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Optimization Research of Fertilizer Guiding Mechanism Based on the Discrete Element Method

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Abstract: - In view of the shortcomings of low uniformity and high discrete of fertilization in orchard, the Discrete Element Method was used to study the fertilization mechanism of the orchard ditching fertilizer applicator. Firstly, on the basis of studying the existing linear fertilizer guiding mechanism, a concave and convex fertilizer guiding mechanism was proposed, and a virtual simulation model of three fertilizer guiding mechanisms was established. Secondly, the basic parameters of granular organic fertilizers were analyzed, and the kinetic model was established by combining the kinetic analysis during the falling process. Finally, the uniformity of fertilization was evaluated by discrete coefficient and was set as the target. The discrete element simulation optimization experiments were carried out on the concave, linear, convex and different curvature radius of the fertilizer guiding mechanism, and the optimal concave fertilizer guiding mechanism and its optimal radius of curvature were optimized. Simulation and field experiments show that among the three kinds of fertilizer guiding mechanisms, the discrete coefficient of the convex fertilizer guiding mechanism is the smallest and the uniformity of fertilization is the highest; in the convex fertilizer guiding mechanism with different curvature radius, the coefficient of discrete is the smallest and the uniformity of fertilization is the highest when the radius of curvature is 600mm; after optimization, the discrete coefficient was reduced from 0.51 to 0.26, and the uniformity of fertilization was increased by 49.02%. This provides scientific basis for design optimization of orchard ditching fertilizer applicator.

Key-Words: - Fertilizer Guiding Mechanism, DEM, Simulation optimization, Discrete coefficient, Uniformity

1 Introduction

Fertilizer is the grain of fruit trees. Fertilization of fruit trees is the key operation link in fruit tree production. The quality of fertilization directly affects the absorption of nutrients in fruit trees. Rational fertilization is the basis for high quality and high yield of fruit trees [1,2,3]. Fruit trees fertilizer predominantly are inorganic fertilizer and organic fertilizer: Inorganic fertilizer is mainly chemical fertilizer, characterized by strong fertility and fast fertilizer efficiency, but it is easy to cause soil structure change, soil organic matter content decline, tree growth and fruit quality reduction; application of organic fertilizer can help improve soil physicochemical properties, improve leaf physiology, increase fruit yield and improve fruit quality [4,5,6]. Fertilization uniformity is a key factor affecting the effect of fertilization operations, and is an important indicator for evaluating the performance and effectiveness of work tools [7,8,9,10]. Patterson et al [11] studied the theoretical motion model and motion mechanism of various fertilizer granules, simulated and tested the fertilizer granule distribution and fertilization uniformity, and analyzed the average error between the theoretical value and the actual measured value, which laid the foundation for the mathematical theoretical model of the fertilizer application machine. P. Van Liedekerke et al [12] used the discrete element method to start the flow of granules from the container, and the plate and the inclined disk are used to simulate the flow of granules affected by the rotating disk. Artur Przywara et al [13] studied the influence of the structure and operating parameters of the centrifugal disc spreader on the spatial distribution of the fertilizer, determined the rotational speed of the disc, the feed position of the fertilizer on the disc, the blade angle on the disc and the type of fertilizer has an effect on the spatial distribution of fertilizer. Villette et al [14] proposed a new method for simultaneously measuring the horizontal flow and vertical flow distribution of a disc-type fertilizer, paving the way for studying the distribution of fertilizer granules and testing the uniformity of fertilization. Aphale et al [15] calculated and tested the trajectories of various fertilizer granules, and obtained the average error between the theoretical value and the actual measured value under different disk rotational speed conditions, which provided a theoretical basis for the test. Zhang Tao et al [16] simulated the fertilization process of the fertilizer-discharging mechanism through discrete elements, formulated design variables and optimization targets, developed motion simulation software and parameterized platform, optimized the structural parameters of the fertilizer-discharging mechanism, and improved the uniformity of fertilization. Chen Xiongfei et al [17] designed a two-stage spiral fertilizer device, and established a mathematical model of the single-circle discharge amount of the fertilizer-fertilizing spiral. It was determined through experiments that the two-stage spiral fertilizer-removing device had better fertilizer-removing effects for various forms and better adaptability with fertilizer. Yang Xinlun et al [18] established the mathematical model of the blade type fertilizer mechanism, formulated the design variables and optimization objectives, developed the motion simulation software and the parameterization platform, and optimized the structural parameters of the blade type fertilizer removal mechanism. Yuan Wensheng et al [19] designed a scoop wheel fertilizer discharge device and established the three-dimensional model for simulation of fertilizer, tested cavitation resistance and uniformity of the amount of fertilizer per hole fertilizer apparatus, and studied the fertilizer discharge effect of the fertilizer discharger under different rotation speeds of the fertilizer components. Lv Jinqing et al [20] carried out simulation tests on the screw-type fertilizer discharge mechanism under different working speed conditions, accurately analyzed the mathematical relationship between the rotational speed and the displacement, realized the optimal design of the screw-type fertilizer discharge mechanism, and improved the uniformity of fertilization.

After comprehensively analyzing the research status at home and abroad, and the effect of fertilizer-discharging mechanism on fertilization uniformity, a conclusion has been made that, at present, the research on the effect of fertilizer-dispensing institutions on fertilization uniformity is mature, but the research on the influence of fertilizer guiding mechanism on fertilization uniformity is still in its infancy. Based on the study of the influence of the fertilizer guiding mechanism on the uniformity of fertilization, this paper optimizes the existing fertilizer guiding mechanism and provides a theoretical basis for the design and processing of the orchard ditching fertilizer machine.

2 Orchard Double-row Ditching Fertilizer Structure Design

2.1 Machine Structure

Double-row orchards ditching fertilizer overall structure is shown in Fig. 1 and Fig. 2, mainly configured by the rack, fertilizer box, transmission, ditching mechanism, mechanism of fertilizer, fertilizer guiding mechanism, and soil covering machine, and the technical parameters of the whole machine are shown in Table 1.

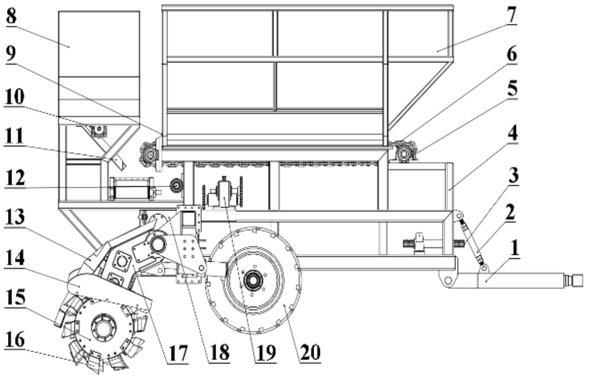


Fig. 1 Main view of the machine

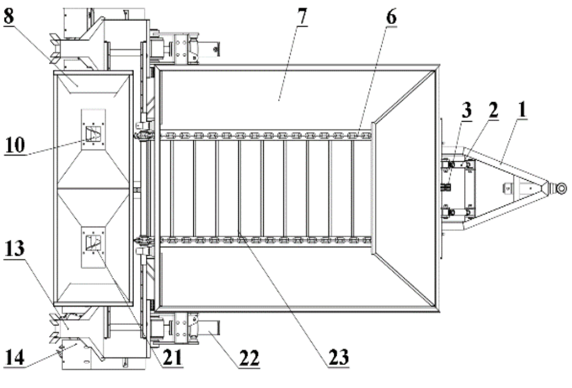


Fig. 2 Vertical view of the machine

1 traction rack 2 adjust pull pipe 3 drive shaft 4 rack 5 base fertilizer sprocket 6 O-chain 7 base fertilizer box 8 fertilizer box 9 base fertilizer outlet 10 auger 11 conveyor board 12 side transmission box 13 fertilizer guiding mechanism 14soil cover 15 trench cutter disc 16 trench cutter 17 trench transmission box 18 main transmission box 19 middle transmission box 20 wheel 21 fertilizer outlet 22 hydraulic cylinder 23 base fertilizer scraper

Table 1. Main technical parameters

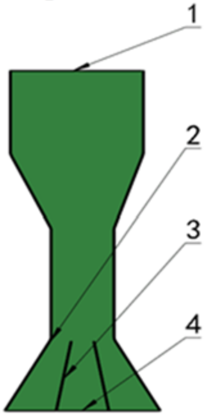
Item	Parameters	Units

Supporting power	≥58	kw
Outline size	3820×2040×2510	mm
Fertilization depth	0~50	mm
Fertilizer application amount	0.5~2	kg.m^{-1}
Base fertilizer application amount	3~5	kg.m^{-1}
Fertilizer box volume	650	L
Base fertilizer box volume	2500	L

2.2 Fertilizer Guiding Mechanism

The fertilization methods in the orchard mainly include the general application of the whole garden, the application of the crown, the application of the ring ditch, the application of the strip ditch, the application of the radial ditch and the application of the hole. For new orchards with wide line spacing and wide plant spacing, strip-shaped furrow fertilization is often used. The strip-shaped furrow fertilization method requires strips of 1000~2000mm long, 300~400mm wide and 300~500mm deep between the rows of fruit trees, then fertilize and cover the soil [21,22].

Because the amount of fertilization in the orchard is large, in order to ensure the smooth fall of the fertilizer, the fertilizer guiding mechanism of the existing orchard trenching and fertilizing machine is mostly a trough-shaped structure, as shown in Fig. 3. Among them, the fertilizer-in port of the fertilizer guiding mechanism is connected with the fertilizer-out port of the fertilizer-discharging mechanism, and the fertilizer-out port of the fertilizer guiding mechanism is equal to the groove width. The fertilizer plug-in plate in the fertilizer guiding mechanism divides the fertilizer-transfer port and the fertilizer-out port into three parts.



1 Fertilizer-in port 2 Fertilizer-transfer port 3 Fertilizer plug-in plate 4 Fertilizer-out port

Fig. 3 Diagrammatic sketch of fertilizer guiding mechanism

3 Fertilizer Granules Motion Analysis

3.1 Determination of Parameters of Fertilizer Granules Characteristics

The fertilizer granules used in the experiment were granular organic fertilizers. 100 granular organic fertilizers were randomly selected as the parameter measurement samples, which were placed on blank A4 paper and measured by image processing technology to obtain the accurate size of the granular organic fertilizer.

First, a black square of 10mm×10mm was fabricated on the red A4 paper as an area calibration, and blank A4 paper with area calibration was used as the background plate. Next, the parameter measurement was randomly scattered on the background board, and the original image of granular organic fertilizers was obtained. The color difference between the test sample and the background plate was used, and a single original image was divided to obtain the threshold value of the other image, as shown in Fig. 4. Finally, according to the area calibration on the background plate in the binary image, the equivalent diameter and circularity of the granular organic fertilizer were calculated, and the minimum equivalent diameter, the minimum circularity, the maximum equivalent diameter and the maximum circularity, the average equivalent diameter and the average circularity of the statistical parameter measurement sample were calculated, as shown in Table 2. The granular organic fertilizer circularity distribution diagram was drawn, as shown in Fig. 5.

$$\text{Circularity } \O = 4\pi S/C^2 \tag{1}$$

$$\text{Equivalent diameter } d = C/\pi \tag{2}$$

$$\text{The average diameter } \bar{D} = D/N \tag{3}$$

$$D = \textstyle\sum_{i=1}^{N} d_i \tag{4}$$

In equations (1), (2), (3), (4):

S-the area of granular organic fertilizer; *C*- the circumference of granular organic fertilizer; *N*-the amount of granular organic fertilizer

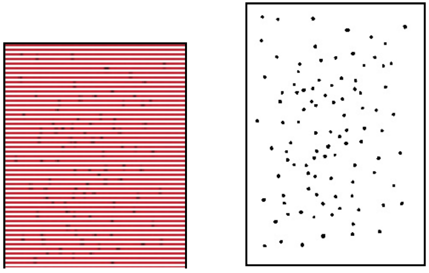

(a) Original image (b) Binary image

Fig. 4 Original image and binary image of granular organic fertilizer

It can be seen from Table 2 and Fig. 4 that the circularity of the 100-parameter measurement samples is 0.93, and the concentration is between 0.90 and 0.97. As the circularity of parameter measurement sample gets closer to 1, the closer the parameter measurement sample is to the sphere [23]. Since the parameter measurement sample has a high circularity distribution, the granular organic fertilizer is assumed to be spherical during the simulation.

Table 2. Parameter of granular organic fertilizer

Granular organic fertilizer	Circumference C(mm)	Equivalent diameter $\overline{D}$(mm)	Circularity Ø
Average value	9.16	2.92	0.93
Minimum value	7.60	2.42	0.90
Maximum value	11.92	3.79	0.97

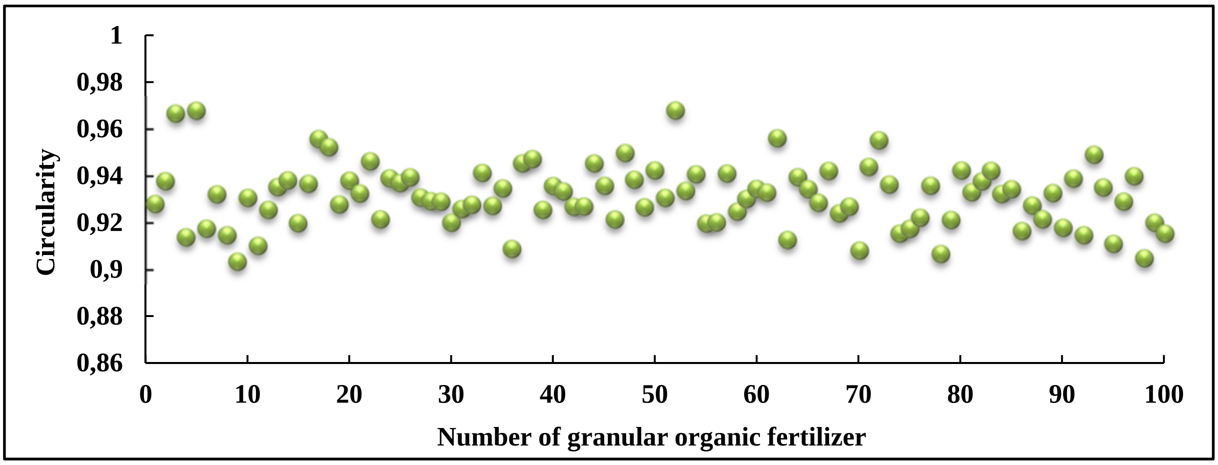


Fig. 5 Circularity distribution of granular organic fertilizer

3.2 The Equation of Motion of Fertilizer Granules in the Fertilizer Guiding Mechanism

Granular organic fertilizers fall into the fertilizer guiding mechanism by means of fertilizer discharge mechanism, with a certain initial velocity v_p. After the granular organic fertilizer enters the fertilizer guiding mechanism, it is subjected to gravity G_p, Buoyancy F_{fp}, and air resistance F_{zp}. After the interaction, it finally falls into the ditch of the orchard trenching and fertilizing machine. The specific process is shown in the Fig. 6 [24].

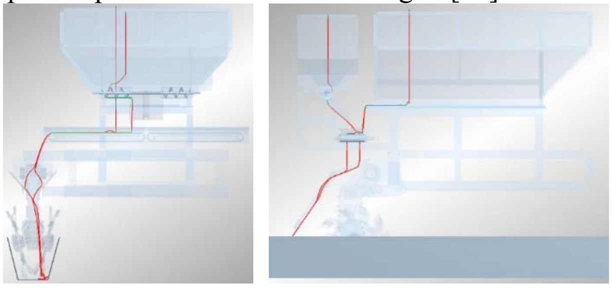


Fig. 6 Falling process of fertilizer

$$\text{Gravity } G_p = \rho_p V_p \tag{5}$$

$$\text{Buoyancy } F_{fp} = \rho_a V_p g \tag{6}$$

$$\text{Air resistance } F_{zp} = \frac{1}{2} K \rho_p S_p V_p^{2} \tag{7}$$

$$\text{Air resistance coefficient } K = \frac{3}{8} C_D \rho_a \frac{1}{\rho_p r_p} \tag{8}$$

There is a correlation between drag coefficient C_D and Reynolds number R_e:

$$R_e = 2\frac{r_p v_p \rho_p}{\eta_a} \tag{9}$$

In equations (5), (6), (7), (8), (9):

ρ_p-granular organic fertilizer density; V_p-volume of granular organic fertilizer; ρ_a -air density; η_a -aerodynamic viscosity; v_P -granular organic fertilizer velocity; S_p -granular organic fertilizer frontal area; r_p-granular organic fertilizer radius; g-gravity acceleration;

Assuming that the positive direction of the *Z* axis is opposite to the direction of gravity of the granular organic fertilizer, the equation of motion of the granular organic fertilizer in the *X*, *Y*, and *Z* directions [25,26] is

$$X\text{ direction } \frac{\mathrm{d}^2x}{\mathrm{d}t^2}=-\mathrm{K}v_{Px}\sqrt{v_{Px}{}^2+v_{Py}{}^2+v_{Pz}{}^2} \quad (10)$$

$$Y\text{ direction } \frac{\mathrm{d}^2y}{\mathrm{d}t^2}=-\mathrm{K}v_{Py}\sqrt{v_{Px}{}^2+v_{Py}{}^2+v_{Pz}{}^2} \quad (11)$$

$$Z\text{ direction } \frac{\mathrm{d}^2z}{\mathrm{d}t^2}=-\mathrm{K}v_{Pz}\sqrt{v_{Px}{}^2+v_{Py}{}^2+v_{Pz}{}^2} \quad (12)$$

In equations (10), (11), (12):
v_{Px}-the velocity component in the X direction; v_{Py}-the velocity component in the Y direction; v_{Pz}-the velocity component in the Z direction;

3.3 Fertilization Uniformity Evaluation

The granular organic fertilizer passes through the fertilizer guiding mechanism and finally falls into the ditch of the orchard ditching fertilizing machine. In order to evaluate the uniformity of fertilization, the distribution range of fertilizer in a ditch is selected as the sampling area, and meshing is performed according to 15 rows and 15 columns, as shown in Fig. 7. Among them, the width of the sampling area is the groove width, and the cell grid size is 20mm×20mm.

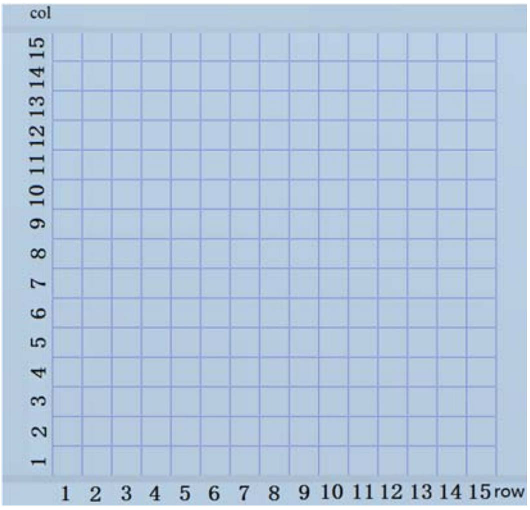


Fig. 7 Mesh partition of sampling regions

The discrete coefficient CV is used as a measure of the uniformity of fertilizer distribution. The equations for calculating the discrete coefficient is:

$$CV=\frac{\mathrm{S}}{\bar{\mathrm{q}}} \quad (13)$$

$$S=\sqrt{\frac{\sum_{i=1}^{n}(q_i-\bar{q})^2}{n-1}} \quad (14)$$

$$\bar{q}=\sqrt{\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{q_i})^2}{n}} \quad (15)$$

In equations (13), (14), (15):

S-standard deviation; $\bar{q}$-The average number of samples in the unit area of the mesh granular organic fertilizer; n-total number of cell grids in the entire sampling area; q_i-the number of samples in *the i-th* unit lattice region granular organic fertilizer;

To better reflect the distribution of granular organic fertilizer in the entire sampling area, the discrete coefficients of the 1th row, and the 15th row are selected as a reflection of the edge area of the distribution of organic fertilizer, discrete coefficients of 5th row, 8th row, 11th row are used as a parameter to reflect the uniformity of granular organic fertilizer distribution in the middle region.

4 Experiment and Analysis

Firstly, the fertilizer guiding mechanism was introduced into the EDEM simulation software and the relevant parameters were set. In order to obtain the effect of the granular organic fertilizer passing through the fertilizer guiding mechanism into the ditch, an open groove of 1000mm in length, 300mm in width and 400mm in depth was set to simulate the ditching of the ditching and fertilizing machine. The open groove was located directly below the export of the fertilizer guiding mechanism, wherein the axis was in the same vertical plane as the central axis of the fertilizer guiding mechanism, and the bottom of the opening groove was 200mm away from the export of the fertilizer guiding mechanism. Secondly, the fertilizer guiding mechanism was set as a random granules generator, so that granular organic fertilizer was randomly generated at the opening port in the simulation process. Among them, the granular organic fertilizer was randomly generated with an average equivalent diameter of 2.92mm as the mean value, a minimum equivalent diameter of 2.42mm, and a maximum equivalent diameter of 3.79mm. Finally, the motion characteristics of the assembly was set up. According to the principle of relative motion, the motion of the assembly was converted into the relative motion of the geometry, that is, the open groove moved in a reverse direction with respect to the fertilizer guiding mechanism at a speed of 0.25m/s [27].

In the simulation experiment, in order to ensure the accuracy of the test data under different structural parameters, the total simulation time was set to 2s, the fixed time step was set to 20%, and the target storage interval was set to 0.04s. The material of the mechanism was set to steel, and the relevant material parameters in the test were shown in Table 3. The dynamic friction coefficient and the static friction factor between the material granules and the different materials were determined by the shear box method and the bevel method respectively. The dynamic and static friction factor measurement test of the material granules and each material was repeated three times, and the test results were averaged; The free fall was utilized. The method was used to determine the collision recovery coefficient between material granules and different materials. The collision recovery coefficient determination test of material granules and the same material was repeated three times, and the test results were averaged. The contact mechanical parameters between different materials were shown in Table 4.

Table 3. Parameter of material

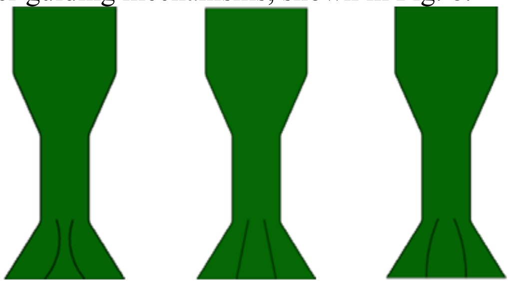
Parameter	Granular organic fertilizer	Fertilizer guiding mechanism	Land
Poisson ratio	0.25	0.45	0.50
Shear modulus/Pa	1×10^7	1×10^6	1×10^8
Density/（$kg\cdot m^{-3}$）	1300	3500	1200

Table 4. Parameter of contact mechanics between materials

Parameter	Granular organic fertilizer—Granular organic fertilizer	Granular organic fertilizer—Fertilizer guiding mechanism	Granular organic fertilizer—Land
Recovery coefficient	0.10	0.45	0.02
Static friction factor	0.30	0.30	1.25
Dynamic friction factor	0.25	0.20	1.25

4.1 Test and Analysis of Different Shapes of Fertilizer Plug-in Plate

In the fertilizer guiding mechanism, the fertilizer plug-in plate was one of the important factors affecting the uniformity of fertilization. The fertilizer plug-in plate of the existing linear fertilizer guiding mechanism was a linear type, and on this basis, a concave and a convex fertilizer guiding mechanism are proposed. Among them, the fertilizer plug-in plate of the concave fertilizer guiding mechanism was a concave curve type, and the fertilizer plug-in plate of the convex fertilizer guiding mechanism was a convex curved type, and the three fertilizer plug-in plates basically covered most guiding fertilizer insertion boards, which covered the main possible types of fertilizer plug-in plates, namely the concave, linear, and convex fertilizer guiding mechanisms, shown in Fig. 8.



(a). concave type (b). linear type (c). convex type

Fig. 8 Diagrammatic sketch of three fertilizer guiding mechanisms

The shape of the fertilizer plug-in plate in the fertilizer guiding mechanism was taken as a single factor variable, and other parameters were unchanged. The simulation tests were carried out on the concave, linear and convex fertilizer guiding mechanisms respectively. Among them, the radius of curvature of the fertilizer plug-in plate of the concave and the linear fertilizer guiding mechanism was set to 350mm.

At 1s, the velocity directions of 330 granular organic fertilizers at the fertilizer outlets of the concave, linear and convex types were measured, as shown in Table 5. Among them, it was represented by -1~1 in the EDEM simulation software. Based on the horizontal speed, the entire speed plane was equally divided into six parts at intervals of 30°, as shown in Fig. 9. The speed direction in Table 5 through

$$\angle\alpha=\frac{v_{fi}}{2}\times180° \tag{16}$$

was converted to the speed plane of Fig. 9, and the amount of granular organic fertilizer in each part was counted. The velocity distribution map of different parts of granular organic fertilizer was drawn, as shown in Fig. 10.

In equation (16):

"$\angle\alpha$"-the angle between the velocity direction of the granular organic fertilizer and the horizontal velocity direction; "v_{fi}"-the speed direction of the i-th granular organic fertilizer;

Table 5. Velocity direction of granular organic fertilizer

Item	Velocity direction of granular organic fertilizer in concave fertilizer guiding mechanism	Velocity direction of granular organic fertilizer in linear fertilizer guiding mechanism	Velocity direction of granular organic fertilizer in convex fertilizer guiding mechanism
Minimum value	-0.98	-0.98	-0.98
Maximum value	0.99	0.99	0.99

Average value	0.18	0.34	0.13
Variance	0.35	0.40	0.30

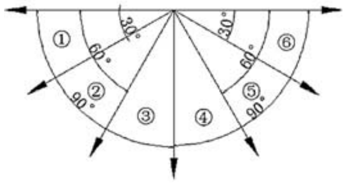


Fig. 9 Partition of velocity direction

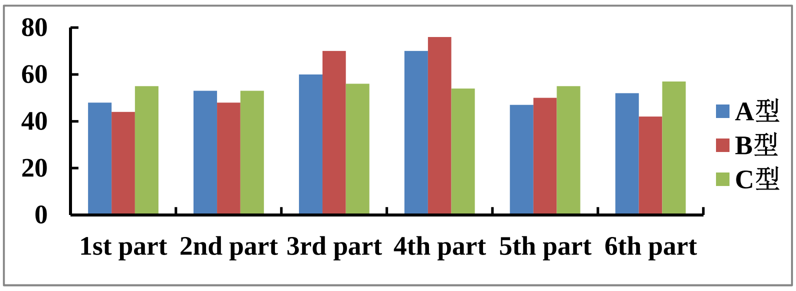


Fig. 10 Distribution of velocity direction in different parts

It can be seen from Fig. 10 that in the concave and linear fertilizer guiding mechanism, the granule direction of the granular organic fertilizer is distributed in the third and fourth parts, and the number of granules is higher than the first, second, fifth and sixth parts; In the convex fertilizer guiding mechanism, the granule direction distribution of the granular organic fertilizer is almost equal in the number of granules in each part. The granular organic fertilizer in the first and sixth parts of the velocity direction is concentrated on both sides of the bottom of the ditch when falling into the bottom of the ditch; the granular organic fertilizer in the third and fourth parts of the velocity direction is concentrated in the bottom of the ditch when falling into the middle part of the bottom of the ditch; the granular organic fertilizer in the second and fifth parts of the velocity direction is concentrated in the middle of the ditch when it falls into the bottom of the ditch. In the concave and linear fertilizer guiding mechanism, when the granular organic fertilizer falls into the bottom of the ditch, it is concentrated in the middle part of the ditch, and the distribution on both sides is less, resulting in uneven distribution of granular organic fertilizer; in the convex fertilizer guiding mechanism, the velocity direction of the granular organic fertilizer is distributed evenly in all parts, and the distribution after falling into the bottom of the groove is relatively uniform.

In order to further evaluate the uniformity of fertilization, the discrete coefficients of the edge region and the middle region in the sampling area were calculated and counted. The results of the discrete coefficients of the edge regions of different fertilizer guiding mechanisms are shown in Table 6. The discrete coefficients of the middle regions of different fertilizer guiding institutions are shown in Table 7.

Table 6. CV of different fertilizer guiding mechanisms in edge region

Edge region	CV of concave fertilizer guiding mechanism	CV of linear fertilizer guiding mechanism	CV of convex fertilizer guiding mechanism
1st row	0.57	0.43	0.36
15th row	0.50	0.54	0.43

Table 7. CV of different fertilizer guiding mechanisms in middle region

Middle region	CV of concave fertilizer guiding mechanism	CV of linear fertilizer guiding mechanism	CV of convex fertilizer guiding mechanism
5th row	0.43	0.50	0.29
8th row	0.42	0.52	0.32
11th row	0.42	0.49	0.28

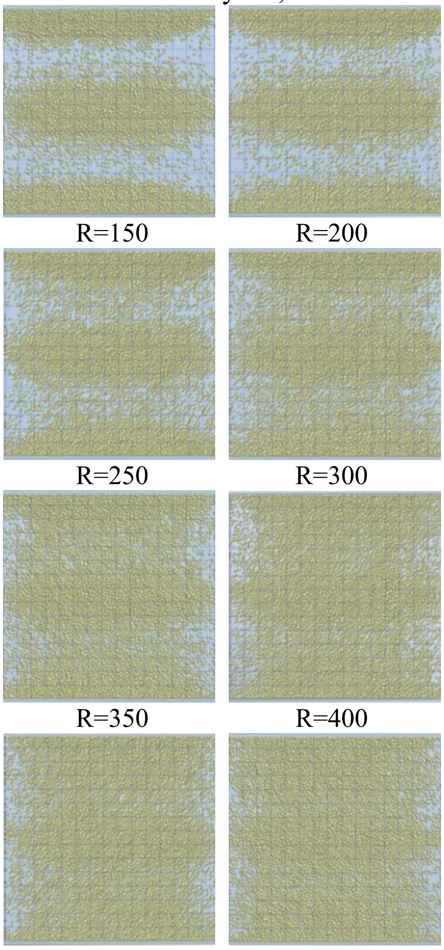
From the discrete coefficients of each region in the sampling area, it can be seen that in the three fertilizer guiding mechanisms of concave, linear and convex that, the discrete coefficients of the edge region and the middle region of the convex fertilizer guiding mechanism are lower than the concave and linear guides. The discrete coefficient of each part of the fertilizer guiding mechanism has the highest uniformity of fertilization.

The shape of the fertilizer plug-in plate changes the speed direction of the granular organic fertilizer, thereby affecting the uniformity of fertilization. The convex fertilizer plug-in plate is superior to the linear and concave fertilizer plug-in plate, and the convex fertilizer guiding mechanism is optimal.

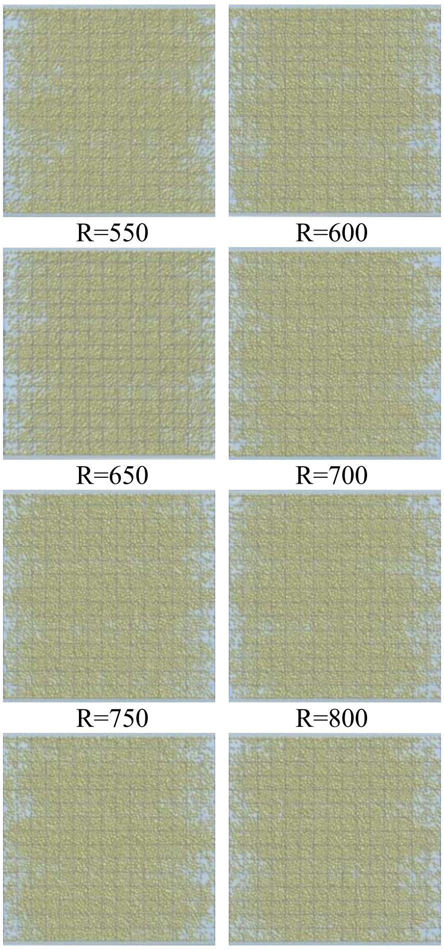
4.2 Test and Analysis of the Fertilizer Plug-in Plate with Different Curvature Radius

In order to further determine the influence of the fertilizer plug-in plate with different curvature radius on the fertilization uniformity in the convex fertilizer guiding mechanism, the radius of curvature of the fertilizer plug-in plate was taken as a single factor variable, with a radius of curvature of

150mm~800mm at intervals of 50mm. The simulation experiment was carried out on the fertilizer plug-in plate, and the simulation results are shown in Fig. 11. Separate the discrete coefficients of the edge region and the middle region at different curvature radius were analyzed, as shown in Table 8.



R=150 R=200
R=250 R=300
R=350 R=400
R=450 R=500



R=550 R=600
R=650 R=700
R=750 R=800
R=850 R=900

Fig. 11 Simulation result under different curvature radius

Table 8. CV under different curvature radius

Curvature radius	Edge region		Middle region		
	1st row	15th row	5th row	8th row	11th row
150	0.99	1.02	0.81	0.82	0.86
200	0.73	0.82	0.67	0.66	0.67
250	0.64	0.54	0.52	0.54	0.54
300	0.53	0.50	0.44	0.39	0.44
350	0.36	0.44	0.29	0.32	0.28
400	0.30	0.32	0.25	0.24	0.30
450	0.21	0.38	0.25	0.21	0.23
500	0.23	0.37	0.19	0.16	0.19
550	0.18	0.31	0.15	0.21	0.16
600	0.19	0.29	0.20	0.18	0.15
650	0.21	0.39	0.16	0.15	0.19
700	0.24	0.36	0.21	0.19	0.17
750	0.28	0.28	0.17	0.20	0.21
800	0.25	0.37	0.14	0.18	0.17

It can be seen from Table 8 that when the radius of curvature is in the range of 150mm~550mm, the discrete coefficient of the edge region and the middle region is gradually decreased; when the radius of curvature is in the range of 550mm~800mm, the discrete coefficient of the edge region and the middle region does not change much; the radius of curvature of the fertilizer plug-in plate affects the uniformity of fertilization within a certain range.

To further describe the relationship between the radius of curvature and the uniformity of fertilization, a cubic polynomial was used to fit the discrete coefficient curves of the edge region and the middle region.

First, at different radius of curvature, the average of the discrete coefficients of the first row and the 15th row is taken as the feature point of the discrete coefficient of the edge region; secondly, at the different radius of curvature, the discrete coefficient of the fifth row, the eighth row, the 11th row is averaged and used as the feature point of the middle region discrete coefficient. Finally, the cubic polynomial fitting is performed on the feature points of the edge region and the middle region to obtain the discrete coefficient fitting curve between the edge region and the middle region. The results of the discrete coefficient fitting are shown in Fig. 12.

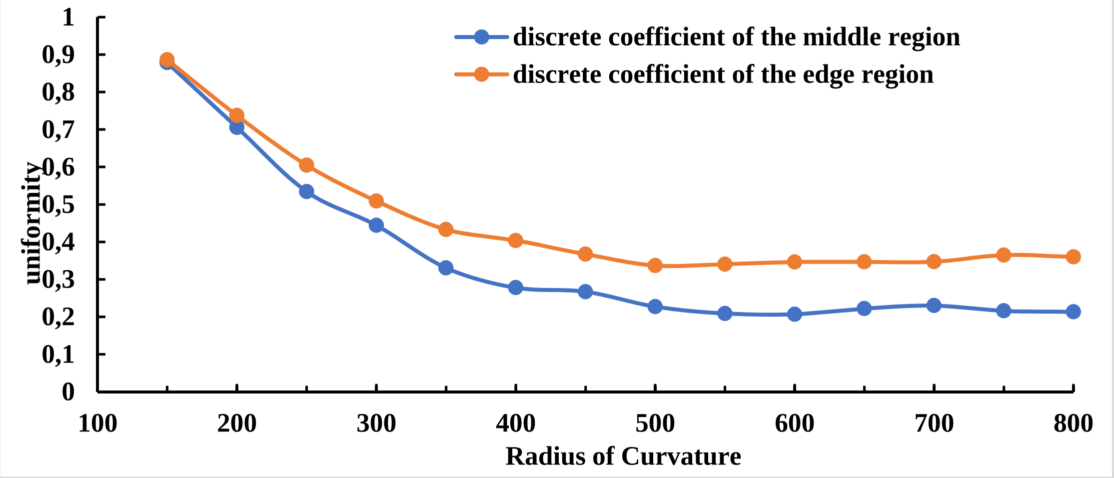


Fig. 12 Fitting curve of CV

It can be seen that the edge region fitting discrete coefficient obtains a minimum value when the radius of curvature is 566mm, and the middle region fitting discrete coefficient obtains a minimum value when the radius of curvature is 596mm. In order to ensure that the discrete coefficients of edge and middle regions are minimized, and combined with processing technology and cost, the optimal curvature radius is finally determined to be 600 mm. In the convex fertilizer guiding mechanism, the radius of curvature of the fertilizer plug-in plate affects the uniformity of fertilization. Under the processing conditions, when the radius of curvature of the fertilizer plug-in plate is 600mm, the cost is low and the uniformity of fertilization is high.

4.3 Field Trials

In mid-June 2017, a field trial was conducted in the experimental farm of Henghe in Shandong Province, as shown in Fig. 13. The farm was a large-scale standardized planting of orchard, with a row spacing of 2.5m and a plant spacing of 1m. The Plant was 3 years old and grows well. The test site was loam, the soil had an absolute moisture content of 23.3%, the soil firmness was 76.0kPa, and the terrain was flat, which provided favorable conditions for the smooth progress of the test. The test prototype was a two-row ditching and fertilizing machine for the orchard. The fertilizer guiding mechanism was a linear fertilizer guiding mechanism before optimization and an external convex fertilizer guiding mechanism with a radius of curvature of 600mm. In order to ensure the accuracy of the experimental data, three regions were randomly selected, and repeated verification tests of three discrete coefficient measurements were performed for each region, and the discrete coefficient curves before and after optimization were plotted, as shown in Fig. 14.

(a). Field operation (b). Fertilization effect in sampling area before and after optimization

Fig. 13 Field Test

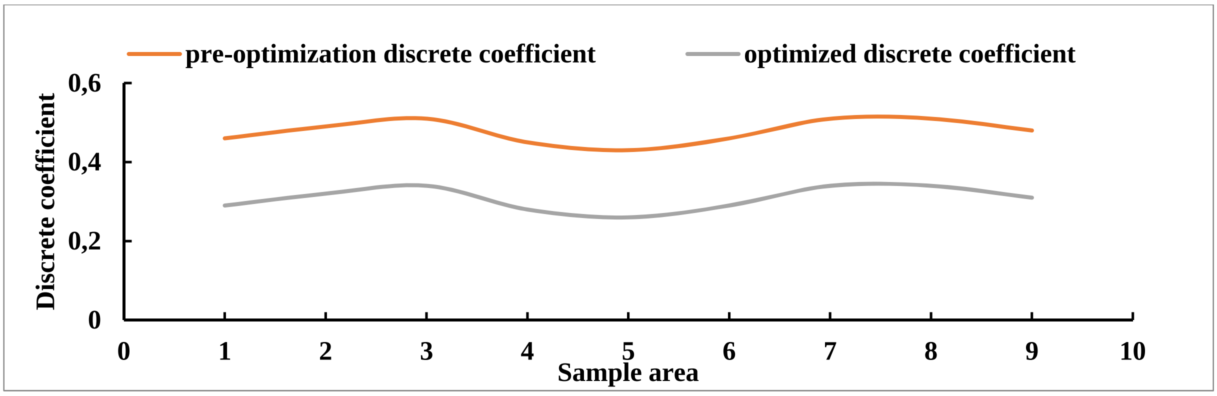


Fig. 14 CV curve before and after optimization in different regions

The experimental results show that the optimized discrete coefficient curve is below the pre-optimization discrete coefficient curve. The optimized discrete coefficient is significantly smaller than the pre-optimization discrete coefficient. The average value of the discrete coefficient of the sampled area before optimization is 0.51. The average value of the discrete coefficient of the sampled area after optimization is 0.26. Fertilization uniformity increased by 49.02%.

After optimizing the parameters of the fertilizer guiding mechanism, under the conditions of the same ditch depth and the speed, the discrete coefficient of the sampling area is reduced, the uniformity of fertilization is improved, and the technical requirements for the ditching and fertilization of the orchard are satisfied.

5 Conclusions

(1) Based on the existing linear fertilizer guiding mechanism, two other fertilizer guiding mechanisms, a concave fertilizer guiding mechanism and a convex fertilizer guiding mechanism are proposed.

(2) By using the shape of the fertilizer plug-in plate as a single factor variable, the three kinds of fertilizer guiding mechanisms of concave, linear and convex type are simulated respectively to determine the convex fertilizer plug-in plate of the convex fertilizer guiding mechanism has the best shape and its uniformity of fertilization is the highest. Among them, the shape of the fertilizer plug-in plate affects the uniformity of fertilization by changing the velocity direction of the granular organic fertilizer.

(3) By using the radius of curvature of the fertilizer plug-in plate as a single factor variable, the simulation experiment is carried out on the convex fertilizer guiding mechanism with the radius of curvature of 150mm~800mm, and the polynomial is used to fit the discrete coefficient of the edge region and the middle region to determine the curve. The convex fertilizer guiding mechanism has an optimum radius of curvature of 600 mm. According to the field test, the discrete coefficient after optimization was reduced from 0.51 to 0.26, and the uniformity of fertilization was increased by 49.02%.

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