DESIGN AND EXPERIMENT ON PRECISION SEED METERING DEVICE FOR NARROW-ROW AND DENSE PLANTING OF SOYBEAN
/
窄行密植大豆精密排种器设计与试验研究

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ABSTRACT
The capability of existing precision seeding for soybean narrow row seeder is limited, to address these limitations; we designed a seed metering device. In this study, the structure and working principle of a precision seed metering device was analyzed, and the structural parameters of the seed counterbore seeding wheel for the seed metering device was designed and optimized. Field tests were carried out with the working speed, forward speed, and inclined angle as test factors, and the seeding qualified index and variation coefficient of uniformity as test indexes. The results showed that: the influence order of the factors affecting on the seeding qualified index, from high to low, was found to the working speed, inclined angle and forward speed. For the variation coefficient of uniformity, the influence order, from high to low, was as follows: the working speed, forward speed and inclined angle. Based on the optimization analysis performed using the Design Expert 8.0.6, it is concluded that when the working speed, forward speed, and inclined angle are 36.50 r/min, 1.47 m/s, and 4.11°, respectively, the seeding performance was optimal. The seeding qualified index and variation coefficient of uniformity were 90.37% and 12.87%, respectively, to reach the national seeding standard grade. This study provides a research basis and technical reference for the design and development of precision seed devices.

摘要
为提高大豆窄行播种机精密播种作业功能，设计了一种精密排种器，分析了精密排种器结构及工作原理，并设计了排种器的排种轮容种型孔结构参数。以排种器工作转速、机具前进速度和排种倾角为试验因素，播种粒距合格指数、重播指数、漏播指数和变异系数为试验指标，进行田间性能试验。结果表明：各因素对粒距合格指数的影响大小顺序均为：工作转速、排种倾角、前进速度。对变异系数的影响大小顺序为：工作转速、前进速度、排种倾角。运用 Design-Expert 8.0.6 软件进行优化分析，得出工作转速为 36.50r/min，前进速度为 1.47m/s，排种倾角为 4.11°时，播种作业性能达最优状态，合格指数和变异系数分别为 90.37%和 12.87%，达到国家播种优等品要求。该研究为精密播种技术和播种装置的设计研发提供了研究基础与技术参考。

INTRODUCTION
Sowing operation is an important basic link in agricultural production, and precision seeding device is an important part of realizing agricultural modernization *(Dayoub et al., 2021; Lei et al., 2021)*. As the core component of the seeding device, the precision seed metering device can be divided into mechanical type and pneumatic type, which is the focus and hot spot of many scholars *(Liao et al., 2020; Robert, 2014; Nesmiyan, et al., 2022)*. The pneumatic type seed metering device has a good versatility, high speed operation and suitable for large seeder, but its complex structure, needs air source and high sealing requirements. *(Bozdogan., 2008; Li et al., 2019).* Mechanical seed metering device a much more precise adaptation of hole sizes to the seed sizes of the crops to be sown *(Cujbescu et al, 2021),* it is widely used for its features of simple structure, stable operation, low cost and easy assembly *(Akhalaia et al., 2021).*

In foreign countries, the seed metering device is mostly studied with high speed operation as the core goal. *Ratnayake and Balasoriya, (2013),* designed an adjustable conical roller seed metering device, which can effectively save fine seeds and improve operation efficiency.

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A 16-counterbore slanting board seed metering device was developed *(Kokuryu, 2011),* which can supply seeds on both sides and is used for large-scale high-speed seeding. They performed an optimization test on the chute mechanism. There are many researches on mechanical seed metering device in China, mainly focusing on the innovative design of single arrangement filling and seed metering device structure, which can meet the specific seeding requirements. *Hensh and Raheman (2022),* designed a metering mechanism comprised a rectangular metering plate with a hole in the middle, and it was kept at the outlet of the hopper, which was actuated by a push–pull type solenoid to drop the seeds in the form of hill. *Emrah and Yildiran (2021)* designed a trough wheel seed arrangement device was designed with 18 mm groove diameter and 11 mm groove depth, the lowest breakage rate was achieved at 160 kg/ha and 2 m/s forward speed. *Laryushin et al. (2021)* designed a kind of coil sowing machine with the grooves of the sectional coil made in the form of a torus to ensure the best uniformity of the distribution of seeds along the length of the row. The dependences of the uneven distribution of seeds along the length of the row on the speed of the coil, the radius of the forming circle of the torus and the thickness of the separation disk of the spool-sowing apparatus are established. *Hou et al., (2020),* designed a kind of flexible mechanical seed clearing and protection precision seed metering device for soybean, adding a filling angle and a flexible seed clearing and protection brush to reduce the seed damage index. An inside-filling air-assisted high-speed precision maize seed-metering device, such as the horizontal stirring notch seed-metering plate and the wheel seed-cleaning mechanism were carried out. *Wang et al., (2021), Xiong et al., (2021),* designed a general mechanical pneumatic combined seed metering device was combined. The device adopts air-blowing-type cleaning and seed unloading of the device.

Hence, to overcome these limitations of research and application of precision seeding device for narrow row dense seeding, to improve the performance of narrow row dense seeding operation, and combining with the physical parameters of soybean seeds and the agronomic requirements of single hill-drop seeding, we designed a kind of single-row capacity seed wheel precision seed metering device earlier stage, but it could not meet the requirements of high-speed seeding, and the qualified index was reduced seriously. Through the capacity seed wheel and capacity seed counter bore shape were optimized, a kind of double-row capacity seed wheel precision seed metering device was designed. This paper expounds its working principle and design of the structural parameters of the key parts. Field experiments were conducted to determine the optimum working parameters and to verify the design, with the objective to enhance the degree of mechanization of the seeding device. Thus, we provide a theoretical support and technical reference for the innovative design of a seeding device for seeders.

MATERIALS AND METHODS

STRUCTURE AND WORKING PRINCIPLE OF THE SEED METERING DEVICE

The seed metering device is main component of the seeder. It is mainly composed of seed box, seed wheel, seed shaft, seed clapboard, seed cleaning wheel, cover board, seed cleaning knife, and seed unloading device, as shown in Fig.1. The seed wheel and the seed shaft are assembled in the seed box, a bearing is arranged between the seed shaft and the seed box, the seed shaft extends out of the seed box to install the drive sprocket. The surface of the seed cleaning wheel is equipped with ductile fluff, and the installation position of the wheel center can be adjusted to effectively improve the utilization rate. With the assembled clearance between the seed wheel and the seed clapboard set 0.8~1.2mm, a bolt is arranged on the outside of the box to adjust the gap so as to adapt to the seeds of different sizes. The seed cleaning knife is set in the seed dropping area, to force the seeds that cannot be thrown out timely to be thrown out, so as not to complete the seed dropping outside the seed dropping area or bring back to the seed filling area, which will affect the seeding precision. The seed unloading device is arranged between the seed filling region and the sowing region; it is fixed by dovetail bolts. During seed unloading, it only needs to screw out the bolts and open the seed unloading board, so as to facilitate the cleaning of the remaining seeds in the seed storage room of the seed device after the sowing operation.

The working process of the seed metering device includes four procedures filling, cleaning, protecting and sowing. In normal operation, the external power source is used to drive the seed shaft by the sprocket, and the seed wheel is driven by the seed shaft to rotate. The seeds are put into the seed storage chamber of the seed metering device. In order to ensure the uniform and stable filling of seeds, the quantity of the seeds in the seed filling area is required to be sufficient and in dynamic balance. During the rotation of the seed wheel, a single seed was filled into the seed type hole of the seed arrangement wheel, and the surplus seeds were easily transported to the seed clearing region with the edge of the hole.

In the seed clearing region, the seed clearing wheel is used to remove the redundant seeds and put them back in the seed filling region, so that only a single seed passes through the seed clearing region, and to be transported to the seed protection region. The seeding protection region protects the seeds from falling off and relative sliding movement, smooth migration into the sowing region. Under the action of gravity and centrifugal force, the seeds in the planting area are sowed accurately to the soil seed bed that has been ditched and prepared to complete the precise planting operation.

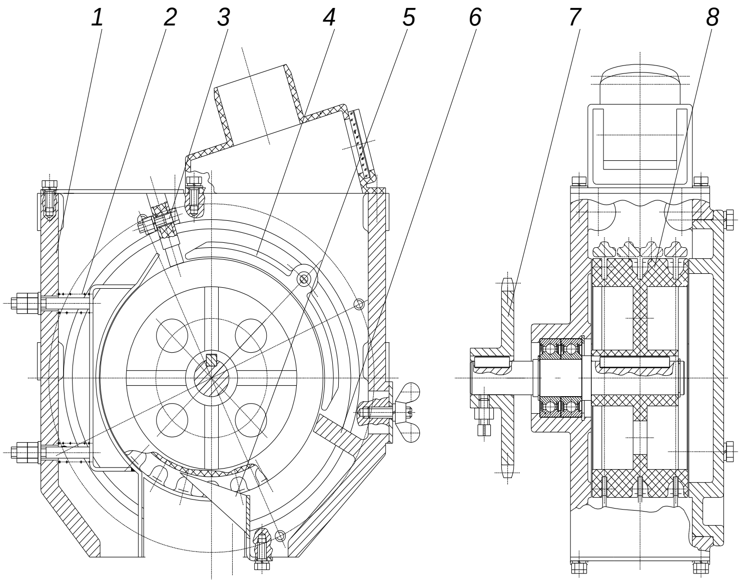


Fig. 1 - Structure of precision seed metering device

1. Seed box; 2. Seed clapboard; 3. Seed cleaning wheel; 4 Cover board;5. Seed cleaning knife; 6. Seed unloading device; 7. Seed shaft; 8. Seed wheel

DESIGN OF THE SEED WHEEL

The seed wheel is the core component of the seed metering device; seeding holes are evenly arranged on its circumferential surface. The seed filling performance of the seed wheel is affected directly by the structure shape, size parameters of the seed wheel and the arrangement of the seed counterbores. In order to improve the seed filling performance of seed metering device, based on the size parameters of typical soybean seeds (Heihe 43) with a wide planting area in Heilongjiang Province, combined with the theory of the brachistochrone, the cross-section curve of the seed counterbore shape was designed. In the process of the seed counterbore shape design, the seed can be quickly filled into the seed counterbore with uniform and stable force, so as to prolong the seed filling time and improve the seed filling stability.

Through the seed counterbore shape was optimized with sectional curve scanning, its main structural parameters of the seed counterbore are diameter D, seed counterbore depth H and the parameters of the scanning sectional curve. The structure parameters of the seed counterbore shape is mainly related to seed geometry, through artificial cleaning process of soybean seeds, a random sample of 1000 grain, to measurement geometry size with electronic digital display vernier caliper (with the precision of 0.01 mm). The mean value of length, width, thickness were 6.51 mm, 6.12 mm and 5.68 mm, respectively, approximation for the ball, thus ignore distribution types of the seeds posture in seed counterbore. According to the triaxial size parameters of soybean seeds, the design of seed counterbore should follow the principle of $D>\bar{l}_0$and $w_0>H>2/3\ \bar{w}_0$, where, $\bar{l}_0$ is the average length of the seeds, $\bar{w}_0$ is the average thickness of the seeds. At last, the opening diameter D of the seed counterbore is 7.00 mm and the depth H is 4.00 mm.

The brachistochrone sectional curve of seed counterbore was analyzed, and the particle P roll to move from the starting point O to no vertical at the bottom of the terminal B, tumble shortest time curve, as shown in Fig.2. Let the circumference of a circle of radius r roll along the line OB, the circular edge point P swept path between two points is the O, B the brachistochrone, θ is turning Angle, the brachistochrone trajectory Equation *(Ding et al., 2018)*.

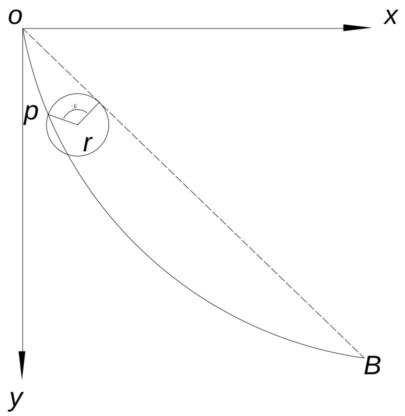
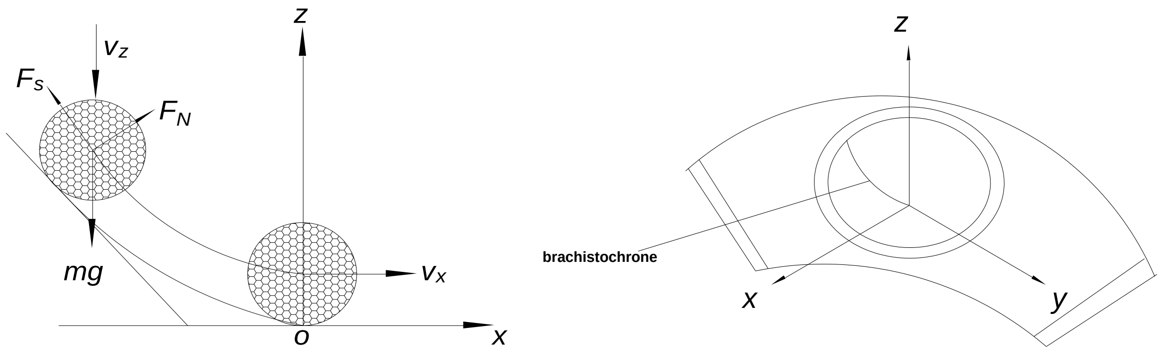


Fig. 2 - Geometric meaning of brachistochrone

$$\begin{cases} x = r(\theta - \sin\theta) \\ y = r(1-\cos\theta) \end{cases} \qquad \theta \in [0, \pi/2] \tag{1}$$

The analysis was made according to the schematic diagram of the abstract model for the actual movement of seed filling into the seed counterbore, as shown in Fig. 3a. When the seed rolls from the opening of the seed counterbore to the bottom of the seed counterbore, the shortest time path that the seed rolls through is the transversal curve of the fastest falling line, as shown in Fig. 3b. The spatial rectangular coordinate system *o-xyz* is established with the center of the bottom of the seed counterbore as the coordinateorigin *o*, and the motion state of seeds in the *xoz* plane is studied as follows:



(a) Brachistochrone sectional curve analysis (b) Seed counterbore shape

Fig. 3 - Analysis of brachistochrone sectional curve

$$\begin{cases} F_N = mg\cos\beta \\ F_s = F_N \tan\varphi \end{cases} \tag{2}$$

where: m is the quality of soybean seeds, kg;

g- acceleration of gravity, m/s^2;

β - tangent angle of the cut curve at the slip point;

φ- friction angle between soybean seeds and seed counterbore;

F_N- bearing strength, *N*

F_s - friction force, *N*.

During the seed filling process, the height of soybean seed rolling is h (the maximum value of depth is h), its transverse displacement is: $\frac{\theta - \sin\theta}{1-\cos\theta}h$.

That is, the seed slides along the brachistochrone to the bottom of the seed counterbore, and power of the friction force F_s can be expressed as:

$$\int_0^{\frac{\theta-\sin\theta}{1-\cos\theta}} mg\cos\beta\tan\varphi dx = mg\cos\beta\tan\varphi\frac{\theta-\sin\theta}{1-\cos\theta}h \tag{3}$$

This process shall satisfy energy conservation law, that is:

$$\frac{1}{2}m(v_z^2 - v_x^2) + mgh = mg\cos\beta\tan\varphi\frac{\theta - \sin\theta}{1-\cos\theta}h \tag{4}$$

v_z is the initial slipping speed of the seeds, m/s²;
v_x - the ending speed of the seeds, m/s²;
h - slipping height of the vegetable seeds, m.

Equations (1)~(4) are combined and simplified to obtain:

$$y = \frac{2gh\cos\beta\tan\varphi}{v_z^2 - v_x^2 + 2gh}x \tag{5}$$

The tangent inclined angle β is:

$$\beta = \arcsin[\sqrt{(\frac{v_z^2 - v_x^2 + 2gh}{2gh\tan\varphi})^2 + 1} - \frac{v_z^2 - v_x^2 + 2gh}{2gh\tan\varphi}] \tag{6}$$

In ideal state, the soybean seeds slip to the bottom of the seed counterbore at the speed v_x=0m/s. The slipping depth h of the seed is h=4.00mm, the frictional angle between the seed and the seed counterbore φ=31º~42º, abscissa of sliding trajectory of seed x=3.50 mm. Substitute it into Equation (6), the tangent dip angle of brachistochrone curve β=16º~23º.

ANALYSIS OF SEED FILLING PROCESS

Various working region division of seed metering devices should follow the principle*(Li et al., 2020)*.The seed filling region is designed to be larger to ensure sufficient seed filling time and high seed filling rate, but too large a seed filling region will increase seed wear; In the seed clearing region, the excess seeds carried in the seed counterbore should be removed as soon as possible, and the single seed should be kept in the seed protecting region in the seed counterbore, and the excess seeds should be put in the seed filling region. The seed protection region ensures that the seeds do not slip relatively in the seed counterbore, so that the seeds can be transmitted steadily to the sowing region; the sowing region ensures that the seeds can be sowed accurately. Based on the above principles and specific locations of the seed groups, the angle of the seed filling region is designed as 110º, the angle of the seed clearing region is 40º, the angle of the seed protecting region is 80º, and the angle of sowing region is 60°, as shown in Fig. 4.

To improve the seeding performance of the seed metering device, it is required that the force of the seed should be stable during the process of transmitting seeds. During the process of seed filling, the critical condition that the seeds are relatively balanced in the seed counterbore without being thrown away was analyzed, and mechanical analysis was conducted on the motion state of the seeds during the stage, as shown in Fig.4. Equilibrium Force System Equation is established based on D'Alembert's Principle.

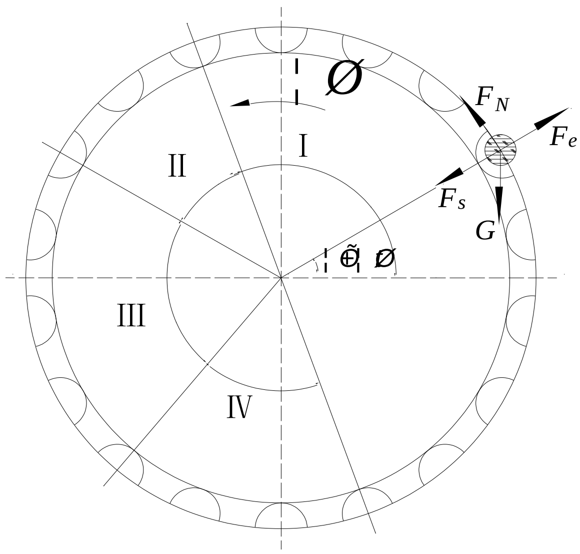


Fig. 4 - Regional division and seed stress analysis

Ⅰ. Filling region; Ⅱ. Cleaning region; Ⅲ. Protecting region; Ⅳ. Sowing region

$$\begin{cases} mg\sin(\varphi+\omega t)+F_s=F_e \\ F_N=mg\cos(\varphi+\omega t) \\ F_e=mR\omega^2=4\pi^2 mRn^2 \\ F_s=\mu F_N \end{cases} \tag{7}$$

μ- the friction coefficient between the seed and the seed counterbore (0.32~0.43)
F_e - the centrifugal force, N
ω - the angular velocity of motion, rad/s
$(\varphi+\omega t)$ - the rotation angle $(0,3\pi/4)$,°

It could be obtained by solving the second derivative of the radial decomposition force in Equation (7):

$$\frac{d^2F_N}{d\omega^2}=-mgt^2[\sin(\varphi+\omega t)+\mu\cos(\varphi+\omega t)]-2mR \tag{8}$$

According to the range of the seed wheel rotation angle (0, 3π/4), it could be judged that the second derivative value of Equation (8) is smaller than 0, that is, the convex curve changing tendency above radial force function, from which it could be known that with the increase of the rotational speed of the seed wheel, the radial force on the seeds increases first and then decreases. So, the maximum force of the seeds should be at the inflection point. To solve the limit value *n* of the working speed under the critical condition of the seed being thrown away, Equation (7) is sorted out and obtained:

$$n\le\sqrt{\frac{g[\sin(\varphi+\omega t)+\mu\cos(\varphi+\omega t)]}{4\pi^2R}} \tag{9}$$

The larger the diameter of the seed wheel, the lower rotational speed is, the more stable the seed filling performance. However, too large the seed wheel will lead to the overall bulky seed metering device. According to the requirements of single grain precision sowing, the rotation radius R was set as 64 mm, the number of seed counterbore was 18, and the relative rotation angle was 40°~130°, Substituted into Equation (9), it is calculated that the working speed of the seed wheel is lower than 65r/min, the seeds will not be thrown away. It provides reference for setting the factor level of working speed in the subsequent test.

TESTING METHOD

The testing material used was soybean Heihe 43, which was planted widely in Heilongjiang Province. The test was conducted from May 9 to 16, 2021, in the test base of Northeast Agricultural University. The soil relative humidity was 19%, and the hardness was 52 KPa. Test equipment narrow row precise seeder, as shown in Fig.5.

Based on the agronomic requirements of soybean growth, the seed spacing of a single row was set as 8 cm, and the sowing depth as 3-5cm, so as to ensure the uniform sowing speed during the operation. The length of the test area should not be less than the theoretical seed spacing length of 250 seeds. The test was repeated for 3 times to test the qualified index and variable coefficient of seed spacing. The test process is shown in Fig.6.

Fig. 5 - Field test of narrow row flat seeder

Fig. 6 - Field test procedure

According to *GB/T6973-2005 Test Method of Simple Grain (Precision) Seeders* and *JB/T10293-2001 Technical Conditions of Simple Grain (Precision)* Seeders, the seeding performance index and uniform performance index of seeding device were studied by theoretical analysis combined with field experiment.

The Equations of seeding stability performance index and uniformity coefficient of variation are as follows:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{10}$$

$$S = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})}{n-1}} \tag{11}$$

$$C = \frac{S}{\bar{\mathrm{X}}} \times 100\% \tag{12}$$

X_i - the seed spacing two adjacent seeds in each row, cm;

$\bar{X}$ - the average of the seed spacing two adjacent seeds in each row, cm;

S - standard deviation, cm;

C - the variable coefficient;

n - the number of sample seed-spacing.

RESULTS

The main factors affecting the seeding performance and uniformity of the seed metering device are the working speed of the seed wheel, the forward speed of the seeder, and the inclined angle of the seed metering device, so they are taken as the test factors. Through a quadratic regression orthogonal combination test, the influence of various influencing factors on the variation rules of seeding qualification index and coefficient of variation were analyzed.

Through a theoretical analysis, combined with the measurement and analysis of the sowing seed spacing, we set the value range of each test factor: the working speed of the seed wheel was set in the range of 20~60 r/min, the forward speed of the device in the range of 1~3 m/s, and the inclined angle of sowing in the range of -20~20 mm. A three-factor, five-level quadratic regression orthogonal combination test was performed to determine the best working parameter combination of the seed metering device. Table1 lists the test design scheme and test results. The measured test data were analyzed via regression analysis and factor variance analysis using the Design-Expert 8.0.6 software, as listed in Table 2.

Table 1

Experimental design and results

Number	Experimental factor			Performance index	
	Working speed x_1 / r·min^{-1}	Forward speed x_2 / m·s^{-1}	Inclined angle x_3 / °	Qualified index y / %	variable coefficient C / %
1	28	1.4	-12	83.12	18.89
2	52	1.4	-12	82.01	20.78
3	28	2.6	-12	81.19	19.94
4	52	2.6	-12	76.02	20.95
5	28	1.4	12	87.41	19.05
6	52	1.4	12	82.03	18.63
7	28	2.6	12	81.43	16.98
8	52	2.6	12	79.56	22.95
9	20	2	0	83.56	17.01
10	60	2	0	75.87	21.89
11	40	1	0	87.78	14.01
12	40	3	0	83.65	19.56
13	40	2	-20	75.91	23.23
14	40	2	20	85.95	17.99
15	40	2	0	90.22	13.45
16	40	2	0	91.36	12.65
17	40	2	0	82.81	11.01
18	40	2	0	91.35	12.25
19	40	2	0	90.62	13.56

Table1
(continuation)

Number	Experimental factor			Performance index	
	Working speed x_1 / r·min^{-1}	Forward speed x_2 / m·s^{-1}	Inclined angle x_3 / °	Qualified index y / %	variable coefficient C / %
20	40	2	0	92.61	10.78
21	40	2	0	85.02	12.76
22	40	2	0	89.61	11.98
23	40	2	0	90.05	13.02

Table2

Measured test data from variance analysis[a]

Index	Source	Sum of squares	df	Mean square	F	P
Qualified index	Model	484.11	9	53.79	6.56	0.0014*
	x_1	51.28	1	51.28	6.25	0.0265*
	x_2	39.81	1	39.81	4.86	0.0462*
	x_3	45.67	1	45.67	5.57	0.0346*
	$x_1 x_2$	0.04	1	0.04	0.00	0.9469
	$x_1 x_3$	0.12	1	0.12	0.01	0.9065
	$x_2 x_3$	0.04	1	0.04	0.00	0.9488
	x_1^2	184.24	1	184.24	22.47	0.0004**
	x_2^2	26.19	1	26.19	3.19	0.0972
	x_3^2	140.69	1	140.69	17.16	0.0012**
	Residual	106.58	13	8.20		
	Lack of Fit	23.49	5	4.70	0.45	0.8012
	Pure Error	83.09	8	10.39		
	Cor Total	590.69	22			
variable coefficient	Model	335.44	9	37.27	19.33	< 0.0001**
	x_1	20.32	1	20.32	10.54	0.0064**
	x_2	12.00	1	12.00	6.23	0.0268*
	x_3	10.13	1	10.13	5.25	0.0392*
	$x_1 x_2$	3.80	1	3.80	1.97	0.1841
	$x_1 x_3$	0.88	1	0.88	0.46	0.5117
	$x_2 x_3$	0.13	1	0.13	0.07	0.7972
	x_1^2	106.27	1	106.27	55.12	< 0.0001**
	x_2^2	42.94	1	42.94	22.27	0.0004**
	x_3^2	142.65	1	142.65	73.99	< 0.0001**
	Residual	25.06	13	1.93		
	Lack of Fit	17.29	5	3.46	3.56	0.0546
	Pure Error	7.78	8	0.97		
	Cor Total	360.51	22			

[a] ** means extremely significant (P < 0.01); * means significant (0.01 < P < 0.05), same as below; df is degree of freedom

Based on the analysis results listed in Table 2, we studied the factors influencing the seeding qualified index, the effects of the working speed, forward speed and inclined angle were significant. The order of the influence from high to low was as follows: working speed, inclined angle, forward speed. Among the factors influencing the variable coefficient, the effects of working speed was extremely significant, forward speed and inclined angle were significant. The order of the influence from high to low was as follows: working speed, forward speed, inclined angle. The regression equation between the fitting performance index and the factor coding value was selected. The regression equations for the seeding qualified index and variable coefficient were as follows:

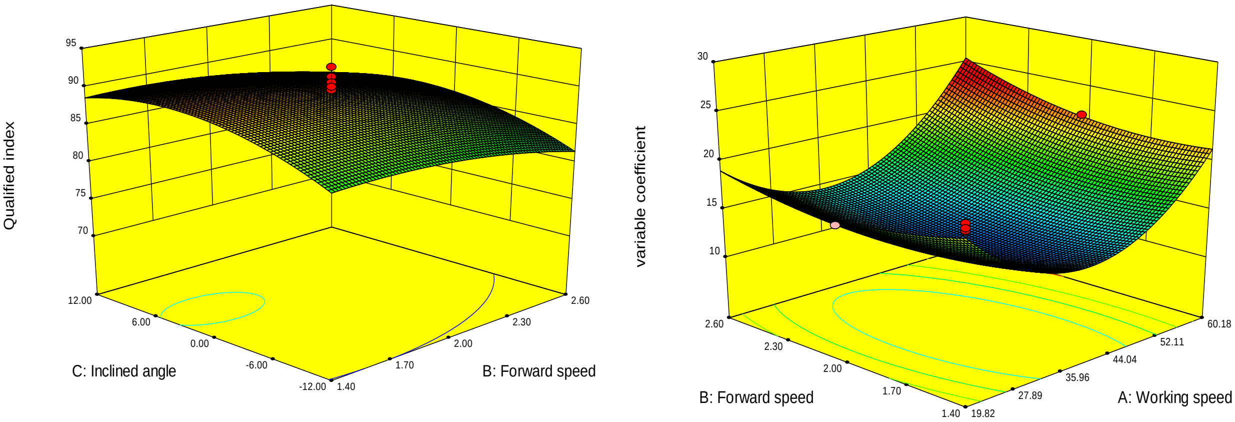
$$y = 62.36 + 1.76x_1 - 2.87x_2 + 0.15x_3 - 0.02x_1^2 - 0.02x_3^2 \quad (13)$$

$$C = 52.98 - 1.36x_1 - 17.02x_2 - 0.07x_3 + 0.02x_1^2 + 4.65x_2^2 + 0.02x_3^2 \quad (14)$$

For an intuitive analysis of the relationship between the performance indicators and the variation coefficient of uniformity and the test factors, Design-Expert8.0.6 was used to establish corresponding surfaces between each indicator and the two most influential factors, as shown in Fig.7.

Based on Equation (13) and the corresponding surface shown in Fig. 7(a), when the forward speed of the seeder is at the zero level (x_2=*2m/s*), the seeding qualified index initially increases and then it decreases with the increase in the working speed, in a similar way it increases first and then decreases with increasing forward speed. When the working speed is lower, the qualified index changes gradually, whereas it increases when the working speed is higher. When the inclined angle is anteverted, the qualified index changes faster, the change becomes slower when the inclined angle is retroverted. When the working speed is approximately 36 r/min and the inclined angle is approximately 4°, the qualified index is found to be maximum.

Based on Equation (14) and the corresponding surface shown in Fig.7(b), when the inclined angle of the seed metering device is at the zero level (x_3=*0°*), the variation coefficient decreases first and then increases with the increase in the working speed, while it decreases first and then increases with increasing forward speed. When the working speed is lower, the variation coefficient changes faster, whereas it changes gradually when the working speed is higher. When the forward speed is lower, the variation coefficient changes gradually, whereas it changes faster when the forward speed is higher. When the working speed is approximately 37 r/min and the forward speed is approximately 4°, the variation coefficient is found to be minimum.



(a) Effects of working speed and inclined angle on the qualified index

(b) Effects of working speed and forward speed on the variable coefficient

Fig. 7 - Effects of working parameters on indexes

Through the analysis of the test data, the optimal combination of the working parameters is determined, and the optimization of each factor is carried out. Based on the agronomic requirements of soybeans in terms of the seeding operation, and combined with the boundary conditions of various factors, we developed a parameterized model using the multi-objective variable optimization method, with the *GB/T6973—2005 Test Method of Simple Grain (Precision) Seeders* and *JB/T10293—2001 Technical Conditions of Simple Grain (Precision)* Seeders, as the inspection standard. Accordingly, the seeding qualified index and variation coefficient of uniformity were analyzed.

The regression equation parameters for the nonlinear programming model are as follows:

$$\begin{cases} \max y \\ \min C \\ s.t. \quad 20\, r/\min \le x_1 \le 60\, r/\min \\ \quad 1m/s \le x_2 \le 3m/s \\ \quad -20° \le x_3 \le 20° \\ \quad 90\% \le y \le 100\% \\ \quad 0 \le C \le 15\% \end{cases} \tag{15}$$

Based on the optimization performed using Design Expert 8.0.6, it is concluded that when the working speed of the seed wheel is 36.50 r/min, forward speed of the seeder is 1.47 m/s, and inclined angle is 4.11°, the Seeding performance was found to be optimal. The seeding qualified index, re-seeding index and miss-seeding index were found to be 90.37%, 4.96% and 4.68%, respectively, and the variation coefficient of uniformity was 12.87%. According to the optimal parameter interval obtained by the optimization analysis, as shown in Fig.8.

When the working speed was 34.38~38.99 r/min, the forward speed was 1.36~1.87 m/s, and the inclined angle was 2.34~5.56°, the seeding qualified index was greater than 90%, both the re-seeding index and the miss-seeding index were less than 5%, the variation coefficient of uniformity was less than 15%.

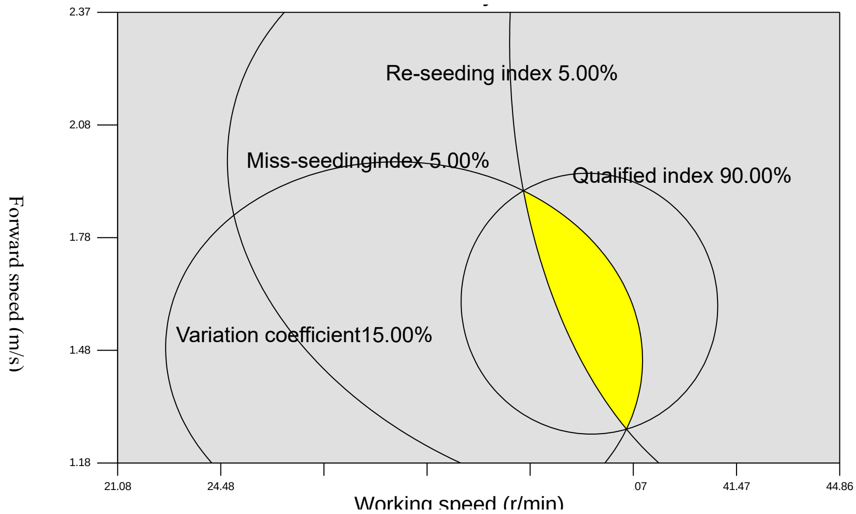


Fig. 8 - Diagram of parameters analysis

CONCLUSIONS

(1) In this study, a precision seed metering device was designed for precision seeding operation, and the structure and working principle were elucidated. Based on the theory of the brachistochrone sectional curve, we designed structure parameter of seed counterbore of seed wheel, to improve the function of seed filling and seed sowing.

(2) The working speed of the seed wheel, the forward speed of the seeder and the inclined angle of the seed metering device as the influencing factors, a multi-factor quadratic regression orthogonal rotation combination test was conducted to study the effects of various factors on the seeding qualified index and the variation coefficient of uniformity. The results showed that: the order of influence of the factors on the seeding qualified index, from high to low, was as follows: the working speed, inclined angle and forward speed. For the variation coefficient of uniformity, the influence order, from high to low, was as follows: the working speed, forward speed and inclined angle.

(3) A multi-objective optimization analysis was performed to establish an optimization model, and the optimal combination of the working parameters of the seed metering device was determined using the Design Expert 8.0.6 software. The results showed that when the working speed, forward speed, and inclined angle are 36.50 r/min, 1.47 m/s, and 4.11°, respectively, the seeding performance was found to be optimal. The seeding qualified index and variation coefficient of uniformity were 90.37% and 12.87%, respectively, to reach the national seeding standard grade. This study provides a research basis and technical reference for the design and development of precision separated amount and seed metering devices.

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