DESIGN AND TESTING OF A PRESS-GROOVE UNIFORM SEEDING MACHINE FOR WHEAT IN HIGH-MOISTURE RICE-STUBBLE FIELDS
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高湿地稻茬麦压沟定深匀播机设计与试验

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ABSTRACT
To address the low quality of mechanized wheat seeding in rice-stubble fields in the middle and lower reaches of the Yangtze River, caused by high soil moisture content and heavy straw coverage, a press-groove uniform seeding machine was designed. Key mechanisms for rotary tillage, precision seedbed preparation, depth-controlled furrow formation, and banded soil covering were developed, and the overall transmission system and blade-roller arrangement were designed to create a wheat seeder suitable for high-moisture rice-stubble fields. Field tests showed that the vegetation coverage rate after operation was 94.2%, the qualified rate of seeding depth was 98.0%, and the coefficient of variation of seeding uniformity was 18.1%. The machine effectively reduced seed skips and exposed seeds during mechanized seeding in high-moisture fields.

摘要
针对长江中下游水旱轮作区稻茬农田土壤含水率高，秸秆覆盖量大等导致小麦机械化播种质量低的问题，本文设计一种压沟匀播机，研发了旋耕、种床精整、定深种沟成型、带状覆土等关键机构，完成了整机传动、刀辊排列等设计，创制一种适用于高湿稻茬农田的小麦播种机，田间试验表明，机具作业植被覆盖率为 94.2%，播深合格率达 98%，播种均匀性变异系数为 18.1%，有效解决了湿烂田机械化播种的"漏播""露籽"等问题。

INTRODUCTION
The rice-wheat cropping system is the predominant agricultural production system in the paddy-upland rotation regions of the middle and lower reaches of the Yangtze River in China and represents the principal cropping pattern for these two staple grain crops in Jiangsu Province. With an annual planting area of approximately 2.7 million ha, Jiangsu accounts for about 35% of the national rice–wheat rotation area, making it the largest rice-wheat double-cropping region in China (*Gao, 2023; Zhang et al., 2021*). As of 2024, Jiangsu Province had more than 90,000 family farms engaged in grain production, with an average operating area exceeding 170 ha per farm. The continuing expansion of production scale has increased the demand for mechanized field operations, creating a need for further improvements in both the quality and technological level of agricultural mechanization (*Guan et al., 2022; Zhang et al., 2023*).

Because of the abundant seasonal rainfall during the wheat planting period, the soil is often heavy and cloddy, with large amounts of crop residue remaining on the field surface. Existing methods, such as shallow rotary tillage seeding and no-till strip seeding in residue-free fields, are poorly suited to these high-moisture operating conditions. Consequently, the uniformity of seeding depth and seed distribution during mechanized wheat seeding in rice-stubble fields often fails to meet agronomic requirements. Problems such as exposed seeds, seed clustering, seedling gaps, and broken ridges are particularly severe (*Chen et al., 2022*). To ensure an adequate field seed population, the seeding rate must be increased by two- to threefold, substantially increasing production costs (*Sun et al., 2024*). In addition, tractor traffic leaves deep wheel ruts, causing considerable disturbance to the field surface. The resulting seedbed is markedly uneven, which adversely affects subsequent rotary tillage and seeding operations.

Because of differences in cropping systems among countries, research on wheat seeding machinery for rice-stubble fields has been more extensive in China, whereas relatively few similar studies have been reported elsewhere. The main research objectives have been to reduce operating power consumption and improve seeding quality (*Aladdin et al., 2021*).

To address poor operating quality and low efficiency caused by soil adhesion and blockage of the rotary tiller during tillage in rice-stubble fields, *Liu Guoyang et al.* established constitutive and contact models for rice-stubble soil, investigated the soil detachment behavior from rotary tiller components, designed an anti-adhesion rotary tiller, and developed an intelligent vibration-assisted anti-adhesion rotary tiller (*Liu, 2024*).

Li Hongwen et al. designed a wide-width precision reduced-rate seeder for rice-stubble fields based on drainage and seeding requirements. The qualified rate of seeding depth was 86.7%, and that of fertilizer placement depth was 93.3% (*Hong Hu, et al., 2016*). To reduce power consumption during tillage, *Hao Jianjun et al.* designed a wedge-shaped drag-reducing rotary tiller. The results showed that, compared with a rotary tiller conforming to the national standard, the new machine was 8.3% lighter and reduced operating power consumption by 9.29% (*Hao Jianjun, et al., 2019*).

Matin et al. addressed the problem of poor seeding quality in paddy-upland rotation areas of Southeast Asia by designing a blade-roller structure equipped with a single row of six rotary tillage blades. Field tests showed that the new blade roller significantly improved seeding quality (*Matin M.A. et al., 2021*). Behera et al. compared the field performance of a rotary tiller and a combined tillage machine. The results showed that the torque requirement of the rotary tiller was 28% higher than that of the combined tillage machine, whereas its draft resistance and total power consumption were lower (*Behera et al., 2021*).

To address problems such as inconsistent seeding depth and poor seeding uniformity in wheat seeding in rice-stubble fields, the present study investigated a press-groove, depth-controlled uniform seeding technology for wheat in high-moisture rice-stubble fields. The proposed technology integrates rotary tillage and seeding, seedbed preparation under high-moisture conditions, and seeding-depth control. It is intended to improve seeding quality, reduce production costs, enhance operating efficiency and crop yield, and support high-quality, efficient, environmentally sustainable wheat production.

MATERIALS AND METHODS

Overall Design of the Seeding Machine

To meet the requirements for wheat seeding in high-moisture rice-stubble fields, the machine developed in this study integrates seedbed preparation and seeding-depth control functions. The corresponding mechanisms are arranged sequentially according to the operating process of fertilization, seedbed preparation (primary and secondary tillage), seed-furrow formation, in-furrow seeding, and banded soil covering. The machine consists of front and rear sections (Fig.1). The primary tillage unit, seedbed preparation unit, rear depth-control press wheel, and banded soil-covering shaft all use side-drive transmission. The two sections are connected by a three-point hitch, and power is introduced through the intermediate gearbox of the front section. The fertilizer-metering shaft and seed-metering shaft are both motor-driven and controlled by a synchronous control system to improve the field uniformity of seeding and fertilization.

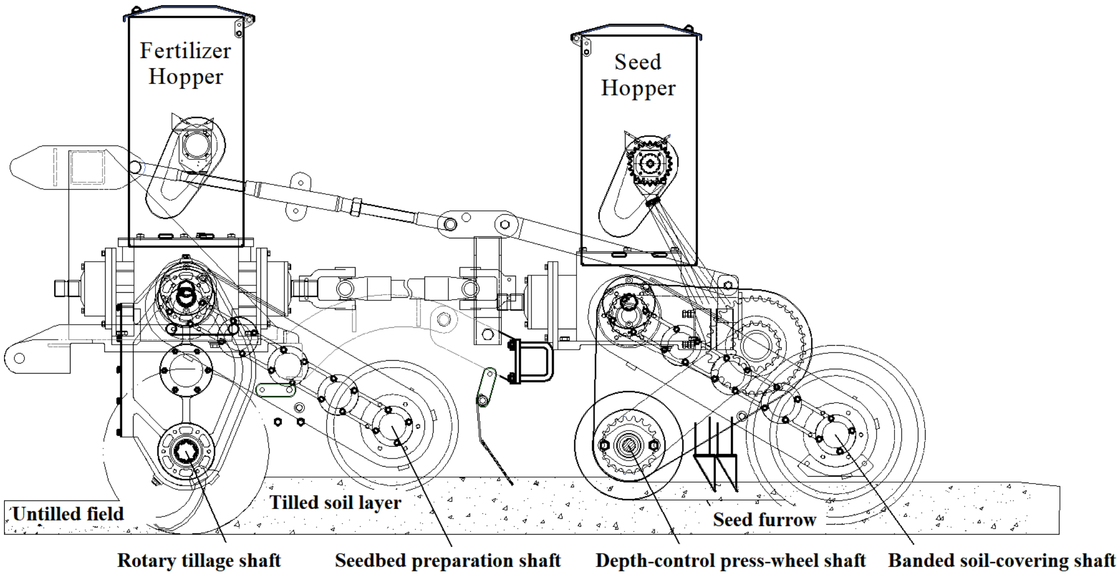
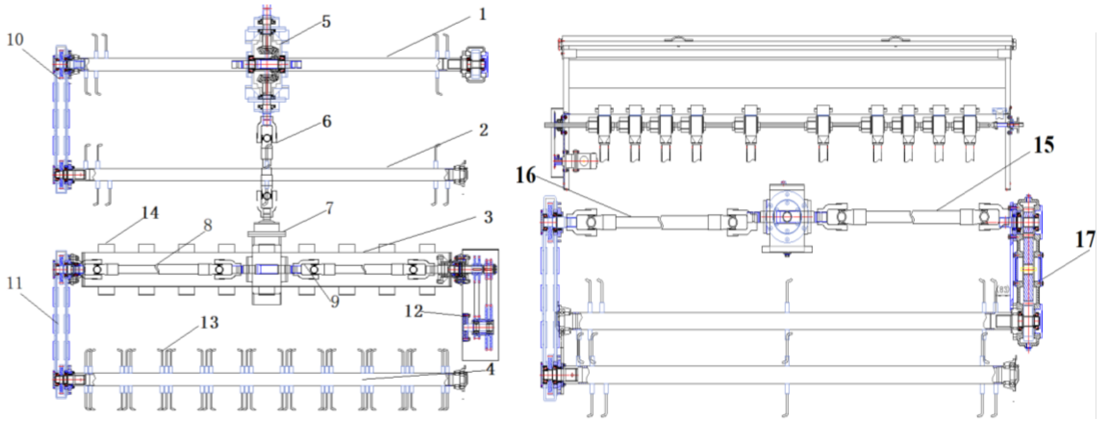


Fig. 1 - Overall schematic design of the seeding machine

The seeder is equipped with four working shafts and therefore has a relatively complex transmission system. Figures 2(a) and 2(b) show the top and front views, respectively, of the overall transmission layout. The transmission process is as follows. The tractor PTO is connected to intermediate gearbox *5*. Power is transmitted through universal-joint drive shaft *15* to side gearbox *17* and then to rotary tillage shaft *1*. Power is also transmitted through universal-joint drive shaft *16* to side gearbox *10* and then to seedbed-finishing shaft *2*. Meanwhile, intermediate gearbox *5* transmits power through universal drive shaft *6* to gearbox *7*, which distributes power to the seed-furrow-forming shaft and gearbox *11*. Gearbox *11* then drives soil-covering shaft *4* to complete the soil-covering operation. The transmission schematic is shown in Fig. 4.

Transmission System Design



(a) top view **(b) front view**

Fig. 2 - Transmission system of the seeding machine

1 - Rotary tillage shaft; 2 - Seedbed preparation shaft; 3 - Depth-control press-wheel shaft; 4 - Banded soil-covering shaft; 5 - Intermediate gearbox; 6 - Universal-joint drive shaft; 7 - Intermediate gearbox; 8 - Universal-joint drive shaft; 9 - Universal-joint drive shaft; 10 - Side gearbox; 11 - Side gearbox; 12 - Side gearbox; 13 - Soil-covering rotary tillage blades; 14 - Depth-control press-wheel; 15 - Right universal joint transmission shaft; 16 - Left universal joint transmission shaft; 17 - Side gearbox

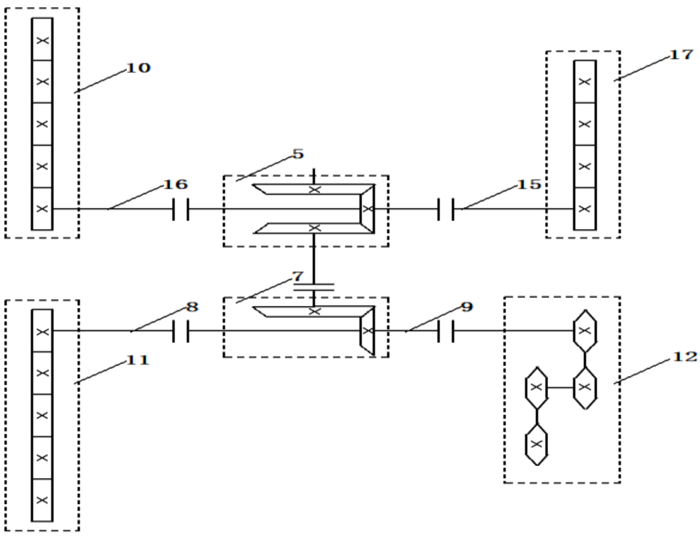


Fig. 3 - Schematic diagram of the transmission mechanism

The rotational speed of the blade shaft was determined using Eq. (1), which accounts for the machine forward speed, blade-shaft rotational speed, and soil-cutting pitch. Because rotary tillage requires a relatively high degree of soil fragmentation, the soil-cutting pitch should not be excessively large; a range of 60–90 mm was considered appropriate.

$$\frac{60V_m}{ZS_{max}} \leq n \leq \frac{60V_m}{ZS_{min}} \tag{1}$$

where: n is the blade-shaft rotational speed, rpm; V_m is the forward speed, m/s; Z is the number of cutting edges. The cutting pitch S was set to 80mm, the forward speed V_m to 1.3m/s, and Z to 2. Based on these values, the rotational speed of the rotary tillage shaft was determined to be 295 rpm, while that of the seedbed preparation shaft was 350 rpm.

Design of key working components

Rotary tiller shaft

The rotary tillage shaft is the main soil-engaging component during tillage and is also a major source of power consumption for the entire machine. Its design should account for force balance, reduced soil blockage, and minimized repeated cutting. In this study, the blades on the rotary tillage shaft were arranged primarily in a helical pattern to ensure balanced loading on both sides. The shaft had a total length of 2304 mm and was equipped with 72 blades, comprising left- and right-curved blades. Two blades were mounted on each cutting plane. The specific arrangement is shown in Fig. 5.

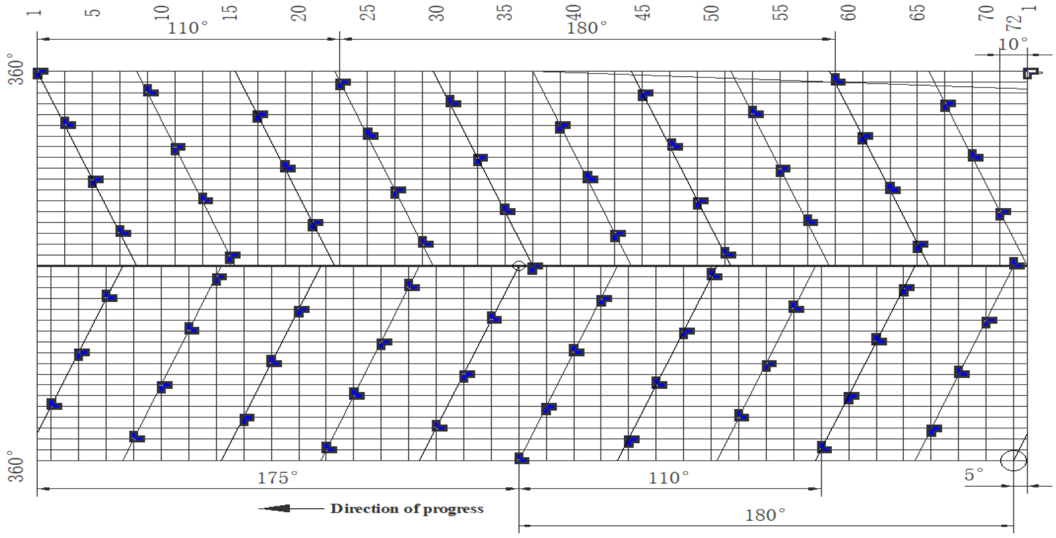


Fig. 4 - Blade arrangement on the rotary tillage shaft

Seedbed preparation shaft

The seedbed soil should be finely tilled and leveled before seeding to facilitate the seeding operation and improve seeding quality. The seedbed preparation shaft is a key component for seedbed preparation. In this study, a high rotational speed and a small rotation radius were adopted based on commonly used blade configurations. The blade rotation radius was set to 175 mm, and the blades were arranged primarily in a helical pattern. The shaft had a total length of 2310 mm and was equipped with 60 blades, comprising left- and right-curved blades. Two blades were mounted on each cutting plane. The specific blade arrangement is shown in Fig. 5.

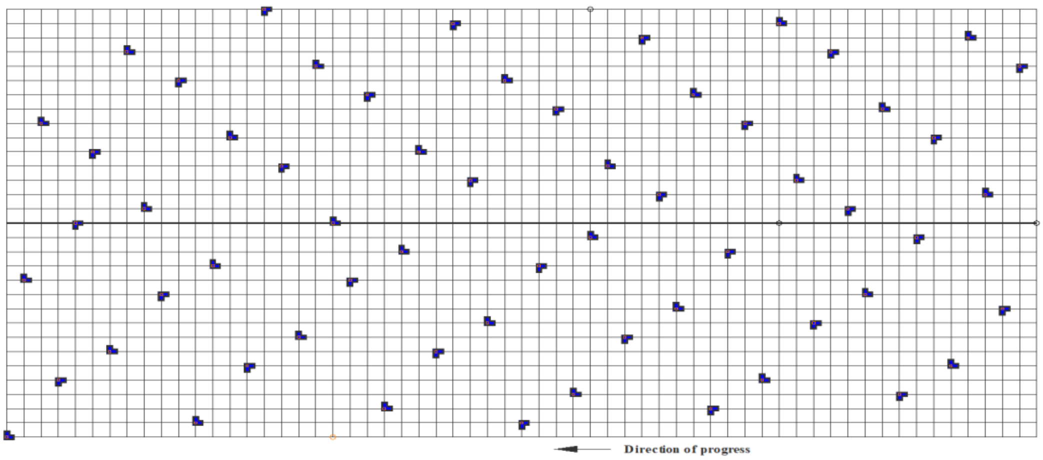


Fig. 5 - Blade arrangement on the seedbed preparation shaft

Depth-limiting press wheel shaft

Seed depth control was one of the technical difficulties in the sowing operation of high-land paddy fields with stubble. This paper aimed to improve the consistency of seed depth and reduce the "exposed seeds" phenomenon. A seed depth forming roller for sowing furrows had been designed. The width of the forming device could be determined according to the width of the seed band, as shown in Figure 6.

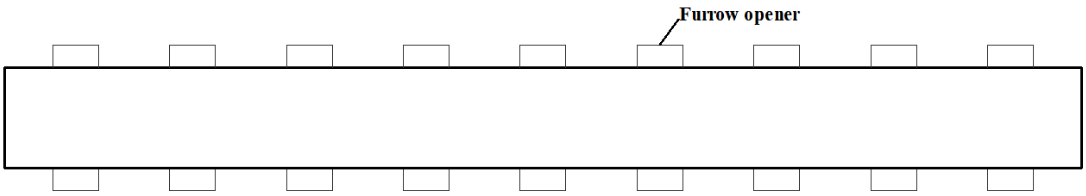


Fig. 6 - Schematic design of the depth-control press-wheel shaft

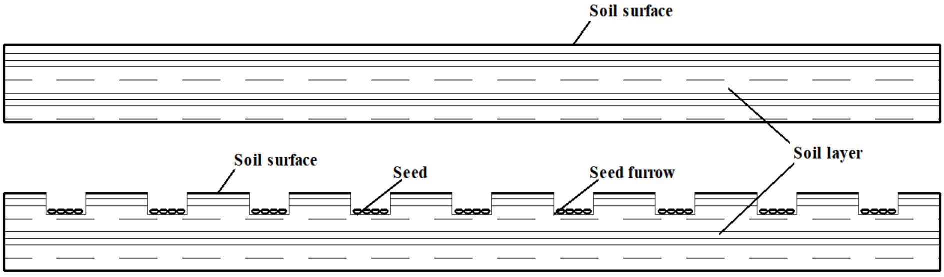


Fig. 7 - Schematic of the seeding operation

Banded soil-covering shaft

Determining the seeding depth is the first step in controlling seed placement depth, while the second step is to achieve a controlled amount of soil covering. Based on the principle of rotary soil covering, a banded soil-covering mechanism was designed, as shown in Fig. 8. The banded soil-covering shaft had a total length of 2304 mm. Nine soil-covering units were arranged in a helical pattern, with six rotary tillage blades in each unit, including four blades at each end, as shown in Fig. 9.

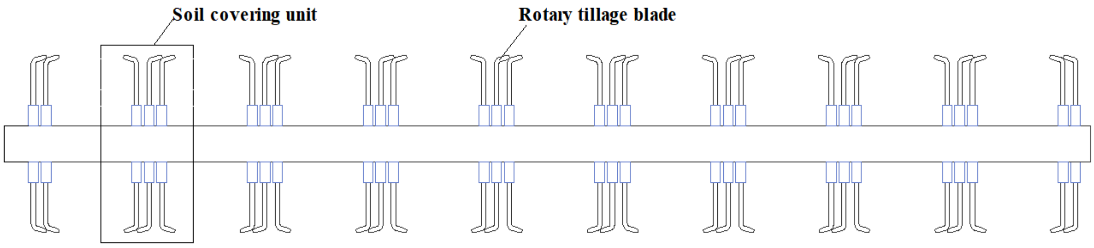


Fig. 8 - Soil-covering unit and rotary tillage blade

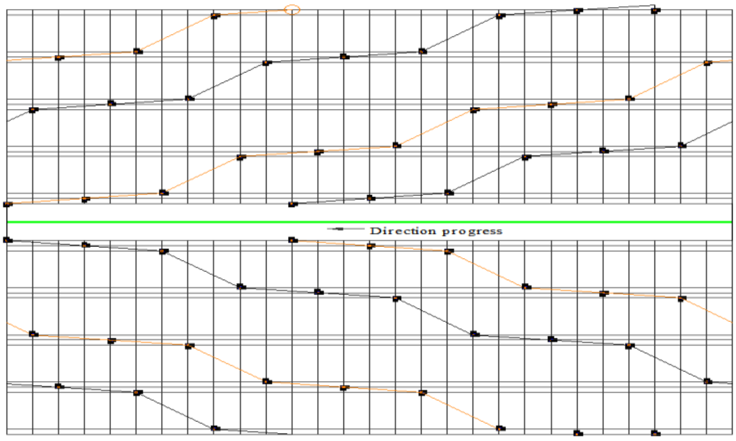


Fig. 9 - Blade arrangement on the banded soil-covering shaft

Experiment and results analysis

Experimental conditions

In October 2024, field tests of the rotary tillage, fertilization, furrow-pressing, and wide-row seeding machine for high-moisture rice-stubble fields were conducted at the Sihong Modern Agricultural Park in Shiji Town, Sihong County, Jiangsu Province. The wheat cultivar used in the tests was ‘Xumai 45’, with a thousand-grain weight of 46.1 g and a bulk density of 803 g/L.

The experimental field was 100 m long and 50 m wide. The rice row spacing was 14 cm, and the stubble height was 22.1 cm. The operating speed was set to 1.3 m/s, and a CFJ2004 tractor was used. The measured soil properties are presented in Table 1, and the field seeding test is shown in Fig. 10. The main instruments used in the tests included a soil moisture meter, soil firmness meter, stopwatch, and measuring tape.

Table 1

Soil properties

Soil depth [cm]	Moisture content	Bulk density [g/cm^3]	Soil firmness [MPa]
0 ~ 10	31.2%	1.08	0.59
10 ~ 20	25.3%	1.32	1.68
20 ~ 30	20.5%	1.57	2.48

Fig. 10 - Field seeding operation

Evaluation indicators and methods

To evaluate the operating quality of the machine under high-moisture field conditions, the qualified rate of seeding depth, seeding uniformity, and vegetation coverage rate were selected as the main performance indicators. The specific evaluation methods were as follows.

Vegetation coverage rate

A large amount of straw residue remained on the field surface, which can adversely affect seeding quality and subsequent seedling emergence. Therefore, the vegetation coverage rate was evaluated. The test method followed the national standard GB/T 5668-2017, *Rotary Tiller*. Before and after operation, five sampling points were selected along the diagonal of the test area. At each sampling point, all stubble and straw lying on the soil surface within a 1 m² area were collected and weighed. The mean values before and after operation were then calculated (*Aqsiq et al., 2018*). The vegetation coverage rate was calculated using Eq. (2):

$$F_b=\frac{W_q\text{-}W_h}{W_q}\times 100 \tag{2}$$

where: F_b is the vegetation coverage rate, [%]; W_q is the mean mass of vegetation before operation, [g]; W_h is the mean mass of vegetation after operation, [g].

Qualified rate of seeding depth

According to the agricultural machinery evaluation guideline DG/T 027-2024, *Rotary Tiller and Seeder*, five test plots were selected in advance within three operating cycles. Thirty measurement points were established in each plot. After seeding and soil covering, the covering soil was carefully removed, and the thickness of the soil layer above the seeds was measured.

The proportion of measurement points with a seeding depth within (h ± 0.5) cm, where *h* is the locally specified agronomic seeding depth, was calculated as the qualified rate of seeding depth (*Agricultural Mechanization Station, 2024*).

Seeding uniformity

According to the agricultural machinery evaluation guideline DG/T 027-2024, the seeding operation was simulated in an open field at the specified operating speed. Seeds were deposited on a horizontal, straw-free surface. Three test plots were selected in advance. In each plot, six rows were measured, and 10 consecutive measurement sections were selected from each row. The coefficient of variation of seeding uniformity was calculated using Eqs. (3)–(6) (*Agricultural Mechanization Station, 2024*).

$$D = \sum_{i=1}^{3} D_i \tag{3}$$

$$X = \frac{1}{3}\sum_{i=1}^{3} X_i \tag{4}$$

$$G = \sqrt{\frac{1}{D}\sum(x - X)^2} \tag{5}$$

$$V = \frac{G}{X} \times 100\% \tag{6}$$

where:

D is the total number of measurement sections; D_i is the number of measurement sections in each test plot; X is the overall mean number of seeds per section; X_i is the mean number of seeds per section in each test plot; x is the number of seeds in an individual measurement section; G is the overall standard deviation; n is the number of measured rows; V is the coefficient of variation of seeding uniformity.

RESULTS AND ANALYSIS

Straw residue removal rate

Table 2

Straw residue mass before and after seeding

Pre-seeding residue mass		Post-seeding residue mass	
Measurement point	**Residue mass [g/m²]**	**Measurement point**	**Residue mass [g/m²]**
1	330.3	1	28.3
2	413.2	2	18.5
3	351.5	3	17.6
4	345.6	4	20.3
5	326.3	5	18.6
Mean	353.4	**Mean**	20.7
Residue removal rate [%]	94.2		

As shown in Table 2, the mean surface residue mass decreased from 353.4 g/m^2 before seeding to 20.7 g/m^2 after seeding, corresponding to a residue removal rate of 94.2%. This substantial reduction in surface residue provided favorable conditions for subsequent seed placement and seedling emergence.

Seeding depth

Table 3

Qualified rate of seeding depth

Indicator	Value
Total number of measurement points	150
Number of qualified points	147
Qualified rate of seeding depth [%]	98

As shown in Table 3, a total of 150 measurement points were evaluated, of which 147 met the specified seeding-depth requirement, resulting in a qualified rate of 98.0%. These results indicate that the machine achieved a high degree of seeding-depth consistency in high-moisture rice-stubble fields.

Seeding uniformity

Table 4

Seeding uniformity indicators

Indicator	Value
D	900
D_0	0
A	0
X	10.6
S	1.91
V [%]	18.1

As shown in Table 4, no empty measurement sections occurred during the seeding operation. The mean number of seeds per section was 10.6, with a standard deviation of 1.91. The coefficient of variation of seeding uniformity was 18.1%, indicating that the seeding performance remained within the acceptable range. The relatively high coefficient of variation may be attributed to the soft and slippery field surface, which could have affected machine travel stability and, consequently, seed distribution.

CONCLUSIONS

Based on the characteristics of the rice-wheat rotation system in the middle and lower reaches of the Yangtze River and the difficulty of controlling seeding depth in high-moisture fields, the following conclusions were drawn:

(1) A press-groove uniform seeding machine was designed, incorporating key mechanisms for seedbed preparation and precise seeding-depth control. The machine was developed to reduce seed skips and exposed seeds during mechanized wheat seeding in high-moisture rice-stubble fields.

(2) The machine incorporated a rotary tillage shaft with a helical blade arrangement, a seedbed preparation shaft, and a banded soil-covering shaft. The overall transmission system was designed and integrated into a complete seeding machine suitable for high-moisture rice-stubble fields. Field tests showed a straw residue removal rate of 94.2%.

(3) Compared with similar machines, it significantly improved the sowing quality. A depth-controlled furrow-pressing seeding method was developed. Field tests showed that the qualified rate of seeding depth reached 98.0%, while the coefficient of variation of seeding uniformity was 18.1%, indicating good seeding-depth consistency and acceptable seeding uniformity under the tested field conditions.

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