Research On The Performance Of Particles Distribution Of Fertilizer Point-applied Device In Root-zone

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Root-zone fertilization (RZF) can improve fertilizer utilization, but the development progress of fertilizer point-applied technology is very slow due to lack of fertilizer point-applied device. In this work, a new type of fertilizer point-application device based on the mechanism of Geneva Drive is taken as the specific analysis object, the impacts of working speed, fertilizer discharging height and fertilizer discharging mass on the fertilizer particles distribution performance are explored by DEM-MBD simulation. Box-Behnken test optimization results show that when the working speed, fertilizer discharge height and fertilizer discharging mass of 3.66 km/h, 27 mm and 4.55 g, the fertilizer distribution length and coefficient of variation were 78.62 mm 7.58%, respectively. Based on the simulation results a fertilizer point-applied device was produced and field experiments were carried out at working speeds of 3.6, 4.5 and 5.4 km/h. The results showed fertilizer particle distribution lengths of 14.58 cm, 16.32 cm and 19.35 cm respectively. This paper can provide a mature mechanical device for fertilizer granule point-application agronomy and improve mechanization and operational quality.

Keywords: Fertilizer point-applied device; Root-zone fertilization; DEM-MBD; Particles distribution

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1. Introduction

With the global grain system facing demand increases by population growth and arable land decline, increasing chemical fertilizers use efficiency in agricultural systems is necessary in order to simultaneously achieve greater crop production and lower environmental impacts [1–3]. According to the literature, approximately 70% of the nutrients required for plant growth come from chemical fertilizers [4]. Due to N leaching and ammonia emission, the use efficiency of N fertilizer is often low (about 30–50%) [5, 6]. The practice of obtaining high yields through extensive use of chemical fertilizers has threatened agro-environmental sustainability in many countries and regions [7].

The traditional (banding) fertilization mode that farmers are accustomed to adopt is that the fertilizer is applied to the position of 5 10 cm from the seed row and 10 cm deep when the corn is sowed. Some fertilizers are located in the soil which is far from the roots and the root system efficiency is very low. The root system cannot absorb the nutrients released by the fertilizer particles in time. Excess fertilizer nutrients leave the cultivated soil due to runoff, leaching or gaseous loss, thereby causing groundwater or air pollution [3, 7–11]. Root-zone fertilization (RZF) is a much more exact deep placement of fertilization to improve the efficiency of fertilizer application and achieve low levels of leaching according to the specific crop [12]. RZF minimizes the contact between soil and fertilizer, the strong inhibition of the high concentration of nutrients in the fertile soil delays the conversion of ammonium nitrogen to nitrate nitrogen, therefore increasing the efficiency of nutrient use [13–18].

In general, RZF is a cleaner production strategy for traditional fertilizer and friendly to farmers, but there is a lack of research on the mechanism of fertilizer granules forming pile and apply of root-zone fertilization machinery. Zhang [19] distributed the fertilizer in the soil layer with a depth of 7∼23 cm directly below the seeds by controlling the opening and closing of the flaps. LS-DYNA is used to simulate and analyze the falling fertilizer status of the point fertilization system based on the SPH algorithm. Wu [20] used the rocker to control the duckbill valve to realize the cavitation of fertilizer, the experimental design was used to optimize the parameters affecting the fertilizer discharge mass per hole and the distance of fertilizer piles, but the fertilizer particles distribution length was not studied.

Based on the above-mentioned, the previous research mostly uses the experimental design and FEM. However, fertilizer particles are a typical multi-particle system. The above-mentioned methods cannot truly reflect the fertilizer particles distribution that is a significant parameter for the RZF performance. Thus, the granular behavior of fertilizer is to be accurately modelled, this is what the DEM can achieve, which DEM is developed to simulate the dynamic behavior of granular material such as granular flow [21].

Based on the mechanism of the Geneva drive, this study has designed a new fertilizer point-application device that can effectively reduce fertilizer granule breakage and improve the fertilizer granule point-applied formation effect. Fertilizer point-application device is taken as the specific analysis object, the impacts of working speed, fertilizer discharging height and fertilizer discharging mass on the fertilizer particles distribution performance are explored by DEM-MBD simulation, and the interactive influence of factors is obtained through Box-Behnken. This paper will provide equipment and technical references for the development of efficient fertilizer application techniques.

2. Materials and method

2.1. Model of fertilizer point-applied device

The main component of fertilizer point-applied machine is shown in Fig. 1(a), which consists of fertilizer tank, fertilizer feeder, fertilizer supply tube, fertilizer point-application device (FPAD), layered plates, shovel body and shovel tip. The shovel body and shovel tip break the soil when the machine travels at a certain speed v_m to open a trench with a depth of 20 cm. At the same time, the fertilizer feeder uniformly discharges the fertilizer in the fertilizer tank, and enters the trench with a depth of 20 cm and FPAD through the fertilizer supply tube.

The FPAD includes discharge wheel, driver wheel and driven wheel (Fig. 1(b)), discharge wheel and driven wheel are connected by bolts as a whole. Driven wheel is driven by driving wheel and the driven wheel rotates 72° for every turn of the driving wheel, and drives the fertilizer wheel to cast one hole of fertilizer at the same time. Due to the fluidity of the soil, part of the soil flows back into the trench, forming a 10cm deep trench under the action of layered plates. The fertilizer discharged from the FPAD enters the trench of 10cm deep, which means that the shallow plough layer fertilizer is applied in point, and the deep plough layer is applied in banding.

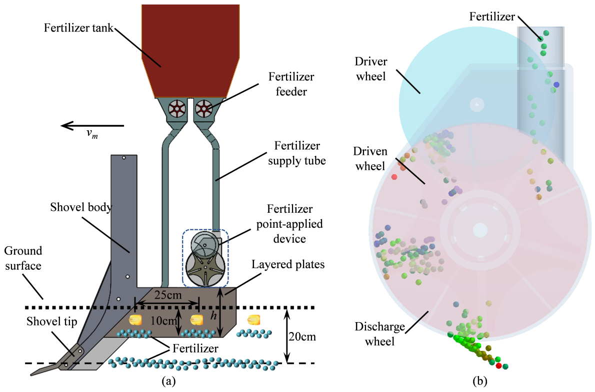

Fig. 1. Model of fertilizer point-applied device: (a) actual model; (b) simulation model based on EDEM.

2.2. Establishment and parameter selection of the EDEM simulation model

This article selects Stanley compound fertilizer $(\mathrm{N} - \mathrm{P_2O_5} - \mathrm{K_2O} \quad 15-15-15)$ produced by Stanley Agriculture Group Co., Ltd. as the research object. Randomly select 100 samples of fertilizer particles, and measure the average triaxial size of the fertilizer particles with a digital caliper (precision 0.01mm) to be about 3.83 mm×3.62 mm×3.45 mm. The equivalent diameter and the sphericity rate are 3.63 and 0.95 respectively. The angle of repose, bulk density, and water content are 31.6°, 984.6 kg/m3, 0.23%, respectively. Due to the high sphericity rate of fertilizer particles, a single sphere with a diameter of 3.63 mm was used in the DEM simulation to establish a fertilizer particle simulation model.

The constitutive parameters and contact parameters of the coated fertilizer particles used in the simulation refer to related literature [22–24], and the values are shown in Table 1.

2.3. Model of Geneva mechanism

The Geneva mechanism (Fig. 2(a)) is a key component of the FPAD, and the movement characteristics of the Geneva mechanism have a direct impact on the fertilizer distribution performance of the FPAD. As shown in Fig. 2(a), the Geneva mechanism is comprised of two wheels, a driver

Table 1. Simulation parameter value table.

Parameter	Fertilizer	ABS	Soil
Poisson's ratio	0.225	0.394	0.3
Real density (kg/m^3)	2474	1060	2500
Shear modulus (Pa)	1.528×10^8	8.9×10^8	1.0×10^6
Collision recovery factor	0.654	0.47	0.02
Coefficient of static friction	0.189	0.42	1.25
Rolling friction coefficient	0.034	0.095	1.24

and a driven. The driver wheel is composed of a cam pin, the blocking wheel and the rotate indentation. The driven wheel is composed of grooves and the locking wheel. The Geneva mechanism is a typical multi-rigid body system and the movement of the driver and driven wheel is complex. In this paper, the DEM analysis model of the FPAD is established based on RecurDyn (Fig. 2(b)), where the position and movement characteristics of mechanical parts can be calculated by multi-rigid body dynamics.

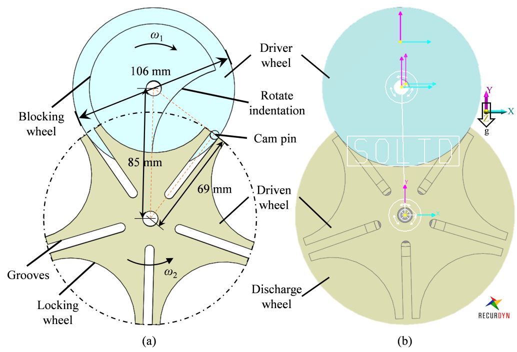

Fig. 2. Model of Geneva mechanism: (a) actual model; (b) simulation model based on RecurDyn.

The multi-rigid body dynamics can be expressed as Equation 1 using the Cartesian method.

$$\begin{cases} M(q,t)\ddot{q} + \Phi_q^T(q,t)\lambda - Q(q,\dot{q},t) = 0 \\ \Phi(q,t) = 0 \end{cases} \tag{1}$$

where, q is the position vector; $\dot{q}$ is the velocity vector; $\ddot{q}$ is the acceleration vector; λ is the Lagrange multiplier; t is the time; M is the mechanical system inertia matrix; Φq is the constraint Jacobian matrix; Q is the external force vector; Φ is the position constraint equation.

2.4. DEM-MBD coupling method

EDEM is used for DEM simulation, which has the MBD coupling interface for data exchange with RecurDyn. During a simulation process of DEM-MBD, EDEM and RecurDyn simulate in an alternating manner. The RecurDyn simulates ahead in time and then passes any position and velocity data of the Geneva mechanism across to EDEM for it to be allowed to simulate to the same point in time. This alternating pattern continues until the simulation time has reached the specified end time, shown in Fig. 3. The time-steps of EDEM and RecurDyn are set to 5×10^{-6}s and 0.01s, respectively, the simulation time is 6s.

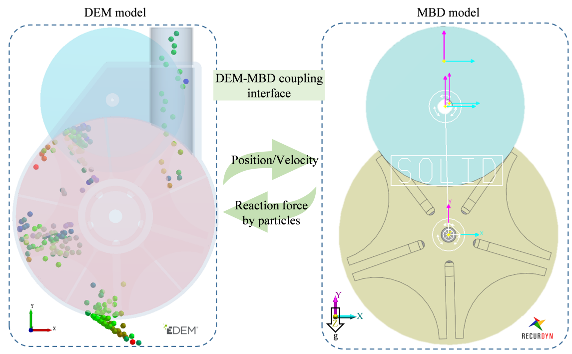

Fig. 3. Schematic diagram of DEM-MBD coupling frame.

2.5. Fertilizer particles distribution performance simulation

To study the operating effect of the hole fertilizer disperser (Fig. 4), set the fertilizer point-applied device to be stationary, and the conveyor belt moves to the right relative to the device. The DEM-BMD method was used to study the distribution length of fertilizer particles under different conditions (working speed, fertilizer discharge height and fertilizer discharging mass).

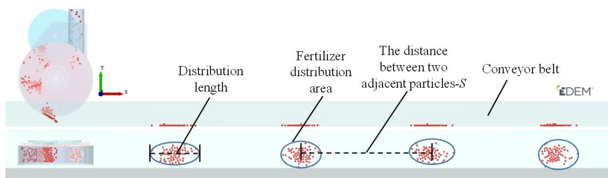

Fig. 4. Schematic diagram of fertilizer particles distribution performance based on simulation.

The calculation method of fertilizer particle distribution length is as follows

$$L_{fi} = X_{ifirst} - X_{ilast} \tag{2}$$

Where $L_f i$ is the distribution length of fertilizer particles in the i-th hole, mm. X_{ifirst} is the x-direction displacement of the particles of the i-th hole fertilizer particles that first fall on the transmission belt, mm. X_{ifirst} is the x-direction displacement of the last particle in the i-th hole fertilizer particle that falls on the transmission belt, mm.

The calculation method of the average particle distribution length of fertilizer is as follows

$$L_f = \frac{\sum_{i=1}^{n} L_{fi}}{n} \tag{3}$$

Where L_f is the average particle distribution length of fertilizer, mm; n is the number of fertilizer holes.

The calculation method of the coefficient of variation of the fertilizer particle distribution length is as follows

$$COV = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n} L_{fi}\left(L_{fi} - L_f\right)^2}}{L_f} \times 100\% \tag{4}$$

Where COV is the coefficient of variation of the fertilizer particle distribution length, %.

In order to establish a quadratic fitting equation between working speed, fertilizer discharging height and fertilizer discharging mass on the one hand, and fertilizer particle distribution length and coefficient of variation of fertilizer particle distribution length on the other, the mathematical expression for the coefficient of determination R^2, which evaluates their correlation, is as follows

$$R^2 = \frac{\left(l\sum(\mathrm{pre}_x \cdot x) - \sum \mathrm{pre}_x \cdot \sum x\right)^2}{\left((l\sum \mathrm{pre}_x^2) - (\sum \mathrm{pre}_x)^2\right) \cdot \left((l\sum x^2) - (\sum x)^2\right)} \tag{5}$$

Where l is the number of samples for each indicator; pre_x is the predicted data; x is the actual data.

A quadratic regression was fitted to the Box-Behnken test data and the mathematical expressions for the P and F values, which reflect the significance of the regression model, are as follows

$$F = \frac{\mathrm{SSR}\,/\,(k-1)}{\mathrm{SSE}\,/\,(n-k)} \tag{6}$$

Where k is the number of variables and n is the sample size; SSA is the between-group error and SSE is the within-group error. The mathematical expressions for SSA and SSE are as follows

$$\begin{aligned} SSR &= \sum_{i=1}^{k}\sum_{j=1}^{n_j}(\bar{x}_i - \bar{\bar{x}})^2 = \sum_{i=1}^{k} n_i(\bar{x}_i - \bar{\bar{x}})^2 \\ SSE &= \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(x_{ij} - \bar{x}_i\right)^2 \end{aligned} \tag{7}$$

In the past, when there was no statistical software (e.g. SPSS, Design-Expert, etc.), people looked up the table to find the critical value of F corresponding to a significance level of 0.05 and see if the F we obtained from the calculation was greater than $F(0.05)$.

P-values can now be found in the software based on the F-distribution probability density function, and if $P<0.05$, the factor is considered to be significantly different in its effect on the dependent variable, and conversely, it is considered to be not statistically different.

3. Results and analysis

3.1. Working speed

When fertilizer discharging height and fertilizer discharging mass are 25 mm and 6.0 g, respectively, the performances of the fertilizer particles distribution length with the working speed are shown in Fig. 5. It can be seen that with the increase of the working speed, the performances of the fertilizer particles distribution length increases rapidly, as shown in Fig. 5(a). In order to further illustrate the relationship between the working speed (v_m) and the fertilizer particles distribution length (y), polynomial fitting (see Fig. 5(a)) was performed with the functional relationship as:

$$y = -4.30143 + 4.29206v_m - 0.17931v_m^2 \tag{8}$$

Formula 8 shows that the relation between the working speed and the fertilizer particles distribution length was a quadratic function, the fitting coefficient R^2 is 0.99456, indicating that formula 8 has a good fit and regression effect on the data. In terms of fertilizer particles distribution quality requirements, the smaller the distribution length, the better for root development and fertilizer absorption during seeds subsequent growth.

Fig. 5(b) shows that as the working speed increases, the distribution of fertilizer particles on the conveyor belt becomes dispersed. The reason may be that the increased velocity of the discharge wheel, resulting in an increase in velocity of particles separating from the discharge wheel.

3.2. Fertilizer discharging height

When working speed and fertilizer discharging mass are 3.6 km/h and 6.0 g, respectively, the performances of the fertilizer particles distribution length with the fertilizer discharging height are shown in Fig. 6. It can be seen that with the increase of the working speed, the performances of the fertilizer particles distribution increases rapidly, as shown in Fig. 6(a). In order to further illustrate the relationship between the fertilizer discharging height (h) and the fertilizer particles distribution length (y), polynomial

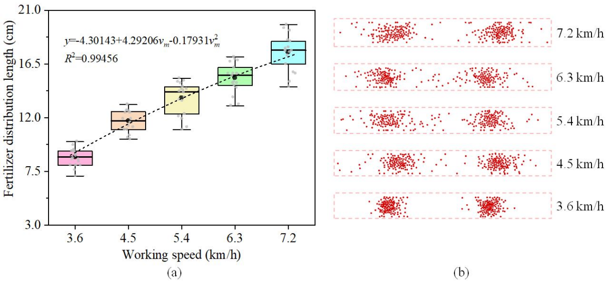

Fig. 5. Variation of the performance of the fertilizer particles distribution with the working speed.

fitting (see Fig. 6(a)) was performed with the functional relationship as:

$$y = 5.49158 + 0.12248h - 0.00035h^2 \tag{9}$$

Formula 9 shows that the relation between the fertilizer discharging height and the fertilizer particles distribution length was a quadratic function, the fitting coefficient R^2 is 0.98937, indicating that formula 9 has a good fit and regression effect on the data.

Fig. 6(b) shows that as the fertilizer discharging height increases, the distribution of fertilizer particles on the conveyor belt becomes dispersed. The reason may be that the trajectory of the fertilizer particles after leaving the discharge wheel is parabolic, and the speed direction between the particles is inconsistent.

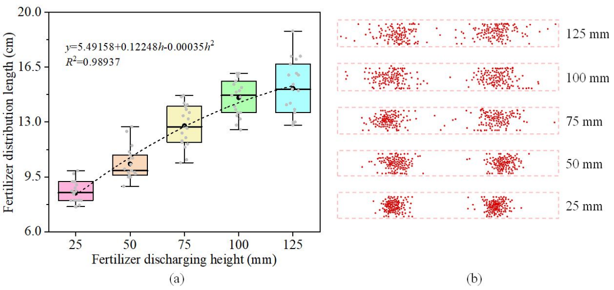

Fig. 6. Variation of the performance of the fertilizer particles with the fertilizer discharging height.

3.3. Fertilizer discharging mass

When working speed and fertilizer discharging height are 3.6 km/h and 25 mm, respectively, the performances of the fertilizer particles distribution with the fertilizer discharging mass are shown in Fig. 7. It can be seen that with the increase of the fertilizer discharging mass, the performances of the fertilizer particles distribution length increases rapidly, as shown in Fig. 7(a). In order to further illustrate the relationship between the fertilizer discharging mass (m) and the fertilizer particles distribution length (y), polynomial fitting (see Fig. 7(a)) was performed with the functional relationship as:

$$y = 3.13778 + 1.04058m - 0.0157m^2 \tag{10}$$

Formula 10 shows that the relation between the fertilizer discharging mass and the fertilizer particles distribution length was a quadratic function, the fitting coefficient R^2 is 0.99540, indicating that formula 10 has a good fit and regression effect on the data.

Fig. 7(b) shows that as the fertilizer discharging mass increases, the distribution of fertilizer particles on the conveyor belt becomes dispersed. The reason may be that the volume of fertility particles increases with the increase of fertilizer discharging mass. Under the same fertilizer application conditions, the larger the size of the fertilizer particles, the larger the range of the fertilizer particles scattered on the conveyor belt.

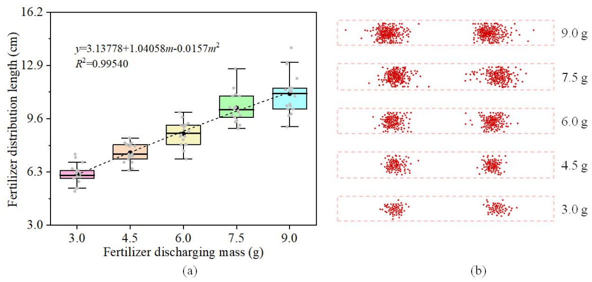

Fig. 7. Variation of the performance of the fertilizer particles with the fertilizer discharging mass.

3.4. Interactions among the factors

The influence of a single factor on the target is considered based on the above analysis. In order to further analyze the influence law of the interaction between factors on the target result, a Box-Behnken test is designed to further analyze the effect of the interaction between the factors on fertilizer particle distribution, using the working speed, fertilizer discharge height and fertilizer discharging mass as the test factors and the fertilizer particle distribution length and coefficient of variation of the fertilizer particle distribution length as the test indicators. The factors and levels of the test are shown in Table 2. The test protocol and test results using Design-Expert 8.0.6 are shown in Table 3.

Multiple regression analysis was fitted to the test results using Design-Expert 8.0.6 and Table 4 shows the regression model ANOVA results for the average particle distribution length of fertilizer and the coefficient of variation of the fertilizer particle distribution length.

Table 2. Test levels and factors

Test level	Speed v_m (m/s)	Height h (mm)	Mass m (g)
+1	7.2	125	9
0	5.4	75	6
-1	3.6	25	3

As can be seen from Tables 4, the P-value of the quadratic regression models for the average particle distribution length of fertilizer and the coefficient of variation of the fertilizer particle distribution length were less than 0.05 and the p-values of the lack of fit terms were greater than 0.05, indicating that the models obtained from the regressions were highly significant and the regression equations were not lack of fit. The quadratic regression equation between each factor and the coefficient of variation of hole length and length was therefore obtained

$$\begin{aligned} y_1 =& -45.75761 + 7.05136v_m + 0.93195h + 15.82502m \\ &+ 0.07575v_m h + 1.31572v_m m + 0.04212hm \\ &- 0.03162v_m^2 - 0.00714h^2 - 1.31972m^2 \\ y_2 =& 10.79456 + 0.46514v_m - 0.00092h - 2.65158m \\ &- 0.00103v_m h - 0.04213v_m m + 0.00365hm \\ &+ 0.10965v_m^2 + 0.00018h^2 + 0.28669m^2 \end{aligned} \tag{11}$$

The ANOVA showed that the working speed, fertilizer discharge height and fertilizer discharging mass all had a significant effect on the average particle distribution length of fertilizer and the coefficient of variation of the fertilizer particle distribution length, the three factors had a significant effect on the average particle distribution length of fertilizer in the order of working speed, fertilizer discharging mass and fertilizer discharge height, and that the three factors had a significant effect on the coefficient of variation of the fertilizer particle distribution length in the order of fertilizer discharging mass, working speed and fertilizer discharge height. The interaction terms all had a significant effect on the average particle distribution length of fertilizer and the coefficient of variation of the fertilizer particle distribution length was not significant.

To analyze the effect of the interaction term on the average particle distribution length of fertilizer, a response surface plot was made as shown in Figure 8.

Figure 8(a) shows the interactive effect of working speed and discharge height on the distribution length of fertilizer particles. It can be seen that as the discharge height and working speed increase, the fertilizer particle distribution length increases. Figure 8(b) shows that the distribution length of fertilizer particles increases as the fertilizer discharging mass and the working speed increase. Similarly, in Figure 8(c), the distribution length of the fertilizer particles increases with the height of the discharge and the fertilizer discharging mass.

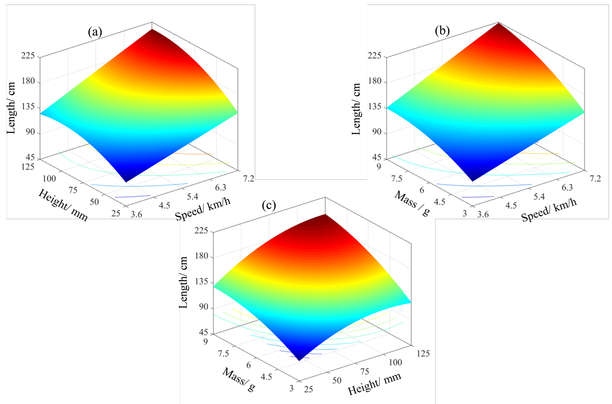

Fig. 8. Interactions among the various factors with the fertilizer distribution length.

In order to solve for the optimal combination of factors within the constraint range, the multi-objective optimization of fertilizer granule formation performance was carried out with the following optimization objective function and constraints, using the minimum distribution length and minimum distribution length variation coefficient as evaluation indicators.

$$\begin{cases} \min y_1 (v_m, h, m) \\ \min y_2 (v_m, h, m) \\ \text{s.t.} \begin{cases} 3.6 \text{ km/h} \le v_m \le 7.2 \text{ km/h} \\ 25 \text{ mm} \le h \le 125 \text{ mm} \\ 3 \text{ g} \le m \le 9 \text{ g} \end{cases} \end{cases} \tag{12}$$

A multi-objective optimization of the regression equation using Design-Expert 8.0.6 resulted in a fertilizer distribution length of 78.62 mm and coefficient of variation of 7.58% for a working speed, fertilizer discharge height and fertilizer discharging mass of 3.66 km/h, 27 mm and 4.55 g, respectively. The fertilizer distribution length of 82.28 mm and coefficient of variation of 8.14%, with relative errors of 4.66% and 7.39% respectively, were obtained by repeating the simulation three times under these conditions, indicating that the regression equation is reliable and can be used to predict the fertilizer granules distribution formation performance under different operating conditions.

Table 3. Box-Behnken experiment design and results

No.	Speed v_m (m/s)	Height h (mm)	Mass m (g)	Length y_1 (mm)	COVy_2 (%)
1	3.6	25	6	86.67	8.37
2	7.2	25	6	144.57	12.96
3	3.6	125	6	127.49	12.31
4	7.2	125	6	212.66	16.53
5	3.6	75	3	90.31	9.81
6	7.2	75	3	150.62	15.36
7	3.6	75	9	132.83	14.43
8	7.2	75	9	221.56	19.07
9	5.4	25	3	79.26	9.99
10	5.4	125	3	116.59	13.69
11	5.4	25	9	132.92	14.75
12	5.4	125	9	195.52	20.64
13	5.4	75	6	161.13	10.92
14	5.4	75	6	158.68	11.22
15	5.4	75	6	164.44	11.51
16	5.4	75	6	160.57	12.37
17	5.4	75	6	159.23	12.64

Table 4. Analysis of variance table.

Source of variance	Length y_1				COV y_2			
	Sum of square	Degree of freedom	F-value	P-value	Sum of square	Degree of freedom	F-value	P-value
Model	26282.63	9	2920.29	<0.0001*	163.99	9	18.22	0.0001*
v_m	10666.06	1	10666.06	<0.0001*	45.13	1	45.13	<0.0001*
h	5451.77	1	5451.77	<0.0001*	36.55	1	36.55	0.0001*
m	7567.55	1	7567.55	<0.0001*	50.20	1	50.20	<0.0001*
$v_m h$	185.91	1	185.91	0.0051*	0.03	1	0.03	0.8224
$v_m m$	201.92	1	201.92	0.0041*	0.21	1	0.21	0.5844
hm	159.64	1	159.64	0.0074*	1.20	1	1.20	0.2101
v_m^2	0.04	1	0.04	0.9523	0.53	1	0.53	0.3889
h^2	1343.08	1	1343.08	<0.0001*	0.87	1	0.87	0.2776
m^2	594.00	1	594.00	0.0002*	28.03	1	28.03	0.0003*
Residual	80.65	7	11.52		4.41	7	0.63	
Lack of Fit	60.28	3	20.09	0.1090	2.21	3	0.74	0.3806
Pure Error	20.37	4	5.09		2.20	4	0.55	
Cor Total	26363.28	16			168.40	16		

Note: $P<0.01$ (highly significant, **); $P<0.05$ (significant, *).

4. Field experiment

In order to verify the accuracy of the simulation tests and the performance in the field, the design and processing of the fertilizer point-applied device was based on the optimal combination of working parameters determined in the above study. The test site is located in Shenze Town, Shenze County, Shijiazhuang City, Hebei Province, China, at 115°13'48.1" E longitude and 38°12'5.4" N latitude. In this section, the fertilizer discharge height and discharge mass were 50 mm and 6.0 g, respectively. The working speed were 3.6 km/h, 4.5 km/h and 5.4 km/h, respectively. Back view of maize precision seeder machine is shown in figure 9.

In the field experiment, the fertilizer particle distribution lengths were 14.58 cm, 16.32 cm and 19.35 cm, respectively. In the DEM model, a fertilizer point-applied device with the same structural and operating parameters as the field experiment was simulated, and the results showed particle distribution lengths of 13.75 cm, 14.92 cm and 17.87 cm, respectively. The particle distribution lengths in field experiment were greater than the lengths in DEM simulation, and the relative error were 6.04%, 9.38% and 8.28%, respectively. The relative errors were reasonably low, which indicated the good overall accuracy of the established DEM simulation model.

5. Discussions

Root zone fertilization is the future direction of efficient fertilization technology. The role of root zone fertilization has been demonstrated in varying degrees in current produc-

Fig. 9. Back view of maize precision seeder machine.

tion practices. Appropriate deep, banding or point-applied can significantly improve fertilizer utilization, mainly by achieving root zone fertilization to different degrees. The point-applied technique applies fertilizer granules within the root zone of the crop, which can significantly improve fertilizer utilization efficiency and reduce fertilizer application, and is the ceiling of the current root zone fertilization technology. Due to the lack of mature point-applied implements, the development of point-applied technology has been slow because, compared to banding fertilization, the mechanical structure of point-applied implements is more complex and requires special mechanisms for intermittent or intermittent fertilizer discharge, in addition to considering the collision motion during fertilizer delivery, correspondence between fertilizer drop position and seed position, etc. In the future development of point-applied applicators, the first thing to consider is the accurate control of fertilizer application volume by point-applied dischargers, then the distribution range of a group of particles in the cultivated soil, and finally the stability of the spatial distance between fertilizer and seeds.

6. Conclusions

In this work, DEM is used to simulate the fertilizer particles distribution in conveyor belt discharged from fertilizer point-applied device. Different working conditions are simulated to reveal their effects on the particles distribution, and the following conclusions can be obtained:

The performances of the fertilizer particles distribution length increases with the increase of the working speed, fertilizer discharging height and fertilizer discharging mass. Box-Behnken test indicates that when the working speed, fertilizer discharge height and fertilizer discharging mass of 3.66 km/h, 27 mm and 4.55 g, the fertilizer distribution length and coefficient of variation were 78.62 mm 7.58%, respectively.

In the field experiment, the fertilizer particle distribution lengths were 14.58 cm, 16.32 cm and 19.35 cm, when the working speed were 3.6 km/h, 4.5 km/h and 5.4 km/h, respectively.

Nowledgements

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