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Article

Design and Optimization of Planting Process Parameters for 2ZYX-2 Type Green Onion Ditching and Transplanting Machine

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Abstract: Considering the current low level of mechanization for domestic green onion planting and the high labor intensity of artificial planting, a 2ZYX-2 green onion ditching and transplanting machine, which can complete ditching, ridging, transplanting, repression, soil covering and other operations, is designed in this study. The Central Composite test design method was carried out with the speed of the transplanting machine, the depth of the opener and the horizontal position of the opener as the experimental factors and with the qualification ratio of perpendicularity, the variation coefficient of the plant spacing and the qualification ratio of the planting depth as the test index. Through the analysis of the model interaction and response surface, the change laws that the influence the machine's forward speed, the depth of the opener and the horizontal position of the opener were studied. The regression model was optimized by Design-Expert 8.0.6 software, and the accuracy of the predicted results was verified by experiments. The optimal working parameters showed that the forward speed of the machine was 0.06 m/s, the depth of the opener was 102 mm, and the horizontal position of the opener was 29 mm. Under conditions of optimal working parameters, the qualification rate of the verticality was 86.83%, the coefficient of variation for the plant spacing was 2.77, and the pass rate of planting depth was 88.26%. The research related to the thesis can provide a reference for the mechanized planting of green onion, which is of great significance to the cost-effectiveness of the green onion industry.

Keywords: Agricultural machinery; motion analysis; green onion; experiment

1 Introduction

Green onion is widely consumed by populations due to its rich nutrition, and special seasoning effects. China is the world's largest green onion cultivation country and contributes 70% of international green onion trade, with an area of 533.3 thousand hectare and a total output of approximately 20 million tons [1]. Green onion in China has a long history of cultivation, across the country, including Shandong Zhangqiu green onion, Liaoning scaly stick green onion, Hebei Haiyang green onion and so on. In addition, regional large-scale planting operations have been formed in Zhangqiu, Shandong Province, and Baodi, Tianjin and Yutian, Hebei Province [2]. With development, farmers' requirements for mechanized transplanting are increasingly urgent, so it is urgent to design a green onion-transplanting machine that is in line with national conditions, to solve the problem of green onion planting in China.

Since the 1960s and 1970s, domestic scholars have introduced foreign technology and combined it with national planting conditions, and a series of reliable transplanting machineries have been further developed. Among these machines are the 2ZT, 2YZ, and 2Z-2 clamp type transplanters; and the 2ZY-2, 2ZB-2, and 2ZQ type chain clamp transplanters, Clamp type and chain clamp transplanters can be used for transplanting bare root seedlings, but the working efficiency is low (approximately 30 plants/min), and the injury rate of seedlings is high [3]; the 2YZ-4, 2ZB-6, and 2ZYB-2 type cup type transplanters, 2ZB-4, 2ZDF, 2ZY-200, and 2ZG-2 type Guide tube transplanters, are suitable for naked seedling transplanting, with low injury rate and high work efficiency (approximately 60 plants/min), but the structure is complicated and the research and development cost is high [4,5]. For onion planting, high planting density, erectility and high survival rate are required.

According to the technical requirements of transplanting green onion, this study has developed a 2ZYX-2 green onion ditching and transplanting machine， this model can integrate functions, such as ditching, ridging, transplanting, repression and covering soil, the aim is to solve the problems of the power wheelbase not being matched with the green onion ridge distance, the artificial transplanting efficiency being low, and the labor intensity being large. Based on the qualification ratio of perpendicularity, the variation coefficient of the plant spacing and qualification ratio of the planting depth, the key parameters of the machine were tested and analyzed, and the response surface model was established to determine the optimal working parameters, to provide a reference for machinery for the transplantation of green onion.

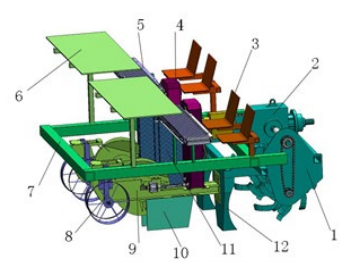
2 Overall Design and Working Principle

2.1 Agronomic Requirements of Green Onion Planting

When planting green onion in China, the plant spacing requirements are 30-50 mm, the row spacing is 650-850 mm, and the planting depth is 50-120 mm, to ensure that the perpendicularity of the onion is above 45°, it is ditched north and south according to the line spacing of 750 mm. The depth and width of the ditch are both 300-350 mm. The person planting the onions follows the principle of "Up and Down", the planting depth must be 70-100 mm higher than the surface of the onion leaf [6-8]. The agronomic requirements of these green onions are very difficult for mechanized transplanting work.

2.2 Overall Design

The whole structure of the one-piece scallion trench-planting and transplanting machine is shown in Fig. 1. The main working parts are arranged symmetrically in accordance with the longitudinal centerline of the machine and tools, which are mainly composed of the horizontal swing seedling structure, covering soil pressure roller, upright planting structure, opener, vertical clamping structure, retaining plate and frame.



1. Rotary tillage structure 2. Rotary tillage gearbox 3. Artificial seat 4. Planting gearbox 5. Horizontal swing seedling structure 6. Green onion storage tray 7. Frame 8. Covering soil pressure roller 9. Upright planting structure 10. Opener 11. Vertical clamping structure 12. Retaining plate.

Figure 1: Structurale diagram of the 20ZYX-2 green onion ditching and transplanting machine

2.3 Working Principle

The onion seedlings were placed on the green onion storage stand before transplanting. During the transplanting operation, the output shaft of the tractor is connected to the gearbox of the rotary tillage device through the universal joint, providing power for the transplanting device. The workers sit on the artificial seat, remove the onion seedlings from the onion storage tray, and sequentially place them into the limit protrusions on the conveyor belt of the horizontal pendulum mechanism; The green onion is placed in the lateral institutions and begin horizontal motion; then the green onion placed into vertical clamp seedling institutions turns from horizontal movement to vertical movement, and when the green onion seedling reaches the bottom of the planting plate, it pass the elastic roller-clamping section, and the green onion seedling is released. At this time, the seedling enters the groove opened by the opener, and the backflow of the tail of the opener covers the root of the onion seedling. Simultaneously, the covering soil pressure roller presses the green onion from the back to the front to compact the soil to complete the planting process.

2.4 Technical Parameters

The main technical parameters of 2ZYX-2 scallion ditching and transplanting machine are listed in Tab. 1.

Table 1: The main technical parameters of 2ZYX-2 scallion ditching and transplanting machine

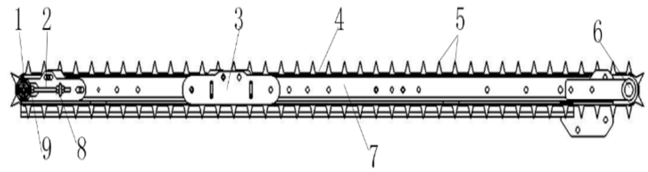
Project	Value
Row spacing/mm	750-850
Plant spacing/mm	30-50
Seedling burial rate/%	≤ 5
Leakage rate/%	≤ 4
Injury rate/%	≤ 5
Number of job rows	2
Planting depth/mm	50-130
Matching Power/kW	≥ 35
Qualification rate of planting depth/%	≥ 75
Operational productivity/(hm^2/h)	0.1-0.18
Shape size (length × width × height)/mm	3100 × 1700 × 1250

3 Key Component Design and Analysis Calculation

The planting system is the core part of the whole transplanter, and the reliability of its performance is the key to improving the efficiency of transplanting, the verticality of onion seedlings and the qualified rate of planting depth. Therefore, it is necessary to analyze the relevant components of the planting system, including the horizontal swing seedling structure, the vertical clamping structure and the vertical planting structure.

3.1 Design of the Horizontal Swing Seedling Structure

As one of the core components of the planting system, the horizontal swing seedling structure is designed to achieve equidistant transmission through artificial seedling throwing, which avoids the randomness of the artificial seedling swing. The horizontal swing seedling structure is located above the side of the vertical seedling-clamping device, which is the premise of stable and efficient operation of the planting system. A schematic diagram of the transverse seedling swing mechanism is shown in Fig. 2. When the onion seedlings enter the horizontal swing seedling structure, the planting gearbox drives the active roller of the horizontal swing seedling structure to rotate and transport the onion seedlings to the vertical clamping structure. The length of the conveyor belt of the transverse seedling swing mechanism is 950 mm according to the operation width, and material with equal spacing flexible PVC is used. According to the diameter range of transplanted onion seedlings, the limit protrusion spacing is 15 mm.



1. Drive roller 2. Tension bar 3. Fixed plate 4. Conveyor belt 5. Limitation protrusion 6. Active roller 7. Frame 8. Tension nut 9. Adjustment hole.

Figure 2: Schematic diagram of the horizontal swinging device

The movement of the seedling body on the horizontal swing seedling structure is a synthesis of the forward motion of the horizontal conveyor belt and the tool, and its trajectory equation is as follows:

$$\begin{cases} x = V_a t + C_1 \\ y = V_d t + C_2 \end{cases} \tag{1}$$

In the formula V_a is the transmission speed of the horizontal conveyor belt, m/s; V_d is the forward speed of the machine, m/s; and C1 and C2 are constants.

As seen in formula (1), the trajectory of the seedling body is a straight line with a slope. The ratio of the horizontal conveyor belt speed of the transverse seedling swing mechanism to the forward speed of the machine determines the trajectory of the seedling body, while the speed of the output roller determines the speed of the conveyor belt.

$$\lambda_1 = \frac{V_a}{V_d} = \frac{\omega R}{V_d} \tag{2}$$

In the formula, ω is the angular speed of the roll, rad/s, and R is the radius of rotation of the roll, mm.

To ensure that the onion seedlings enter the vertical seedling clamping mechanism in a horizontal state, the following conditions should be met:

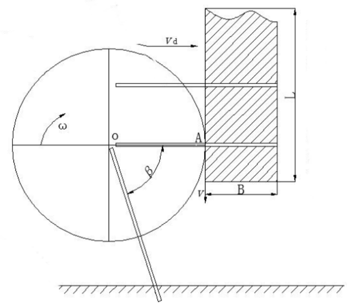
$$\lambda_1 = \frac{V_a}{V_d} = \frac{\omega R}{V_d} = 1 \tag{3}$$

According to the preliminary test, the optimum transplanting speed of the machine is 0.06 m/s, and the rotating radius R of the roller is 40 mm according to the design value and rotating speed:

$$\omega = \frac{V_d}{R} = \frac{0.06}{0.04} = 1.5 \text{rad/s} \tag{4}$$

3.2 Design of the Vertical Clamping Structure

The vertical seedling clamping mechanism is used as the medium for onion seedling transmission. The conveyor belt material, speed and width of the conveyor belt determine the movement state of the onion seedlings, thus affecting the planting effect. Simultaneously, it was found that if the speed of the conveyor belt of the vertical seedling clamping mechanism was not synchronized with the speed of the planting disc of the upright planting structure, the onion seedlings would tear and rotate at the clamping point, which would increase the damage rate of the onion seedlings. A schematic diagram of the movement process of the onion seedlings is shown in Fig. 3.



ω is the rotational speed of the planting disc, rad/s; *β* is the angle of rotation before the planting onion seedlings in soil (º); O is the center of the planting disc; A is the holding point of the onion seedlings; *V* is the conveyor belt transmission speed of the vertical seedling clamping mechanism, m/s; *B* is the conveyor bandwidth of the vertical seedling clamping mechanism, mm; and *L* is the length of the vertical seedling clamping conveyor belt, mm.

Figure 3: Diagram of the movement process of the onion seedlings

The conclusion drawn by Hu Jun [2]. is that the conditions for onion seedlings to be transported horizontally in the conveyor belt of the vertical seedling clamping mechanism are as follows:

1) The onion seedlings enter the planting plate at point A, and point A is located on the horizontal central line of point O in the center of the planting plate.
2) Before point A, the distance between the holding points of the onion seedlings on the planting plate are less than the diameter of the onion seedlings.
3) At point A, the movement speed of the conveyor belt of the vertical seedling clamping mechanism is equal to the rotational speed of the planting disc.

In practice, the velocity of the vertical seedling-clamping conveyor belt at point A does not easily equal to that of the planting disc, so a relative velocity is proposed in the paper. When the relative speed of the contact between onion seedlings and the wall of the planting plate is too high, the maximum contact pressure will exceed the maximum yield point of the onion seedlings and cause damage to the onion seedlings. Therefore, the relative speed of contact between onion seedlings and the planting plate should be controlled. The contact between onion seedlings and the planting plate should be defined as the point contact. The calculation process refers to the mechanical properties of broccoli seedlings as follows [8]:

$$V=\left(\frac{3F_E}{4E^*R^{\frac{1}{2}}}\right)^{\frac{5}{6}}\left(\frac{16E^*R^{\frac{1}{2}}}{15m}\right)^{\frac{1}{2}} \tag{5}$$

$$\frac{1}{R}=\frac{1}{R_p}-\frac{1}{R_g} \tag{6}$$

$$\frac{1}{m}=\frac{1}{m_p}+\frac{1}{m_g} \tag{7}$$

$$E^*=\frac{1-\mu_p}{E_p}+\frac{1-\mu_g}{E_g} \tag{8}$$

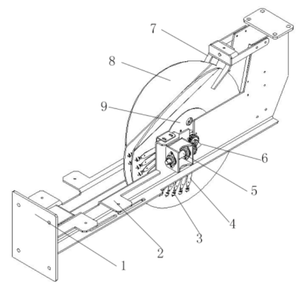
In the formula, *V* is the maximum relative velocity allowed, m/s; F_E is the contact pressure, N; *R* is the equivalent radius; R_P is the radius of planting plate; R_g is the average radius of the onion seedling, mm; *m* is the equivalent mass; m_P is the quality of the planting plate; m_g is the average mass of the seedling, kg; E* is the equivalent elastic modulus; E_p is the elastic modulus of the planting plate; E_g is the elastic modulus of the seedling body, MPa; μ_p is Poisson's ratio of the onion seedlings; and μ_g is Poisson's ratio of the planting plates.

Combined with the onion seedling transmission conditions and the maximum speed analysis allowed, the design of the vertical clamping mechanism width B is 100 mm and the height L is 700 mm, as shown in Fig. 3; the material is pressed with flexible PVC. The test results show that the working performance of the mechanism is reliable, and the working mode of the conveyor belt of the transverse seedling swing mechanism has a high degree of coordination.

3.3 Design of the Upright Planting Structure

3.3.1 Determination of Planting Plate Parameters

The erect planting mechanism is located at the lower back of the vertical clamping mechanism, and its performance directly affects the quality and efficiency of the whole transplanting operation. The mechanism is mainly composed of a pair of rubber planting trays, a pair of elastic roller-clamping devices, a limit fork, a planting shaft and so on. The main function of the vertical seedling-planting mechanism is to transfer the onion seedlings by the vertical seedling-clamping mechanism and rotate those 90° before planting them in the soil. This requires the same distance, depth and better upright degree of the transplanted plants. The structure's schematic diagram is shown in Fig. 4.



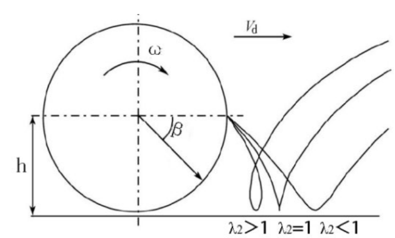
1. Fixed bracket 2. Frame 3. Elastic roller 4. Elastic roller bracket 5. Planting shaft 6. Gear 7. Limiting fork 8. Planting disc 9. Fixed disc.

Figure 4: Structural sketch of erect seedlings

The linear velocity of the planting disc in a circular motion is called V_{a1}, and the ratio of the circular velocity of the planting disc V_{a1} to the transplanting speed V_d of the machine tool is called λ_2:

$$\lambda_2 = \frac{V_{a1}}{V_d} \tag{9}$$

According to the working principle of the machine, when λ_2 is less than 1, any point on the trajectory of the planting tray has no backward horizontal speed, and the onion seedlings will lean forward. When λ_2 is more than 1, the horizontal component of the absolute speed of the planting tray is opposite to the direction of the forward speed of the machine, and the verticality of the onion seedlings is the highest at this time. The Trajectory of the planting disc is shown in Fig. 5.



H is the height from the seedling body center to the planting ground, mm; ω is the rotation speed of the planting plate, rad/s; V_d is the forward speed of the whole machine, m/s; and *β* is the angle between the axis of the seedling body and the horizontal plane when the seedling body begins to break away from the planting plate(°).

Figure 5: Trajectory of the planting disc

According to the experience of the transplanter manufacturer, the value of λ_2 ranges from 1.0 to 2.0 [9]. If λ_2 is too large, the onion seedlings easily accumulate at the end of the transverse seedling swing device. If λ_2 is too small, the transporting efficiency of the onion seedlings will be reduced. Therefore, the value of λ_2 is 1.5, and the rotational speed *n* of the planting plate can be calculated according to the speed of the transplanter V_d.

The quality of transplanting will decrease if the forward movement speed is too fast, and the efficiency will decrease if the transplanting speed is too slow. The horizontal movement velocity V_d of the machine tool is determined by plant distance *H* and artificial seedling swing frequency *F*. The specific relationship is as follows:

$$V_d = \frac{HF}{60} \tag{10}$$

The ideal planting distance of onion seedlings is 30-50 mm, which is limited by the operator's ability, the artificial planting frequency is 30-50 plants per minute. If the planting distance is $30 \leq H \leq 50$ mm and the artificial planting frequency is $30 \leq F \leq 50$ plants per minute, the transplanting speed of the machine should be $0.015 \leq V_d \leq 0.04$ m/s. When the two operators swing the seedlings simultaneously, the transplanting speed of the implement should be 0.03-0.08 m/s, which is set as $V_d = 0.06$ m/s in this paper. The radius of rotation of the planting plate is determined by the height of the onion seedlings. According to the height of the transplanted onion seedlings, 100-220 mm, the radius of the planting plate is 250 mm.

$$n = \frac{30\lambda_2 V_d}{\pi R} = \frac{30 \times 1.5 \times 0.06}{\pi \times 0.25} = 3.4 \tag{11}$$

In the formula, *n* is the rotational speed of the planting disc, r/min; and R is the rotation radius of the planting disc, mm.

The rotational speed of the planting disc $n = 3.4$ r/min = 0.36 rad/s was obtained from formula (11).

3.3.2 Motion Analysis of Seedlings in the Process of Planting

In the process of transplanting onion seedlings, to ensure the verticality of the onion seedlings and reduce the impact of onion seedlings, it is necessary for onion seedlings to cover the soil in a static state, which requires that the whole machine provide a relatively static state for onion seedlings under a certain forward speed [10,11] that is, zero-speed planting. However, in the actual planting operation, it is difficult for onion seedlings to obtain absolute zero speed at the moment of landing due to the influence of the clamping force of the planting tray and the random error of the movement of the conveying chain, so a zero speed planting state is only an ideal state.

In the process of planting seedlings, the two planting plates of the planter are opened, and the elastic roller-clamping device pushes the planting plate backward with the onion seedlings to make the onion seedlings leave the planting plate smoothly. Simultaneously, the loosened soil on both sides of the planting tray returns to the seedlings, and the seedlings are crowded from both sides and behind. The onion seedlings are fixed by the Earth-covered pressing wheel. Because the seedling falling time is short and the planting tray needs to be opened quickly, the elastic roller-clamping device can push the onion seedlings backward more quickly. To avoid a greater impact on the onion seedlings, the planting tray should have a forward speed.

According to the above analysis, and by ignoring the influence of the angle between the two planting plates, the speed conditions that the onion seedlings should meet in the seedling falling process are as follows:

$$V = V_{CX} + V_m \tag{12}$$

In the formula, V_{cx} is the horizontal linear velocity of the planting disc rotation, m/s; and V_m is the speed of the elastic roller-clamping device used to push the onion seedlings backward, m/s.

Assuming that the onion seedlings are released when the planting disc rotates around ωt, the movement speed of the onion seedlings is the combined velocity of the rotational speed ωt of the planting disc and the horizontal motion V_d of the whole machine, and its motion trajectory equation is as follows:

$$\begin{cases} x = R\cos(\omega t) + V_d t \\ y = -R\sin(\omega t) + h \end{cases} \tag{13}$$

In the formula, x and y are the displacement of the planting disc in the X axis and Y axis directions, mm; R is the radius of the planting disc, mm; ω is the angular velocity of the planting disc, rad/s; V_d is the forward speed of the whole machine, m/s; and h is the vertical distance from the center of the disc to the planting ground, mm.

The horizontal velocity V_x and vertical velocity V_y of the planting disc can be obtained by deriving the time from the left and right sides of the (13) formula.

$$\begin{cases} V_x = V_d\text{-}R\omega\sin(\omega t) \\ V_y = \text{-}R\omega\cos(\omega t) \end{cases} \tag{14}$$

The instantaneous velocity V at the edge of the planting disc is as follows:

$$V = \sqrt{V_x^2 + Vy^2} = \sqrt{V_d^2 + R^2\omega^2 \text{-} 2V_dR\omega\sin(\omega t)} \tag{15}$$

The instantaneous velocity V cosine at the edge of the planting disc is as follows:

$$\cos\phi = \frac{V_x}{V} = \frac{V_d\text{-}R\omega\sin(\omega t)}{\sqrt{V_d^2 + R^2\omega^2 \text{-} 2V_dR\omega\sin(\omega t)}} \tag{16}$$

The horizontal speed Vx determines the transplanting quality of the transplanter when the onion seedlings are released. To make the onion seedlings enter the soil smoothly, the speed must satisfy $Vx > 0$; otherwise, the onion seedlings will move towards the advanced direction of the machine, and the seedlings will become lodged or have a lower vertical degree. Simultaneously, Vx can not be infinite; otherwise, the onion seedlings will not fall into the ditch after release, and the qualified rate of the planting depth of onion seedlings will be greatly reduced when the soil has collided with the soil squeezed by both sides of the Earth-covering roller [12,13].

$$Vx = V_d - R\omega\sin(\omega t) > 0 \tag{17}$$

As seen in formula (17), the maximum rotation angle ωt of the onion seedlings around the planting disc can be obtained according to the horizontal velocity V_d of the machine and the radius R and rotation speed ω of the planting disc.

$$\sin(\omega t) = \frac{V_d}{R\omega} = \frac{0.06}{0.25 \times 0.36} = 0.67 \tag{18}$$

$$\omega t = \arcsin 0.67 = 42° \tag{19}$$

The following assumptions are made for the movement process of seedlings from clamping to planting in the ground:

1) Simplify the seedling as a cylindrical rigid body model, and the center of mass is at the center of the seedling.
2) By ignoring the vibration and bounce of the seedling during the clamping process, the seedling is free to fall at the initial velocity after it is separated from the disc.
3) The simplified collision between the seedling and ground is a plastic collision, and the motion after collision is a fixed-point motion around point A. The momentum moment of the collision force to point A is 0, and the momentum moment of the seedling is conserved.

When the distance between the two planting plates is larger than the diameter of the onion seedlings, the onion seedlings are released to make a free falling motion with an initial velocity. The motion model is shown in Fig. 6.

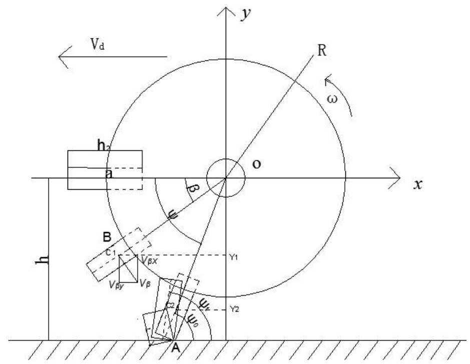


Figure 6: Motion model of seedling clamping to release

Note: point a is the holding point of the seedling; h_2 is the total length of the seedling, mm; ψ_0 is the angle between the axis of the initial seedling planting state and the horizontal plane (°); ψ_t is the angle between the axis of the final seedling planting state and the horizontal plane (°); point A is the lowest point when the seedling turns the angle ψ, mm; point B is the lowest point when the seedling begins to leave the planting plate; point O is the center of the planting plate; L is the distance from point C_2 to point A, mm; C_1 is the center of mass of the seedling; Y_1 is the vertical coordinate corresponding to the center of mass C_1, mm; C_2 is the center of mass of the seedling beginning to contact the planting ground; Y_2 is the vertical coordinate corresponding to the center of mass C_2, mm; V_β is the velocity when the seedling begins to fall freely; $V_{\beta x}$ is the horizontal velocity when the seedling moves freely; and $V_{\beta y}$ is the vertical velocity when the seedling moves freely, m/s.

The angle between the axis and the horizontal plane of the seedling is β when the seedling begins to leave the tray, and the angular velocity rotates when the seedling falls off the tray. When the seedling contacts the planting ground after time t, the angle of the rotation of the seedling is ωt, and the eventual planting inclination of the seedling is ψ.

$$\psi=\beta+\omega t \tag{20}$$

The seedling body falls at the initial speed of $V_{\beta Y}$ in the process of falling. During the process of falling, the seedling body is only subjected to gravity. The seedling body experience a free-falling motion

$$V_y=-\frac{dy}{dx}=-gt-R\omega\cos\beta \tag{21}$$

By integrating formula (21) with time t, the y-axis displacement Yy of seedlings in free falling stage are obtained as follows:

$$Y_y=-\frac{1}{2}gt^2-R\omega t\cos\beta \tag{22}$$

The height of the onion seedlings during the free falling stage is as follows:

$$Y_3=h-Y_1=h-R\sin\beta \tag{23}$$

Namely,

$$Y_y=Y_3 \tag{24}$$

$$\frac{1}{2}gt^2+tR\omega\cos\beta=R\sin\beta-h \tag{25}$$

Which is simplified as follows:

$$t=\frac{\sqrt{\left(R\omega\cos\beta\right)^2-2g\left(R\sin\beta-h\right)}}{g} \tag{26}$$

In time t, the displacement Xx of the seedling body in the X-axis direction is as follows:

$$X_x = \left(\omega\sin\beta - V_d\right) \times \frac{\sqrt{\left(R\omega\cos\beta\right)^2 - 2g\left(R\sin\beta - h\right)}}{g} \tag{27}$$

According to the differential equation of the rigid body rotating around a fixed axis, the equilibrium equation of the seedling motion after touching the ground is as follows:

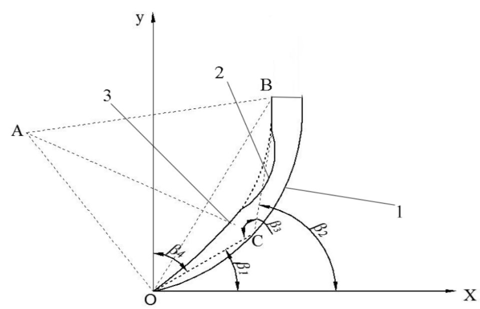
$$J_A \frac{d^2\psi}{dt^2} = \sum M_Z\left(F_A\right) = mgL\left(\sin\psi_t - \sin\psi_0\right) \tag{28}$$

3.4 Design and Position Analysis of Ditcher

The ditcher is a component that acts directly on the soil. The angle β of the ditcher's entry greatly influences the cover of the onion seedlings' return flow. A β that is too small will lead to larger tip angle and lower strength; a β that is too large will lead to larger resistance and worse soil entry performance; the range of β should be between 15°-55°. The structure sketch of the ditcher is shown in Fig. 7, assuming that the equation of the arc working face of the trencher is as follows:

$$\left(x-a\right)^2 + \left(y-b\right)^2 = R^2 \tag{29}$$

In the formula, a and b are the coordinates of the center of the circle; and R is the radius of the circle, mm.



1. Main body 2. Wing shovel face 3. Main shovel face

Figure 7: Schematic diagram of the main structure of the ditcher

Let the coordinate of the O point be (0, 0) and B point be (30, 100), i.e., L_{OB} = 105 mm, and β_1 and β_2 are the entrance angles of the trencher. To adapt to the trenching of different soil layers, $\beta_1 = 20°$, $\beta_2 = 50°$, and point A is the center of the circle where the working arc is located, C is the intersection of the O and B points on the arc, and there are △OAC, △OAB and □OABC:

$$\sin\frac{\beta_2 - \beta_1}{2} = \sin\frac{180° - \beta_3}{2} = \sin\beta_4 = \frac{L_{OB}}{2R} \tag{30}$$

R = 203 mm, O (0, 0) and B (30, 100) are substituted for (29) to obtain the arc curve equation of the trencher:

$$\left(x+166\right)^2 + \left(y-60\right)^2 = 203^2 \tag{31}$$

The formula for calculating the angle of entry at any point of the arc OB in the working face is as follows:

$$\sin\frac{\beta_2 - \beta}{2} = \frac{D}{2R} \tag{32}$$

D is the distance from any point of the arc surface to the O point, mm.

The optimum penetration depth of the trencher is 100 mm, its coordinates are (33, 100), D = 105, and it can be substituted into the (32) formula to obtain a value of $\beta = 30°$.

The size of the horizontal position of the ditcher is determined by the displacement of the horizontal direction of the onion seedling when it falls freely, and the distance can be obtained by formula (27). The horizontal position of the ditcher will determine the location of the return flow. If the release point of the onion seedlings is before the return flow position, the onion seedlings will incline in any direction; if the release point of the onion seedlings is after the return flow position, the planting depth of the onion seedlings will become shallow or the amount of soil covered will be insufficient, and the lodging phenomenon will occur. Therefore, the horizontal position of the ditcher plays an important role in the onion seedling planting process. The experiment proves that the optimal horizontal position of the ditcher is 29 mm.

4 Field Trials

4.1 Test Conditions

To verify the working performance and rationality of the parameter design of the 2ZYX-2 scallion trenching and transplanting machine, field experiments of scallion trenching and transplanting machine were carried out in the scallion test base of Qingzhou Hualong Machinery Technology Research and Development, in April 2019. The scallion seedlings used in the experiment were raised in a greenhouse with a standard size of 10 × 22 holes and the seedling age was 28 days. The average seedling height was 160 mm. The test base has a flat terrain, no sand or gravel hard in the soil, soil compactness of 12.5 N/cm, land length of 120 m, and surface water contents of 9.8% (0-50 mm), and 13.5% (60-100 mm), which meet the requirements of JB/T10291-2013 for the test soil of "Dryland Planting Machinery".

The test instruments and equipment mainly include the 2ZYX-2 scallion trenching and transplanting machine, Dongfanghong 1000 tractor, vernier caliper, tape measure, stopwatch, moisture meter, ruler, universal angle meter, and so on.

a. Before work

b. After work

Figure 8: Field experiment of the 2ZYX-2 scallion ditching and transplanting machine

4.2 Test Indicators and Test Methods

A central composite test design was adopted. The eligibility rate of the vertical degree, variation coefficient of plant spacing and planting depth were taken as evaluation indexes. Response interview experiments were conducted to study the transplanting speed, the depth of the ditcher and the horizontal position of the ditcher. According to the design calculation and theoretical analysis and pretest results, the zero horizontal transplanting speed of the test factors is 0.04 m/s, the depth of the trencher is 100 mm, and the horizontal position of the trencher is 25 mm. The horizontal coding of each variable is determined as shown in Tab. 2.

Table 2: Actual value and code of variable

Coding level	Factor		
	Transplanting speed X_1/(m·s^{-1})	Depth of furrow Opener X_2/mm	Horizontal location of furrow opener X_3/mm
-1.682	0.01	66	8
-1	0.02	80	15
0	0.04	100	25
1	0.06	120	35
1.682	0.07	133	40

1) Determination of qualification rate of verticality Y_1

The qualified rate of erectness is defined as the erect state of onion seedlings after planting, and the percentage of onion seedlings whose angle between the main stem and ground is greater than or equal to 60° accounts for the measured number of transplanted plants. According to the angle ψ, the planting state of the onion seedlings can be divided into lodging ∈ [0°, 60°] and qualified ∈ (60°, 90°]. According to the mechanical industry standard of the People's Republic of China (JB/T10291-2001), the angle between the main stem and the ground of the onion seedlings after planting is measured by a universal angle meter, and the maximum value is determined four times. Then, the qualification rate of verticality is calculated [14-17].

$$T = \frac{N_{ZL}}{N} \times 100\% \tag{33}$$

In the formula, T is the qualified rate of the upright degree of onion seedlings, %; N_{ZL} is the number of upright plants, plants; and N is the total number of measured plants, plants.

2) Measurement of the qualification rate of planting depth Y_2

The qualified rate of planting depth is defined by measuring the vertical distance between the intersection point of the onion seedling and soil surface and the root of the onion seedling, which is the planting depth of onion seedling. The percentage of qualified onion seedlings and the total number of tested plants is called the qualified rate of planting depth. Referring to (JB/T10291-2013) "Dryland Planting Machinery", the actual planting depth is qualified in the range of -10-20 mm of the theoretical planting depth. The standard stipulates that the index be more than 75%. The formula for calculating the qualified rate of planting depth is as follows:

$$H = \frac{N_h}{N} \times 100\% \tag{34}$$

In the formula, H is the qualified rate of planting depth, %. N_h is the total number of plants with qualified planting depth, plants.

3) Measurement of the coefficient of variation for the plant spacing Y_3

The variation coefficient of plant spacing is defined as the standard deviation percentage and the average of the actual plant spacing measured in a certain planting interval. Referring to JB/T10291-2013 "Dryland Planting Machinery", the average distance of every three onion seedlings was measured by tape ruler, and the coefficient of variation of the plant distance was calculated as follows:

$$\begin{cases} CVx = \dfrac{S_x}{\bar{x}} \times 100\% \\ \bar{x} = \dfrac{\sum_{i=1}^{n} x_i}{n} \\ S_x = \sqrt{\dfrac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \end{cases} \tag{35}$$

In the formula, CVx was the variation coefficient of the plant spacing of onion seedlings, %; Sx was the standard deviation of the plant spacing, %; $\bar{x}$ represents the plant spacing, mm; and x_i was the measured plant spacing, mm.

5 Test Results and Analysis

5.1 Test Results

According to the Central Composite test principle, the test scheme and results are shown in Tab. 3.

Table 3: Test scheme and results

No.	X_1	X_2	X_3	Y_1/%	Y_2%	Y_3/%
1	1	1	-1	80.2	3.6	76.1
2	1	1	1	77.8	3.57	81.9
3	-1	1	-1	90.1	2.2	85.4
4	0	-1.682	0	77.1	2.06	77.1
5	-1	-1	1	80.7	2.95	86.4
6	0	0	-1.682	75.9	2.01	83.3
7	0	0	1.682	71.3	3.14	87.5
8	1.682	0	0	83.2	4.5	79.7
9	0	1.682	0	86.9	2.59	71.2
10	1	-1	-1	80.2	2.4	80.9
11	-1	1	1	83.2	2.87	84.9
12	-1	-1	-1	81.2	2.48	85.1
13	1	-1	1	78.5	3.25	86.5
14	-1.682	0	0	86.7	2.7	88.9
15	0	0	0	92.3	1.96	90.8
16	0	0	0	91.7	1.5	94.5
17	0	0	0	87.4	1.7	90.7
18	0	0	0	92.1	1.52	88.7
19	0	0	0	91.4	1.72	90.3
20	0	0	0	92.3	1.94	91.9

5.2 Establishment of the Regression Model and Analysis of Variance

Design-Expert 8.0.6 software was used to establish the response surface regression model of transplanting speed, depth of trencher, horizontal position of trencher on eligibility rate of erectility, coefficient of variation of plant spacing and eligibility rate of planting depth, and the variance analysis of the regression model was conducted.

Tab. 4 shows that the eligibility rate of erection degree, variation coefficient of plant spacing and qualification rate of planting depth are all less than 0.01, which indicates that the regression model is highly significant. The p values of the missing items are all greater than 0.05, which indicates that the regression equation has a high fitting degree and can replace the real test results for analysis. The order of significance of each test factor influencing the qualified rate of erectness from large to small is the depth of trencher, the speed of transplanting and the horizontal position of trencher. The order of significance of each test factor influencing the variation coefficient of plant spacing from large to small is the speed of transplanting, the horizontal position of the trencher and the depth of the trencher; The order of significance of each test factor influencing the qualification rate of planting depth from large to small is the speed of transplanting, the depth of trencher and the horizontal position of the trencher.

Regression terms x_2, x_2^2, and x_3^2 had significant effects on the eligibility rate of erectility ($P < 0.01$), x_1, x_3 and x_1^2 had effects ($P < 0.05$); and regression terms x_1, x_3, x_1^2, x_2^2, and x_3^2 had significant effects on the coefficient of variation of plant spacing ($P < 0.01$), and x_2, and x_1x_2 had effects ($P < 0.05$); for the eligibility rate of planting depth regression terms x_1, x_1^2 and x_2^2 had significant effects ($P < 0.01$), while x_2, x_3 and x_3^2 had effects ($P < 0.05$).

Design-Expert 8.0.6 software was used to carry out a multiple regression fitting analysis of the test results in Tab. 4. The quadratic regression model of the coding value was obtained, which showed that the qualified rate of erectness, the coefficient of variation of plant spacing and the qualified rate of planting depth were affected by various test factors, as shown in formulas (36)-(38).

Y_1=91.14-1.79x_1+1.99x_2-1.41x_3-1.51x_1x_2+0.41x_1x_3-0.89$x_2x_3$1.79x_1^2-2.84x_2^2-5.81x_3^2 (36)

Y_2=1.72+0.39x_1+0.15x_2+0.28x_3+0.24x_1x_2-0.04x_1x_3-0.085x_2x_3+0.67x_1^2+0.22x_2^2+0.3x_3^2 (37)

Y_3=91.06-2.33x_1-1.5x_2+1.41x_3-1.02x_1x_2+1.33x_1x_3-0.20x_2x_3-1.85x_1^2-5.44x_2^2-1.46x_3^2 (38)

Table 4: Variance analysis of Variance analysis of regression model for upright degree

Index	Source	Sum of squares	df	Mean square	P	Significance
Eligibility rate of erection degree Y_1/%	Model	725.97	9	80.66	< 0.0001	**
	x_1	43.55	1	43.55	0.0131	*
	x_2	54.1	1	54.1	0.0073	**
	x_3	27.09	1	27.09	0.0389	*
	x_1x_2	18.3	1	18.3	0.0795	
	x_1x_3	1.36	1	1.36	0.6061	
	x_2x_3	6.3	1	6.3	0.2787	
	x_1^2	46.38	1	46.38	0.0111	*
	x_2^2	115.98	1	115.98	0.0006	**
	x_3^2	485.89	1	485.89	< 0.0001	**
	Residual	48.03	10	4.8		
	Misstated item	30.07	5	6.01	0.2928	
	Pure error	17.96	5	3.59		
	All items	774	19			
Variation coefficient of plant spacing Y_2	Model	11.47	9	1.27	< 0.0001	**
	x_1	2.09	1	2.09	0.0001	**
	x_2	0.31	1	0.31	0.0422	*
	x_3	1.09	1	1.09	0.0014	**
	x_1x_2	0.44	1	0.44	0.0192	*
	x_1x_3	0.013	1	0.013	0.6453	
	x_2x_3	0.058	1	0.058	0.337	
	x_1^2	6.4	1	6.4	< 0.0001	**
	x_2^2	0.67	1	0.67	0.0064	**
	x_3^2	1.33	1	1.33	0.0007	**
	Residual	0.57	10	0.057		
	Misstated item	0.37	5	0.075	0.246	
	Pure error	0.19	5	0.039		
Qualification rate of planting depth Y_3/%	Model	615.65	9	68.41	0.0001	**
	x_1	74.38	1	74.38	0.0023	**
	x_2	30.84	1	30.84	0.026	*
	x_3	27.17	1	27.17	0.0343	*
	x_1x_2	8.4	1	8.4	0.2029	
	x_1x_3	14.05	1	14.05	0.1087	
	x_2x_3	0.32	1	0.32	0.7957	
	x_1^2	49.28	1	49.28	0.008	**
	x_2^2	426.11	1	426.11	<0.0001	**
	x_3^2	30.74	1	30.74	0.0262	*
	Residual	45.27	10	4.53		
	Misstated item	26.43	5	5.29	0.3595	
	Pure error	18.83	5	3.77		
	All items	660.92	19			

After eliminating the insignificant items in the model, the regression equation of models Y_1, Y_2 and Y_3 is optimized, such as (39)-(41).

Y_1=91.14-1.79x_1+1.99x_2-1.41x_3-1.79x_1^2-2.84x_2^2-5.81x_3^2 (39)

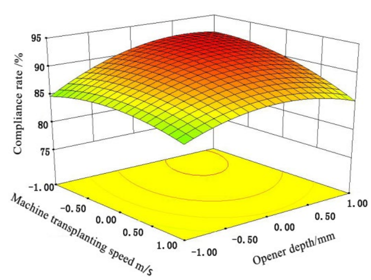
Y_2=1.72+0.39x_1+0.15x_2+0.28x_3+0.24x_1x_2+0.67x_1^2+0.22x_2^2+0.30x_3^2 (40)

Y_3=91.06-2.33x_1-1.5x_2+1.41x_3-1.85x_1^2-5.44x_2^2-1.46x_3^2 (41)

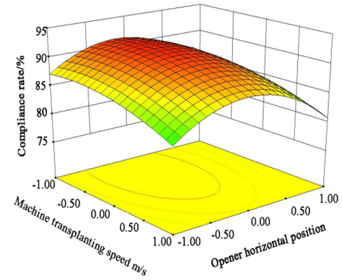
5.3 Analysis of the Two-Factor Interaction Effect

In regression Eqs. (36-38), the level of any one factor was 0. The effects of the other two factors on the eligibility rate of erectility, the coefficient of variation of plant spacing and the eligibility rate of planting depth were studied. Design-Expert 8.0.6 software was used to analyze the response surface of the interaction factors, as shown in Fig. 9.

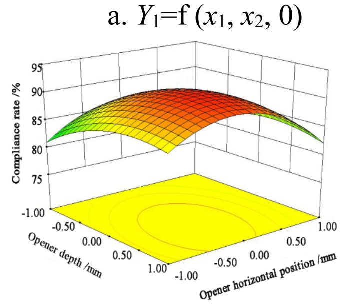
As seen in Fig. 9(a), the eligibility rate of verticality of onion seedlings increases first and then decreases with an increase in the depth of ditcher at the same transplanting speed, and increases first and then slowly with the increase in transplanting speed at the same ditcher depth; as seen in Fig. 9(b), the qualified rate of vertical degree increases first and then decreases with the increase in the horizontal position of the ditcher at the same transplanting speed, and increases first and then slowly with the increase in the transplanting speed of the ditcher at the same horizontal position; as seen in Fig. 9(c), the qualified rate of vertical degree increases first and then decreases with an increase in the horizontal position of the ditcher at the same ditcher depth, and decreases with the increase of the depth in the ditcher at the same horizontal position. As seen in Fig. 9(d), the coefficient of variation of plant spacing decreases first and then increases with the increase in transplanting speed at the same ditcher depth, and decreases first and then increases with the increase in ditcher depth at the same transplanting speed. As seen in Fig. 9(e), the coefficient of variation of plant spacing decreases first and then increases with an increase in the horizontal position of the ditcher, and decreases first and then increases with the increase in ditcher depth at the same horizontal position of the ditcher. As seen in Fig. 9(f), the coefficient of variation of plant spacing decreases first and then increases with the increase in transplanting speed at the same horizontal position of the trencher, and decreases first and then increases with the increase of horizontal position of trencher at the same transplanting speed. As seen in Fig. 9(g), the qualified rate of planting depth decreases slowly with the increase in transplanting speed, and increases first and then decreases with an increase in the depth of ditcher at the same transplanting speed; As seen in Fig. 9(h), the qualified rate of planting depth decreases with the increase in transplanting speed at the same horizontal position of the ditcher ,and at the same transplanting speed, with the increase of the horizontal position of the ditcher it increases slowly and then decreases slowly; As seen in Fig. 9(i), the qualified rate of planting depth increases first and then decreases with an increase in the depth of the ditcher at the same horizontal position, and increases slowly with an increase in the horizontal position of the ditcher at the same depth.



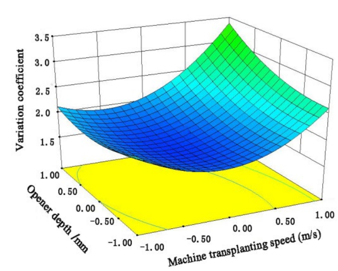
a. Y_1=f (x_1, x_2, 0)



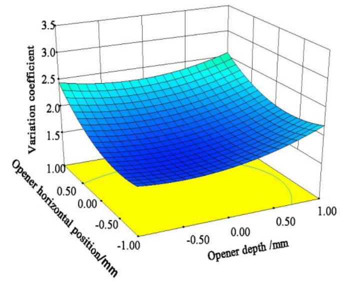
b. Y_1=f (x_1, 0, x_3)



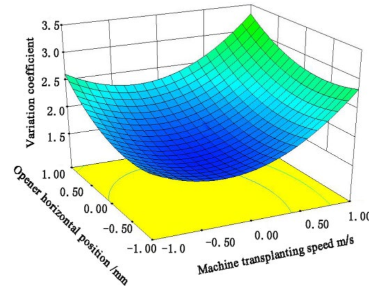
c. Y_1=f (0, x_2, x_3)



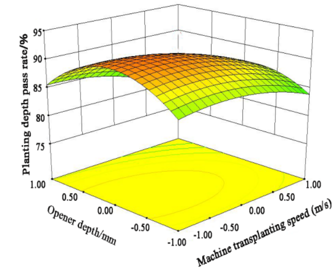
d. Y_2=f (x_1, x_2, 0)



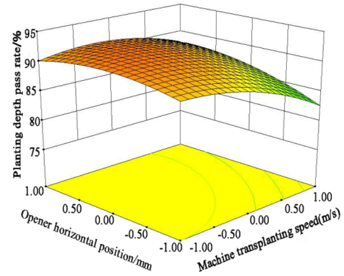
e. Y_2=f (0, x_2, x_3)



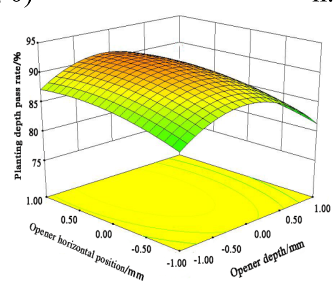
f. Y_2=f (x_1, 0, x_3)



g. Y_3=f (x_1, x_2, 0)



h. Y_3=f (x_1, 0, x_3)



i. Y_3=f (0, x_2, x_3)

Figure 9: Response surface of interactive factors influencing the test indicators

6 Model Optimization and Experimental Verification

6.1 Parameter Optimization

According to the operation performance requirements of the 2ZYX-2 scallion trenching and transplanting machine, the qualifying rate of erectness is required to be high, the coefficient of variation of plant spacing must be small, and the qualifying rate of planting depth must be high. Due to the inconsistent influences of various factors on the target value, global multi objective optimization [18-21] is needed. Taking the qualified rate of vertical degree, variation coefficient of plant spacing and qualified rate of planting depth as objective values, the optimum design of the three test variables, namely, transplanting speed of the machine tool, ditcher depth and horizontal position of the ditcher, were carried out. The optimum constraints are as follows:

$$\begin{cases} \max Y_1 = f_1(X_1, X_2, X_3) \\ \min Y_2 = f_2(X_1, X_2, X_3) \\ \max Y_3 = f_3(X_1, X_2, X_3) \\ \text{s.t} \begin{cases} X_1 \in (0.01, 0.07) \\ X_2 \in (66.36, 133.64) \\ X_3 \in (15, 40) \end{cases} \end{cases} \tag{42}$$

To find the best combination of parameters, Design-Expert 8.0.6 software was used to solve the optimization problem, considering the influences of three factors on the eligibility rate of verticality, variation coefficient of plant spacing and planting depth of onion seedlings. The optimum combination of working parameters was obtained: the transplantation speed of the machine was 0.06 m/s, the depth of the ditcher was 102.03 mm, and the horizontal position of the ditcher was 29.43 mm. At this time, the qualifying rate of vertical degree was 85.96%, the coefficient of variation of plant spacing was 2.98, and the qualifying rate of planting depth was 87.48%.

6.2 Verification Test

According to the results of the model optimization, the optimum parameters are rounded appropriately. The transplantation speed of the machine is 0.06 m/s, the depth of the ditcher is 102 mm, and the horizontal position of the ditcher is 29 mm. Five repeated tests are carried out to verify the optimum parameters. The results are shown in Tab. 7. The average qualifying rate of erection degree was 87.34%, which was higher than 85.96% of the model predicted results, the average variance coefficient of plant spacing was 2.938, which was less than 2.98 of the model predicted results, and the average qualifying rate of planting depth was 89.98%, which was higher than 87.48% of the model predicted results.

Table 7: Verification testing results

Items	Compliance rate/%	Variation coefficient	Planting depth pass rate/%
1	88.92	2.86	91.51
2	87.32	3.05	89.84
3	86.7	2.96	88.75
4	86.78	2.93	90.32
5	86.98	2.89	89.46
Measured mean	87.34	2.938	89.976
Predicted value	85.96	2.98	87.48
Relative error/%	1.38%	4.20%	2.50%

The results showed that the relative errors of the measured and predicted qualifying rates of erectility, plant spacing variation coefficient and planting depth were all less than 5%. The measured values agreed with the predicted values, which indicated that the regression model was reliable.

Simultaneously, the target values were tested with the depth of the ditcher at 102 mm, the horizontal position of the ditcher at 29 mm and the transplanting speed between 0.01 m/s and 0.10 m/s. The curve changes in the target values under different transplanting speeds are shown in Fig. 10. When the transplanting speed was 0.06 m/s, the target value was the best. The transplantation speed is 0.07 m/s and 0.08 m/s, and the target value decreases, but the difference between them is small when the transplanting speed is 0.06 m/s, and it meets the requirements of the transplanting operation. Therefore, transplanting speeds of 0.07 m/s and 0.08 m/s can be considered in the actual transplanting operations to improve the operation efficiency; simultaneously, it was found that when the transplanting speed exceeded 0.08 m/s, the frequency of artificial seedling placement was exceeded, and the transplanting effect was poor, so it was not suitable for the operation. The above research could provide theoretical guidance for the actual transplanting operation of onions, and has important significance for cost-savings and increases in efficiency in the onion industry.

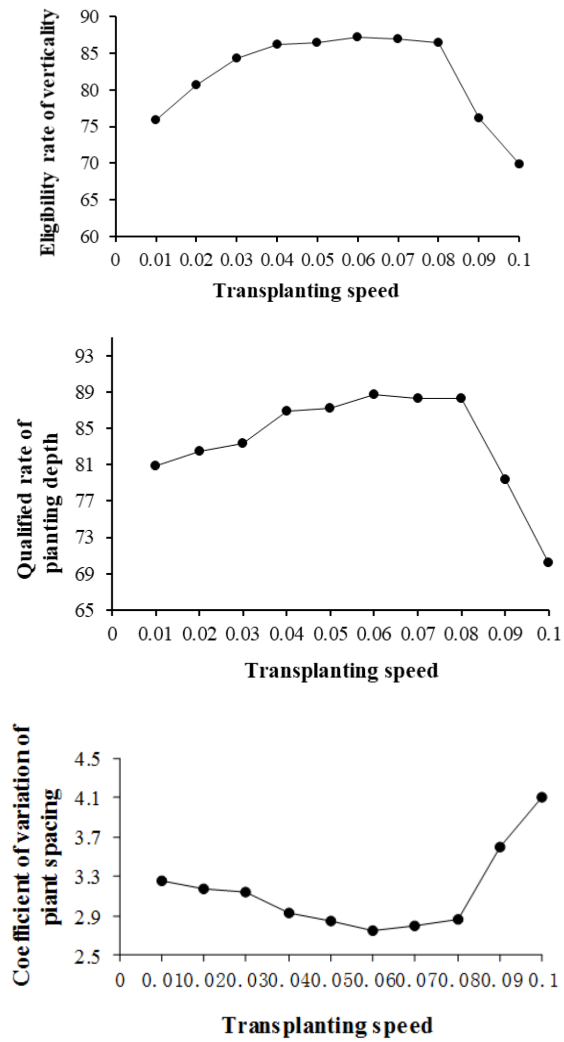


Figure 10: Curve change in target value at different transplanting speeds

7 Conclusion

1) A 2ZYX-2 integrated machine was designed for trenching and transplanting onions. The machine can complete ditching, ridging, transplanting, pressing and covering soil at one time. Through a theoretical analysis and experiments, the mechanism and parameters of key components such as horizontal swing seedling structure, vertical seedling clamping mechanism and upright planting structure are determined, which provides a theoretical basis for optimization and upgrading of scallion transplanters.

2) A quadratic regression model was established using the Central Composite test design method [22-24]. The quadratic regression model was used to determine the response index of the qualifying rate of upright degree, variance coefficient of plant spacing and qualifying rate of planting depth of onion seedlings. The effects of transplantation speed, depth of ditcher and horizontal position of ditcher on the response index were obtained.

3) Design-Expert 8.0.6 was used to optimize the model, and the qualifying rate of erectness, variation coefficient of plant spacing and planting depth were taken as the test indexes. The optimum combination of working parameters was as follows: the transplantation speed of the machine was 0.06 m/s, the depth of the ditcher was 102 mm, and the horizontal position of the ditcher was 29 mm. The qualifying rate of upright degree was 87.34%, the coefficient of variation of plant spacing was 2.938, and the qualifying rate of

planting depth was 89.98%.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. Liu, J. W. (2018). *Design and research of the double-row green Chinese onion combined harvester (M.S. Thesis)*. Shandong Agricultural University, Tai'an.
2. Hu, J. (2003). *The optimum design method and tests of a scallion transplanter with two flexible metal disks (M.S. Thesis)*. China Agricultural University, Beijing.
3. Han, X., Chen, H. T. (2018). Design and optimization experiment of separation device for tomato chain paper pot seeding transplanter. *Transactions of the Chinese Society for Agricultural Machinery, 49(5),* 161-168.
4. Yu, X. G., Yuan, W. S., Wu, C. Y. (2011). Research and development status of the oilseed rape transplanter in china and improvement of clip-chain transplanter. *Journal of Agricultural Mechanization Research, 33(1),* 232-239.
5. Zhao, Z. W., Chen, H. T., Lai, Q. H., Ren, K. K. (2009). Design of separating device for the chain pot seedling of sugar beet. *Journal of Agricultural Mechanization Research, 31(12),* 80-82.
6. Feng, J., Qin, G., Song, W. T., Liu, Y. J. (2002). The kinematic analysis and design criteria of the dibble-type transplanters. *Transactions of the Chinese Society for Agricultural Machinery, 05,* 48-50.
7. Yang, L., Su, Y. M., Zhang, D. X. (2014). Motion analysis and performance test of corn paper pot seedlings transplanter. *Transactions of the Chinese Society of Agricultural Engineering, 30(13),* 35-42.
8. Wang, Y., Chen, J. N. (2014). Mechanics property experiment of broccoli seedling oriented to mechanized planting. *Transactions of the Chinese Society of Agricultural Engineering, 30(24),* 1-10.
9. Zheng, W. X., Lü, Z. Q., Zhang, W. Z. (2019). Design and test of single row sweet potato vinere cycling machine. T*ransactions of the Chinese Society of Agricultural Engineering, 35(6),* 1-9.
10. Shi, T. (2015). Development and test of automatic corn seedling transplanter. *Transactions of the Chinese Society of Agricultural Engineering, 31(3),* 23-30.
11. Zhou, D. Y., Sun, Y. J., Ma, C. L. (2003). Design and analysis of a supporting-seedling mechanism with cam and combined rocker. *Transactions of the Chinese Society of Agricultural Machinery, 5,* 57-60.
12. Cai, G. H., Zeng, A. J., Song, W. T. (2009). Kinematic analysis and design criteria of the flexible disc transplanters. *Journal of Huazhong Agricultural University, 28(2),* 253-256.
13. Bao, Y. D., Yang, C., Zhao, Y. L., Liu, X. L. (2017). Collision injury assessment of mechanical harvesting blueberry fruit based on collision deformation energy. *Transactions of the Chinese Society of Agricultural Engineering, 33(16),* 283-292.
14. Hou, J. L., Liu, W., Zhang, W. Z. (2018). Design of precision pneumatic cup seed-metering device for potato. *Transactions of the Chinese Society of Agricultural Engineering, 34(24),* 18-28.
15. Zhao, Y., Liu, X., Xue, X. L., Zhang, W. X. (2018). Optimal design and experiment of fully-automated potted eggplant seedling transplanting mechanism. *Transactions of the Chinese Society for Agricultural Machinery, 49(5),* 152-160.
16. Wang, W. M., Dou, W. G., Wang, C. G. (2009). Parameter analysis of the planting process of 2ZT-2 beet Transplanter. *Transactions of the Chinese Society for Agricultural Machinery, 40(1),* 69-73.
17. Chen, X., Hu, Q., Xu, Z., Ding, Y., Mai, Q. et al. (2019). Simulation analysis on quasistatic characteristics of multistage face gears with double crown surface. *Computer Modeling in Engineering & Sciences, 118(2),* 447-470.

18. Jia, H. L., Zheng, J. X., Yuan, H. F. (2017). Design and experiment of a double-v-shaped furrow opener of soybean seeder. *Journal of Jilin University (Engineering and Technology Edition), 47(1),* 323-331.

19. Wang, Y. W., Tang, Y. H., Wang, J., Cheng, S. M**.** (2016). Parameter optimization for dibble-type planting apparatus of vegetable pot seedling transplanter in high-speed condition. *Transactions of the Chinese Society for Agricultural Machinery, 47(1),* 91-100.

20. Zhou, F. J., Lu, J., Du, J. X. (2014). Parameters optimization and experiment of corn-paper transplanting machine with seedling disk. *Transactions of the Chinese Society of Agricultural Engineering, 1,* 18-24.

21. Lü, J. Q., Shang, Q. Q., Yang, Y. (2016). Design optimization and experiment on potato haulm cutter. *Transactions of the Chinese Society for Agricultural Machinery, 47(5),* 106-114.

22. Wang, J. L. (2016). *Theoretical analysis and experimental study on vegetable transplanlter (Ph.D. Thesis)*. Shenyang Agricultural University, Shenyang.

23. Wang, Y. W., He, Z. L., Wang, J., Wu, C. Y. (2018). Experiment on transplanting performance of automatic vegetable pot seedling transplanter for dry land. *Transactions of the Chinese Society of Agricultural Engineering, 34(3),* 19-25.

24. Zhang, J. X., Yang, C., Guo, J. X. (2018). Design and experiment of hob-type joint operation machine for silage corn root stubble plucking and residual plastic film collecting. *Transactions of the Chinese Society of Agricultural Engineering, 34(6),* 25-34.