DESIGN AND OPERATION PARAMETERS OPTIMIZATION OF 4SGMS-220 PLOUGH LAYER RESIDUAL FILM RECOVERY MACHINE
/
4SGMS-220 型耕层残膜回收机的设计及参数优化

Xing Jianfei[1, 3], Wang Xufeng*[1, 3], Hu Can[1, 2, 3], He Xiaowei[1, 2, 3], Guo Wensong[1, 3], Wang Long[1, 2, 3] [1)]
[1)]College of Mechanical and Electronic Engineering, Tarim University, Alar Xinjiang, 843300 / China;
[2)] College of Engineering, China Agricultural University, Beijing, 100083 / China;
[3)] Key Laboratory of Colleges & Universities under the Department of Education of Xinjiang Uygur Autonomous Region, Alar Xinjiang 843300/ China
Tel: +86 13779803762; E-mail: wxfwyq@126.com
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ABSTRACT

In view of the harm of residual film retention to soil environment in Xinjiang which even affected the germination of seeds and hindered the growth of crop roots in severe cases, in this paper, a 4SGMS-220 plough layer residual film recovery machine with a ground preparation device is designed. The main part of the machine is composed of a filming mechanism, a conveying mechanism, a soil crushing roller, and a film collecting box. The machine can achieve simultaneous film lifting, film stripping, collecting membrane and suppression operations. In this paper, primary focus is placed on the design of the filming mechanism, while the movement trajectory of the comb teeth and the filming condition are analysed in detail. In order to obtain the optimal combination of equipment and operating parameters, the equipment traveling speed, the filming device rotational speed, and the comb teeth depth are used as the influencing factors. Furthermore, the residual film recovery rate and impurity rates are employed as test indicators for three-factor three-level response surface experiment and optimization via Design-Expert software. The results indicate that optimal operation is achieved for the machine travel speed of 4.1 km/h, the filming device speed of 106 min^{-1}, and the comb tooth soil penetration depth of 139.2 mm. The residual film recovery rate is equal to 74.32%, while the residual film impurity rate is equal to 7.11%. The difference between the test results and the predicted values is relatively small. Thus, it can be concluded that the optimized model is reliable.

摘要

针对新疆残膜滞留对土壤环境产生了一定破坏、严重时会出现影响种子发芽和阻碍作物根系生长等问题，该文设计了一种带有整地装置的 4SGMS-220 型耕层残膜回收机,4SGMS-220 型耕层残膜回收机由起膜机构、输送机构、碎土辊、镇压辊和集膜箱等组成，可一次性完成起膜、脱膜、集膜、平土及镇压作业。机具重点设计了起膜机构和脱膜机构，并对梳齿的运动轨迹和脱膜条件进行了分析。为得到机具与作业参数的最佳组合，将机具行进速度、起膜辊转速、梳齿入土深度作为影响因素，以残膜回收率和残膜含杂率为试验指标进行三因素三水平响应面试验，利用 Design-Expert 软件进行优化。结果表明，机具行进速度 4.1km/h、起膜辊转速 106r/min、梳齿入土深度 139.2mm 时作业最佳，残膜回收率为 74.32%，残膜含杂率为 7.11%，试验结果与预测值相差较小，优化模型可靠。

INTRODUCTION

The crop growth soil environment affects the final crop yield. With the large-scale utilization of the film covering technology, environmental dependence of the crop growth can be effectively solved (*Zhao et al., 2017; Li et al., 2017*). Xinjiang is a large province of plastic film mulching cultivation, with cotton being the main planting crop, accounting for 74.3% of the country's total cotton planting area with the film input of more than 200,000 t per year (*Hu et al., 2019; Liu et al., 2018*). Owing to the incomplete film recovery, the remainder of the broken film requires ploughing the entire ground to the tillage layer. With time, a relatively large amount of residual film retention is accumulated. Hence, crop growth and development may be hindered (*Jiang et al., 2019; Ye et al., 2020*).

[1] *Xing Jianfei, Lec.; Wang Xufeng, Prof. Ph.D.; Hu Can, Ph.D. Stud.; He Xiaowei, Ph.D. Stud.; Wang Long, Ph.D. Stud.; Guo Wensong, A. Prof. Ph.D.*

In order to ensure a sustainable development of cotton fields and speed up the control of the residual film pollution, in June 2018 the State Council of the CPC Central Committee issued the Opinions on Comprehensively Strengthening ecological environment Protection and Resolutely Fighting pollution Prevention and Control. Furthermore, in 2020, the Ministry of Agriculture and Rural Affairs along with additional four departments jointly issued the Measures for the Administration of Agricultural Film, which is imperative for solving the problem of the residual film pollution in the tillage layer.

The residual film of all cotton field soil layers in Xinjiang is relatively scattered. According to *Yan et al., (2014)*, the tillage layer residual film is mainly concentrated at 0-300 mm depth (*Lin et al., 2019*). According to *Hu et al. (2019)* the average residual amount in Xinjiang region is 206.46 kg/hm^2, which exceeds the film limit of 75 kg/hm^2. The presence of the residual film in the tillage layer has seriously affected the development of the bed and root system of cotton species (*Liu et al., 2020*). Currently, there is a shortage of applicable tools for the tillage layer residual film recovery. (*Liu et al., 2019; Luo et al., 2018*). Thus, the mechanized recovery of the tillage layer residual film presents a problem that must be solved. Field experts and researchers in China have designed and analysed the film starting points of the tillage layer residual film. *Zhang et al. (2017)* proposed a chain-toothed tillage film recovery machine which can recover approximately 150 mm of residual film. However, the chain-tooth film consumption power is relatively large, while the maintenance of implements is quite complex. *Xie et al. (2019)* designed a curved tooth rolling layer residual film recovery machine. By employing the curved roller-tie film mechanism, the machine can complete the middle-till layer residual film recovery, with the corresponding depth of operation and width being 55 mm and 800 mm (*Han et al., 2021*), respectively. However, depth of operation does not meet the requirements. Furthermore, amongst other issues, the machine has low operating efficiency.

The key to the recovery of the tillage layer residual film is the starting film (*Sun et al., 2018*). In this paper, in order to solve the problem of the tillage layer residual film recovery, a 4SGMS-220 machine is designed and tested. The machine is designed according to the film recovery parts of the current tillage film recovery machine characteristics. The machine can simultaneously complete the membrane, film release, film collection, flat soil, and suppression operation. By analysing the function and structure of the combing film mechanism and the film stripper mechanism, parameters of each device are determined, field tests are performed, regression equations with the help of response surface analysis are established, optimal parameters selected, verification is carried out, and a test basis for design of the subsequent tillage residue recovery machine is provided.

MATERIALS AND METHODS

Overall structure

The configuration of the combing layer residue recovery machine is shown in Figure 1. The main components of the machine are: the traction frame, frame, transmission, depth limit wheel, film-lifting mechanism, film-stripping mechanism, syringe, conveyor chain, conveying chain active shaft, vibration wheel, crushed soil roller, film collection box, flat plate, suppression roller, and the walking wheel. The main parameters of the combing layer residue recovery machine are provided in Table 1.

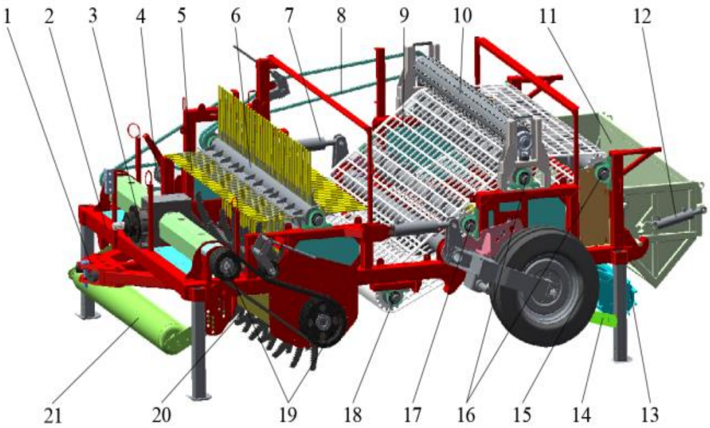


Fig. 1 - 4SGMS-220 residual film recovery machine

1) traction frame; 2) rack; 3) deceleration box; 4) tension pulley; 5) film belt; 6) film-stripping roller; 7) walking wheel hydraulic cylinder; 8) delivery chain; 9) delivery chain; 10) soil crushing roller; 11) film box; 12) film collection Box hydraulic cylinder; 13) suppression roller 14) flat plate; 15) walking wheel; 16) transmission chain; 17) vibration wheel; 18) transmission chain active shaft; 19) belt drive; 20) comb starting mechanism; 21) depth limit wheel.

Table 1

Main technical parameters

Items	Values
Overall dimension (mm×mm×mm)	4476×3264×1678
Matched power (kW)	100
Mode of traction	Traction type
Operation width (mm)	2200
Total weight of machine (kg)	3150

Working principle

As shown in Figure 1, when field work is performed, the implement tow frame is connected to the tractor suspension. The output shaft behind the tractor is connected to the implement gearbox. The output shaft provides the power output, and the chain drive transfers the power to the film starting mechanism, the film disfilming mechanism, the conveyor chain active shaft, and the crushing roller. The membrane knife rotates into the soil and grabs onto the residual film in the soil tillage layer. When the film disfilm belt and the combing membrane knife reverse their respective rotations, Under the action of the film belt, the film soil mixture on the film knife can be thrown onto the conveying chain. The film-lifting device rotates clockwise, while the disfilm device rotates counterclockwise. Thus, with the help of the disfilm belt, the film-and-soil mixture is thrown via combing epidural knife onto the conveyor chain. Vibration wheel and the crushed soil roller vibrate the membrane soil mixture and break the soil. This, in turn, causes the membrane-earth separation. The residual film in the transport chain is accumulated in the film collection box. Hence, the recovery of the residual film is completed.

Design of key components

The starting membrane mechanism

The combing film mechanism is one of the key machine components, as shown in Figure 2. In order to prevent combs from being subjected to excessive instantaneous force, production of Soil accumulation due to rotation, membrane leakage or other phenomena, the comb arrangement requirements between the portrait and the landscape have to be met (Zhang et al.,2017). The combs are placed in a double helix arrangement, with the starting points being 180° apart. The two adjacent combs are spaced 60 mm apart in the axial direction with a total of 72 teeth. The two adjacent teeth are angled at 20°, and the film roll diameter is equal to 180 mm.

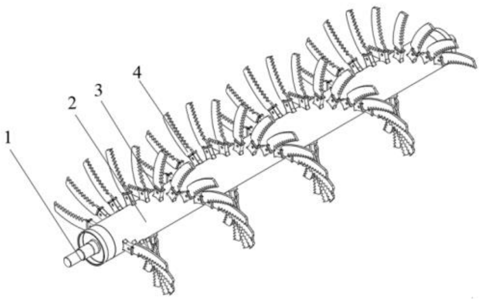


Fig. 2 - The filming mechanism

1) Filming axis; 2) Film roll; 3) Knife seat cover; 4) The membrane knife for combing

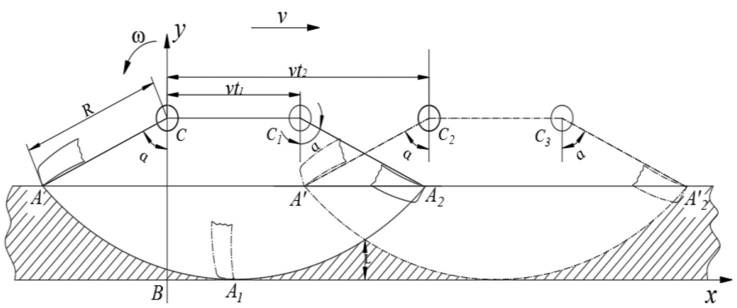


Fig. 3 - The motion trajectory of two adjacent combs

Leakage prevention conditions ensuring continuous operation

Film continuity during the implement operation should be ensured, while appearance of the tillage layer residual film leakage should be avoided. Thus, when a comb is unearthed, the adjacent combs simultaneously enter the soil film (*Wang et al., 2020*). The motion trajectory of two adjacent combs is shown in Figure 3.

A to A_1 motion trajectory equation can be written as:

$$\begin{cases} x = vt + R\sin\omega t \\ y = R - R\cos\omega t \end{cases} \tag{1}$$

According to Eq. (1) and Figure 3:

$$\begin{cases} L = R(1-\cos(\alpha - \omega t)) \\ C_1C_2 = v(t_2 - t_1) \end{cases} \tag{2}$$

Conversion to Eq. (2) is simplified as follows:

$$\begin{cases} t = \dfrac{t_1}{2} \\ C_1C_2 = v(t_2 - t_1) \end{cases} \tag{3}$$

When *A'* and A_2 are simultaneously occurring, the membrane critical condition of the 3rd comb entering the soil is:

$$C_1C_2 = 2R\sin\alpha \tag{4}$$

The soil nature of the southern Xinjiang is mainly composed of sandy soil. According to the relevant data, the optimal seeding depth is equal to 30-40 mm. At this depth, both cotton seeding rate and quality are ideal. The root quality distributed at 0-100 mm depth accounts for more than 74.38%, the distribution depth of the seedling root system at 100-150 mm is beneficial to cotton production (Dong et al., 2013). In order to reduce the effect of residual film on development of the cotton root system, the film depth should meet the $R - L - R\cos\alpha > 150$ criterion:

$$R - \left[R(1-\cos\frac{\omega t_1}{2}) \right] - R\cos\alpha > 150 \tag{5}$$

After meeting the requirements of cotton seeding and seedling development, conditions for residual film recovery and membrane leakage avoidance should be met:

$$\begin{cases} R(\cos\dfrac{\omega t_1}{2} + \cos\alpha) > 150 \\ v(t_2 - t_1) < 2R\sin\alpha \end{cases} \tag{6}$$

where t_1 is time from the film knife entrance into the soil film until the unearthing point, s; *Z* represents the same circumferential membrane knife number; and $\theta = 2\pi/\mathrm{z}$ is the same circumferential membrane inter-tooth angle.

Then, for $t_3 = 2\pi/z\omega$ and $t_3 = t_2 - t_1$, Eq. (6) can be obtained:

$$\begin{cases} \cos\alpha > \dfrac{150}{2R} \\ \sin\alpha > \dfrac{\pi v}{z\omega R} \end{cases} \tag{7}$$

In Eqs. (2)-(7), C_1, C_2 is the centre of rotation of the comb teeth at different times; t_1 represents the time required for the membrane knife combing from *A* to A_2, s; t_2 represents the interval between the two adjacent combs entering the soil, s; and t_3 represents the time between the first and the last comb, s.

According to the prototype design structure, comb tooth film cutter gyration radius is equal to *R* = 375 mm. The residual film of the plough layer in the 0-200 mm cotton field is recovered. The comb tooth length is equal to 280 mm. Movement trajectory analysis of the combed film knife shows that the initial entry angle is α = 65.1°, and the number of the same circumferential film knife is *Z* = 2. According to the operating conditions of the residual film recovery tool, the operating speed of the set implement is 4-6 km/h (1.11-1.67 m/s). According to Eq. (7), ω>5.6 rad/s. In other words, the speed is greater than 54 r/min.

According to the aforementioned results, it can be seen that a decrease in the film roll speed results in a decrease of the film starting efficiency. If the film roll speed is relatively fast, film combing process will cause residual film destruction. According to the theoretical calculation and the actual film-starting effect in the field, it is determined that the starting film roller speed should be 100 r/min, which meets the film-starting requirements.

Stripping mechanism

Plough layer residual film geometric shapes and sizes are different. In order to ensure smooth removal of the film, the stripping mechanism is designed. It is mainly composed of the stripping roller, the stripping belt, and the reinforcing rib of the fixed plate. The film removal mechanism is shown in Figure 4.

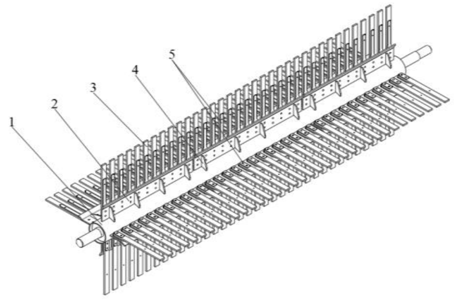
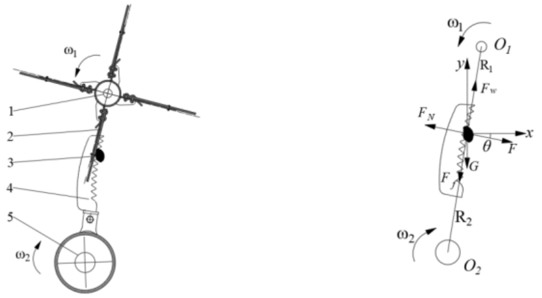


Fig. 4 - Demoulding mechanism
1) Stripping roller; 2) Strip fixed plate 3) Stripping belt; 4) Reinforcing rib of the fixed plate; 5) Belt pallet



a b

Fig. 5 - Residual film instantaneous stress analysis diagram
1) Stripping roller; 2) Stripping belt; 3) Membrane soil mixture; 4) The membrane knife for combing; 5) Film lifting roller

Disfilming process analysis

In order to ensure the membrane disfilming effect, a step-by-step disfilming method is employed. This can reduce the residual membrane movement travel and damage. Thus, according to the disfilm condition analysis, for each turn of the film teeth, the film belt is guaranteed to hang with the film teeth at least 2 times (*Xie et al., 2019*). Residual membrane transient force analysis diagram is shown in Figure 5.

During operation, the stripping mechanism rotates counterclockwise. The influence of the electrostatic adsorption can be neglected during the stripping process. Thus, the residual film can be smoothly removed from the film lifting teeth if the centrifugal force provided by the stripping belt is greater than that of the film lifting teeth on the residual film (*Li et al., 2012*). Therefore, the condition of the film removal is as follows:

$$\begin{cases} F_w > F_f + G\cos\theta \\ F > F_N \end{cases} \tag{8}$$

$$F_w = \frac{mv^2}{R_1} \tag{9}$$

$$G = mg \tag{10}$$

By simplifying Eq. (8), Eq. (11) is obtained:

$$v_1 > \sqrt{\frac{(F_f + mg\cos\theta)R_1}{m}} \tag{11}$$

where F_f is the comb teeth force on the residual film, N; F is the residual film stripping belt force, N; F_N is the comb teeth supporting force on the residual film, N; m is the mass of the residual film on the comb teeth, Kg; g is the acceleration due to gravity, N; θ is the angle between the stripping force and the horizontal direction, °; and R_1 is the simplified radius of the release roller, m.

Since the F_f direction points towards the centre of the film roll, 1 mg is taken to test F_f. In order to increase the number of contact points between the stripping belt and the comb teeth, the $\omega_1 > k\ \omega_2$ requirement has to be met. In this paper, parameter k is taken as 2. Parameter ω_1 is the angular velocity of the stripping roller, while ω_2 is the angular velocity of the film lifting roller. According to the film roller speed, it can be seen that when ω_1 is 21 rad/s, the film release requirements are met.

Working performance test

Test conditions

In order to verify the operating performance of the 4SGMS-220 residual film recovery machine, the prototype was trial-produced and field tested in November of 2019. The test site was the 8th company of the 10th Regiment of the First Division of Xinjiang Production and Construction Corps. The test field was mainly composed of the sandy loam with continuous film coating. The cotton field area was approximately 3 hm^2, the film thickness was 0.01 mm, the soil moisture content of the cotton field was 17.6-21.4%, the soil firmness was 28 kg/cm^2, and the wind speed was 1.9 m/s. The test is shown in Figure 6, and the power was provided by Dongfanghong 1504.

Fig. 6 - Field trial

Determination of test indicators

The test indicators are based on the relevant requirements in the national standards GB/T 25412-2010 "Residual Plastic Film Recovery Machine" and GB/T 25413-2010 "Farmland Plastic Film Residue Limits and Determination".

The selected test response indicators are the residual film recovery rate p_1, and the residual film impurity rate p_2, which are used to express the efficiency of the machine tool:

$$p_1 = \frac{M_0 - M_1}{M_0} \times 100\% \tag{12}$$

$$p_2 = \frac{G_1 - M}{G_2} \times 100\% \tag{13}$$

where:

M_0 is the residual amount of the plastic film prior to the test, Kg; M_1 is the residual amount of the mulching film after the test, Kg; G_1 is the mass of the residual film and cotton stalk mixture after the test, Kg; M is the weight of the residual film in the mixture, Kg; and G_2 is the weight of all cotton stubble in the test area, Kg.

Experimental design

17 test areas were selected in the test field of 10 groups and 8 companies, with a single area equal to 2.4 m×50 m. The selected machine travel speed A, film take-up roller speed B, and the comb tooth penetration depth C are taken as the influencing factors. The residual film recovery rate p_1 and the residual film impurity rate p_2 are employed as the test indicators. The experimental design is conducted via Design-Expert software Box-Behnken. Three-factor three-level response surface analysis method is employed. A total of 17 sets of experiments were carried out, and the residual film recovery rate and impurity rate were obtained. The test factor level table is shown in Table 2, while the result is presented in Table 3.

Table 2

Test factor level table

Level	Factor: Machine travel speed A (km/h)	Film take-up roller speed B (r/min)	Comb tooth penetration depth C (mm)
1	3	90	120
0	4	100	150
-1	5	110	180

RESULTS AND DISCUSSION

Table 3 data is analysed via data analysis function in Design-Expert software. The variance analysis of the residual film recovery rate and the residual film impurity rate is shown in Table 4.

The results indicate that the model is extremely significant if p < 0.0001, whereas lack of fit is achieved if p > 0.0001. This indicates that the regression model of the residual film recovery rate and the impurity rate has a high degree of fit with experimental results.

Test results

Table 3

Test results

Serial number	Test factor level table: Machine travel speed A (km/h)	Film take-up roller speed B (r/min)	Comb tooth penetration depth C (mm)	Response index: Residual film recovery rate p1/%	Residual film impurity rate p2/%
1	-1	0	-1	68.6	6.3
2	0	1	1	75	9.6
3	0	0	0	75.3	7.3
4	0	0	0	75.6	7.2
5	-1	1	0	73.8	7.4
6	0	0	0	75.4	7.1
7	1	1	0	74.3	8.1
8	-1	-1	0	69.5	7
9	0	-1	-1	67.7	6.7
10	-1	0	1	72.6	9.2
11	0	-1	1	73.3	8.8
12	0	0	0	74.9	6.9
13	0	0	0	75.1	7
14	1	-1	0	72.1	7.8
15	1	0	1	73.5	9.8
16	0	1	-1	73.8	6.8
17	1	0	-1	72.1	6.5

According to the data sample in Table 4, three selected factors have an interactive effect. According to the software Design-Expert, multiple regression equation fitting is developed to establish the travel velocity of the machine, the rotational speed of the film roll, and the depth of the comb tooth which affects the residual film. The regression equations of the recovery rate p_1 and the residual film impurity rate p_2 are:

$$p_1 = 75.26 + 0.98A + 1.79B + 1.49C - 0.52AB - 0.73AC - 1.10BC - 1.76A^2 - 10.8B^2 - 1.73C^2 \quad (14)$$

$$p_2 = 7.10 + 0.29A + 0.20B + 1.39C - 0.025AB + 0.1AC + 0.17BC + 0.22A^2 + 0.25B^2 + 0.63C^2 \quad (15)$$

Table 4

Regression model analysis of variance table

Index	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob >F	Significance
Residual film recovery rate	Model	92.77	9	10.31	60.92	< 0.0001	**
	A	7.61	1	7.61	44.94	0.0003	**
	B	25.56	1	25.56	151.06	< 0.0001	**
	C	17.7	1	17.7	104.61	< 0.0001	**
	AB	1.1	1	1.1	6.52	0.038	*
	AC	2.1	1	2.1	12.43	0.0097	**
	BC	4.84	1	4.84	28.6	0.0011	**
	A^2	12.97	1	12.97	76.64	< 0.0001	**
	B^2	4.91	1	4.91	29.02	0.001	**
	C^2	12.6	1	12.6	74.47	< 0.0001	**
	Residual	1.18	7	0.17			
	Lack of Fit	0.89	3	0.3	4.08	0.1041	
	Pure Error	0.29	4	0.073			
	Cor Total	93.96	16				
Residual film impurity rate	Model	18.85	9	2.09	38.83	< 0.0001	**
	A	0.66	1	0.66	12.26	0.01	**
	B	0.32	1	0.32	5.93	0.045	*
	C	15.4	1	15.4	285.59	< 0.0001	**
	AB	0.0025	1	0.0025	0.046	0.8357	
	AC	0.04	1	0.04	0.74	0.4176	
	BC	0.12	1	0.12	2.27	0.1755	
	A^2	0.21	1	0.21	3.95	0.0871	
	B^2	0.26	1	0.26	4.88	0.0629	
	C^2	1.64	1	1.64	30.5	0.0009	**
	Residual	0.38	7	0.054			
	Lack of Fit	0.28	3	0.093	3.7	0.1193	
	Pure Error	0.1	4	0.025			
	Cor Total	19.22	16				

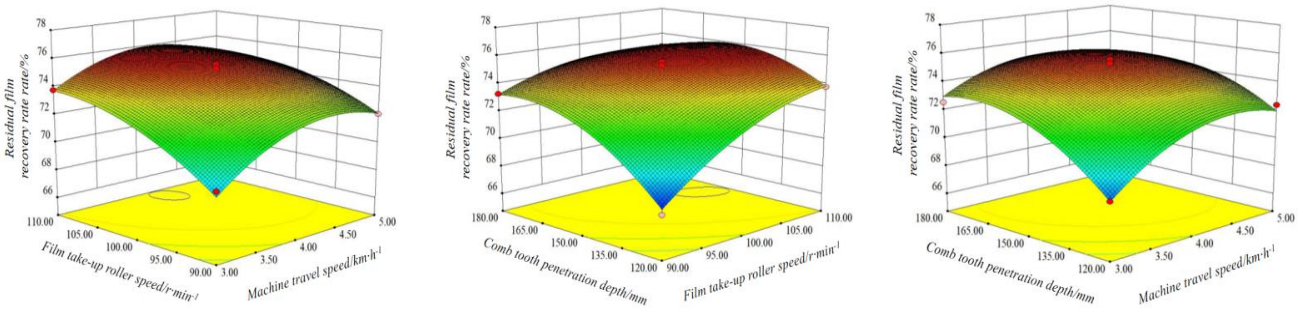
Note: P<0.05(significant)/P<0.01(extremely significant**)*

Influence of various factors on recovery rate of the residual film

According to Figure 7a, when the comb tooth penetration depth of 150 mm is achieved, as the traveling speed of the machine and the rotational speed of the film roll increase, the residual film recovery rate first increases and then decreases. This can be observed from the contour plan. As a result, film pick-up roller velocity forms a non-linear relationship with the operating speed of the machine. When the travel speed of the machine is 4 km/h and the film pick-up roller speed is 100 r/min, optimal residual film recovery effect is achieved. When the machine travel velocity and the film take-up roller velocity continue to increase, the relationship between the linear velocity of the comb tooth tip on the film take-up device and the machine travel velocity cannot be satisfied. Hence, the residual film cannot be continuously applied when the film is captured, resulting in residual film pickup rate being reduced.

It can be seen from Figure 7b that when the comb tooth filming speed is determined, as the comb tooth depth increases from 120 mm to 180 mm and the machine travel speed increases from 3 km/h to 4 km/h. The recovery rate of residual film showed a slight change trend of first increase and then decrease. As the depth of the comb tooth penetration and machine travel speed increase simultaneously, the recovery rate of the residual film increases first and then decreases. This is due to the increase in the working depth, which increases the amount of residual film and improves the interaction between the comb teeth and the residual film. The force continues to increase, and as the traveling speed increases, the residual film is broken during the film formation process. This, in turn, increases the difficulty of recovering the residual film.

According to Figure 7c, when the filming device speed is less than 110 r/min and the comb tooth penetration depth increases from 120 mm to 180 mm, the residual film recovery rate shows an initial increasing trend which then decreases. Generally, as the film roll speed and comb tooth penetration depth increase simultaneously, the residual film recovery rate first increases and then decreases. This is due to the linear speed increase in the filming device and the filming depth. The amount of the residual film on the plough layer increases, and the film cannot be lifted to successfully throw the residual film onto the conveying device, resulting in a decrease in the recovery rate of the residual film.



a) *b)* *c)*

Fig. 7 - Influence of various factors on recovery rate of the residual film

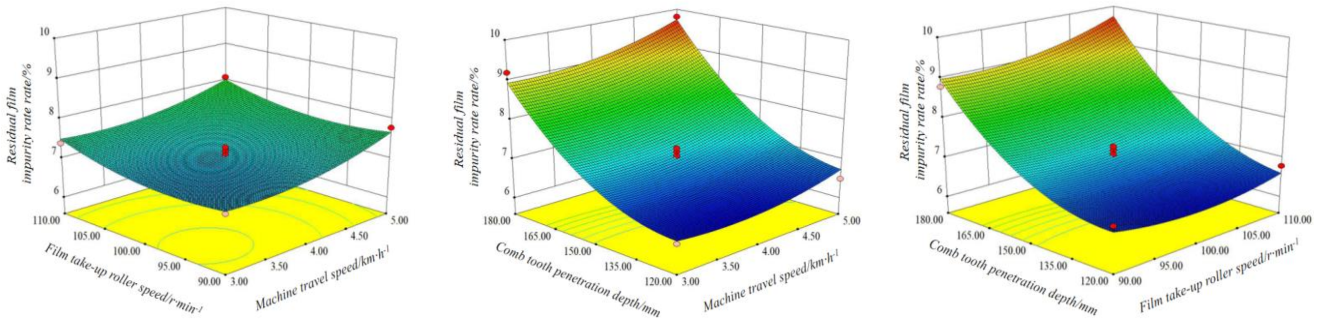
Influence of various factors on impurity rate of the residual film

According to Figure 8a, when the machine tool comb tooth penetration depth is determined, as the machine travel speed and the film roll speed increase, the residual film content first decreases and then slightly increases. When the machine travel speed is 4 km/h and the film-forming roller speed is 100 r/min, the residual film impurity rate is the lowest.

According to Figure 8b, when the rotational speed of the film roll is determined, the impurity content of the residual film first gradually increases with the increase of the soil penetration depth and the traveling speed of the machine. When the comb tooth penetration depth is greater than 144 mm, the impurity rate increase of the residual film is obvious. For the traveling speed of the machine equal to 3 km/h and the comb tooth depth of 120 mm, the residual film impurity rate is the lowest. In general, the residual film impurity rate increases with an increase in the comb tooth penetration depth and the machine travel speed. With the continuous increase in the soil depth and the machine traveling speed, the mixture of membrane impurities also increases. This results in a gradual increase in the impurity rate of the residual membrane.

According to Figure 8c, when the tool travel speed is determined, as the depth of the comb teeth increases, the impurity rate of the residual film also demonstrates a gradual increase trend. When the comb tooth penetration depth is less than 132 mm, with an increase in the rotational speed of the filming device, the residual film impurity rate will first slowly decrease and then slightly increase.

The rotational machine speed is 90 r/min in the filming device, and the comb tooth penetration depth is equal to 120 mm. Here, the residual film contains the smallest impurity rate. Generally speaking, the impurity rate of the residual film increases with an increase in the comb teeth depth and the rotational speed of the film roll. This is because an increase in the soil penetration depth causes an increase in the content of the impurity mixture. Furthermore, the rotational speed of the film forming roller increases, which consequently increases the contact frequency of the tooth and the impurity mixture. Lastly, this increases the impurity mixture from the farmland. Because of the inability of timely filtration, this leads to an increase in the impurity rate of the residual film.



a b c

Fig. 8 - Influence of various factors on the impurity content of the residual film

Parameter optimization and experimental validation

In order to improve the recovery rate and reduce the impurity rate of the residual film, the Optimization function in Design-Expert is used to optimize the solution. The following optimal parameters are obtained: the machine traveling speed of 4.1 km/h, the film roll speed of 106 r/min, and the comb tooth penetration depth of 139.2 mm. For these parameters, the recovery rate of the residual film is 75.5%, and the impurity rate of the residual film is 6.88%.

In order to ensure the practicability of the optimized parameters, they are utilized for validation tests. The film roll rotational speed of 106 r/min, and the comb tooth penetration depth of 139.2 mm are employed. The recovery rate of the residual film is equal to 74.32%, which is 1.18% lower than the theoretically optimized value. The impurity content of residual film is 7.11%, which is lower than the theoretical optimization value of 2.3%. By comparing the field test results with the predicted results, it can be concluded that negligible difference between the results exists. Therefore, the optimization model is reliable. Optimization results can be used for the selection of optimal operating parameters of the comb-type plough layer residual film recovery machine.

CONCLUSIONS

Aiming at the difficulty of recovering the residual film of the cultivated layer in Xinjiang, a comb-type residual film recovery machine of the cultivated layer was developed, and the feasibility of the machine was verified through field experiments. Studies have shown that the main factor that affects the recovery rate of residual film is the rotation speed of the film pick-up roller, and the main factor that affects the film impurity rate is the depth of comb teeth into the soil. Use Design-Expert software Box-Behnken optimization module to optimize the parameters, and get the best operating parameters as follows: machine travel speed 4.1km/h, film roll speed 106r/min, comb tooth depth 139.2mm, field test verification, residual film recovery rate is 74.32%, and the residual film impurity rate is 7.11%. The optimized model is reliable and meets the operating requirements of the plough layer residual film recovery machine. This study provides a theoretical reference for the research and development of the residual film recovery machine in Xinjiang.

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