

DESIGN AND TEST OF AIR-SUCTION PEANUT PRECISION MULCH-FILM AND HILL-DROP PLANTER

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The air-suction peanut precision mulch-film and hill-drop planter is developed aiming at the problems and requirements existing in the peanut ridge of the Mulch-film Planter. The paper introduces the structure and working principle of the machine and makes motion analysis on punching process. In view of the punching parts, absorbing seeds device, mulching film device and mulching soil device of the machine are designed. The punching characteristics of hill-drop wheel are studied, and the parametric equations of the soil hole contour are established. The paper also analyzes the influence of the structural parameters of hill-drop wheel on the size and shape of the soil hole, performs force analysis to the peanut seeds of the suction hole in the process of seed extraction by the planter plate and determines the conditions in which the peanut seeds are adsorbed effectively. The machine field performance test results show that with the increasing of equipment operation speed, film hole length increases, qualified rate of the punching dislocation reduces, hole spacing increases and the qualified rate of seed extraction reduces, sowing depth changes little, the grain number in each hole is variable, sowing repeating phenomenon is reduced, seeding leakage increases. Test results show that the machine performance is stable, all parts work smoothly. When the machine speed is 0.76 m/s, the negative pressure of seed absorption is 4.65 kPa, the working quality is the highest and all indicators fulfill the requirements optimally.

Keywords: Hill-drop Planter, Planting on the film, Punching characteristics, Structure, Parametric equations

1. Introduction

Film-covering planting is an important characteristic of peanut production in China. Due to its effect on improving temperature and moisture conservation of soil and because it makes full use of the deep soil water, it can effectively promote crop growth and agricultural water saving. It has been widely applied to most peanut producing areas in China. At present, the peanut planting mechanization

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degree using mulching film is low. It is an agronomic process that basically uses sowing first and then film-covering, and break film to unclose seedlings before emergence. This approach translates into a low mechanization degree and poor seeding quality. Mulching Film and punching planting is a new planting technique developed in recent years. Due to small disturbance on soil, it is beneficial to keep moisture conservation and drought resistance, can also save the time of mulching film manually. However, the existing planter on the film also has certain technical problems on seeding performance; the domestic research on mulch-film and hill-drop planting is basically in the stage of single technology. It is still in the initial stage for system integrations and teamwork technology research [1-12]. Therefore, this paper develops a two-line air-suction for the peanut precision mulch-film and hill-drop planter and its key component structure and work characteristics are studied. Through field experiment, its operation performance and existing problems are analyzed.

2. Agricultural technical requirements of Peanut planting

Mechanized planting of peanut belongs to precision sowing. Taking the present references for reference [14], the agricultural technical requirements when peanut ridge makes machine planting as follows. (1) Remove surface impurities, the scarification layer after soil preparation should be greater than 6 cm; the soil surface should be fine and crushing without obvious surface residue. (2) Ridge height is 10-12cm and ridge width is 50-60cm. Two rows of peanuts is sowed on the ridge and the small spacing is 25-35cm. (3) The best sowing depth is 5cm. Sowing depths should be consistent; the absolute value of error does not exceed 20% for the prescribed sowing depth. The ground with low temperature or high soil humidity can be appropriately shallow sowing, and should be no less than 3cm; on the contrary, it can be deepened and should be no more than 6 cm. (4) The sowing hill spacing between two lines of the peanut is usually 15.5-18.5cm; Error of the hill spacing cannot exceed 10% of the prescriptive hill spacing. The density with good soil fertility is small and with poor soil is large.

3. The overall structure and technical parameters

3.1. The structure and working principle

This machine is mainly composed of ridging plough, fertilizing device, mulching film device, hill-drop wheel and soil covering device. Its structure is shown in Fig. 1.

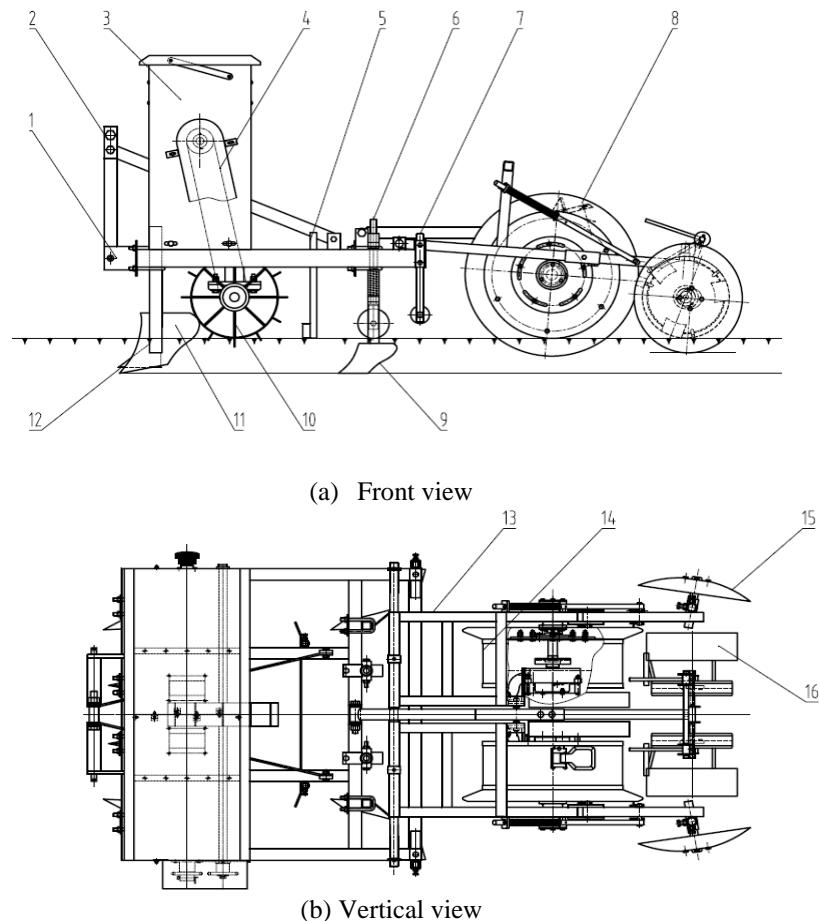


Fig.1 Structural sketch of air-suction peanut precision Mulch-film and hill-drop planter

- 1. Frame 2.Traction frame 3. Fertilizing device 4. Fertilizing transmission chain 5. Flat plate
- 6. Pressing soil wheel 7. Mulching film device 8. Punching parts 9. Furrow opener 10. Ground wheel 11. Ridging plough 12. Fertilizer opener 13. Hill-drop wheel stent, 14. Hill-drop wheel
- 15. Overburden disc 16. Overburden wheel

The machine is hanged on the tractor by the three-point traction frame. Hill-drop wheel uses air-suction device, which uses the negative pressure generated by the draught fan to separate the seeds and precision absorption through the seed extraction disk. The seeds absorbed are taken out of the room and put into punching parts with the hill-drop rotating. When the machine operates, ridging plough begins to ditch. Ground wheel drives fertilizer apparatus operation through transmission chain and pushes the seed manure through fertilizer pipe by means of fertilizer furrow opener into fertilizer ditch. The flat plate smoothes the ridge surface and press wheel presses a certain depth of seed ditch in the seedlings field. Furrow opener ploughs ridge bitch and mulching film device completes film covering on the ridge. Hill-drop wheel rotates forward on the film, whose punching parts punches the film and then implements the process of film breaking,

punching and sowing in the seedlings. Finally, the overburden disk pushes the soil on both sides of the ridge furrow into the ridge furrow and overburden wheel, implementing soil mulching at the film sides and in the seedlings field.

3.2. Technical parameters

Technical parameters are shown in Tab.1.

Table 1

Technical parameters of air-suction peanut precision mulch-film and hill-drop planter	
Name	Technical parameters
Mating power	Agricultural four-wheel tractor above 18.3kw
Overall dimension/mm (Length×Width×Height)	1948×1000×845
Adaptive row spacing/mm	300~500
working width /mm	500~800
Film mulching width /mm	600~1000
Hill-drop row spacing /mm	18.0/27.0/36
Planting rows	2Rows
Sowing depth/mm	40~60
Type of seed-metering Device	Air-suction, two grains at each hole
Fertilizer box capacity/kg	50
Type of fertilizer apparatus	external groove wheel φ80mm
Overburden device	overburden wheel: φ280mm; overburden disc φ360mm
productivity	0.24~0.36hm ² /h (Second gear drive)
Structural quality /kg	260
Transmission mechanism	fertilizer apparatus, chain-drive, Speed ratio 1:1 fertilizer apparatus, Hanging wheel mechanism, Speed ratio 1:1.5
Ridging device	ridging plough
Ground wheel	Steel wheel with finger, flange width 150mm, diameter 360m
Fan	impeller diameter 380mm, Quality 4.6kg, working speed 5200r/min

4. Operation characteristics and design of the key components

4.1. Movement analysis of punching process

When the machine moves forward, the movement of the punching parts is the compound motion and the synthesis of horizontal motion and rotation around the axis. The main structural parameters of the punching parts include radius of the wheel body R , depth of the punching H_1 , angle of the fixed duck mouth α , the central angle β_c of C on the activated duck mouth. Setting the slip ratio of hill-drop wheel is η , rolling radius of hill-drop wheel is R_0 ($R_0 = R/(1-\eta)$), the

activated duck mouth rolling around C is θ , radius of the activated duck mouth endpoint from rotation center C is R_e . From references [13], the hill-drop wheel forms soil hole, which is shown in Fig. 2.

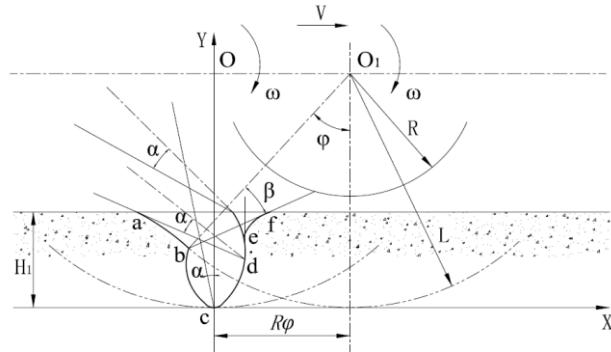


Fig.2 The outline of the soil hole formation process

Where, c is taken as the coordinate origin to establish the rectangular coordinate system. The trajectory of fixed duck mouth cusp forms segment bc and de . Parametric equation is as follow.

$$\begin{cases} x_{de(bc)} = R_0 \varphi - L \sin \varphi \\ y_{de(bc)} = L(1 - \cos \varphi) \end{cases} \quad (1)$$

Segment cd is formed in the opening process of the activated duck mouth cusp; its parametric equation is as follow.

$$\begin{cases} x_{cd} = R_0 \varphi - R_c \sin(\varphi - \beta_c) + R_e \sin(\beta - \theta) \\ y_{cd} = L - R_c \cos(\varphi - \beta_c) + R_e \cos(\beta - \theta) \end{cases} \quad (2)$$

Front of the duck mouth extrudes soil in the process of unearthing and forms segment ef in fig.4. Its parametric equation is as follow.

$$\begin{cases} x_{ef} = R_0 \varphi - [R_0 \sin(\varphi + \beta) - L \sin \beta] \cos(\varphi + \beta) \\ y_{ef} = L - R_o + [R_0 \sin(\varphi + \beta) - L \sin \beta] \sin(\varphi + \beta) \end{cases} \quad (3)$$

Behind of the fixed duck mouth forms segment ab in Fig.4 in the process of interring into the soil; its parametric equation is as follow.

$$\begin{cases} x_{ab} = R_0 \varphi - [R_0 \sin(\varphi - \alpha) + L \sin \alpha] \cos(\varphi - \alpha) \\ y_{ab} = L - R_o + [R_0 \sin(\varphi - \alpha) + L \sin \alpha] \sin(\varphi - \alpha) \end{cases} \quad (4)$$

Set the soil hole length L_{af} is the displacement of A_i on the X -axis from a to f . The parametric equation is as follow.

$$L_{af} = |x_f - x_a| \quad (5)$$

It can be derived from (4) and (5).

$$\begin{cases} x_f = R_0\varphi_f - [R_0 \sin(\varphi_f + \beta) - L \sin \beta] \cos(\varphi_f + \beta) \\ x_a = R_0\varphi_a - [R_0 \sin(\varphi_a - \alpha) + L \sin \alpha] \cos(\varphi_a - \alpha) \end{cases} \quad (6)$$

Setting the depth of punching is H_1 , φ_a and φ_f can be derived as follows.

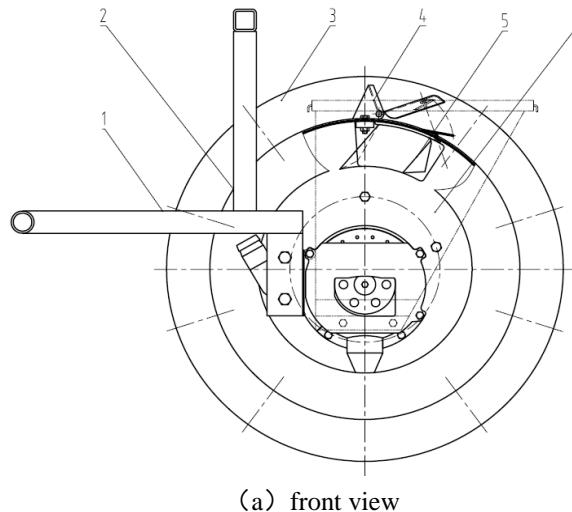
$$\begin{cases} \varphi_f = \arcsin \left[\sin \beta + \sqrt{\sin^2 \beta - 4(L - R_0 - H_1) \cdot R_0 \cdot \frac{1}{L^2} \cdot \frac{L}{2R_0}} \right] - \beta \\ \varphi_a = \arcsin \left[-\sin \alpha - \sqrt{\sin^2 \alpha - 4(L - R_0 - H_1) \cdot R_0 \cdot \frac{1}{L^2} \cdot \frac{L}{2R_0}} \right] + \alpha \end{cases} \quad (7)$$

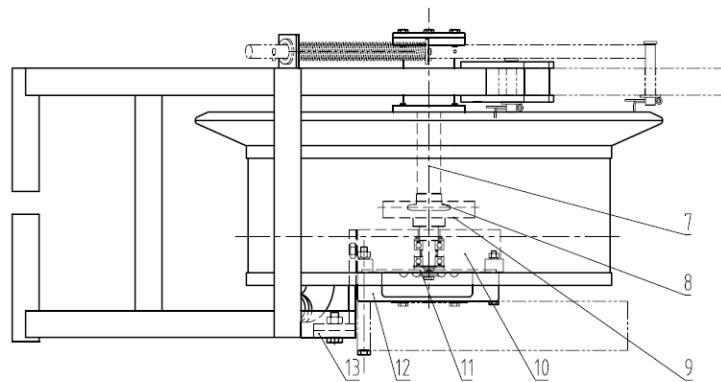
Take equations (6) and (7) into equation (5), L_{af} can be calculated. It can be analyzed from the above, when R , α and β increase, L_{af} increase; the influence of R on L_{af} increases with the increasing of α and β . Therefore, the value of R can be determined through the size of duck mouth angle and the structure of hill-drop wheel, and take as small as possible. With the increasing of α and β , the increasing trend of L_{af} increases obviously, which makes the soil hole and film hole increases. Therefore, the solution of α and β value should take as small as possible under the condition that requirement of ground breaking and capacity performance is met. L_{af} would increase when slip ratio η increases, and with the increasing of η , the influence of R on L_{af} increases. Therefore, R value should take as small as possible when it meets the structural requirements of hill-drop.

4.2. Design of hill-crop wheel

4.2.1. The structure of punching roller

As shown in Figure 3, the punching roller designed is mainly composed of bracket, the roller body, pressing film wheel and the punching parts.





(b) Vertical view

Fig.3 Structural sketch of the punching roller

1. Bracket 2. Roller body 3. Pressing film wheel 4. Punching parts 5. Seeds catching box 6. Seeds box 7. Transmission shaft 8. Sprocket 9. Inner roller sprocket 10. Gas chamber 11. Metering plate 12. Seeds chamber 13. Connecting board

Roller body is installed vertically on the bracket through the transmission shaft and hitched with the bracket through the frame. It can float up and down to ensure full contact with the surface and lift at the same time when encounter obstacles to avoid damage of cavitation components. Pressing film wheel is connected with the roller body through bolts. Punching parts are composed of fixed duck mouth, activated duck mouth and the pressing plate. Activated duck mouth and fixed duck mouth attach and form a closed hollow cavity. When the machine operates, the seeds fall into the closed cavity. When the duck mouth breaks the film for punching on the soil, the pressing plate is contacting with the ground gradually; the activated duck mouth is opened, and the seeds in the closed cavity are put into the soil hole.

4.2.2. The structural of absorbing seeds parts

As shown in Figure 4, the air-suction metering device is mainly composed of gas chamber, metering plate, seed chamber and gas pipe. Gas chamber is installed on the transmission shaft through the bearing and fixed by the connecting plate and hill-drop wheel bracket. The seed chamber is installed on the air chamber. When machine moves forward, metering plate rotates through transmitting axis and adsorbs the seed; when seeds are driven to the lower endpoint of the gas chamber, the negative pressure is terminated. Under the action of gravity, seeds enter into the corresponding inoculation box.

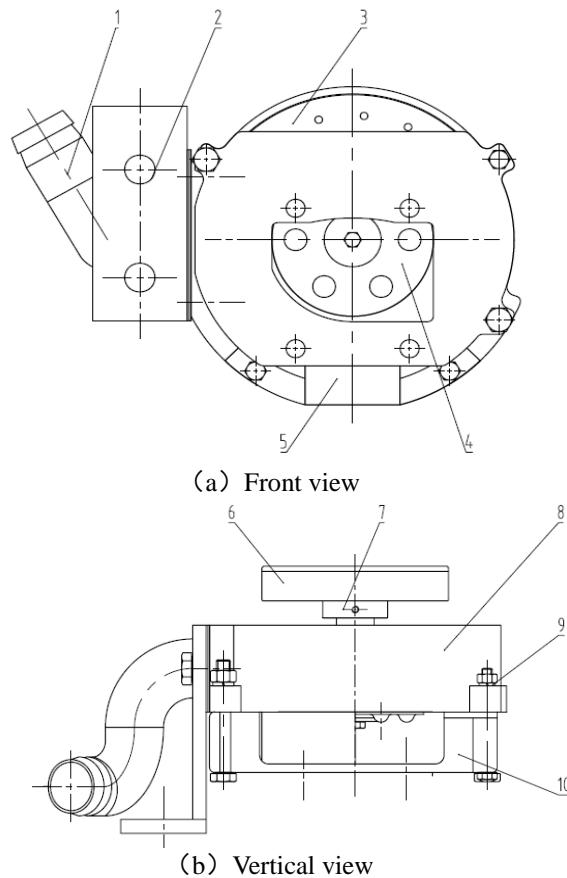


Fig.4 Structure sketch of air-suction metering device

1. Gas pipe 2. Connecting plate 3. Metering device 4. Stirring seeds device 5. Leading seeds device
 6. Internal roller sprocket 7. Transmission shaft 8. Gas chamber 9. Connecting parts 10. Seeds chamber

The absorption and force situation of the seeds in the absorption area is shown in Fig.5. G is the gravity of peanut seeds; F_m is the centrifugal force that seeds rotate along the metering plate; F_x is the internal friction of the seeds; N is the bearing reaction of the suction hole on the seeds, combined by N_1 and N_2 . When the seeds are absorbed and move along the suction hole, the force conditions should be satisfied as follows.

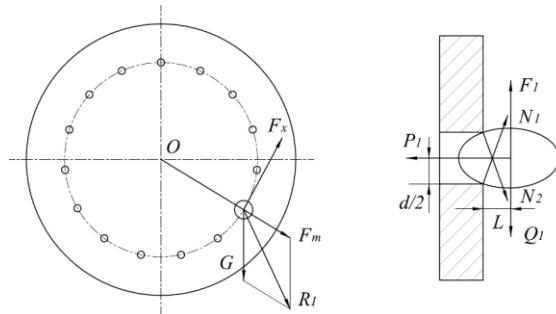


Fig.5 The force analysis of peanut seeds adsorbed

$$\begin{cases} P_1 \frac{d}{2} \geq Q_1 L \\ F_1 = f P_1 = Q_1 \end{cases} \quad (8)$$

In equation (8), d (m) is the radius of suction hole; L (m) is the distance between the seeds gravity and the metering plate; Q_1 (N) is the resultant force of G , F_x and F_m ; F_{s1} (N) is the friction generated by seeds absorbing in the suction hole; f is the friction coefficient of suction hole and the seeds; N (N) is the bearing reaction force.

The critical vacuum degree is achieved through the relationship of suction and vacuum degree,

$$H_C = \frac{P_1}{S} \quad (9)$$

Where, S (m^2) is the area of suction hole, $S = \pi d^2 / 4$; H_C (Pa) is the critical vacuum degree of air chamber. The following condition should be met if a suction hole absorbs a seed,

$$P_1 \frac{d}{2} = Q_1 L \quad (10)$$

The critical vacuum degree can be achieved from equation (9) and (10):

$$H_C = \frac{2LQ_1}{Sd} \quad (11)$$

Only when the critical vacuum degree in the air chamber is greater than H_C , peanut seeds can be effectively adsorbed on the suction hole.

4.3. The structure of overburden device

The overburden device is mainly composed of overburden discs and overburden rollers. The overburden rollers are composed of pull rod, soil scraper device, rollers, retaining soil plate and guide soil plate, as shown in figure 6.

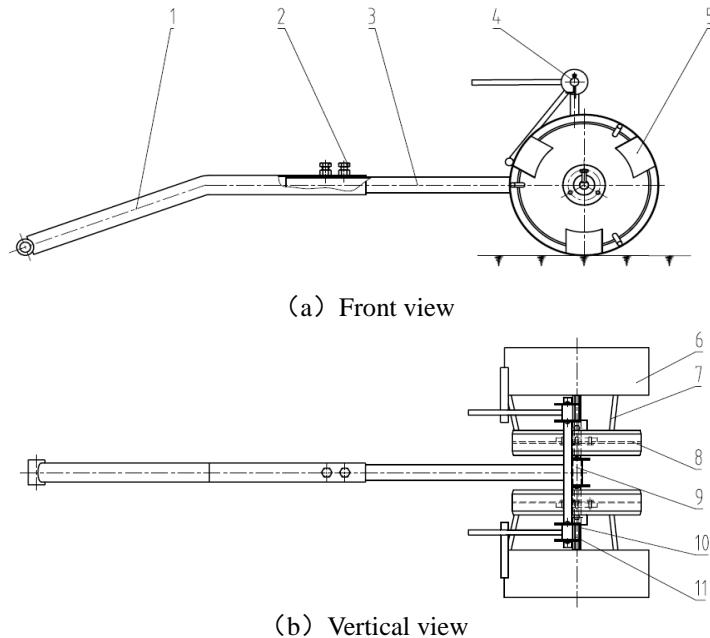


Fig.6 Structural sketch of overburden device

1. Pull rod | 2. Fastening bolt 3. Pull rod || 4. Soil scraper device 5. Guide soil plate 6. Roller 7. Connecting rod 8. Retaining soil plate 9. Axis supporting 10. Connecting axis 11. Wheel base regulation groove

The overburden device is connected by a spring thoroughly. Through the adjustment of the spring, the force of overburden disk and roller on the ground can be adjusted and float up or down simultaneously; it can be raised up when it faces with obstacles to realize the function of overload protection. When the machine moves forward, the pull rod brings the rollers to roll forward. After the overburden disk takes soil into the rollers, the soil is led into the rollers through the guide soil plate for mulching soil of the seedlings. The soil and weeds adhered to the overburden roller are cleared by soil scraper device.

4.4. The structure of mulching film device

The mulching film device mainly consists of fixed seat, regulation connecting rod and film installation wheel, as shown in Fig. 7. The adjustment of the connecting rod can adjust the laying height or angle of the film and adapt to the laying with different width.

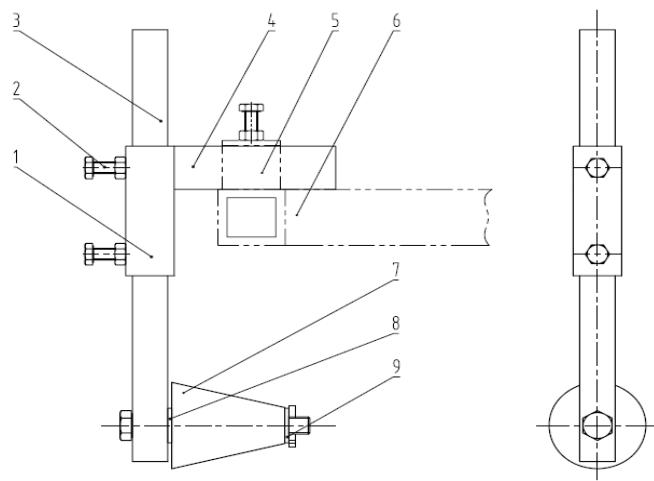


Fig.7 Structure sketch of mulching film device

1. Fixed seat 2. Fastening bolt 3. The longitudinal adjusting connecting rod 4. The transverse adjusting connecting rod 5. Fixed supporting 6. Frame 7. Film installation wheel 8. Wheel axle 9. Fixed shield ring

5. Field experiment

Field performance experiment of the prototype machine is used to test the operation performance of the machine, as shown in Figure 8.



Fig.8 Field experiment of Air-suction Peanut Precision Mulch-Film and Hill-drop Planter

5.1. Experiment conditions and methods

The operation speed is 0.32 m/s, 0.76 m/s and 1.02 m/s respectively. The negative pressure is 4.65 kPa, peanut varieties is four grains of red. In the experiment, test area length is 50m. Every 20 holes are selected for a little test area and five little test areas are selected randomly in the test area. The film hole is selected as test point. The film hole size, punching dislocation quantity, seeding

depth, hole spacing and grain number in each hole are determined, the qualified rate [14, 15] is calculated according to the formula (12).

$$\theta_i = \frac{100N_i}{N} \% \quad (12)$$

Where, $\theta_i(\%)$ is the qualified rate; N is the total number of each performance index determined in the district; N_i is the index number meeting the requirements of each performance inside the area.

5.2. The experiment results

Single factor analysis method is used to test the film hole length, punching dislocation rate, seeding depth under the film, hole spacing and grain number in each hole under different operating speed. Statistical analysis results are shown in table 2; operation effect of the hill-drop planter is shown in Fig. 9.

Table 2
Statistical analysis of test index

test index	operating speed /m.s ⁻¹	average value	mean square deviation	variation coefficient	the qualified rate/%
length of the film hole /cm	0.32	3.59	0.25	0.069	/
	0.76	3.73	0.31	0.083	/
	1.02	3.84	0.41	0.106	/
punching dislocation quantity /cm	0.32	1.12	0.90	0.803	97.0
	0.76	1.28	1.92	0.150	96.0
	1.02	2.21	2.24	1.014	94.0
Seeding depth /cm	0.32	4.96	0.42	0.084	95.0
	0.76	4.91	0.42	0.085	95.0
	1.02	4.64	0.52	0.112	90.0
Hole spacing /cm	0.32	16.03	0.44	0.027	95.0
	0.76	16.17	0.49	0.030	95.0
	1.02	16.23	0.22	0.014	90.0
Grain number in each hole/ N	0.32	1.97	0.48	0.244	94.0
	0.76	1.95	0.44	0.223	95.0
	1.02	1.76	0.55	0.314	94.0

According to the experimental results and analysis, it is known that with the increasing of the machine operation speed, the film hole length and its variable coefficient increases; the phenomenon of film-tearing and film-picking is more obvious. With the increasing of the operation speed, the qualified rate of punching dislocation reduces. When the speed is greater than 1.02 m/s, the qualified rate cannot meet the requirements of operation. This is due to the increasing of the machine speed, the longitudinal extrusion or extrusion of the film by the punching parts and file mulching device aggravates and the film transformation aggravates, which leads to the aggravation of punching dislocation

and the qualified rate decreases. With the increasing of the machine speed, seeding depth changes little; operation speed increases and seeding depth is smaller, uniformity and the qualified rate are both decreased. When the negative pressure of seeds adsorbing is certain and with the increasing of operating speed, the fluctuation of grain number in each hole is bigger. That is mainly because that with the increasing of operating speed, seed extraction time decreases, and the needed extraction force increases, which leads to the multiples seeding phenomenon decreases; seeding leakage phenomenon increases, the qualified rate increases firstly and then decreases. The experimental result is shown that when the machine speed is 0.76 m/s, the qualified rate of the punching grain number is the best.



Fig.9 Working effect of Air-suction Peanut Precision Mulch-Film and Hill-drop Planter

6. Conclusions

(1) Performance of the air-suction precision mulch-film and hill-drop planter designed is stable when it is used for field operation. All parts work smoothly and all the operation indexes meet the design technical requirements optimally.

(2) Machine speed has distinctly effect on the quality of operation quality. Film-tearing and film-picking phenomenon aggravates with the increasing of speed. Film hole length becomes large, hole spacing and the qualified rate of punching dislocation reduces; leakage phenomenon increases and multiples seeding phenomenon reduces.

(3) According to the field operation experiment of hill-drop wheel, it is determined that when the operation speed is 0.76 m/s and negative pressure of seeds absorbing is 4.65 kPa, the operating quality of the planter is the best. When the punching dislocation rate is 4.0%, the qualified rate of seeding depth is 95.0%. The punching and seeding quality of the planter can meet the operating requirements more optimally.

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R E F E R E N C E S

- [1]. X. L. Lv, M. J. Liu, and Z. C. Hu. "Research development of peanut seeding technology and equipment on the film", Chinese Agricultural Mechanization, no.1, 2012, pp.89-92
- [2]. W. Z. Liu, M. Q. Zhao, and W. M. Wang. "Theoretical analysis and experiments of metering performance of the pneumatic seed metering device", Transactions of the CSAE, **Vol.26**, no.9, 2010, pp.133-138
- [3]. W. Cao, J. H. Ding, and Z. C. Li. "Research and Design on Precision Hill-drop Sowing Wheel", Agricultural Equipment and Vehicle Engineering, **Vol.211**, no.2, 2009, pp.21-25.
- [4]. X. G. Chen, M. Wang. "Study on Key Factors of the Duckbill Punch Roller-type Pneumatic Metering Device", Journal of Agricultural Mechanization Research, no.3, 2011, pp.130-137.
- [5]. X. L. Lv, Z. C. Hu, H. J. Zhang and W. Wang. "Design and Research of the Air-Suction Peanut Precision Dibbler", Advanced Materials Research, **Vol. 945-949**, 2014, pp.330-334
- [6]. X. R. Lv, X. L. Lv and L. H. Zhang. "Design of holes distance adjustable device of duckbill seeder", Applied Mechanics and Materials, **Vol. 834-836**, 2014, pp.1668-1671
- [7]. S. D. Yang, R. C. Du, Z. D. Guo and P. S. Diao. "Design of Combined Punch Planter", Journal of Agricultural Mechanization Research, no.11, 2007, pp.118-119
- [8]. X. L. Lv, M. Zhang, X. R. Lv and W. M. Wu. "Design of the Plant Spacing Adjustable Dibbler", Applied Mechanics and Materials, **Vol.574**, 2014, pp. 239-242.
- [9]. X. L. Lv, W. Wang, X. R. Lv and W. M. Wu. "Research of the Punching Mechanism and Design of the Punching Device of the Peanut Mulching Film and Punching Planter", Applied Mechanics and Materials, **Vol. 602-605**, 2014, pp.507-510
- [10]. Q. X. Liao, J. X. Huang and G. Liu. "Design and experiment of precision metering device for slot wheeled seeder", Transactions of the Chinese Society for Agricultural Machinery, **Vol.42**, no.2, 2011, pp.63-66
- [11]. E. Ahmadi, H. R. Ghassemzadeh and M. Moghaddam. "Development of a precision seed drill for oilseed rape", Turkish Journal of Agriculture and Forestry, **Vol.32**, no.5, 2008, pp.451-458
- [12]. C. L. Liu, J. N. Song and J. C. Wang. "Design and experimental research of air-suction roller rice precision direct seed-metering device", Journal of China Agricultural University, **Vol.17**, no.2, 2012, pp.134-138
- [13]. H. A. Wei, S. L. Shao. "Analysis and evaluation on a roller type film mulching hill-drop planter for wheat", Journal of Gansu Agricultural University, **Vol.35**, no.4, 2000, pp.419-423
- [14]. NY/T 987-2006, "Film laying planter operation quality", The agricultural industry standard of the People's Republic of China, 2006.
- [15]. J. Liu, T. Cui and D. X. Zhang. "Experimental study on pressure of air-blowing precision seed-metering device", Transactions of the Chinese Society Agricultural Engineering (Transactions of the CSAE), **Vol.27**, no.12, 2011, pp.18-22