage width equals the working area κ_i of four sets of rotary tillage blades, which is 250 mm, resulting in a total rotary tillage width of 500 mm. Substitution of the data into Equation (12) shows that the actual soil disturbance rate is calculated to be 32.9%, meeting the operational requirement that the tillage soil disturbance volume does not exceed 40%.

4.2.4. Sowing Uniformity

The field sowing uniformity test results are shown in Table 6. The sowing speed setting of the row seeder was adjusted according to the actual field operation speed, in compliance with sowing requirements. The measured value for the number of seeds per single test interval was approximately 15 seeds, with a seed drying rate of 1.4% and an overall coefficient of variation below 18.00%. The results indicate that seedling emergence in the sowing rows was relatively uniform, with no instances of missing or broken seedlings observed.

Table 6. Experimental results of seed distribution uniformity.

Ranking Order	Measurement Section										Average Inter-Plant Spacing (cm)	Coefficient of Variation (%)
	Inter-Point Spacing											
	1	2	3	4	5	6	7	8	9	10		
1	5.5	7.5	7.4	5.2	7.0	5.5	5.1	5.9	7.1	6.3	6.45	14.94
2	6.8	7.2	6.9	7.3	6.0	6.9	6.5	7.2	7.4	7.1	6.93	6.09
3	6.4	6.2	5.3	5.6	6.5	4.8	7.2	5.6	5.2	6.5	5.93	12.55
4	4.9	5.5	6.1	6.5	6.9	6.2	5.6	5.3	6.8	5.9	5.97	10.97
5	6.4	4.3	5.6	7.0	8.5	6.2	5.7	7.2	6.2	6.5	6.36	17.40
6	6.3	8.0	7.2	6.4	5.2	7.5	6.8	6.2	5.6	6.7	6.79	12.82

4.2.5. Seeding Depth

The seeding depth results are shown in Table 7, with an average seeding depth range of 2.8–2.98 cm. The no-till cotton seeder demonstrated superior seeding depth compliance rate and consistency. The average seeding depth fell within the agronomically required range of 25–35 mm. The field trial's results were largely consistent with the simulation test outcomes, with an overall coefficient of variation below 13.00%.

Table 7. Experimental results of seed depth uniformity.

Ranking Order	Measurement Section										Average Inter-Plant Coefficient of Vari- Spacing (cm)ation (%)	
	Inter-Point Spacing											
	1	2	3	4	5	6	7	8	9	10		
1	3.0	3.1	2.5	3.1	2.6	3.0	2.4	3.2	3.0	2.8	90	9.72
2	2.8	3.2	2.8	2.9	3.3	3.1	2.8	2.6	2.7	3.2	100	8.21
3	3.1	2.8	2.4	2.8	2.4	2.9	2.6	3.2	2.5	3.3	90	12.26
4	2.9	2.3	3.0	3.2	2.9	2.7	2.8	2.6	3.3	2.7	90	10.26
5	3.2	3.0	2.6	2.8	3.1	3.0	3.2	3.3	2.7	2.9	100	7.72
6	3.3	3.0	3.3	2.5	2.3	3.0	3.2	2.9	2.8	3.4	90	12.10

4.3. Field Growth Conditions

Morphological characteristics of cotton at different growth stages are shown in Figure 19. Maturity stage measurements revealed an average plant height of 95.5 cm, a boll diameter of 82 mm, and lint yield of 8916 kg/ha. In contrast, the traditional planting method yielded only 8178 kg/ha of lint during the same period, representing an increase of 738 kg/ha. On the basis of the data above, it is concluded that the no-till planting model positively impacts cotton yield, providing scientific support for agricultural production [34,35].

Compared with the discrete element simulation results, the field planting depth and its stability were lower than the simulation's outcomes. The discrepancy arises because simulation environments are relatively idealized, whereas actual field conditions are more complex and variable. These include inconsistent straw diameters, variations in straw coverage and soil moisture content, and uneven ground surfaces caused by tire compaction during the previous crop's autumn harvest. The combined effect of these factors reduces the stability of seeding depth. Additionally, field observations revealed that increasing the forward speed exacerbates the machine's vibration and reduces operational stability, thereby compromising work quality. Excessively high forward speeds adversely affect the uniformity and stability of both seeding depth and spacing, while excessively low speeds diminish operational efficiency. Testing determined that a forward speed of 4.5 km·h⁻¹ is optimal for the seeder. At this speed, the seeding depth averages approximately 28 mm, with a qualified seeding depth rate of 93.3% and a coefficient of variation for seeding depth of 12.26%.

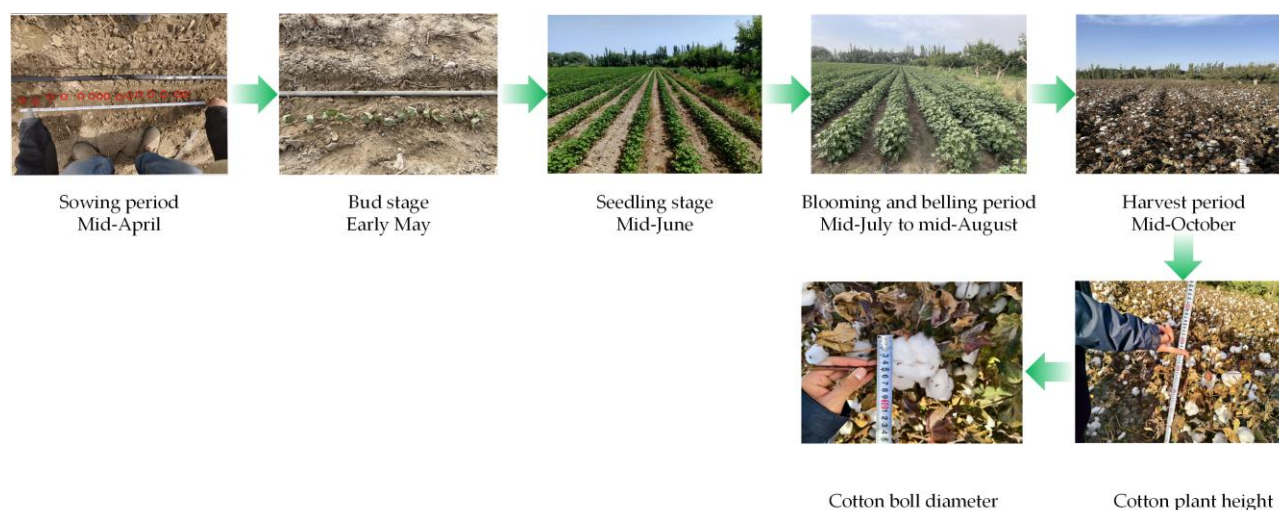


Figure 19. Cotton production mode in Xinjiang.

5. Conclusions

This study proposes a seed-band rotary tillage no-till cotton planter, exploring the arrangement scheme and cooperative operation principles of the rotary tillage–furrow opening–compaction assembly. Through single-factor experiments and discrete element numerical simulation methods, the influencing patterns on seeding quality and compaction performance were analyzed. Field trials were conducted for validation, yielding the following conclusions.

(1) Discrete element simulation results indicate that the significant factors affecting seeding and rolling quality, ranked from highest to lowest, are forward speed, compaction wheel depth, and the rotary tiller blade's penetration depth. When the forward speed is 4.5 km/h, the rotary tiller's working depth is 100 mm, the rotary tiller's rotational speed is set to 450 rad/min, the compaction wheel's depth is 10 mm, and the compaction wheel's working depth is 20 mm, the compaction roller achieves good leveling of the tilled soil surface, and the compaction wheel provides effective seeding bed compaction. Under the optimal parameter combination, the simulation results showed an average seeding depth of 26.51 mm with a coefficient of variation of 12.64%, and an average seeding spacing of 61.62 mm. These values meet the agronomic requirements for no-till cotton seeding under drip irrigation conditions in arid regions.

(2) The field test results indicate that under the optimal simulated parameter combination, the actual seeding depth was approximately 28 mm with a coefficient of variation of 12.26%. The seeding depth compliance rate reached 93.3%, while the average seeding spacing was 64.05 mm with a coefficient of variation of 12.46%, demonstrating excellent seeding performance that is consistent with the simulation results and complies with the agricultural practices requirements for cotton cultivation in Xinjiang region.

(3) This study still has some limitations. To address the lack of field experimental data, future field trials will incorporate measurements of soil temperature, moisture content, and microclimate conditions. Additionally, a large amount of surface straw is partially buried underground after rotary tillage, preventing cotton seeds from reaching their intended positions, thereby compromising sowing efficiency and resulting in reduced uniformity of planting. Future research may focus on optimizing sowing uniformity by adopting more appropriate seed distribution patterns and speed regulation mechanisms.

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References

1. National Bureau of Statistics of China. *China Statistical Yearbook 2025*; China Statistics Press: Beijing, China, 2025.
2. Shi, Z.L.; Wang, M.J.; Zhang, X.J.; Zhang, Y.; Li, M.H.; Lu, D.M. Design and Test of Folding Cotton Wide Film Spreading Precision Seeder. *Trans. Chin. Soc. Agric. Eng.* **2024**, *55*, 53–62.
3. Hu, C.; Wang, X.F.; Chen, X.G.; Tang, X.Y.; Zhao, Y.; Yan, C.R. Current Situation and Control Strategies of Residual Film Pollution in Xinjiang. *Trans. Chin. Soc. Agric. Eng.* **2019**, *35*, 223–234. <https://doi.org/10.11975/j.issn.1002-6819.2019.24.027>.
4. GB/T 25413-2010; Limit and Determination Standard of Residual Plastic Film in Farmland. State Administration for Market Regulation: Beijing, China, 2010. (In Chinese)
5. Dong, H.G.; Liu, T.; Li, Y.G. Effects of Plastic Film Residue on Cotton Yield and Soil Physical and Chemical Properties in Xinjiang. *Trans. Chin. Soc. Agric. Eng.* **2013**, *29*, 91–99. <http://www.tcsae.org/en/article/id/20130811>.
6. Ma, Y.; Li, Z.; Xu, Y.; Li, C.; Ding, H.; Li, C.; Tang, Q.; Liu, M.; Hou, J. The Development of No-Tillage Seeding Technology for Conservation Tillage—A Review. *Sustainability* **2025**, *17*, 1808. <https://doi.org/10.3390/su17051808>.
7. Zhang, X.Q.; Yang, W.F.; Xu, Y.J. Effects of Main Tillage Methods on Soil Structure, Nutrients and Micro-Ecological Environment of Upland in China: A Review. *Ecol. Environ. Sci.* **2019**, *28*, 2464–2472. <https://doi.org/10.16258/j.cnki.1674-5906.2019.12.020>.
8. Zhang, J.; Li, Y.L.; Li, B.G.; Zhou, H. Conservation Tillage Enhances Phosphorus Use Efficiency by Regulating Root Distribution and Soil Phosphorus Stratification in the Black Soil Region of Northeast China. *Soil Tillage Res.* **2026**, *258*, 107060. <https://doi.org/10.1016/j.still.2026.107060>.
9. Yan, L.; Dong, T.H.; La, Y.P. Effects of No-Tillage and Straw Returning on Soil Aggregates Composition and Organic Carbon Content in Black Soil Areas of Northeast China. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 181–188.
10. Wang, X.; Zhou, H.; Zhou, H.; Ji, J. Research Progress and Development in Anti-Blocking Methods for No-Till Seeders in Regenerative Agriculture. *Biosyst. Eng.* **2025**, *257*, 104215. <https://doi.org/10.1016/j.biosystemseng.2025.104215>.
11. Sadiq, M.; Li, G.; Rahim, N.; Tahir, M.M. Sustainable Conservation Tillage Technique for Improving Soil Health by Enhancing Soil Physicochemical Quality Indicators under Wheat Mono-Cropping System Conditions. *Sustainability* **2021**, *13*, 8177. <https://doi.org/10.3390/su13158177>.
12. Zhu, Y.; Li, J.Y.; Zhang, C.Y. Effects of long-term conservation tillage on black soil organic carbon components in sloping farmland. *Trans. Chin. Soc. Agric. Eng.* **2023**, *39*, 103–111. <https://doi.org/10.11975/j.issn.1002-6819.202303015>.
13. He, J.; Li, H.W.; Chen, H.T. Research Progress of Conservation Tillage Technology and Machine. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 1–19.
14. Li, H.; Ji, W.Y.; Shi, N.Y. Analysis on the Response Law of Soil Compaction with Depth Based on Roller Compacting Device. *Soybean Sci.* **2025**, *44*, 117–128.
15. Becker, R.K.; Barbosa, E.A.A.; Giarola, N.F.B.; Kochinski, E.G.; Povh, F.P.; de Paula, A.L.; Cherubin, M.R. Mechanical Intervention in Compacted No-Till Soil in Southern Brazil: Soil Physical Quality and Maize Yield. *Agronomy* **2022**, *12*, 2281. <https://doi.org/10.3390/agronomy12102281>.
16. Shang, J.J.; Liu, D.M.; Song, X.T.; Han, Y.B.; He, S.T.; Zhang, Y.; Liu, L.Y.; Chen, H.T. Sowing Depth Stability Analysis and Test Verification of No-Tillage Planter Parallel 4-Bar Row Unit. *Heliyon* **2024**, *10*, e36721. <https://doi.org/10.1016/j.heliyon.2024.e36721>.
17. Gao, Y.Y.; Zhai, C.Y.; Yang, S.; Zhao, X.G.; Wang, X.; Zhao, C.J. Measurement Method and Mathematical Model for the Seeding Downforce of Planter Row Unit. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 1–9. <https://doi.org/10.11975/j.issn.1002-6819.2020.05.001>.
18. Cao, X.P.; Wang, Q.J.; Li, H.W.; He, J.; Lu, C.Y.; Xu, D.J.; Wang, X.H. Design and experiment of pneumatic pressure control device for no-till planter. *Int. J. Agric. Biol. Eng.* **2023**, *16*, 37–46.
19. Oliveira, L.; Ortiz, B.; Pate, G.; Way, T.; Silva, R. Soil and Crop Response to Varying Planter's Downforce in Corn and Cotton Fields. *Smart Agric. Technol.* **2025**, *10*, 100798. <https://doi.org/10.1016/j.atech.2025.100798>.

20. Du, J.; Heng, Y.; Zheng, K.; Luo, C.; Zhu, Y.; Zhang, J.; Xia, J. Investigation of the Burial and Mixing Performance of a Rotary Tiller Using Discrete Element Method. *Soil Tillage Res.* **2022**, *220*, 105349. <https://doi.org/10.1016/j.still.2022.105349>.
21. Zhao, P.F.; Ju, X.T.; Yang, P.K.; Zheng, Z.Q.; Huang, Y.X.; Gao, X.J.; Shi, J.T. Design and Experiment of Fertilizer Pipe Front-Mounted Wheat Wide Seedling Belt Rotary Tillage Fertilization Planter. *Trans. Chin. Soc. Agric. Eng.* **2024**, *40*, 12–21.
22. Wei, W.Z. *Development and Key Components Design of Wheat Subsoiling Broad Seedlings and No-Tillage Planter*; Shandong University of Technology: Zibo, China, 2017. (In Chinese)
23. Karayel, D.; Jotautienė, E.; Šarauskis, E. The Effect of Furrow Opener and Disc Coulter Configurations on Seeding Performance under Different Residue Cover Densities. *AgriEngineering* **2024**, *6*, 1277–1288. <https://doi.org/10.3390/agriengineering6020073>.
24. Rosu, B.; Voicu, G.; Constantin, G.-A.; Tudor, P.; Stefan, E.-M. Aspects Regarding the Physical Parameters and Wear in the Work Process of the Disc Openers for Seeding Machines. *Agriculture* **2024**, *14*, 1066. <https://doi.org/10.3390/agriculture14071066>.
25. Ye, R.; Ma, X.; Zhao, J.; Liao, J.; Liu, X.; Xi, L.; Su, G. Optimization and Design of Disc-Type Furrow Opener of No-Till Seeder for Green Manure Crops in South Xinjiang Orchards. *Agriculture* **2023**, *13*, 1474. <https://doi.org/10.3390/agriculture13081474>.
26. Liu, H.G.; Li, Z.J.; Li, L. Effects of Deep Vertical Rotary Tillage Depth on the Improvement of Soil Physicochemical Properties and Cotton Yield in the Current Year and the Following Year in Severe Saline Land in Southern Xinjiang of China. *Trans. Chin. Soc. Agric. Eng.* **2024**, *40*, 45–57. (In Chinese)
27. Liu, Q.Y.; Liu, X.L.; Li, G.Z. Fractal Characteristics and Driving Factors of Soil Particle Size in the Surface Layer of Xinjiang. *Arid Land Geogr.* **2026**, *49*, 56–68.
28. Wei, S.; Zhang, C.H.; Zhan, Z.Y. Simulation and Optimization Test of Imitation Furrowing Process of Cotton Direct Seeding Machine Based on DEM-MBD Coupling. *Trans. Chin. Soc. Agric. Mach.* **2025**, *56*, 275–289+341.
29. Zhang, J.; Xia, M.; Chen, W.; Yuan, D.; Wu, C.; Zhu, J. Simulation Analysis and Experiments for Blade-Soil-Straw Interaction under Deep Ploughing Based on the Discrete Element Method. *Agriculture* **2023**, *13*, 136. <https://doi.org/10.3390/agriculture13010136>.
30. Fang, H.; Ji, C.; Tagar, A.A.; Zhang, Q.; Guo, J. Simulation Analysis of Straw Movement in Straw-Soil-Rotary Blade System. *Trans. Chin. Soc. Agric. Eng.* **2016**, *47*, 60–67.
31. Yan, D.X.; Yu, J.Q.; Wang, Y.; Zhou, L.; Yu, Y.J. A General Modelling Method for Soybean Seeds Based on the Discrete Element Method. *Powder Technol.* **2020**, *372*, 212–226. <https://doi.org/10.1016/j.powtec.2020.05.054>.
32. Ma, Y.; Wang, Z.; Shi, L.; Zhao, W.; Sun, B.; Dai, F.; Li, H. Determination of intrinsic parameters and calibration of contact parameters for wheat seed particles. *J. China Agric. Univ.* **2025**, *30*, 175–184.
33. *DG/T 028-2019; General Outline for Popularization and Appraisal of Agricultural Machinery: No-Tillage Seeder*. China Agriculture Press: Beijing, China, 2019.
34. Akplo, T.M.; Yemadje, P.L.; Imorou, L.; Sanni, B.; Boulakia, S.; Sekloka, E.; Tiftonell, P. Minimum Tillage Reduces Variability and Economic Risks in Cotton-Maize Rotations in Northern Benin. *Field Crops Res.* **2025**, *324*, 109795. <https://doi.org/10.1016/j.fcr.2025.109795>.
35. Wang, F.Y.; Han, H.Y.; Lin, H.; Chen, B.; Kong, X.H.; Ning, X.Z.; Wang, X.W.; Yu, Y.; Liu, J.D. Effects of Planting Patterns on Yield, Quality, and Defoliation in Machine-Harvested Cotton. *J. Integr. Agric.* **2019**, *18*, 2019–2028. [https://doi.org/10.1016/S2095-3119\(19\)62604-3](https://doi.org/10.1016/S2095-3119(19)62604-3).

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