DESIGN AND EXPERIMENT OF SUSPENDED ROTARY TILLAGE RIDGE AND FILM MULCHING MACHINE
/
悬挂式旋耕起垄覆膜一体机的设计与试验

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ABSTRACT
Considering the planting mode and agronomics requirements of the existing facilities, the high-power rototilling ridge hoisting and lamination machine is difficult to operate in the greenhouse of the facility, and the small hanging rotary ridge raiser has technical problems such as insufficient horsepower. This paper designs the hanging rotary tillage ridging and film - covering machine. The machine realizes a single operation process to complete rotary tillage, ridging, drip irrigation, film laying and film edge covering soil suppression and other mechanized compound operations. The innovatively designed adjustable ridging device of this machine can steplessly adjust the size of the ridge. The ridge height after operation of the machine is 25-35 cm, the ridge width is 70-80 cm, the ridge shape is arc-shaped, the size is adjustable, and the operation efficiency is improved being 0.17-0.23 hectares/hour, the machine driving speed is set at low speed 1 gear. The machine has high operating efficiency, the arc-shaped ridge body is uniform and compact. the ridge body has a large lighting surface, the film is tightly laid, and it is close to the ridge surface without wrinkling. By test data analysis, the tillage depth stability is 93%, the ridge height qualified rate is 100%, the ridge width qualified rate is 85%, the ridge spacing qualified rate is 95%, the film edge covered soil thickness is 40 mm, the working efficiency is 0.802 hm²/h, the fuel consumption per hectare is 9.02 kg·h/m², and the three shifts work without fault. To sum up, it meets the agronomic requirements of ridging and film planting.

摘要
针对现有设施吊蔓西甜瓜种植模式与农艺要求，市场上已有大功率旋耕起垄覆膜机难以进入设施温室中作业，小型旋耕起垄机又会有马力不足等技术难题，本文设计了悬挂式旋耕起垄覆膜复式作业机，该机具实现了一个作业流程即可完成旋耕、起垄、铺滴灌带、铺膜及膜边覆土镇压等机械化复式作业。该机具创新设计的垄形可调式起垄器，可无级调整垄形大小，该机作业后的起垄高度 25-35cm，垄宽 70-80cm，垄形弧形、大小可调，作业效率 0.17-0.23 公顷/小时，拖拉机行驶速度挂在低速 1 挡，该机具作业效率高，圆弧形垄体均匀紧实，垄体采光面大，铺膜严实，紧贴垄面，不起皱，无破损，通过试验数据分析，耕深稳定性 93%，垄高合格率 100%，垄宽合格率 85%，垄间距合格率 95%，膜边覆土厚度 40mm,作业效率 0.802hm2/h,每公顷燃油消耗量 9.02kg·hm-2，并且三班次作业无故障。综上，可满足设施吊蔓西甜瓜耕整地机械化作业需求。

INTRODUCTION
With the adjustment of agricultural industry institutions, China's "rural revitalization" supporting policy implementation, agricultural efficiency, the effect of increasing farmers' income, the initiative of Chinese farmers to develop superior crops, especially cash crops such as watermelon and melon on raised beds in winter,which have been at an unprecedented high, farmers urgently need a complete function, price appropriate, suitable for greenhouse rotary tillage ridge mulching operation duplex machine, to reduce labour intensity, improve work efficiency, save operation cost, increase the production income. In northern China, such machines are relatively numerous, but most of them are high-power large machines, which are not suitable for greenhouse rotary farming ridge operation; in southern China, rotary tillage machinery supporting with walking tractors has been widely used, but the single function cannot achieve multifunctional duplex operation.

The planting mechanical ridging and film covering soil mainly have artificial and mechanical operation. The artificial ridge surface is uneven, the ridge is not straight and is time-consuming, and the production efficiency is low [1]. The machine is mainly ridging (*Zhang Jin, 2021; Wang Xiaomei, 2019*) the whole land should be ploughed and cleared before ridging, which consumes the most power in the process of western melon planting. Besides, the land preparation and ridge film mulching are conducted separately and the operation efficiency decreases, which seriously restricts the rapid development of the whole technology on double ridges.

In the 1970s, developed countries such as European countries began to develop and promote new agricultural machinery and tools adapted to the requirements of high-yield agriculture, and study the operation technology and supporting machinery and tools for rational utilization of water and soil resources (*Wang Xiaome, 2019*; *Liang Zheng, 2008*). For example, MAS5 made in Spain and 506 made in Germany are hand wheeled rotary cultivators (*wEISE G, 2008*; *Wang Wenzhi, 2013*). In the early stage of Chinese research on rotocultivator, the rotocultivator is mainly matched with walking tractor. In recent years, microcultivator and compound or combined operation machine have become a research hotspot. *Zong Minhua et al.* designed corn rotary tillage ridge-raising and film-laying machine, which is mainly used for furrow and furrow setting, spraying (herbicide), fertilizing (granular fertilizer), film-laying and film-edge soil pressing before seeding of corn with whole film on double ridges. Reducing the number of operations, greatly saves costs and increases agricultural production efficiency. It is suitable for the whole film mulching operation on double ridges and ridges in hilly and Sichuan areas with relatively flat surface, suitable humidity and less debris such as weeds and stones (*Shahgolig, 2010; Zong Minhua, 2022*). Some authors designed and developed a rotary ridge hoisting machine for Arbor planting that integrates deep rotary tillage and high ridging operation (*Prasanna, 2011; Fu Jie, 2020*). Chen Yanyu et al. designed an all-in-one scallion furrow and ridge fertilization machine and conducted field experiments (*Chen Yanyu, 2019*). Tang Fei et al designed a double spiral rotary tillage ridger for tobacco fields (*Hua Jianpin, 2014; Tang Wei, 2018*). All the above designed tools have large vibration, high oil consumption, uneven soil breakage rate and other phenomena in the process of rototillage ridging operation, which are mainly caused by the unreasonable installation angle and distribution of the tool holder, the unbalanced force of the tool shaft and other factors, and the optimization design is carried out by changing the form of blade arrangement and the installation Angle of the tool holder.

According to the preliminary calculation of the technical parameters of the machine, the machine can improve the operation effect by 40%~60% compared with the traditional artificial planting, each machine can replace 15~30 labour force, and the work efficiency can be improved by 5~20 times. Mechanized joint operation reduces the number of operation links and machines into the land, reduces the labour intensity, improves the efficiency of agricultural production, realizes soil moisture conservation, drought resistance, water saving and cost saving, and reduces the damage of the machines and tools, reduces the unit operation cost and fuel consumption, and can effectively save energy. The large-scale application of machines and tools will provide strong technical support for the water-saving technology of whole membrane ridge cultivation and the planting technology of western melon ridge membrane furrow, promote the development level of mechanized operation in other major producing areas in China, and will radiate and drive the rapid development of agriculture in the main production areas of western melon ridge planting. On the basis of sufficient market research, through the optimization and innovation of a number of parameters, the "greenhouse hanging vine and melon ridge mulching film seeder" was developed, which integrates ridging, drip irrigation belt, film covering, soil covering and other processes into one, and that can realize labour saving and high efficiency.

MATERIALS AND METHODS

Whole structure and working principle - Whole structure of the machine

1GQS-80 rotary tillage ridge and film mulching machine is mainly composed of rotary tillage device, ridging device, soil mulching device and frame and other components.

The specific structure is shown in Figure 1. The whole machine has the following overall dimensions (length x width x height) 1700 mm x 1300 mm x 1100 mm. The rotary tillage device and ridging device are fixed through the front frame beam of the machine, and the length of the front frame beam is 1350 mm. The gearbox of rotary tillage ridge machine is designed to have low speed, neutral and high speed gear, low speed gear for rotary tillage ridge operation, and high speed gear for film mulching operation. After the operation, the machine walks in neutral, and the knife shaft does not rotate at this time. The speed of knife shaft is 350 r/min in low speed gear and 860 r/min in high speed gear. The 3D final assembly drawing is shown in Figure 1, and its physical diagram is shown in Figure 2.

Fig. 1 – Overall rotary tillage ridging mulch applicator

Fig. 2 – Appearance

For operation, as shown in Figure 3, the power transmission of rotary farming ridge laying machine is transmitted from the universal coupling and transmission shaft to the transmission through the supporting tractor power output shaft. The knife shaft is arranged in the middle of rotary farming knife on both sides of the ridge cutter. The power of the transmission is driven by the gear box to rotate the rotary farming knife shaft to complete the ploughing. The film mulching device covers the agricultural film on the ridges in sequence under the traction of the tractor, at the same time the soil mulching device will cover the soil evenly to both sides of the film longitudinal, the suppression wheel compacts the overlying soil of the mulch film, thus completing the compound working procedures of rotating tillage, ridging and mulching.

Fig. 3 –Field operation

Planting agronomic qualification

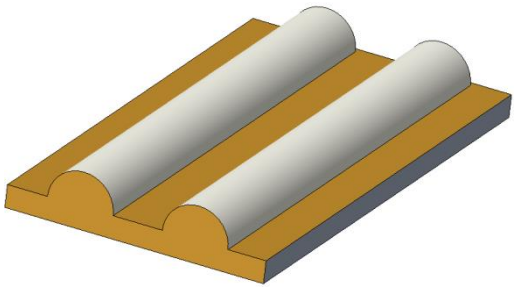

Fig. 4 - Ridging type cantaloupe cultivation and planting mode

Ridging type cantaloupe cultivation and planting technology has been studied for many years by agricultural technology department, promotion of a new type of drought resistance farming technology will be combined with ridge planting of new planting technology, the agronomy requirements being: ridge width 70-80

cm, ridge height 25~35 cm, ridge spacing 70 cm, mulching film covering ridge, plant spacing according to local agronomic requirements (*Chen Xinyu, 2021*). The main characteristics of this planting mode include tilting the soil, rotating tilling, fertilizing, mulching, and then sowing on the top of the ridge when the appropriate planting time, which can effectively increase the temperature, reduce evaporation, effectively improve the environment of the growth of the crops, improve the water utilization.

Combined with the agronomic characteristics of ridge planting, the main parameters of rotary-tillage ridging filming machine are shown in the table1.

Table 1

Rotary-tillage ridging filming machine technical parameters

No.	Project	Technical parameters
1	Version	1GQS-80
2	Type of power	traction type
3	Tractor power（kW）	25.7
4	Ridge width（tunable, cm）	70-80
5	Ridge height (cm)	25-35
6	The shape of the ridge	Round arch
7	Number of rotary cutting blades (put)	18
8	Number of ridge knives (put)	24
9	Outline dimensions length × width × height: (cm)	170 x 130 x 110
10	Rotary tillage depth (cm)	10-15
11	Operation speed（km·h）	4.5
12	Machine weight/kg	~ 500 kg
13	Number of operators (including tractor driver)	3

Design analysis of key rotary-tillage ridging filming machine

Design of rotary tillage and ridge lifting knife shaft

The main difference in the design of ridging and rotary knife shaft is the welding angle of the knife holder on the shaft. The lateral view direction of the rotary tillage cutter seat is 90° from the axis of the cutter shaft, while the ridge base and the tool axis have a certain angle (*Jiang Weiwen, 2022*). When the angle between the ridge holder and the knife shaft axis is out of scope, the soil resistance of the ridge cutter is too large, and the small angle will lead to the insufficient amount of soil and the height of the ridge lifting cannot meet the requirements of ridging (*Gu Yang, 2022; Luo Yanlei, 2021*). *Yong-Joo's* test results show that (*Yong-Joo Kim, 2013*), the most suitable angle between ridge cutter seat and ridge cutter axis is 20°. In the rotary farming industry, the working load is larger than the ridge operation, and the diameter of the rotary blade shaft is greater than the diameter of the ridge blade, the design is 55 mm, the casting blade base is welded on the knife shaft, the ridge blade shaft diameter is 45 mm, and the 8 mm thick steel plate is welded on the knife shaft.

The welding position of rotary plough holder and ridge holder on the knife shaft is arranged according to the agronomic requirements of planting hanging vines and melon ridges, which can meet the requirements of ridge size and reduce the area of rotary tillage. The rotary tiller and ridge cutter seats are shown in Figure 5，the physical picture is as shown in Figure 6.

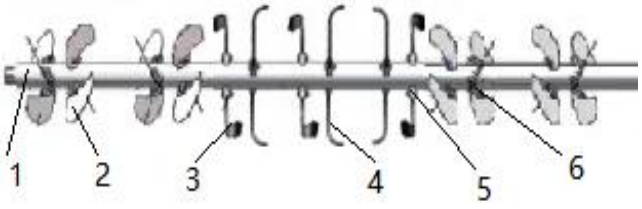

Fig. 5 -Rotary tillage ridge blade shaft assembly

1- Cutter shaft；2-Ridge knife；3-Right curved knife；4-Left curved knife；5-Rotary plough knife seat；6-Ridge knife seat.

Fig. 6 - Physical picture of the rotary tillage ridge blade shaft

Design of rotary-plough knife and ridge-raising knife

The function of rotary tillage device is mainly to break the soil ploughing, so the curved blade with strong soil turning function is selected, and the blade is narrow. The curved blade is divided into left and right cutlass, the left and right scimitars are interleaved on the tool shaft. Install the shaft staggered to ensure the radial force balance of the knife shaft. The shape of the rotary ploughing blade and the installation on the blade shaft are shown in Figure 7. The ridge blade mainly piles the soil from the middle to the sides, so the knife body is wide and the blade mouth is slightly curved, in the shape of a fan blade. The arrangement of the ridge blade on the shaft should also balance the radial force of the shaft. The shape of the ridge blade and the mounting on the blade shaft are shown in Figure 8.

Fig. 7 - Spinning knife

Fig. 8 - Ridging knife

Optimization of the blade and its arrangement

In order to reduce the power consumption of rotary tillage ridge machine, this paper is based on the traditional national standard rotary tillage knife, the rotary plane and the forward direction of the unit are appropriately tilted at a certain angle, and the Archimedes spiral line is still used in the rotary tillage blade mouth. The test shows that the power consumption of oblique rotary knife is 8. 75% lower than that of national standard rotary knife.

The arrangement of rotary ridge blade determines the performance of rotary ridge machine. This paper adopts the double-head screw blade arrangement, and the number of knives meets the array 4n ± 2 = the total number of blades (*Mo Cankun, 2006; Sui Xiuxu, 2016*). There are 18 rotary ploughing knives and 24 ridge knives, of which n is the natural number.

The blades were arranged as shown in Figure 9. There are two spiral blades on the entire segment; the adjacent blades are 40, or 20 per turn. There was a machete buried in the ground; the peripheral angle between two adjacent blades is 180; the axial distance between two adjacent blades is 45 mm.

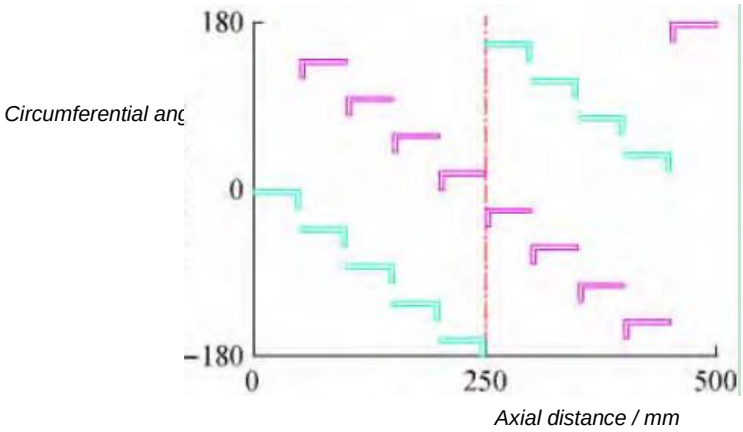

Fig. 9 - Blade layout

Transmission system design

The transmission mode is gear transmission. The transmission diagram of the rotary tillage machine is shown in Figure 10. The power is transmitted to the reducer gear of the rotary tillage machine through the PTO shaft, transmitted to the chain gear through the drive shaft, and then transmitted to the knife shaft by the chain shaft, which drives the rotary shaft to cut the soil and drives the ridge knife to ridge the soil block (*Xie Bin, 2016; Wang He, 2022*).

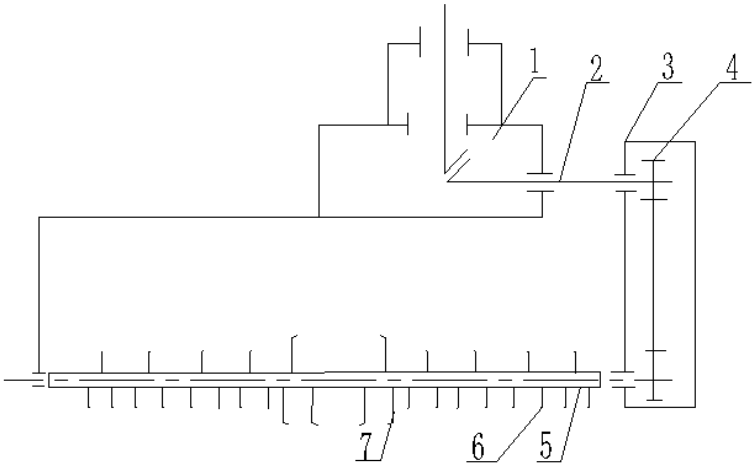

Fig. 10 - Transmission system diagram of rotary tillage ridge lifting machine

1- Decelerator; 2 - Transmission shaft; 3 - Chain box; 4 – Chain; 5 - Knife pivot; 6 -Spinning knife;7 - Ridge knife

According to the established optimization model of power consumption per unit volume, the range of n is 180 ~ 250 r/min, the standard speed of the transmission shaft is 540 r/min, and the transmission ratio from the drive shaft to the knife shaft is 2.25, where the gearbox transmission ratio i_1 = 1.5; the transmission ratio of the chain transmission i_2 = 1.5.

Field experiment and data analysis

Test site and equipment

The test field was dry land with deep soil layer, loose soil and medium fertility. The previous crop was corn planted on double ridges with whole film, and the experiment was conducted after the previous crop was cleared. The test area is 6 hectares (*Shu-yi wang, 2013; Wang Jianchao, 2011*). The Yellow Sea Jinma 354 tractor, which is matched with the prototype, was used for the test. The Yellow Sea Jinma 354 tractor has a power output of 25.7 kW.

Test instruments and equipment

Stopwatch, leather tape, steel tape, steel tape and post are used in the test, which can meet the test requirements.

Test time and place

The prototype was tested on January 20, 2022. The test site was conducted in the field of Baima Base, Nanjing City, Jiangsu Province, China. The test plot was flat with a length of 400 m and a width of 200 m. The soil quality was sandy loam, which could meet the test requirements.

RESULTS

Test items and test results

In order to understand and master whether the prototype can meet the design requirements and technical performance indexes, the stability of tillage depth, the qualified rate of ridge height and width, the qualified rate of ridge spacing, the shape of ridge, the thickness and width of soil cover and the working efficiency were tested. The results are shown in Table 2.

Table 2

Test result of miniature ridge mulcher

No.	Project	Agronomic and technical requirements	Determination results	Determinant
1	Deep tillage stability （%）	≥80	93	qualified
2	Ridge high pass rate （%）	≥75	100	qualified
3	Ridge width pass rate （%）	≥70	85	qualified
4	The qualified rate of ridge spacing （%）	≥75	95	qualified
5	The thickness of the membrane side cover （mm）	30-50	40	qualified
6	Working performance （hm^2/h）	0.802		
7	Fuel consumption per hectare （$kg \cdot hm^{-2}$）	9.02		
8	Fault situation	Three shift operation without fault	meet the requirement	qualified

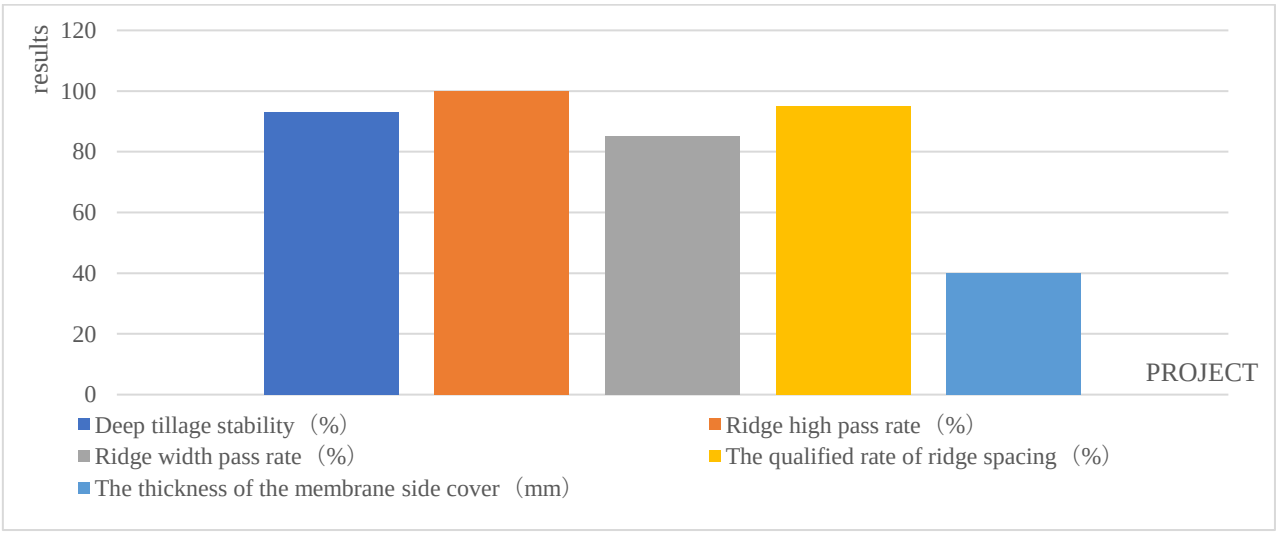

Fig. 11 – Graphical variation of the analysed parameters

Through the field test, the main performance index of this machine has reached the design requirements, and can meet the agronomic requirements of rotary tillage, ridging and film laying.

CONCLUSIONS

(1) The successful research of the hanging rotary tillage ridging and film laying machine provides an advanced, reliable and applicable model for the operation of rotary tillage ridging and film laying in the greenhouse environment. The model is reasonable in design, compact in structure, simple in operation and convenient in use, and can be matched with small and medium-sized four-wheel tractor. After rotating tillage and soil preparation, the machine carries out ridging and film laying in time according to soil moisture. It has the characteristics of high operation speed and good film laying quality. This machine can further improve the working efficiency, reduce the labour intensity and reduce the working cost, and has a good prospect of popularization and application.

(2) According to the above test results, the statistical calculation of the stability of rotating tillage depth, the width and height of ridges, the thickness and width of longitudinal soil cover, the qualified rate of ridge spacing, the thickness of film edge soil cover and the working efficiency can be obtained. The tillage depth stability is 93%, the ridge height qualified rate is 100%, the ridge width qualified rate is 85%, the ridge spacing qualified rate is 95%, the film edge covered soil thickness is 40 mm, the working efficiency is 0.802 hm^2/h, the fuel consumption per hectare is 9.02 $kg \cdot hm^{-2}$, and the three shifts work without fault. To sum up, it meets the agronomic requirements of ridging and film planting.

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