# DESIGN AND EXPERIMENT ON THE SINGLE-DITCH AND DOUBLE-ROW OPENER FOR NARROW ROW FLAT SEEDER
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# 单沟双行播种开沟器设计与试验分析

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## ABSTRACT
*In order to improve the opener of the seeder and its lightweight structure, a new type of opener is designed. The overall structure and working principle of a single-ditch double-row opener are analyzed, and the structural parameters of machete cutting soil and the soil guide board are designed and optimized. Using the penetration angle of machete cutting soil and the included angle of the soil guide board as test factors, field experiments were conducted. As the test indexes, the working resistance, the sowing coefficient of variation, and the depth coefficient of variation were used to analyze the effect of the opener. The results showed that in terms of working resistance, the penetration angle of the machete cutting edge and the included angle of the soil guide board were extremely significant, and the included angle was greater than the penetration angle regarding the influence degree. In terms of the sowing coefficient of variation, the penetration angle was significant, and the included angle was extremely significant. Regarding the depth coefficient of variation, the penetration angle was extremely significant, and the included angle of the guide soil board was significant. Based on the optimization analysis by using the Design Expert 8.0.6, it is found that the performance of the opener is optimal when the penetration angle and the included angle are 50.03° and 42.36°, respectively. The working resistance, the sowing coefficient of variation, and the depth coefficient of variation are 61.47N, 6.49% and 4.22%, respectively. After verification, the results are basically consistent, and the seeding and trenching performance meets the agronomic requirements. This study can provide a basis and technical reference for the design and development of the ditching technology and opener.*

## 摘要
*为提高播种机开沟器开沟作业功能及轻量化结构，设计了一种单沟双行播种开沟装置，阐述分析了开沟器总体结构及工作原理，并设计了开沟器切土弯刀和分土板等关键部件的结构参数。以切土刀刃入土角和分土板夹角为试验因素，开沟工作阻力、播种变异系数和开沟深度变异系数为开沟器作业性能试验指标，进行田间试验。结果表明，对工作阻力影响，两因素均为极显著，且切土刀刃入土角>分土板夹角；对播种性能影响入土角为显著，夹角为极显著；对开沟深度变异系数影响，入土角为极显著，夹角为显著。运用 Design-Expert 8.0.6 软件进行优化分析，得出入土角 50.03°，夹角 42.36°时，播种开沟作业性能最优，工作阻力、播种变异系数和开沟深度变异系数分别为 61.47N、6.49%和 4.22%。进一步通过田间试验验证，结果基本一致，播种开沟性能完全满足要求。该研究为播种机开沟器的设计研发提供了研究基础与技术参考。*

## INTRODUCTION
The opener is an important part of the seeding machinery. During the sowing process, it is an in-soil component that is in direct contact with the soil to prepare the seedbed. Its role is to build the seed ditch, guide seeds into the soil layer of the ditch and provide a favorable environment for stable planting of seeds. The seedbed quality and seeding quality are affected by the work performance of the opener *(Collins and Fowler, 1996; Barr et al., 2018a; Botta et al., 2010).*

There are many types of openers, such as hoe-shovel type, core share type, ship-shaped shovel type, sliding knife type, and disc type *(Lu 2020; Zhan et al., 2021)*. The shape of seeding ditches is mostly V-shaped, which can improve the seeding accuracy, but the disturbance to the soil is large.

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The wet soil layer of trenching soil is easy to mix with the dry soil layer, resulting in the mixed wet and dry soil covering the seeds when returning to the soil. This is not conductive to soil moisture retention and will affect seed germination. Openers have been studied deeply *(Singh et al., 2016, Singh et al., 2017; Ozmerzi et al., 2022). Jia et al (2017)* designed a sliding knife opener, which can improve the seeding accuracy by opening a V-shaped ditch, and is suitable for the ditching of seeds with small particle size. *Zhao et al, (2022*), designed a serration opener for double-row on ridges, which can cut the root system of maize for no-tillage operation with better working stability. *Lü et al, (2018),* designed a split sliding knife opener to analyze the movement law of soil particles on the ditcher during ditching and backfilling. *Li et al, (2022),* designed a combined opener for sugarcane lateral planting, with effective seed dropping depth. The power consumption and trenching resistance of rotary tillage were studied. *Mustafa et al, (2017a); (2017b)* established a dynamic simulation model of the interaction between the trench cutter and soil. It is more accurate to simulate the contact model of soil particles by combining the delay elastic model and the linear cohesion model. *Barr et al, (2018b),* used the discrete element simulation method to study the influence of structural parameters of the ditcher on soil movement and mechanical performance. *Vamerali et al, (2006),* designed a wide-airfoil no-till opener with acute angle to solve the lack of soil compactness in seedbed. *Saeys et al, (2018),* studied the sliding cutting and hewing cutting methods of the ditcher, and found that the sliding cutting method had less operating resistance. *Sahu et al, (2018),* compared the trenching performance and fuel of different ditchers for the research of power saving. *Ahmad et al, (2020),* used computer technology to conduct discrete element simulation of disk ditcher and studied the influence law of ditching resistance. *Vilaseca et al, (2013),* carried out hot stamping of PVD coating on trenching materials to reduce the friction and drag.

Most of the openers are single row V-shaped, which can improve the seeding accuracy. However, there are few researches on double-row seeding openers. To this end, a sliding knife single-ditch and double-row seeding opener is studied. The soil layer is first cut with a single sliding knife, and then the soil guide board pushed into a seed trench, by a middle partition board to separate the double row seedbed belt. The working principle of the opener and the structural parameter design of key components are explained through the kinematic analysis of the contact between soil particles and the opener. The optimal operating parameters were determined through field tests and the design was validated with the aim of optimizing the structural parameters of the opener. Thereby a theoretical support and technical reference is provided for the innovative design of the opener.

## MATERIALS AND METHODS

### Structure and working principle of the seed metering device

The integral structure of narrow row flat seeder is shown in Fig. 1.

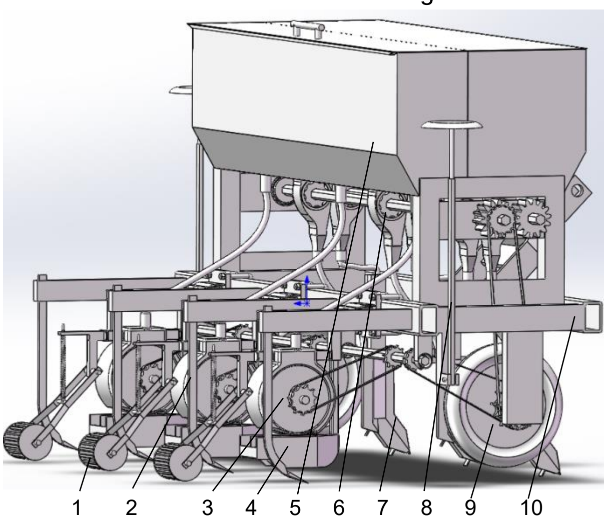


**Fig. 1 - Structure of narrow row flat seeder**

*1. Compacting device; 2. Subsoiling and covering shovel; 3. Seed metering device; 4. Seed opener; 5. Seed and fertilizer box; 6. Fertilizer apparatus; 7. Fertilizer opener; 8. Mark scraper device; 9. Drive support wheel; 10. Mainframe*

It consists of mainframe, seed and fertilizer box, fertilizer apparatus, fertilizer opener, seeding monomer (seed metering device, seed opener, compacting device), subsoiling and covering shovel, drive support wheel, and mark scraper device. A partition is designed inside the seed and fertilizer box to separate the seed and fertilizer with a volume ratio of 4:1. It is installed on the mainframe.

The fertilizer apparatus is installed in forequarter of the baseboard of the seed and fertilizer box, and it is connected with a fertilizer opener installed on the front beam of the mainframe by a telescopic hose to complete the fertilization operation. The seeding unit is arranged on the rear beam of the mainframe, with adjustable line spacing in the range of 30-50 cm. The connection is configured in a single hinged form, which has independent replication function and can also shorten the length of the machine to move the machine center of gravity forward. The seeding unit is arranged with the seed metering device, seed opener, and compacting device. The subsoiling and covering shovel is installed on the back beam support of the mainframe. The drive support wheel, mark scraper device are installed on the beam of the mainframe.

Seed opener is an important part of narrow flat bottom of seeding device. Its role is to build seed ditches and provide favorable environment for the smooth implantation of seeds. Its structural rationality will directly affect the sowing quality. The single-slide knife double-row flat-bottom opener is mainly designed for the crops that can be planted in narrow row and close flat. The opener is mainly composed of a soil cutting knife, a divide soil board, a guide soil board, a soil resistance board, a middle partition board, and a support board, as shown in Fig. 2.

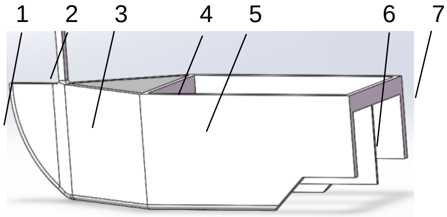


**Fig. 2 - Structure diagram of seed opener**

*1. Soil cutting knife; 2. Handle; 3. Soil guide board; 4. Support board;*
*5. Soil resistance board; 6. Middle partition board; 7. Connecting board*

During operation, the front machete penetrates the soil, guiding the soil board cut through the soil. The soil is separated by the soil resistance board on both sides to form a rectangular groove, opening a flat seed furrow. The cutting surface illustrating the relationship between the furrow shape and the seed is shown in Fig. 3. The notched structure is designed at the end of soil resistance board, so that the moist soil can fall back to the covering seed belt in time and the seeds can contact fully with the moist soil for germination. The middle partition board of the opener can separate two rows of seed ditches, with the functions of strengthening and isolating restriction, ensuring the planting of seeds in the intended seed belt, and reducing the reseeding and miss-seeding caused by seed bouncing. The support board and the connecting board play the role of supporting and reinforcing the soil resistance board on both sides.

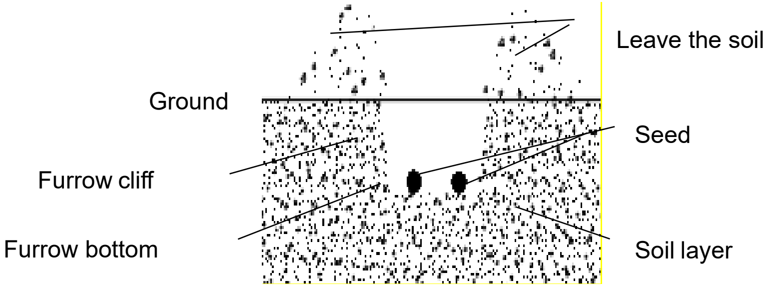


**Fig. 3 - Diagram of the furrow shape and seed distribution**

***Design of the curve for machete cutting edge***

The soil resistance arising when the machete cuts into the soil is closely related to the shape of the cutting edge curve. During the cutting process, the soil is subjected to the cutting of the machete, and the soil particles undergo a relative displacement, sliding down along the cutting edge curve of the machete. Since the cutting resistance decreases with the increase of the cutting angle and increases with the increase of the friction angle, as well as the entry resistance increases with the increase of the entry angle, the curved cutting edge is more advantageous in labor than the straight one. As the speed increases, the growth rate of traction resistance of the ditcher is linear > parabola > exponential curve > arc curve *(Liu et al., 2021; Liu et al., 2019)*. In the design, the edge curve is formed by the intersection of symmetrically arranged soil breaking surface. The curve of the arc function is selected as the curve of the machete cutting edge, and the coordinate system is established for the analysis, as shown in Fig. 4.

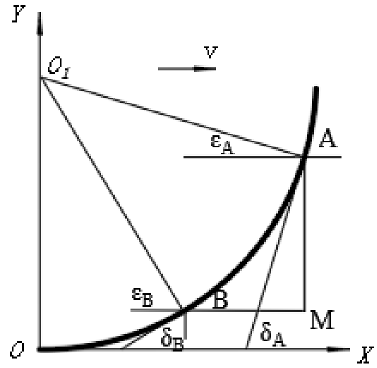


**Fig. 4 - Diagram of machete curve**

The curve equation *AB* of the machete cutting edge follows the relationship:

$$y = R + \sqrt{R^2 - x^2} \tag{1}$$

Taking two points, $A\ (x_A, y_A)$ and $B\ (x_B, y_B)$ on the arc function curve of the radius $R$, point $A$ is the upper vertex of the machete curve, and point $B$ is the bottom termination point of the machete curve. The slope of the machete cutting edge at points $A$ and $B$ can be expressed as:

$$\begin{cases} \frac{dy_A}{dx_A} = \frac{x_A}{\sqrt{R^2 - x_A^2}} = tan\delta_A = \tan\left(\frac{\pi}{2} - \varepsilon_A\right) \\ \frac{dy_B}{dx_B} = \frac{x_B}{\sqrt{R^2 - x_B^2}} = tan\delta_B = \tan\left(\frac{\pi}{2} - \varepsilon_B\right) \end{cases} \tag{2}$$

where, $\varepsilon_A$ is the cutting angle at $A$, °; $\varepsilon_B$ is the cutting angle at $B$, °; $\delta_A$ is the tangent with a forward direction angle at $A$, °; $\delta_B$ is the tangent with a forward direction angle at $B$, °; $\varepsilon_A$ and $\delta_A$ are the complementary angles, and similarly, $\varepsilon_B$ and $\delta_B$ are the complementary angles.

The difference $L_{AM}$ between points $A$ and $B$ in the vertical direction, i.e., the height of cutting into the soil, is as follows:

$$L_{AM} = y_A - y_B \tag{3}$$

Thus, the simultaneous Equations (1) - (3) can be obtained

$$y = \frac{L_{AM}}{sin\varepsilon_B - sin\varepsilon_A} + \sqrt{\frac{L_{AM}^2}{(sin\varepsilon_B - sin\varepsilon_A)^2} - x^2} \tag{4}$$

Equation (4) shows that the shape of the curve *AB* of the machete cutting edge is determined by the parameters of the cutting angle s$\varepsilon_A$ and $\varepsilon_B$ and the height difference $L_{AM}$. To make the opener more versatile and wear resistance, the sliding machete is made of cast steel. Considering the agricultural requirements of soybean seeding, the maximum depth of sowing $l_{AM}$ is set to 80 mm, and the curve height of the machete is set to 100 mm. The condition for soil particles to slip downward in ditching is that the cutting angle should be greater than the friction angle. The relationship between the two cutting angles and the friction angle is $\varepsilon_B > \varepsilon_A > \varphi$. The parameter $\varepsilon_B$ is an important factor affecting the working resistance. When the machete cuts into the soil, its movement direction is vertically downward. At this time, the cutting angle of point B is not too small, to prevent difficulty in cutting into the soil. To meet the conditions for cutting into the soil, too large resistance, the angle should be greater than the friction angle $\varphi$. The friction angle is generally between 15° - 38°.$\Phi$ is set to 23° to determine the maximum range of the cutting angle, 23° < $\varepsilon$ < 67°.

***Design of the guide soil board and soil resistance board***

To ensure that two rows of seeds are sown smoothly in their respective seeding row areas, the ditching width is large. Considering the requirement of saving electricity, reducing soil disturbance, not too wide ditching, combined with the requirements of planting multiple crops, it is generally designed to 100-120 mm. According to the requirements of crop growth, the row spacing is not less than 50 mm, and the width of the opener is designed as 100 mm. That is, the end span of the soil guide board is equal to the span of the soil resistance board on both sides, and it is 100 mm. The front span of the soil guide board is equal to the thickness of the back end of cutting soil of the machete. Length $L$, included angle $\beta$ and groove width $b$ follows the relationship:

$$L = \frac{b}{2\sin(\beta/2)} \tag{5}$$

It can be seen that the length of the soil guide board increases with the decrease of the included angle *β*. According to the law that the smaller the included angle of the soil guide board is, the smaller the resistance of the furrow soil, the included angle of the soil guide board is designed. However, the longer the soil guide board, the stronger the soil disturbance, and the more the relative movement of soil particles is intensified. The wet and dry soil is mixed, with the dry soil interlayer directly covering the seeds, which affects the water absorption of seeds, and it is not easy to germinate. The angle of the soil guide board is thus needed to be designed and analyzed. Soil particles are treated as loose particles and kinematics analysis is carried out on the guide soil board. During the ditching, the ditching device is set to move at a constant speed, and the tillage depth is stable. The analysis of the movement of soil particles on the soil plate and retaining plate of the ditching device is shown in Fig. 5. Soil particles on the contact surface of the soil guide board are subject to supporting the force $N$ and the friction force $f$. The supporting force is decomposed into $N_1$ along the contact surface and $N_2$ along the forward velocity direction. The angle between the forward velocity direction and the normal line is $\theta$. The soil particles slide on the contact surface, and the soil squeezing angle is $\alpha$. Since the tangential force is greater than the friction resistance, the contact surface of the ditcher has a sliding and cutting effect on the soil.

The resultant force on soil particles is $R$, and the direction is the same as the motion of soil particles. In this case, the differential equation of the motion of soil particles is as follows:

$$m\frac{d^2x}{dt^2} = N(tan\theta - tan\varphi) \tag{6}$$

$$m\frac{d^2y}{dt^2} = 0 \tag{7}$$

$$N = \frac{mg}{2tan\alpha} \tag{8}$$

The velocity $v$ and displacement $s$ of soil particles on the contact surface is as follows:

$$v = \frac{gt}{2}\frac{tan\theta - tan\varphi}{tan\alpha} \tag{9}$$

$$s = \frac{gt^2}{2}\frac{tan\theta - tan\varphi}{tan\alpha} \tag{10}$$

When the soil particles move to the back edge of the soil guide board, they begin to move along the soil resistance board. Soil particles are subjected to the friction $f_1$ of the soil resistance board and the friction $f_2$ of the soil edge layer, extruding $N'$. The friction angle between soil particles is $\varphi'$.

In this case, the motion differential equation of soil particles is as follows:

$$m\frac{d^2x}{dt^2} = N'(tan\varphi' - tan\varphi) \tag{11}$$

The instantaneous velocity $v'$ of the soil particle escaping from the soil resistance board is as follows:

$$v' = \sqrt{\frac{Lg[(tan\varphi' - tan\varphi) + tan\varphi' - tan\varphi)sin\theta}{tan\alpha}} \tag{12}$$

Where, the included angle $\theta$ between the forward velocity and the normal, the included angle $\beta$ of the soil guide board of the opener, the relationship between the included angle is $\theta + \beta/2 = \pi/2$. According to the design method of ship-type trenching plough *(Wang et al., 2019)*, the value range of the included angle of the soil guide board is determined as 30°<$\beta$<70°, shown in Fig. 5. When the soil particles moved to both sides under the action of soil guide board, the rectangle furrow is formed, the bottom of the furrow is flat and the seeding depth is consistent. After the soil resistance board passes, the wet soil particles naturally fall back to the seed groove to ensure that the seeds are fully in contact with the wet soil, thereby improving the regularity of seedlings.

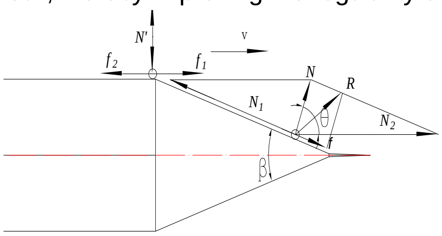


**Fig. 5 - Kinematic diagram of soil particles at soil guide board and soil resistance board of the opener**

### *Testing material and equipment*

The testing material used is soybeans that are widely grown in Heilongjiang Province. The test was conducted from May 4 to 11, 2022, in the test base of Northeast Agricultural University. The relative humidity of soil was 26% and the hardness was 359 kPa. The test equipment narrow row flat seeder is as shown in Fig.6.

**Fig. 6 - Field test of narrow row flat seeder**

***Testing method***

Based on the agronomic requirements of soybean, the spacing between single rows of seeds was set as 80 mm, and the sowing depth as 50 mm to ensure the uniform sowing speed during operation. According to *GB/T6973-2005 Test Method of Simple Grain (Precision) Seeders* and *JB/T10293-2001 Technical Conditions of Simple Grain (Precision)* Seeders, *NY/T740-2003 Field Ditching Machinery Operation Quality*, the seeding performance index and trenching depth performance index of seeder were studied through theoretical analysis and field experiments. The test process is shown in Fig. 7(a) ~(c). The variable coefficient $C_b$ of the seeding is as follows:

$$\bar{X} = \frac{\sum_{i=1}^{m} X_i}{m} \tag{13}$$

$$C_b = \sqrt{\frac{\frac{1}{\mathrm{m\text{-}1}}\sum_{i=1}^{m}(X_i - \bar{X})}{\bar{\mathrm{x}}}} \tag{14}$$

where, $X_i$ is the seed spacing of two adjacent seeds in each row, mm; $\bar{X}$ is the average of the seed spacing of two adjacent seeds in each row, mm, and $m$ is the times of tests.

The formula for the variable coefficient $C_h$ of trenching depth is as follows:

$$\bar{h} = \frac{\sum_{i=1}^{n} h_i}{n} \tag{15}$$

$$C_h = \sqrt{\frac{\frac{1}{n}\sum_{i=1}^{n}(h_i - \bar{h})}{\bar{h}}} \times 100\% \tag{16}$$

where, $h_i$ is the sowing depth difference value, mm; $\bar{h}$ is the average of sowing depth difference value, mm, and $n$ is the times of tests.

The main factors affecting the trenching performance and working resistance of the trencher are the penetration angle of the cutting edge of the machete and the angle of the soil guide plate. As a test factor, through the quadratic regression rotary orthogonal combination test, the change law of the influencing factors on the working resistance, the variation coefficient of sowing and variation coefficient of the depth of trenching is analyzed.

(a) (b) (c)

**Fig. 7- The process test of performance for the opener**

*(a) Working status of the opener; (b) The measurement of seeding spacing; (c) The measurement of trenching depth*

## RESULTS AND ANALYSIS

### *Performance test of the opener*

The machine works at a uniform speed of 2 m/s and the trenching depth is 50 mm. On the basis of the design and analysis of the machete cutting edge and the soil guide board, combined with the seeding distance, the value range of each test factor is determined. The penetration angle *ε* of the machete cutting edge of the opener is 23°-67°. The included angle *β* of the guide soil board of the opener is 30°-70°. The two-factor five-level quadratic regression orthogonal combination design is used to seek the best combination of working parameters of the seeding opener. The coding of experimental factors and level is shown in Table 1, and the design scheme and results of the test are shown in Table 2. The measured data of the test are analyzed by using the design-Expert 8.0.6 software regression analysis and factor variance analysis, as shown in Table 3.

**Table1**

**Coding of experimental factors and level**

| Code number | Penetrating angle *ε* (°) | Included angle *β* (°) |
|---|---|---|
| 1.414 | 67 | 70 |
| 1 | 61 | 64 |
| 0 | 45 | 50 |
| -1 | 29 | 36 |
| -1.414 | 23 | 30 |

**Table 2**

**Experimental design and results**

| Number | Experimental factor | | Performance index | | |
|---|---|---|---|---|---|
| | Penetrating angle $x_1$ / ° | Included angle $x_2$ / ° | Resistance $y_1$ / N | Variable coefficient of sowing $y_2$ / % | Variable coefficient of depth $y_3$ / % |
| 1 | -1 | -1 | 68 | 9.86 | 3.05 |
| 2 | +1 | -1 | 60 | 6.18 | 6.61 |
| 3 | -1 | +1 | 85 | 13.94 | 5.45 |
| 4 | +1 | +1 | 72 | 8.95 | 5.34 |
| 5 | -1.414 | 0 | 79 | 9.05 | 3.56 |
| 6 | +1.414 | 0 | 66 | 8.64 | 6.87 |
| 7 | 0 | -1.414 | 69 | 6.98 | 3.67 |
| 8 | 0 | +1.414 | 89 | 11.56 | 6.74 |
| 9 | 0 | 0 | 61 | 7.34 | 3.96 |
| 10 | 0 | 0 | 60 | 8.86 | 4.72 |
| 11 | 0 | 0 | 59 | 6.91 | 3.11 |
| 12 | 0 | 0 | 66 | 8.15 | 4.01 |
| 13 | 0 | 0 | 71 | 6.92 | 3.07 |
| 14 | 0 | 0 | 67 | 5.45 | 2.68 |
| 15 | 0 | 0 | 70 | 6.63 | 4.98 |
| 16 | 0 | 0 | 63 | 7.94 | 4.35 |

**Table 3**

**Variance analysis**

| Index | Source | Sum of squares | df | Mean square | *F* | *P* |
|---|---|---|---|---|---|---|
| Resistance | Model | 967.64 | 5 | 193.53 | 10.33 | 0.0011 |
| | $x_1$ | 193.90 | 1 | 193.90 | 10.35 | 0.0092 |
| | $x_2$ | 410.19 | 1 | 410.19 | 21.90 | 0.0009 |
| | $x_1 x_2$ | 6.25 | 1 | 6.25 | 0.33 | 0.5763 |
| | $x_1^2$ | 63.28 | 1 | 63.28 | 3.38 | 0.0959 |

| Index | Source | Sum of squares | df | Mean square | *F* | *P* |
|---|---|---|---|---|---|---|
| | $x_2^2$ | 294.03 | 1 | 294.03 | 15.70 | 0.0027 |
| | Residual | 187.29 | 10 | 18.73 | | |
| | Lack of Fit | 41.42 | 3 | 13.81 | 0.66 | 0.6009 |
| | Pure Error | 145.88 | 7 | 20.84 | | |
| | Cor Total | 1154.94 | 15 | | | |
| **Variable coefficient of sowing** | Model | 51.70 | 5 | 10.34 | 6.13 | 0.0075 |
| | $x_1$ | 10.73 | 1 | 10.73 | 6.36 | 0.0303 |
| | $x_2$ | 22.63 | 1 | 22.63 | 13.41 | 0.0044 |
| | $x_1 x_2$ | 0.43 | 1 | 0.43 | 0.25 | 0.6250 |
| | $x_1^2$ | 7.33 | 1 | 7.33 | 4.35 | 0.0637 |
| | $x_2^2$ | 10.58 | 1 | 10.58 | 6.27 | 0.0312 |
| | Residual | 16.87 | 10 | 1.69 | | |
| | Lack of Fit | 9.14 | 3 | 3.05 | 2.76 | 0.1214 |
| | Pure Error | 7.73 | 7 | 1.10 | | |
| | Cor Total | 68.57 | 15 | | | |
| **Variable coefficient of depth** | Model | 22.15 | 5 | 4.43 | 6.98 | 0.0047 |
| | $x_1$ | 8.26 | 1 | 8.26 | 13.03 | 0.0048 |
| | $x_2$ | 3.74 | 1 | 3.74 | 5.90 | 0.0355 |
| | $x_1 x_2$ | 3.37 | 1 | 3.37 | 5.31 | 0.0440 |
| | $x_1^2$ | 3.41 | 1 | 3.41 | 5.38 | 0.0428 |
| | $x_2^2$ | 3.36 | 1 | 3.36 | 5.30 | 0.0441 |
| | Residual | 6.34 | 10 | 0.63 | | |
| | Lack of Fit | 1.50 | 3 | 0.50 | 0.72 | 0.5704 |
| | Pure Error | 4.85 | 7 | 0.69 | | |
| | Cor Total | 28.49 | 15 | | | |

As shown in Table 3, in terms of the working resistance, the penetrating angle of the machete cutting edge and the included angle of the soil guide board of the influencing factors are extremely significant. The included angle of the soil guide board is greater than the penetrating angle of the machete cutting edge regarding the influence degree. In terms of the variation coefficient of sowing, the penetrating angle of the machete cutting edge is significant, and the included angle of the soil guide board is extremely significant.

In terms of the variation coefficient of depth, the penetrating angle of the machete cutting edge is extremely significant, and the included angle of the soil guide board is significant. The regression equation between the fitting performance index and the factor coding value is selected.

The regression equations for the working resistance coefficient of variation, seeding coefficient of variation, and depth coefficient of variation are:

$$y_1 = 64.63 - 4.92x_1 + 7.16x_2 \text{-} 1.25x_1x_2 + 2.81x_1^2 + 6.06x_2^2 \tag{17}$$

$$y_2 = 7.28 - 1.16x_1 + 1.68x_2 \text{-} 0.33x_1x_2 + 0.96x_1^2 + 1.15x_2^2 \tag{18}$$

$$y_3 = 3.86 + 1.02x_1 + 0.68x_2 \text{-} 0.92x_1x_2 + 0.65x_1^2 + 0.65x_2^2 \tag{19}$$

To more intuitively analyze the relationship between the performance indicators and test factors, Design-Expert 8.0.6 software is used to establish the corresponding surface between each indicator and factor, as shown in Fig.8 - Fig.10.

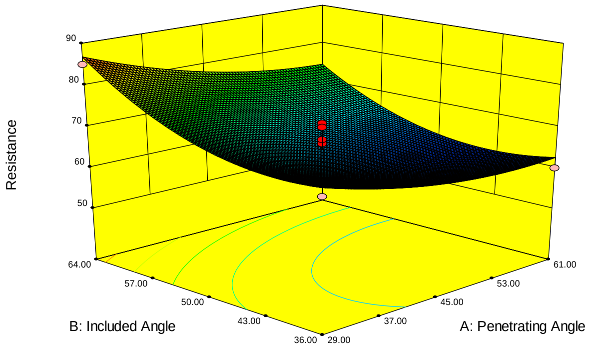


**Fig. 8 - Effects of factors on the resistance**

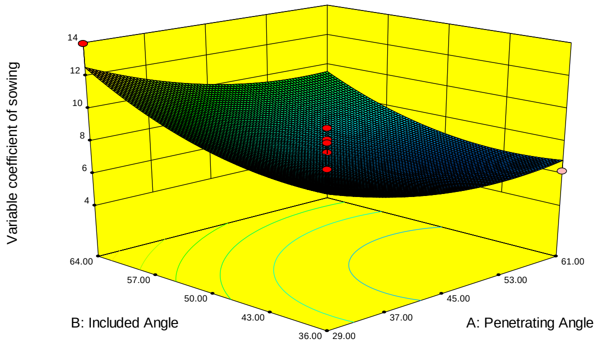


**Fig. 9 - Effects of factors on the variable coefficient of sowing**

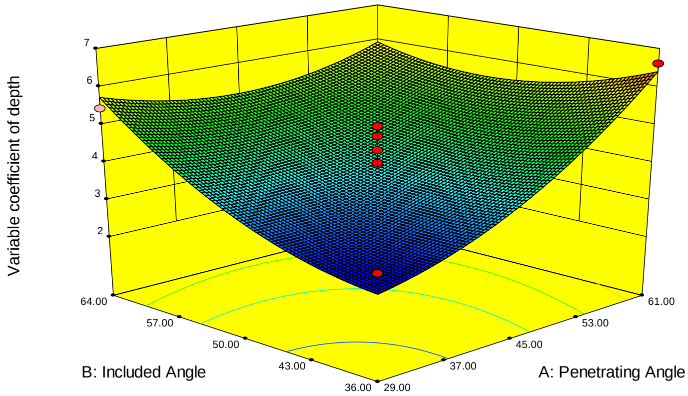


**Fig. 10 - Effects of factors on the variable coefficient of depth**

### *Influence analysis of various factors on the performance index of opener*

According to Eq. (17) and Fig. 8, the working resistance decreases first and then increases with the increase of the penetration angle, and increases with the increase of the included angle. When the penetrating angle was about 50° and the included angle was 40~45°, the working resistance was the minimum.

According to Eq. (18) and Fig. 9, the variation coefficient of sowing decreases first and then increases with the increase of the penetration angle, and decreases first and then increases with the increase of the included angle. When the penetration angle was 45-53° and the included angle was about 43°, the variation coefficient of sowing was the minimum.

According to Eq. (19) and Fig.10, the variation coefficient of depth increases with the increase of the penetration angle, and increases first and then decreases with the increase of the included angle. When the penetrating angle was 45-53° and the included angle was 38~43°, the variation coefficient of depth was the minimum.

### *Optimization of test results*

As shown in the test data, the optimal combination of working parameters is obtained, and the design for each factor is optimized. According to the agronomic requirements for crop sowing, and combined with the boundary conditions of various factors, the parameterized model is optimized.

According to *GB/T6973-2005 Test Method of Simple Grain (Precision) Seeders* and *JB/T10293-2001 Technical Conditions of Simple Grain (Precision)* Seeders, *NY/T740-2003 Field Ditching Machinery Operation Quality*, Using the multi-objective variable optimization method, the working resistance, seeding coefficient of variation, depth coefficient of variation and regression equation parameters of the nonlinear programming model are established:

$$\begin{cases} \min y_1 \\ \min y_2 \\ \min y_3 \\ s.t. \quad 23° \le x_2 \le 67° \\ \quad\quad 30° \le x_2 \le 70° \\ \quad\quad 0 \le y_1 \le 70 \\ \quad\quad 0 \le y_2 \le 15\% \\ \quad\quad 0 \le y_3 \le 10\% \end{cases} \tag{20}$$

According to the principle of optimization, and the Design Expert8.0.6 optimization analysis, it is concluded that the penetrating angle is 50.03°, and the included angle is 42.36°. The sowing opener was optimal, the working resistance, the variation coefficient of sowing, the variation coefficient of depth was 61.47 N, 6.49% and 4.22%, respectively. The optimal parameter combination interval is obtained according to the optimization analysis, as shown in Fig.11. When the penetrating angle is 28.09~83.94°, the included angle is 25.54 - 60.16°; the working resistance is less than 70 N; the sowing coefficient of variation is less than 15%, and the depth coefficient of variation is less than10%.

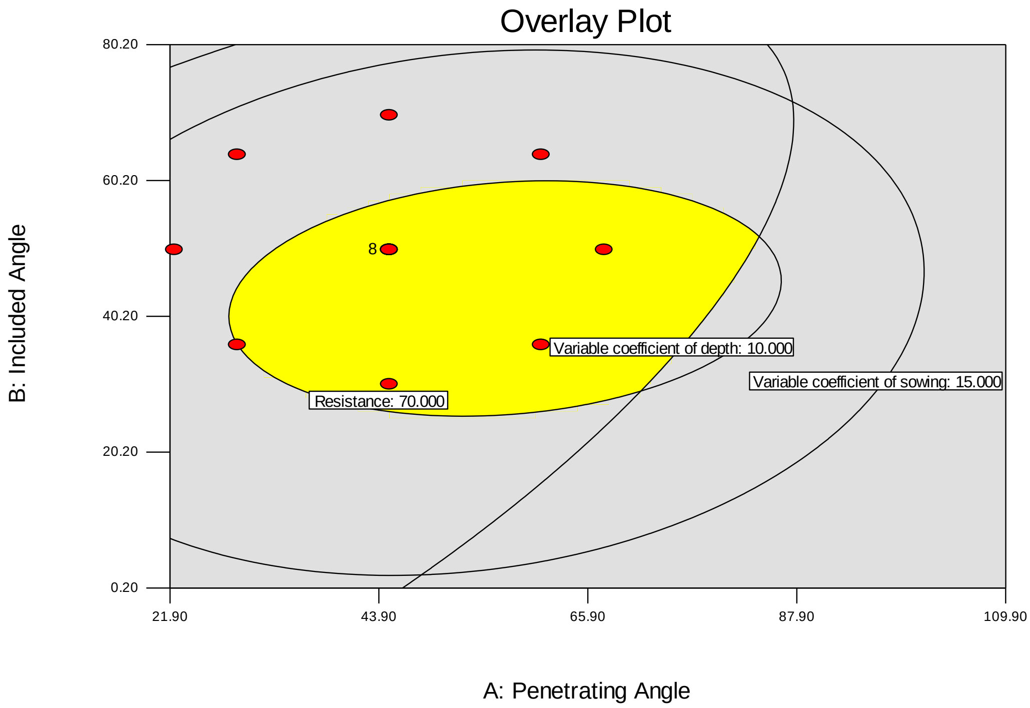


**Fig. 11 - Diagram of parameters analysis**

***Verification of optimization results***

According to the optimal parameter range obtained by the optimization analysis, two sets of data are selected for validation testing. The test data of each group were repeated for five times and the mean value is as shown in Table 4.

**Table 4**

**Results of verification experiment**

| Number | penetrating angle $x_1$/° | included angle $x_2$/° | working resistance $y_1$/N | variation coefficient of sowing $y_2$/% | variation coefficient of depth $y_3$/% |
|---|---|---|---|---|---|
| **1** | 50 | 42 | 62.26 | 6.81 | 4.56 |
| **2** | 51 | 43 | 63.33 | 6.99 | 5.05 |

From Table 4, it is found that the verification test results are consistent with the theoretical optimization results, and the trenching performance meets the agronomic requirements.

## CONCLUSIONS

(1) In this study, a single-trench double-row machete flat bottom opener was designed for precision seeding, and its structure and working principle were elucidated. Based on the equation of arc curve, the machete cutting edge was designed. The theory of kinematic analysis was used to design the soil guide board and soil resistance board to enhance the drag reduction performance and the quality of trenching.

(2) Taking the penetrating angle of machete cutting edge and the included angle of the soil guide board as the influencing factors, a multi-factor quadratic regression orthogonal rotation combined test was conducted to study the effects of various factors on the working resistance, the sowing coefficient of variation, and the depth coefficient of variation. The results showed that: in terms of the working resistance, the penetrating angle of machete cutting edge and the included angle of the guide soil board of the influencing factors were extremely significant, and the included angle of the soil guide board was greater than the penetrating angle of machete cutting edge regarding the influence degree. In terms of the sowing coefficient of variation, the penetrating angle of machete cutting edge was significant, and the included angle of the soil guide board was extremely significant. In terms of the depth coefficient of variation, the penetrating angle of machete cutting edge was extremely significant, and the included angle of the soil guide board was significant.

(3) A multi-objective optimization analysis was performed to establish an optimization model. The optimal combination of the working parameters of the opener was determined using the Design Expert 8.0.6 software. The results showed that when the penetrating angle was 50.03° and the included angle was 42.36°, the sowing opener performance was optimal. The working resistance, the sowing coefficient of variation, and the depth coefficient of variation were 61.47N, 6.49% and 4.22%, respectively. After verification, the results are basically consistent, and the sowing and trenching performance meets the agronomic requirements.

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