Operation analysis and parameter optimization of drum type soil-covering device

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Abstract: Up-film pot seedling transplanter is not stable in soil output, causing exposed and fallen seedlings, insufficient up-film daylighting and other problems. Based on the research on soil-covering process and principle of soil-covering device of transplanter, a theoretical model of the soil taking volume was established, the soil output principle of soil-covering drum was analyzed, the theoretical soil output volume was calculated, and the influences of structural parameters on soil output were studied. The field tests based on the influences of structural parameters on soil output was conducted using Box-Behnken experiment design, and a mathematical model between soil output and declination, vertical center distance (i.e. the depth in soil of soil-covering disc), and height of screw blades of soil-covering disc was established. Optimized analysis on the response surface was conducted based on parameter range and target soil output range. Results show that the soil output increases when the declination of the soil-covering disc increases from 20° to 40°, or the vertical center distance increases from 4-6 cm; the change of screw blade height has small impact on the soil output; The optimal structural parameters combination for the soil-covering device was obtained with the included angle of soil-covering disc of 37°, vertical center distance of 5.5 cm, and height of screw blades of 5 cm. With this optimal parameters combination, the soil output of 1 m soil-cover belt is 4.84 kg, which is basically the same with the actual volume of 4.53 kg and can ensure the stability of the soil output and provide reference for the optimization design of soil-covering device.

Keywords: up-film transplanting soil-covering, soil-covering device, soil output, model, optimization
DOI: 10.25165/j.ijabe.20211403.5383

Citation: Xu H Z, Tian D Y, Liu J D, Niu Z H, Li Q. Operation analysis and parameter optimization of drum type soil-covering device. Int J Agric & Biol Eng, 2021; 14(3): 123–129.

1 Introduction

Northwestern area in China is dry and has less rainfall with low earth temperature in the early spring. The crops (e.g. cotton, fruits, vegetables, etc.) are planted normally by film mulching and under-film drip irrigation[1,2]. For manual sowing and planting, farmers need to first clear and flatten the soil, pave the drip belt and ground film, make drills on the film, then sow in the hole or transplant pot seedlings, and at last mulch soil on the seeds or root of the pot seedlings. However, manual operation takes time and energy, which cannot satisfy the large field planting. Therefore, mechanical planting has become another option. During mechanical planting, planter or transplanter accomplishes the drip belt paving, ground film paving, and soil covering at one time, which is of extremely high efficiency. However, the soil output is not stable due to the insufficient control of soil-covering device.

Inadequate soil output will lead to insecure covering of the film which might be blown up by wind[3], causing fallen or exposed seedlings, or seeds unable to bud. However, excessive soil output will reduce the effective lighting area. The seeds may have difficulties in budding or seedlings couldn't turn green easily, affecting the later growth and yields of the crops.

Current domestic up-film soil-covering devices include roller type, drum type, rotary tillage type, and scrape type. Li et al.[4,5] studied a soil-covering device getting soil from the side of film and covering soil transversely. Their study is to seek an optimal structural parameters combination of soil-covering device, and no general theoretical analysis is conducted on the device. Zhao et al.[6,7] studied a drum type soil-covering device which cannot realize a continual soil covering. Shao et al.[8] designed a rotary tillage type soil-covering device which is appropriate for full-film soil covering. Also other types of film covering and soil covering mechanisms were studied such as tiny ridge type[9], double-ridge horizontal belt type[10], and crosswise-belt type[11], all of these can meet the needs of film covering and soil covering for sowing in arid areas. Sun et al.[12] discussed a scrape lifting belt type soil-covering device and conducted a specific theoretical analysis and calculation on the whole soil-covering process and principle. However, the device cannot be applied to the soil-covering analysis of drum type soil-covering device due to its particularity. Therefore, this paper is designed to make a further study on the soil output of drum type soil-covering device on automatic transplanter.

Automatic transplanter transplants tray seedlings cultivated in greenhouses. During the transplanting, the speed of the transplanter is hard to keep constant, which means the planting frequency of the transplanter will keep changing and the plant

Received date: 2020-09-05 **Accepted date:** 2021-02-26
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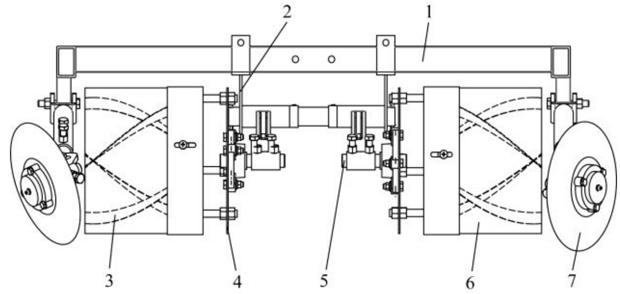
distance of the planted seedlings will be also different[13-15]. So the pot seedlings with different plant distances should be covered with a certain amount of soil to ensure the upright degree of the seedlings[16,17]. To realize this, we need to accurately adjust the parameters of the soil-covering device and realize a continual and equal amount of soil-covering to satisfy the demand of seedling growth in soil coverage. This paper analyzed the soil transport principle of the soil covering drum and calculated the theoretical soil output volume, a mathematical model between soil output and declination, vertical center distance (i.e. the depth in soil of soil-covering disc), and height of screw blades of soil-covering disc was established. Optimized analysis on the response surface was conducted based on parameter range and target soil output range. With this optimal parameters combination, the soil output of volume required for pot seedling transplanting was achieved, which provide references for the optimized design of soil-covering device on automatic transplanter.

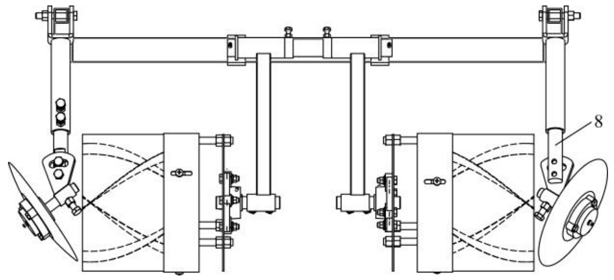
2 Structure of soil-covering device and working principle

Up-film automatic transplanter is mainly composed of rack, drive device, film paving device, drip belt paving device, ditching and mulching and soil-covering device, transplanting device, and road wheel, etc. The functions include automatic film mulching, drip belt paving, automatic drilling on film, automatic transplanting, and automatic soil-covering on film[18,19].

The soil-covering device of the automatic transplanter mainly consists of soil-covering disc and up-film soil-covering basket, as shown in Figure 1. The soil entrance face of the disc and the basket forms an angle with the ground, which keeps unchanged after adjusting the soil-covering disc. The lower end of the supporting arm connects the back shaft in the middle of the soil-covering basket, and the upper end connects the rack of the device. This angle changes with the height of the rack from the ground; the position of the soil-covering disc is adjusted by the soil-covering adjusting device connecting to the rack; the up-film soil-covering basket consists of back shaft, soil-retaining disc, outer wall of drum, and screw blade.



a. Front view



b. Vertical view

1. Rack 2. Supporting arm 3. Screw blade 4. Soil-retaining disc 5. Back shaft 6. Drum out wall 7. Soil-covering disc 8. Soil-covering adjusting device.

Figure 1 Structure of soil-covering device

During transplanting, the soil-covering disc cuts the soil to cover soil on the sides of the ground film, and delivers soil to the soil entrance of the soil-covering basket[20]. The soil-covering basket, under the effect of friction with the ground, moves and rotates in the direction of the transplanter, with cutting soil slipping to the end of the screw blades along the track of the blades. The distance between the end of the screw blades and the soil exit can enable a continual soil-covering. Under the effect of soil-covering disc, cutting soil keeps coming in and out of the soil-covering (the output soil is called the soil output), forming a soil-covering belt for the transplanting of pot seedlings. To ensure the lighting area on the ground film, we can use the soil-retaining disc to restrict the soil-covering width.

3 Soil covering process and establishment of soil output model

3.1 Soil covering process of soil-covering device

When transplanter is moving forward, the soil-covering device would cover soil on the film, as shown in Figure 2. The soil-covering disc takes soil and covers the two sides of the ground film, leaving two belts of triangle grooves in the middle of the ground film. Then the transplanter would plant pot seedlings on the soil-covering belts.

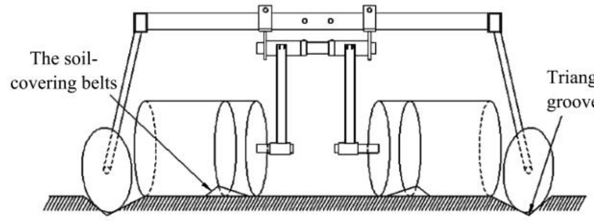


Figure 2 Process of soil covering

During the whole soil covering process, excessive soil output would reduce lighting area and seriously influence the growth of pot seedlings, while insufficient soil output would cause exposed or fallen seedlings. Therefore, it is important for the optimization and adjustment of parameters of soil-covering device to calculate an accurate soil output at the final planting position of pot seedlings[15].

The soil covering process of soil-covering device can be divided into three stages: soil taking, soil entering, and soil outputting. The soil-covering disc and the soil-covering basket will accomplish these three stages. The soil taking volume is determined by the direction and the contacting area of the soil-covering disc with the soil, and the entering volume is determined by the position of the soil-covering disc at the entrance face of the soil-covering basket. The output volume is related with various factors, such as the structure of the soil-covering basket and the walking speed of the transplanter.

3.2 Calculation of taking volume and entering volume of soil

3.2.1 Model simplification process

The structure of the soil-covering parts was parameterized to calculate the taking volume and entering volume of soil, as shown in Figure 3. A field observation of automatic up-film transplanter shows a great impact of shallow depth of soil-covering disc (the vertical difference between the center of the entrance face of the soil-covering basket and the center of the soil-covering disc relative to the level ground) on the soil output volume. For the convenience of calculation, we simplified the soil taking model and soil entering model, and considered the influence of the soil-covering regulating device instead of the rear lift of tractor on the depth of soil-covering disc in soil. The maximum soil volume between the soil-covering disc and the entrance of soil-covering basket is stable, and the thickness of the soil output is always equivalent with the vertical height of the screw blades. So a calculation model for the taking volume and entering volume of soil, taking soil-covering disc as the spherical cap and the circle center at the crown bottom as the center of the soil-covering disc[21,22].

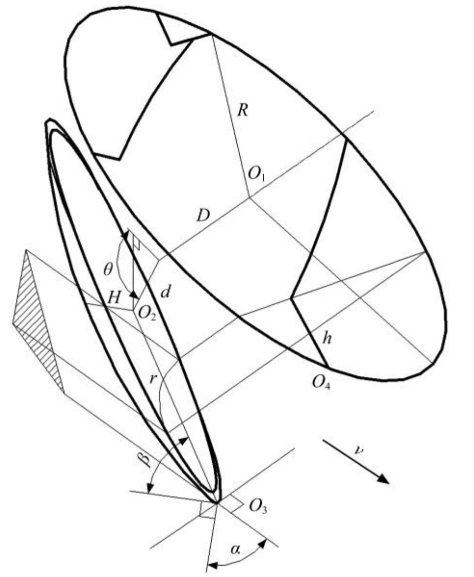


Figure 3 Structural parameters of soil-covering device

In Figure 3, R is the radius of the outer wall of soil-covering basket drum; h is the vertical height of the screw blades; r is the radius of the spherical bottom; H is the height of the spherical cap; α is the included angle between spherical bottom and the entrance surface of the drum; β is the included angle between spherical bottom and the level ground; O_1 is the center of the entrance surface of the drum; O_2 is the center of the spherical bottom; O_3 is the lowest point of the spherical cap and the soil after adjustment by soil-covering regulating device; O_4 is the lowest point of the round face of the drum entrance; D is the vertical distance from the center of the spherical bottom face to the entrance face of the drum; d is the rod length adjusted by the soil-covering regulating device; θ is the angle adjusted; v is the walking speed of the transplanter. The triangle is a projection of the spherical cap and the soil contact area in the movement direction of the transplanter.

The final position of the spherical cap after adjusted by soil-covering regulating device can be seen as the change of a curved surface in a 3D spatial coordinate system.

The 3D spatial system was established with O_1 as the origin, as shown in Figure 4. The X axis is parallel to the level ground, and the positive axis direction is opposite to the walking direction of the transplanter; Y axis starts from O_1 point, which is perpendicular to the level ground and the positive axis direction is vertical downward; the plane of X axis and Y axis is the same as the entrance face of the drum. A horizontal line connecting the highest points of the screw blades crosses with the entrance circle of the drum at K point and G point. Then two lines introduced from K point and G point vertical to the entrance face of the drum cross the spherical cap at I point and J point, and the vertical line introduced from O_4 crosses the spherical cap at M point. The space formed by these points and lines of K, G, J, I, O_4, M is called the effective soil capacity, i.e. the maximum soil volume that the stably working soil-covering disc and the basket can accommodate.

E point and F point are the nearest and farthest points on the central curve of the spherical face parallel to the level ground from the entrance face of the drum.

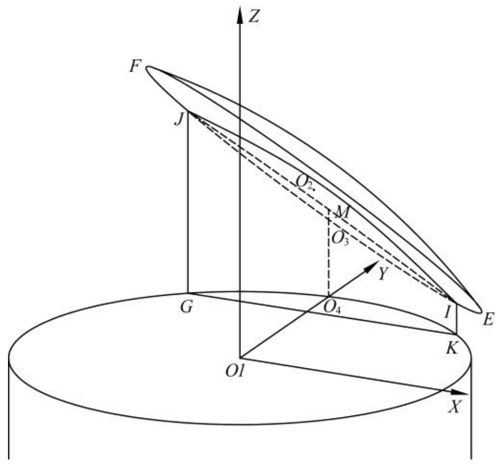


Figure 4 Mathematical model of soil-covering parts

The spherical curved surface can be regarded as the final position at the entrance face of the drum after four transformations: initial position, the center of the spherical cap O_2 coincides with O_1, and translates a distance of D along the positive direction of Z axis. The coordinates of the reference points are $O_3(0, r, D)$, $E(r, 0, D)$, $F(-r, 0, D)$, and $O_2(0, 0, D)$; the coordinates of the reference points after movement in the first quadrant are: $O_3(d\cos\theta, r+d\sin\theta, D)$; $E(r+d\cos\theta, d\sin\theta, D)$; $F(d\cos\theta - r, d\sin\theta, D)$; and $O_2(d\cos\theta, d\sin\theta, D)$.

The coordinates of the reference points after a rotation of α angle with the straight line passing O_2 and horizontal with Y axis as the rotating axis are: $O_3(d\cos\theta, r+d\sin\theta, D)$; $E(r\cos\alpha+d\cos\theta, d\sin\theta, D-r\sin\alpha)$; $F(d\cos\theta-r\cos\alpha, d\sin\theta, D+r\sin\alpha)$; $O_2(d\cos\theta, d\sin\theta, D)$.

The coordinates of the reference points after a rotation of angle β with XO_1Z plane with the straight line passing O_2 and has an angle α with X axis as the rotating axis are:

$O_3(d\cos\theta-r\cos\beta\sin\alpha, r\sin\beta+d\sin\theta, D-r\cos\beta\cos\alpha)$;

$E(r\cos\alpha+d\cos\theta, d\sin\theta, D-r\sin\alpha)$;

$F(d\cos\theta-r\cos\alpha, d\sin\theta, D+r\sin\alpha)$;

$O_2(d\cos\theta, d\sin\theta, D)$

3.2.2 Calculation of soil taking volume

To calculate the soil taking volume, we need to know the size of the soil-covering disc, i.e. the contact area A of the spherical cap with soil. The spherical cap area $S=\pi(r^2+H^2)$; the projection area of the plane which is perpendicular to the XO_1Z plane and has an α angle with X axis is $S\sin\beta$; the projection height is $2r\sin\beta$; the vertical distance from the lowest point of the spherical cap O_3 to the $y=R$ plane is $(r\sin\beta+d\sin\theta)-R$; then the spherical size sectioned by the $y=R$ plane is:

$$A=\frac{S\sin\beta[(r\sin\beta+d\sin\theta)-R]}{2r\sin\beta} \quad (1)$$

where, S is the spherical cap area, cm^2; R is the radius of the outer wall of soil-covering basket drum, cm; r is the radius of the spherical bottom, cm; d is the rod length adjusted by the soil-covering regulating device, cm; β is the included angle between spherical bottom and the level ground; θ is the adjusted angle. The final projection area along the positive direction of X axis is:

$$\frac{S\sin\alpha[(r\sin\beta+d\sin\theta)-R]}{2r} \quad (2)$$

The soil taking volume can be calculated by:

$$V = vt\frac{S\sin\alpha[(r\sin\beta + d\sin\theta) - R]}{2r} \quad (3)$$

where, v is the walking speed of the transplanter, m/s; t is the walking time, s. Soil taking volume can be calculated by:

$$Q = \rho V = \rho\, vt\frac{S\sin\alpha[(r\sin\beta + d\sin\theta) - R]}{2r} \quad (4)$$

where, ρ is the soil density, g/cm^3.

3.2.3 Calculation of soil entering volume

When transplanter is moving forward, the soil-covering disc will push the soil going up and accumulating in a certain direction, forming a short-distance flowing phenomenon. When the accumulation reaches a certain height, an effective soil entering volume is formed. To accurately calculate the entering volume, the lower part sectioned by the introduction line of Y axis is used as the cross sectional area of the soil entering volume, i.e. the cross section that soil entering the soil-covering basket.

Cross sectional area:

$$\begin{aligned} A_1 &= 2\int_0^{\sqrt{R^2-(R-h)^2}}[\sqrt{R^2-x^2}-(R-h)]dx \\ &= R^2\arcsin\left(\frac{\sqrt{R^2-(R-h)}}{R}\right) - (R-h)\sqrt{R^2-(R-h)^2} \end{aligned} \quad (5)$$

The shortest distance from the nearest point O_3 on the soil-covering disc to the soil entrance face is $D-\cos\beta\cos\alpha$, and the effective soil entering volume is:

$$\begin{aligned} V_1 &= A_1(D - r\cos\beta\cos\alpha) \\ &= \left[R^2\arcsin\left(\frac{\sqrt{R^2-(R-h)}}{R}\right) - (R-h)\sqrt{R^2-(R-h)^2}\right] \\ &\times (D - r\cos\beta\cos\alpha) \end{aligned} \quad (6)$$

Assume the flowing speed of soil in the effective entering volume space $v_1=\lambda v'$; λ is a constant concerned with α; v' is concerned with v; other properties of the soil would also influence v_1. During the time t, the entering volume is:

$$Q_1 = \rho v_1 t A_1 \quad (7)$$

3.3 Soil output principle and theoretical soil output volume

Figure 5 shows a stable soil volume when the soil-covering drum rotates anticlockwise. The right part of the screw blades is the major space for soil carrying. The closer to the screw blades, the easier the soil can be carried by the screw blades. The screw blades, which make anticlockwise rotation, is approximately a rectangular plate composed of many small rectangles. The small rectangles rotate 90° around the center O_1 from the lowest point to the position parallel to the level ground to realize the carrying of the soil. During this process, the soil moves under the effect of gravity and friction when the soil-covering drum axis is upward, and there is a minimum volume at the right space between the screw blades and outer drum wall. The shadow area in Figure 5 is the cross sectional area of this volume space.

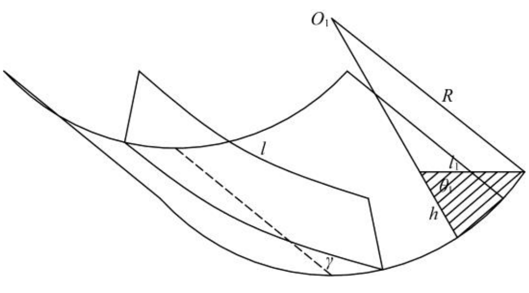


Figure 5 Structural parameters inside soil-covering drum

In Figure 5, θ_1 is the included angle between the upper plane of minimum soil carrying and the screw blades (when rotating 90°). This value is connected with the screw blade height h, the outer wall radius of drum R, soil properties, friction coefficient between soil and drum outer wall. Investigations found that this angle can be detected. l_1 is the upper plain width of soil; l is the length of screw blades; γ is the helical angle of the screw blades.

In order to calculate the shadow area S_{shadow}, we constitute a sectorial area S_{sector} by introducing two radius lines from O_1 center to connect the bottom of screw blades and right side of the upper plane of soil to form a sectorial area S_{sector}. l_1, R and $R-h$ form the triangle area $S_{triangle}$.

$$S_{triangle} = \frac{(R-d)l_1\sin\theta}{2} \quad (8)$$

$$S_{sector} = \frac{\arccos\left[\frac{R^2+(R-d)^2-l_1^2}{2R(R-d)}\right]\pi R^2}{360} \quad (9)$$

$$\begin{aligned} S_{shadow} &= S_{sector} - S_{triangle} \\ &= \frac{\left[\frac{R^2+(R-d)^2-l_1^2}{2R(R-d)}\right]\pi R^2}{360} - \frac{(R-d)\times l_1\sin\theta}{2} \end{aligned} \quad (10)$$

Soil carrying volume

$$\begin{aligned} V_2 &= S_{shadow}\times l\sin\gamma \\ &= \left[\frac{\arccos\left[\frac{R^2+(R-d)^2-l_1^2}{2R(R-d)}\right]\pi R^2}{360} - \frac{(R-d)\times l_1\sin\theta}{2}\right]\times l\sin\gamma \end{aligned} \quad (11)$$

where, d_1 is the distance between screw blades, then in the time t, the theoretical soil output volume will be:

$$Q_2 = \frac{td_1}{v}\times\rho V_2 \quad (12)$$

4 Soil-covering field test

4.1 Test materials and equipment

4.1.1 Test field

The test field should be ploughed and flattened before the test. Big soil blocks, stones, straws and weeds should be cleared, and the soil quality should satisfy the agricultural requirement for soil covering and planting[23,24]. The soil moisture should not exceed 20% appropriate for seedlings planting. The field test of soil-covering device was conducted in May 2018 in the test field (length ≥50 m, width ≥5 m) of Mechanical and Electrical Engineering College of Shihezi University. Test object: pepper plug seedlings with average height 14.5 cm, average crown about 5.5 cm and good growth. The pepper seedlings were transplanted with soil-covering device.

4.1.2 Test equipment

Instruments used to measure soil volume and relevant parameters; one experimental 2MZQ up-film automatic transplanter[19], the whole machine is 2670 mm × 1740 mm × 1380 mm, supporting power is 33 kW, one set of film, two working rows, duck-mouth planter, two disc openers (diameter 230 mm), four 250 mm round roll press wheels, row spacing is 40 mm, the plant distance adjusting is 22-40 mm, the theoretical lighting width is 90 mm; one John Deere 454 tractor; two electronic stopwatches; two steel taps of 2 m; two measuring tapes of 100 m; two triangular rules; several surveyor's poles of 1.5 m; JJ3000 electronic scale (precision 0.1 g); SDT-100 soil moisture meter.

4.2 Test plan and method

Analysis of soil-covering principle and preliminary tests showed that the final soil output volume is influenced by the diameter of the soil-covering disc (disc area), disc angle, depth of disc in soil, and vertical height of screw blades. According to the projection area formula, when the disc area is confirmed, the factors that influence the soil taking volume are disc angle, depth in soil, and height of screw blades. Chen et al.[4,5] studied the influences of the included angle between the soil-covering disc with the walking direction, the depth in soil and the height of screw blades on the soil output volume when the camber angle of the disc was 10°. The deflection angle of the soil covering disc, the vertical center distance that was the depth of the soil covering disc, and the height of the spiral blade were selected as the test factors, and the soil transport (the soil-covering quality of one-meter distance of a single film) as the evaluation index. According to the dryland planting machinery operating standard[25] and the requirements of the working parameters of the pot seedling film transplanting machine[18], the value range of the influencing factors were determined. Box-Behnken method was used to conduct a three factors and three levels test plan, as shown in Table 1 and Table 2. During the test, the diameter of the soil-covering drum is 28 cm, the diameter of the soil covering disc is 26 cm, the walking speed is 3 km/h, the disc deflection is 20°-50°, the vertical center distance is 4-8 cm, and the screw blades height is 4-6 cm.

Table 1 Factor level table

Levels	Factor		
	The disc deflection α/(°)	Vertical center distance $d\sin\theta$/cm	Screw blades height h/cm
1	20	4	4
2	35	6	5
3	50	8	6

Table 2 Test results

Number	A: the disc deflection α/(°)	B: vertical center distance $d\sin\theta$/cm	C: screw blades height h/cm	Soil output /kg·m^{-1}
1	35.00	6.00	5.00	5.27
2	35.00	4.00	4.00	2.82
3	35.00	6.00	5.00	5.17
4	35.00	6.00	5.00	5.03
5	50.00	4.00	5.00	2.34
6	35.00	4.00	6.00	2.61
7	20.00	6.00	6.00	3.63
8	50.00	6.00	4.00	3.05
9	35.00	8.00	6.00	4.72
10	35.00	8.00	4.00	3.88
11	20.00	6.00	4.00	4.46
12	20.00	4.00	5.00	3.12
13	35.00	6.00	5.00	5.22
14	50.00	8.00	5.00	4.14
15	35.00	6.00	5.00	5.37
16	20.00	8.00	5.00	3.39
17	50.00	6.00	6.00	4.01

4.3 Variance analysis of soil output and model optimization

4.3.1 Variance analysis of soil output

Quadratic regression fitting analysis was conducted on the results of Table 2 using Design Expert 8.0, and the following regression equation of soil output can be obtained:

$$Q_2 = -14.325 + 0.028\alpha + 2.592dsin\theta + 4.086h + 0.013\alpha dsin\theta$$
$$+0.030\alpha h + 0.131dsin\theta h - 0.004\alpha^2 - 0.281(dsin\theta)^2 - 0.582h^2$$

As shown in Table 3, regression model p<0.0001 and lack of fit p>0.05, indicating a significant regression model and a non-significant lack of fit, which can fully reflect the relationship between the disc deflection, vertical center distance and screw blades height with the soil output. The determination coefficient of the model R^2=0.9774. This soil output model can explain 97.74% change of its response value. The test error of the model is small, which can be used to analyze and predict the soil output volume.

Table 3 Variance analysis results

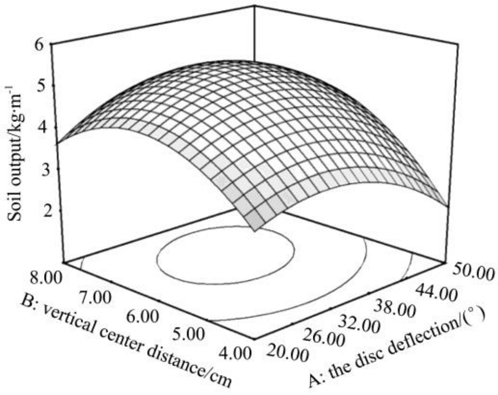
Error sources	Mean square sum	Free degree	Mean square	F value	p value
Model	16.06	9	1.78	33.70	<0.0001
A	0.14	1	0.14	2.65	0.1475
B	3.43	1	3.43	64.80	<0.0001
C	0.072	1	0.072	1.36	0.2812
AB	0.59	1	0.59	11.05	0.0127
AC	0.80	1	0.80	15.12	0.0060
BC	0.28	1	0.28	5.20	0.0565
A^2	2.99	1	2.99	56.39	0.0001
B^2	5.30	1	5.30	100.11	<0.0001
C^2	1.43	1	1.43	26.95	0.0013
Surplus	0.37	7	0.053		
Lack of fit	0.31	3	0.10	6.48	0.0514
Pure error	0.063	4	0.016		
Correction sum	16.43	16			

4.3.2 Response surface analysis of soil output

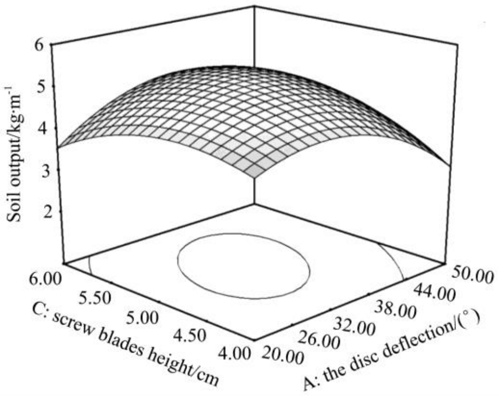
The response surface figure of the soil output obtained by Design Expert 8.0 can directly reflect the influences of the interaction between the variables on the soil output. According to the p value in Table 3, the primary and secondary sequence of factors influencing soil output is: the vertical center distance (i.e. the depth of disc in soil), the disc deflection, and the height of screw blades. The response surface under the interaction of the three factors is shown as Figure 6.

As shown in Figure 6, the surface chart formed by two variables of the vertical center distance and the included angle of the soil-covering disc has the most obvious convexity. With the increase of the included angle of soil-covering disc, the soil output will also increase in a certain range but will decrease if the included angle keeps increasing. Both the vertical center distance and the included angle presented nonlinear variation. Compared with the included angle of soil-covering disc, the variation of the vertical center distance to the soil output is larger, which is in accordance with the field test (the depth in soil has large impact on the change of soil output).

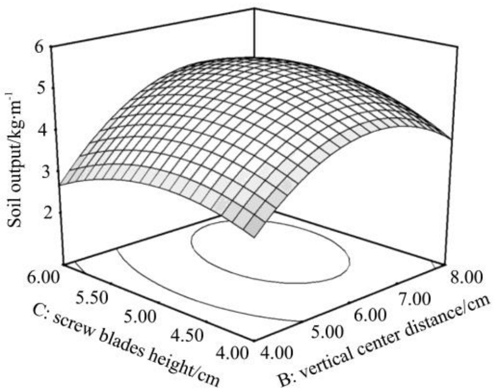
The convexity of the curved surface formed by the two variables of screw blade height and included angle of soil-covering disc is the smallest compared with that of the other two surfaces, while the surface convexity formed by the screw blade height and the vertical center distance is moderate. The transplanter can adjust the depth in soil. When the depth is small, small volume of soil will be taken, and the soil carried inside the drum is unable to cover the bottom screw blades. At this time, the soil output is very fast, but the volume is also very small; when the depth is large, large volume of soil will be taken, the soil will accumulate in the soil space, and the soil carried inside the drum is able to cover the bottom screw blades. At this time, the soil output is relatively low, but the volume is also very large.



a.



b.



c.

Figure 6 Response surface of soil output

4.4 Parameters optimization

The soil output volume has large impact on the transplanting and lighting area of pot seedlings. Excessive soil output would affect the lighting area, while insufficient soil output would prolong the greening period of pot seedlings after transplanting. By referring the requirement of national standard JB/T 10291-2013[25] on the planting depth of pot seedlings and the pot seedling growth observation test, our preliminary test is conducted on 15-18 cm wide soil-covering belt, with the up-film soil-covering height of 2-5cm and soil volume of 1m distance on the belt of 3-5 kg. Results show that all the transplanted seedlings can grow normally. Parameters were optimized as following based on the soil output model to realize a required soil output volume: choose 30°-45° as the variation range for the included angle of the soil-covering disc to further reduce the angle adjustment scope; the vertical center varies at 5-9 cm to enlarge the depth regulating scope; set the height of screw blades at 5-6 cm to reduce the value range and confirm the best value; input the regulating scope and target soil volume range in Design Expert 8.0, and the following optimal parameters were obtained: included angle of soil-covering disc is 37.33°; vertical center distance is 5.38 cm; height of screw blades is 5.11 cm; soil output (the soil-covering quality of one-meter distance of a single film) is 4.84 kg/m.

5 Verification test

To verify the reliability of the selected structural parameters of the soil-covering device and to facilitate the regulation of soil-covering regulating device, the optimized parameters were slightly adjusted in the verification test: the included angle of soil-covering disc, 37°; the vertical center distance, 5.5 cm; the height of screw blades, 5 cm. The soil output model is verified by field test at the test field of Shihezi University in July 2018. As shown in Figure 7, the walking speed of the transplanter is 3 km/h. Three groups of testing data from two 20 m long soil-covering belts were obtained. Take the soil three times from 1 m long soil-covering belt randomly from each group. Weigh the soil, and totally 9 data were obtained. Take the average of the data, the measured soil transport volume of the 1 m length soil-covering belt is 4.53 kg, which is basically consistent with the theoretical predicted value. It can ensure the stability of soil volume of drum type soil-covering device and can satisfy the requirement of 3-5 kg soil volume in transplanting pot seedlings. The distance between the two soil-cover belts is about 200 mm, the width of the lighting surface on the side of the mulch film is about 100 mm, and the lighting area is sufficient.

Figure 7 Verification test

6 Conclusions

1) This paper analyzed the soil-covering process and principle of the soil-covering device of up-film automatic transplanter, constructed theoretical models of soil taking volume and soil entering volume of soil-covering device, studied the soil output principle of soil-covering drum, and calculated the theoretical soil output volume, which provided theoretical basis for the design and parameters optimization of soil-covering device of automatic transplanter.

2) Based on the relationship between the established objective

function of soil output and the parameters, a regression equation of soil output was established. According to the field test, the soil output increases with the vertical center distance and included angle of soil-covering disc, while the height of screw blades has insignificant impact on the soil output. The decreasing order of the significance on the soil output is: vertical center distance, included angle of soil-covering disc, and height of screw blades.

3) Within the parameter limit interval, the optimized parameters of the soil-covering device are: included angle of soil-covering disc, 37°; vertical center distance, 5.5cm; height of screw blades, 5 cm. With this optimized parameters combination, the soil output of 1m long soil-covering belt is 4.84 kg and the testing value is 4.53 kg, which is close to the theoretical prediction and can satisfy the soil output requirement of 3-5 kg during transplanting of pot seedlings.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 51565048, 51605312), and the talent project of Guilin University of Technology (Grant No. GLUTQD2018012). The authors thank the anonymous reviewers for their constructive suggestions on the paper.

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