Research Progress and Prospect of Mechanized Harvesting Technology in the First Season of Ratoon Rice

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Abstract: The first seasonal harvest technology of ratoon rice requires the least rolling with suitable stubble height required by agronomy when the ratoon rice is nearly mature. Mechanized harvesting in the first season of ratoon rice needs to finish harvesting, threshing, cleaning, straw treatment, grain transportation, grain collection and other processes at one time with a low rolling rate and low rolling degree. Limited by the production conditions such as wet and soft fields, and wet, thick and strong straw, harvest technology with high efficiency and a low rolling rate of ratoon rice in the first season has become the key technology and research focus affecting the yield of ratoon rice. In this paper, we analyzed the planting and popularization of ratoon rice in China, summarized the planting mode and agronomic characteristics of ratoon rice, highlighted the research status of mechanized harvesting equipment for the first season of ratoon rice, especially the specialized harvesters, and illustrated in detail the technical characteristics and research trends of key segments such as chassis, header, and processes such as threshing and cleaning, and straw and stubble treatment of ratoon rice harvesters. In addition, we summarized the application status and value of lightweight technology, performance monitoring and fault diagnosis technology, grain quality detection technology and automatic navigation technology of mechanized harvest in the first season, explained the main problems and reasons affecting the development of ratoon rice harvest mechanization in China, and illustrated the prospect of its research focus and tendency.

Keywords: ratoon rice; harvester; rolling rate; rolling degree; stubble height

1. Introduction

Ratoon rice refers to the production of a second rice crop in one cropping season developed from regenerating rice tillers from nodal buds of the stubble that was left behind after the first seasonal rice harvest. It can make full use of temperature and light resources, as well as save labor and seed. In addition, with high quality, the ratoon rice can help to increase both production and income, which is of great significance to improve China’s total grain output and ensure national food security [1,2].

Ratoon rice is planted in many parts of the world, mainly in eastern and southern Asia, some countries in Africa, the southern United States and Latin America [3,4]. Among them, ratoon rice is planted in large areas in the Texas rice planting area and the Gulf Coast planting areas in the United States, as well as in India and Japan. Thailand, the Philippines, Brazil, and other places own large total planting areas of ratoon rice, but the field scale is small.
China has a long history of ratoon rice planting, which began in the Western Jin Dynasty. After the Qing Dynasty, it was planted in Sichuan, Jiangxi, Jiangsu, Anhui, Hubei, Zhejiang and the Yunnan-Guiuzhou region. During this period, the yield of ratoon rice was low. By 1960, the yield of ratoon rice was still no more than 900 kg/ha, so ratoon rice planting has not been acknowledged as a particular planting method. Therefore, it was only planted in a few areas as a remedial measure to deal with the food loss or production reduction after unexpectable disasters. With the improvement of rice cultivation and planting technology, the yield of ratoon rice increased slightly [5,6] by 1970, with the maximum yield of ratoon rice in some areas reaching 2250.9 kg/ha, which further expanded its planting area and scale. By 1980, agricultural workers began to explore the peculiar planting and cultivation mode of ratoon rice, and the yield was further improved up to 3750.9 kg/ha. The emergence and development of a special cultivation mode has promoted the rapid growth of ratoon rice planting area. By 1997, the plant area of ratoon rice in China had exceeded 5.19 × 10^5 ha, making China a country with the largest planting area in the world. In the 21st century, the planting area in Sichuan, Chongqing and Fujian in southern China reaches 3.3 × 10^6 ha. In the last ten years, ratoon rice has been rapidly popularized in Hubei, Hunan and Jiangxi, among which Hubei was the most rapid with a ratoon rice planting area of 2.1 × 10^5 ha.

In the National Planting Structure Adjustment Plan (2016–2020), the Ministry of Agriculture and Rural Affairs proposed to promote the development of ratoon rice in southwest China, the middle and lower reaches of the Yangtze River and south China according to local conditions. In addition, “high yield cultivation technology of ratoon rice”, “comprehensive cultivation technology of ratoon rice” and “high yield and efficiency cultivation technology of mechanized harvesting ratoon rice” were promoted as extension technologies in these areas from 2009 to 2010, 2015 to 2018, and 2017 to 2018. The corresponding research on the first season harvest technology and equipment of ratoon rice has become the focus of the research on the supporting technology of ratoon rice in recent years. These policy orientations have prompted many provinces in southern China to pay more attention to it, and the promotion area of ratoon rice has increased rapidly. The attention that different provinces paid to ratoon rice is shown in Figure 1.

![Figure 1. Attention paid to ratoon rice in different provinces in China.](image-url)

The first season of traditional ratoon rice harvest depends on manual work. With the continuous expansion of planting area, the contradiction between labor shortage and the excessive production scale is becoming more and more serious. In order to improve the yield in the first season, the advantage of manual harvesting in the first season is obvious with nearly no rolling, contributing to little negative impact on the ratoon season. Manual harvest requires many labor resources. However, farmers nowadays have little enthusiasm in planting ratoon rice with more agricultural population transferring to big cities. Therefore, machinery harvest is a megatrend in ratoon rice harvesting.
In order to promote the germination of ear head in the ratoon season, the stubble must be kept appropriately high during mechanized harvest in the first season, and ensure low rolling rate and light rolling degree. Existing common harvesters usually lead to large rolling and damage areas, resulting in production reduction in the ratoon season, and further lowering the economic benefits of ratoon rice production. The above contradictions limit the further promotion of the planting scale of ratoon rice.

2. Harvest Pattern of Ratoon Rice in the First Season

In order to improve the annual yield of ratoon rice, it is necessary to have high yield in the first season and full heading in the second season. The yield in the first season is mainly determined by rice varieties, production conditions (light, temperature, water, fertilizer, etc.) and cultivation management measures, while the yield in the second season is determined by the harvest, growth conditions and management measures in the first season.

The factors in the first season affecting the yield of ratoon rice in the second season include harvest time, stubble height, harvest method, etc., among which the harvest time has the greatest impact on the yield in both the first and second season. If the rice is harvested too early, the grains will not be ripe enough to offer normal yield; If the rice is harvested too late, the growth period of ratoon rice in the second season will be delayed into months without enough heat, resulting in irregular earing and low production in the second season. Generally, to harvest when 90% of the rice in the first season is ripe can guarantee not only the maximum yield but also the rapid germination of regenerative tillers [7,8].

The height of stubble is significantly correlated with the yield in the ratoon season. High stubble has more regenerated axillary buds and sufficient nutrition. Therefore, the regenerated tillers can germinate more quickly and the seed setting rate is higher in ratoon season. However, if the growth of ratoon rice is uneven and the ear head is small, the growth situation will be the opposite when the stubble is low. As shown in Figure 2, during the first harvest, we need to keep the second and the third regenerated axillary and allow the fourth regenerated axillary to come into ear with a protect stem of 50–60 mm [9,10]. At present, the stubble of first season mechanized harvested ratoon rice is generally 350–500 mm in the middle and lower reaches of the Yangtze River.

![Stubble height of rice plant after the first-season harvest.](image)

There are two modes of harvest in the first season of ratoon rice: manual harvest and mechanical harvest. Since the former has little damage to rice stubble, according to relevant studies, the yield of ratoon rice harvested by machine in the second season is 3.8–20.1% lower than that by manual harvest due to different types of combine harvesters and harvesting conditions. The main reason for the yield reduction is that the rice stubble in the rolling area is seriously damaged in the mechanical harvest, leading to less germination.
of regenerated tillers, resulting in a yield accounting for only 7.6–17.2% of the total yield in the ratoon season [11].

Based on the above agronomic studies, the agronomic requirements of mechanical harvest in the first season of ratoon rice can be summarized as follows:

1. Low rolling rate and slight rolling degree.

The yield in the second season can be directly increased by decreasing the rolling because of the adverse effect of rolling area on the germination of rice stubble. The degree of rolling by the moving parts of the harvesting machine also determines the germination effect of the rolling stubble pile. When the damage degree of the pile is slight, it can still grow out again, but the growth period will be longer.

2. High trafficability in wet and soft field.

The first harvest of ratoon rice is mostly in the middle and early ten days of August. Due to the hot and rainy weather and insufficient drying time, the field drainage is not free, resulting in serious silt, which requires high passing performance of the harvester chassis.


In the first season of ratoon rice, the best harvest time is when 90% of the grain is yellow. At this time, the stem is still green and the moisture content is high. Because of the strong regeneration ability of ratoon rice, the stem is relatively strong. Therefore, it is required that the harvesting, transporting, threshing, and cleaning performance should be good enough to deal with the large machine operation load and large chance of straw twining.

4. The straw needs to be smashed without covering the stubble excessively.

Generally, when the harvester works, it will discharge the rice straw, leaves and other miscellaneous residues into the field. If the straw is not smashed or scattered unevenly, it will remain in the upper part of the rice stubble. In the case of later rainfall, it is easy to cause the rice straw to rot and affect the germination of the regenerated ear head as shown in Figures 3 and 4. Therefore, the straw needs to be smashed during mechanical harvest in the first season and should not cover the stubble excessively.
3. Research Status of Mechanical Harvesting Equipment for Ratoon Rice in the First Season

Although ratoon rice is planted in many countries and regions around the world, China pays the highest attention to the specialized harvesting machinery for ratoon rice. The farmland in the United States has a large scale and high degree of mechanization. It has harvesters with large cutting width for operation with a low rolling rate. There is no special model for the first harvest of ratoon rice. In addition, the harvesters used in the United States have a too large cutting width and overall shape and a heavy weight, which is difficult to meet the first season harvest conditions and needs of ratoon rice in the middle and lower reaches of the Yangtze River. There is a mechanization level lag in India, Vietnam, Bangladesh and other south and Southeast Asian countries and some African countries, so the research on mechanical harvesting technology of ratoon rice has not been carried out.

3.1. Rolling Rate

During the operation of the harvester, the ratio of the rolling area of the walking parts to the harvesting area is called the rolling rate without considering the repeated rolling [12].

For the wheel harvester, if the front and rear wheels are equally spaced, the ratio of the sum of the width of the two front or rear wheels to the theoretical effective cutting width is called the straight rolling rate. If the front and rear wheels are not equally spaced, the ratio of the sum of the widths of the walking wheels to the theoretical effective cutting width is called the straight rolling ratio. When the wheel width is smaller than the row spacing of the ratoon rice, theoretically the row walking can be realized, so the rolling ratio is 0.

When the crawler harvester walks in a straight line, the ratio between the sum of the widths of the two crawlers and the theoretical effective cutting width is called the straight rolling rate (also without considering the situation of repeated rolling). As shown in Figure 5, in the case of full-width straight harvest, the straight rolling rate $\eta$ is:

$$\eta = \frac{2b}{Z} \times 100\%$$

- $b$: the track width, mm
- $L$: the track grounding length, mm
- $Z$: Z is cutting width, mm; $B$: track gauge, mm

Figure 5. Structure model of track harvester. Note: $Z$ is cutting width, mm; $B$ is track gauge, mm; $b$ is the track width, mm; $L$ is track grounding length, mm.
The rolling degree of the harvester on the rice stubble can be explained by the grounding specific pressure. The smaller the grounding pressure is, the lighter the rolling degree of the harvester to the rice stubble and the better the trafficability in the wet and soft paddy field environment will be, which makes it less liable for the harvester to get stuck. The greater the grounding specific pressure is, the more serious the damage of the crawler to the axillary bud will be. Therefore, to lighten the weight of the whole machine is an important research direction for the development of the first season harvester of ratoon rice.

3.2. Common Harvesters

At present, there are a small number of media reports in China on the first season harvester of ratoon rice, which is mainly a simple improvement or simple prototype of the traditional harvester, and there is no mature product directly used for large-scale production of actual harvest. In recent years, the mechanization level of rice in the whole process has improved rapidly in China. In order to increase production in the second season, many farmers with a small planting area still harvest manually. In some areas, miniature paddy wheel rice harvesters are used for harvesting, resulting in low production efficiency and high labor intensity.

As shown in Figure 6, the Tiejia 4LZ-0.3 miniature paddy wheel harvester can be used for harvesting in the first season of ratoon rice. Its walking wheel has a diameter of 330 mm and a width of 100 mm, which can walk between rows without damaging rice piles. However, it is difficult to walk and inefficient in wet and soft fields with deep mud feet, and it can only harvest about one mu of land in one hour.

Table 1 shows the main structural parameters of conventional crawler harvesters used by many agricultural cooperatives in China. It can be seen that the straight rolling rate of these harvesters is more than 40%, while that of some models are even as high as 53.40%. However, the contribution rate of these rolling rows to the yield of ratoon season is only 7.6–17.2%, indicating that the existing common harvesters had a serious impact on the yield of ratoon season. Existing ratoon rice planting is mostly by cooperatives and farmers with large planting area, and the first harvest needs to be completed within about a week in the middle of August, so the conventional caterpillar harvester is often used. Although there is more rolling, it has become a forced choice.

Table 1. Structural parameters of several common harvesters.

<table>
<thead>
<tr>
<th>Type</th>
<th>Gauge (mm)</th>
<th>Cutting Width (mm)</th>
<th>Min. Track Length (mm)</th>
<th>Min. Track Clearance (mm)</th>
<th>Min. Track Grounding Weight (kg)</th>
<th>Straigh Rolling Rate (%)</th>
<th>Grounding Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yanmar</td>
<td>300</td>
<td>330</td>
<td>1000</td>
<td>50</td>
<td>300</td>
<td>4.0</td>
<td>53.40</td>
</tr>
<tr>
<td>Kubota</td>
<td>230</td>
<td>300</td>
<td>1500</td>
<td>50</td>
<td>200</td>
<td>4.5</td>
<td>53.40</td>
</tr>
<tr>
<td>Tiejia 4LZ-4.0Z</td>
<td>200</td>
<td>300</td>
<td>1650</td>
<td>50</td>
<td>100</td>
<td>4.0</td>
<td>45.00</td>
</tr>
<tr>
<td>Tiejia 4LZ-4.0E</td>
<td>200</td>
<td>300</td>
<td>1650</td>
<td>50</td>
<td>100</td>
<td>4.0</td>
<td>45.00</td>
</tr>
<tr>
<td>Tiejia 4LZ-4.0B</td>
<td>210</td>
<td>300</td>
<td>1650</td>
<td>50</td>
<td>100</td>
<td>4.0</td>
<td>42.86</td>
</tr>
<tr>
<td>Liulin</td>
<td>200</td>
<td>300</td>
<td>1650</td>
<td>50</td>
<td>100</td>
<td>4.0</td>
<td>45.00</td>
</tr>
</tbody>
</table>
Table 1. Structural parameters of several common harvesters.

<table>
<thead>
<tr>
<th>Type</th>
<th>Feeding Rate/ (kg/s)</th>
<th>Cutting Width/ mm</th>
<th>Track Gauge/ mm</th>
<th>Track Grounding Length/mm</th>
<th>Track Width/ mm</th>
<th>Minimum Ground Clearance/mm</th>
<th>Vehicle Weight/ kg</th>
<th>Straight Rolling Rate/%</th>
<th>Grounding Pressure/ kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liulin 4LZ-4.0B</td>
<td>4.0</td>
<td>2100</td>
<td>1150</td>
<td>1650</td>
<td>450</td>
<td>350</td>
<td>3280</td>
<td>42.86</td>
<td>22.09</td>
</tr>
<tr>
<td>Kubota PRO988Q</td>
<td>4.0</td>
<td>2300</td>
<td>1350</td>
<td>1890</td>
<td>500</td>
<td>290</td>
<td>3670</td>
<td>43.48</td>
<td>19.42</td>
</tr>
<tr>
<td>WORLD 4LZ-4.0E</td>
<td>4.0</td>
<td>2000</td>
<td>1150</td>
<td>1650</td>
<td>450</td>
<td>320</td>
<td>3000</td>
<td>45.00</td>
<td>20.20</td>
</tr>
<tr>
<td>Donghe 4LZ-4.0Z</td>
<td>4.0</td>
<td>2000</td>
<td>1150</td>
<td>1650</td>
<td>450</td>
<td>345</td>
<td>3170</td>
<td>45.00</td>
<td>21.35</td>
</tr>
<tr>
<td>Yanmar 4LZ-4.5A</td>
<td>4.5</td>
<td>2060</td>
<td>1215</td>
<td>1885</td>
<td>550</td>
<td>350</td>
<td>4030</td>
<td>53.40</td>
<td>19.10</td>
</tr>
<tr>
<td>Zoomlion PL60</td>
<td>6.0</td>
<td>2100</td>
<td>1150</td>
<td>1650</td>
<td>450</td>
<td>315</td>
<td>3310</td>
<td>42.86</td>
<td>22.29</td>
</tr>
</tbody>
</table>

The rolling rate and degree are the main performance indexes to evaluate the mechanized harvesting effect of ratoon rice in the first season. Through the description of the definition and calculation method of the rolling rate, it can be seen that the cutting width, the width of chassis grounding parts, gauge, grounding length and other structural parameters are the main factors affecting the rolling rate, and the weight reduction of the machine is the main solution to reduce the rolling degree.

3.3. Specialized Harvester for the First Season of Ratoon Rice

Widening the header and narrowing the support are the main technical scheme of developing the harvester for the first season of ratoon rice.

Increasing cutting width is one of the most direct methods to reduce rolling rate. After increasing the cutting width, the turning times of the same field and the straight rolling area will decrease, thus the total rolling rate is reduced. However, if the header is simply widened, it is difficult to control the speed during harvest to ensure smooth threshing and cleaning function, which make it easy to cause “indigestion”. If the threshing and cleaning device is optimized directly on the basis of increasing the cutting width, it is inevitable to increase the structure parameters and the load and weight of the whole machine, aggravating the degree of rolling. In addition, after increasing the cutting width, the volume of the grain bin should be increased to avoid new rolling area caused by repeated rolling during frequent grain unloading.

It is also an effective technical scheme to adopt a narrow wheel walking chassis or narrow crawler chassis with light working parts. Theoretically, zero rolling can be achieved when the narrow wheel chassis can walk exactly along the row when harvesting, but the grounding ratio of the narrow wheel support is large, which will easily cause vehicle sinking. When the working parts are light, the size will be small and the feeding amount will also be small, leading to low harvesting efficiency.

In recent years, many universities and scientific research institutes in China have developed wheel type, crawler type, backpack type, self-propelled and other forms of specialized harvesters for the first season harvest of ratoon rice, as shown in Table 2 [13–19].
<table>
<thead>
<tr>
<th>R&amp;D Unit</th>
<th>Type</th>
<th>Structure and Effect</th>
<th>Structure Features and Main Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huazhong Agricultural University</td>
<td>Grain header</td>
<td>Harvest the ear head only; Transplanter chassis; No rolling walking in the row; Cutting width 1600 mm; Wheel width 90 mm; Working speed 0.37–0.69 m/s; Walking power 9.5 kW; Working power 6.3 kW; Feeding rate 1.8 kg/s; Productivity 3.6 mu/h.</td>
<td></td>
</tr>
<tr>
<td>Huazhong Agricultural University</td>
<td>Light high clearance wheel harvester</td>
<td>Transplanter chassis; No rolling walking in the row; Cutting width 1600 mm; Wheel width 90 mm; Working speed 0.35 m/s; Walking power 9.5 kW; Working power 20.1 kW; Feeding rate 1.4 kg/s; Productivity 2.2 mu/h.</td>
<td></td>
</tr>
<tr>
<td>Huazhong Agricultural University</td>
<td>Track harvester with double headers double threshing cylinders</td>
<td>Crawler chassis; Rolling rate 28%; 1 walking chassis; 2 sets of headers; 2 sets of thresher and cleaning devices; peg-tooth transverse axial flow drum; pneumatic cleaning; Cutting width 2550 mm; Working speed 0.24 m/s; Walking power 13.2 kW; Working power 20 kW; Feeding rate 1.6 kg/s; Productivity 2.0 mu/h; Rolling rate 27.5%.</td>
<td></td>
</tr>
<tr>
<td>Huazhong Agricultural University</td>
<td>4LZ-4.0-type double-channel feeding harvester</td>
<td>1 crawler chassis; 1 double-channel header; 2 sets of symmetrically arranged thresher and cleaning devices and smashing and scattering devices; 1 grain bin; Cutting width 3000 mm; Gauge of the chassis 1500 mm; Track grounding length 1800 mm; Track width 400 mm; Working speed 0.8 m/s; Feeding rate 4.0 kg/s; Productivity 2.0 mu/h; Rolling rate 26.7%.</td>
<td></td>
</tr>
<tr>
<td>South China Agricultural University</td>
<td>Wheel-type harvester</td>
<td>High clearance 4WD Chassis; 125 mm solid narrow wheel for paddy field; Ground clearance 600 mm; Cutting width 2100 mm; Working speed 0.53 m/s; Power 36.8 kW; Feeding rate 2.0 kg/s; Productivity 2.0 mu/h.</td>
<td></td>
</tr>
<tr>
<td>South China Agricultural University</td>
<td>Triangular crawler harvester</td>
<td>Triangular crawler; Track width 280 mm; Wheel track 1500 mm; Wheelbase 1800 mm; Track grounding length 800 mm; Minimum ground clearance 600 mm; Working speed 0–4.5 m/s; Power 74.5 kW; Feeding rate 4.0 kg/s; Productivity 4.0 mu/h; Rolling rate 31.7%.</td>
<td></td>
</tr>
<tr>
<td>Jiangsu University</td>
<td>4LZ-5.0-type combine harvester</td>
<td>Crawler chassis; Cutting width 2800 mm; Track width 300 mm; Feeding rate 5.0 kg/s; Productivity 2.0 mu/h; Rolling rate 26.9%.</td>
<td></td>
</tr>
</tbody>
</table>
The machines developed by Huazhong Agricultural University have various forms, covering almost all harvester models. The structure of the double-channel full feeding ratoon rice harvester is relatively novel, which adopts a chassis carrying two sets of working parts to increase the cutting width and the feeding amount. Its double channel header can divert the materials entering the header, shorten the straw conveying distance and reduce the blockage of the header. The straw smashing and scattering device can smash the straw from the threshing cylinder and scatter them to the rolling area directly without covering the rice stubble, which is conducive to the germination of regenerative tillers and helps to increase the yield in the ratoon season. In addition, its straight rolling rate is only 26.7%, which can reduce the rolling rate by about 20 percent compared with other common harvesters. Fu Jianwei et al. also measured the yield of the ratoon rice in the second season after harvesting with this machine and a common harvester, and observed the growth in the ratoon season (Figure 7). The results showed that the machine could increase the yield of ratoon rice by 77.3 kg per mu, with an increase of 23.9%. However, the inconvenience in transport caused by the width of the whole machine is a difficult problem affecting the marketization of the machine. The width of the whole machine should be reduced from the overall structure, and further optimized by being foldable or quick disassembly of the header.

![Figure 7](image_url)

**Figure 7.** Growth conditions of ratoon rice harvested by machine in the second season. (a) A week after being harvested by a double-channel feeding harvester; (b) a week after being harvested by a common harvester; (c) ratoon rice in its mature period.

By comparing the structural forms and parameters of the common harvesters in Table 1 and the ratoon rice harvesters in Table 2, it can be seen that the ratoon rice harvester mainly widens the header and narrows the width of the chassis supporting parts on the basis of the common harvesters. The rolling rate of the crawler-type specialized harvester for ratoon rice is about 20 percent lower than that of a common harvester. The wheel width of wheel type ratoon rice harvester is less than the row spacing of ratoon rice plants (generally the row spacing is 300 mm and the plant spacing is 150 mm). Theoretically, it can walk between rows, so the rolling rate could be 0.

The two harvesters by South China Agricultural University have great advantages in reducing the rolling rate, but their chassis trafficability needs to be further improved, especially when walking or turning in wet and soft fields. The 4LZ-5.0 ratoon rice harvester designed by Jiangsu University directly increases the cutting width of the 5.0 kg/s harvester to 2800 mm, narrows the track width to 300 mm, making it easy to process and suitable for low-speed harvesting with a low rolling rate. However, due to the large specific grounding pressure of the whole machine, the passing performance in wet and soft fields is not so satisfactory, and the distance of straw transportation is longer with the increase of cutting width, which may aggravate the blockage. At present, these harvesters are basically prototypes, and have not been mass produced or put on the market. The main reason lies in lack of reliability of harvesters, and the contradiction between low rolling rate and lightweight has not been reasonably optimized.

4. Research Status of Key Components of Ratoon Rice Harvester

The development of the whole machine of the ratoon rice harvester in the first season is mainly from the perspective of reducing the ratio of the width of the grounding parts of
the walking chassis to the cutting width. In this process, it is necessary to ensure the smooth operation and reasonable collocation of the working parts of each process. In addition, due to the agronomic requirements and the particularity of materials in the first season of ratoon rice harvest, the requirements of different working parts are also different from those of common harvesters.

4.1. Chassis

At present, there are mainly three types of agricultural machinery chassis, namely wheel type, caterpillar type and wheel-track combination type. The first two types are the most common chassis types of agricultural machinery.

The selection and design of the chassis of ratoon rice harvester, as a part which rolls the straw directly in the first season harvest, is vital to lower the rolling rate and lighten the rolling degree. The rice transplanter chassis was used in the ratoon rice ear reaper and light height gap wheel ratoon rice harvester developed by Zhang et al., which, however, had problems of in turning and walking. Therefore, the adaptability of this kind of chassis in wet and soft field is less satisfying. Guo et al. [20] believed that the wheel chassis with mall turning radius and flexible turning ability should be adopted for the first season harvester of ratoon rice, and pointed out the rolling rate could be reduced when the wheel harvester walks on the same rolling lines in the field. He et al. [21] also proposed that the crawler harvester could reuse the crawler’s rolling rows to reduce the rolling area. Qian et al. [22] proposed that it is necessary to strengthen the combination of agricultural machinery and agronomy, to select rice varieties with a firm stem base and good toughness for ratoon rice, to control the soil moisture content during harvest, and to reduce the weight of the crawler harvester, so as to reduce the mechanical rolling loss during harvest.

Based on the design theory of tracked vehicles, Lei et al. [23] established a walking chassis structure model and a straight walking and turning rolling model of a full-tracked ratoon rice harvester, taking cutting width, track gauge, track grounding length, track width, turning radius, chassis center axis and the longitudinal distance between the cutter on the header as the influencing factors. Considering the planting row spacing, plant spacing and hole diameter, the influence law of various parameters on the rolling rate was analyzed, as shown in Figure 8. When walking straight, the rolling rate decreased with the increase of the ratio of cutting width to track width; when turning, the rolling rate of the full crawler harvester decreased with the increase of turning angle and turning radius. The rolling rate was not affected by the longitudinal distance between the central axis of the chassis and the cutter. When the gauge and the difference between cutting width and gauge were the common multiple of row spacing and plant spacing, it was conducive to reduce the rolling rate. Under the same grounding specific pressure, the increase of cutting width would reduce the rolling rate. In order to reduce the rolling rate, in the structural design of the full crawler ratoon rice harvester, the crawler width and grounding length should be reduced, the cutting width should be increased, the common multiple of row spacing and plant spacing should be taken as the gauge, the difference between cutting width and gauge should be the minimum common multiple of row spacing and plant spacing, and the rotary walking should be adopted on the premise of satisfying the grounding specific pressure. Combined with the shape and area of the field, the larger turning radius is preferred. In agronomy, there should be an integer multiple relationship between row spacing and plant spacing.
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![Figure 8](image-url)

Figure 8. Rolling model of ratoon rice in the first season. (a) Straight and turning rolling model of full crawler harvester; (b) field walking model of the harvester.

Based on this model, Lei et al. analyzed the dynamic performance of the full crawler chassis and designed a full crawler ratoon rice harvester chassis. The model was very effective for the formulation of structural parameters of crawler ratoon rice harvester. On this basis, it can carry out the research on operation path planning with a low rolling rate and low rolling degree as the optimization goal, provide path reference for manual driving mode and provide necessary path basis for automatic navigation driving of the harvester. However, the model is only used to calculate the rolling area of a single turn of the harvester. Based on this model, whether the total rolling area and the total rolling rate model of the whole field can be further established, and whether the rolling rate can be optimized in combination with path planning to improve the yield in the ratoon season, is an important direction of the research on the mechanized harvesting technology in the first season of ratoon rice.

Based on the requirements of low loss and rolling rate, Lin et al. [24] proposed a loss-reducing track of ratoon rice harvester, which could reduce the contact area with the paddy field so as to reduce the rolling rate. Lin et al. [25] proposed a rhombic four-wheel ratoon rice harvester chassis that could avoid rice stubble, which could realize that the walking wheel avoids rice stubble during harvest automatically. Obviously, in addition to the structural innovation of its contact parts, the research on the chassis of the ratoon rice harvester adopts intelligent technology to realize stubble avoidance walking, and improving the accuracy of row walking is also an important way to reduce the rolling rate combined with the agronomic conditions of planting and harvesting.

### 4.2. Header

As the first working part to contact with rice plants, the reap by the header is the primary link to determine the working performance of the whole machine. Only when the header runs smoothly can the materials be smoothly sent to the threshing device. The cutting width determines the working speed and efficiency of the whole machine. The uniformity of the auger conveying on the header is an important guarantee to determine whether the threshing cylinder will be blocked.

European and American countries have large operating fields and large harvester cutting width, but it is difficult to transport on the road after the cutting width is increased. In order to solve the contradiction between header width and road trafficability, most European and American countries transport header disassembly separately and assemble it before harvest. Although it takes time and effort, it has high reliability, in which simplicity and convenience of disassembly should be considered in product design. Figure 9
shows the header of John Deere S660 harvester and the body machine after removing the header [26].

![Figure 9. John Deere S660 combine harvester. (a) Removable header; (b) the machine after removing the header.](image)

At the same time, in order to solve the transportation problem caused by a too large cutting width, the folding header can also be popularized and applied. At present, the folding header is most widely used in the corn harvester. It is mainly composed of one main header, two foldable headers and a hydraulic system. The foldable function is mainly completed by the hydraulic cylinder driven by the hydraulic system. In recent years, a folding header has also appeared in the rice harvester. Compared with the corn harvester, the structure of the header of the rice harvester is relatively complex because it has reel components. Currently, some models in Claas, John Deere and other companies adopt foldable header design, as shown in Figure 10, which are Claas TUCANO450 combine harvester with unfolded header and folded header [27].

![Figure 10. CLASS TUCANO 450 combine harvester. (a) Unfold status of the header; (b) fold status of the header.](image)

It is obvious that although there is no research on the ratoon rice harvester in Europe, America and other countries, the above various foldable headers and their transfer modes for large harvesting equipment can be used as a reference for the development of ratoon rice harvester, especially the design of a header. At present, there is considerable research on header structure optimization and electro-hydraulic control abroad. Hirai et al. [28] analyzed the interaction relationship between reel and crop, theoretically analyzed its kinematics and established the kinematics model. Besides, he studied the dynamic response under the bending action of crop stem during reel operation, and simulated the influence of loading speed on bending reaction force. Maughan et al. [29] explored the effects of the cutting speed of cutters, installation inclination and blade structure on straw cutting power consumption, and found that cutting speed and installation inclination have the greatest impact on cutter cutting power consumption. Sharobeem [30] developed a combined header with low loss rate and can continuously and stably transport materials to the subsequent threshing and cleaning operations. Pari et al. [31] studied the loss caused by the header and developed a special reap header, which can reduce the loss. Fuchs et al. [32] improved the follow-up conveying device to make the feeding of materials from the header to the conveying channel smoother. Chaab et al. [33] tested the header loss of
New Holland TC5070 combine harvester, obtained the optimum parameters of auger speed, operation speed and stubble height, and established a functional model to predict header loss. Zareei et al. [34] found that the operating speed of the machines, reel speed and stubble height are the main factors affecting the header loss, and determined the optimal combination with the lowest header loss rate by orthogonal test. Hobson et al. [35] designed a conveyor belt harvester header, which can reduce the header loss. The measured loss was only 27 kg/hm², which was only half of the loss caused by common headers. Lopes et al. [36] designed a header height control system based on LQG/LTR, which can automatically adjust the header height according to the actual operation.

At present, the research on the header in China mainly focuses on the conventional harvester, including the overall improvement design of the header and the structural design of three main components: the reel, spiral auger and cutter. In addition, the research on noise and vibration reduction, loss reduction and other aspects are also included. Optimizing the design and structural innovation of the traditional harvester header to better meet the harvesting needs of different crops, improve efficiency and reduce losses is a main direction for scholars to study the overall performance of the header for many years.

Chen et al. [37] designed a folding header of corn harvester, but the flexibility and reliability are not satisfying. Li et al. [38] designed a separating-combined header, which can preliminarily cut, thresh, and separate the cut rapeseed plants. The screw auger and reel were analyzed under dynamics and kinematics theory, and the reasonable parameters were obtained. Ji et al. [39] developed a stripping header of a rapeseed combine harvester, which could realize the functions of reel, stripping off, throwing and cutting. Through simulation analysis, the structural motion parameters of the main working parts such as the reel, drum and cutter were determined. Qian [40] simplified and improved the design of the header and the whole machine of the 4LZ-1.0 harvester to make it easy to disassemble and install. Li et al. [41] designed an air blowing header and established a uniform air blowing model to solve the problem of large grain residue and difficult cleaning on the header of the harvester. Liu et al. [42] designed a special header for a reel-type oil sunflower combine harvester, theoretically analyzed the posture of oil sunflower stalk in the process of grain separation, and simulated and analyzed the motion track of reel. Zhao et al. [43] designed an anti-winding header for the flax harvester. By installing an anti-winding plate with a knife rest between the telescopic fingers of the header auger and adding a conveyor belt in front of the header, the problems of flax stalk winding the header and massive accumulation were solved.

The structure design, performance improvement, noise and vibration reduction, loss reduction and parameter control of the header of combine harvester have been studied in many aspects. The structure of the traditional header has been constantly optimized and improved, and various specialized headers with novel structures have also appeared. The design of folding header has been started in China, but it is mostly concentrated on corn headers, and there are few folding header products suitable for grain harvesters. In addition, due to the lack of research on ratoon rice harvester, there is little research on specialized headers suitable for a ratoon rice harvester, especially the winding blockage caused by large amount of straw feeding and long conveying distance of header caused by increasing cutting width to reduce rolling rate. Light weight, transportation convenience, large cutting width and high efficiency are the main problems to achieve low rolling rate in the first season of ratoon rice. Therefore, in the process of developing a specialized harvester for the first season of ratoon rice, we need to focus on the parameter matching of the header, learn from the research methods of the harvester and header at home and abroad, and use the corresponding advanced technology to develop special harvesting machinery and a supporting header suitable for the first harvest of ratoon rice under agronomic requirements.

Due to the large amount of straw in the first season of ratoon rice, Chen et al. [44] designed additional cutters to be installed at the bottom of the header of the harvester to improve the cutting efficiency and reduce the load. During operation, the cutter harvests
the ear head, the additional first cutter cuts the straw to be returned to the field in advance to return it to the field as soon as possible, and the additional second cutter is used for stubble retention at a specified height.

Fu [45] designed a special double-channel header for ratoon rice for their double-channel feeding ratoon rice harvester. As shown in Figure 11, during operation, the grain divider divides the grain to be harvested into the cutting range according to the cutting width, the upper ear head and stem of ratoon rice contact with the cutter are cut off under the action of the reel, and the cut crop is transferred into the header by the reel, which is gripped and transported by the rotating two-way spiral conveyor blades to the left and right sets of telescopic fingers, which transfer the collected crops to two feeding inlets and they are then grabbed by the conveyor chain rake, so as to complete the whole header operation process. The whole process effectively divides the crop quantity, reduces the material at the single feeding inlet to half, reduces the operation load, avoids blocking the header and subsequent conveying and threshing process due to excessive instantaneous feeding, and improves the operation efficiency and adaptability to complex working conditions. However, the header is wide and inconvenient to transport, so the quick-disassembly structure and foldable header are the key research contents of the specialized harvester for the first season of ratoon rice when widening the width of the header.


4.3. Threshing and Cleaning

4.3.1. Threshing

The threshing and separating device can separate the grains on the ear, which is mainly composed of a feeding device, roller, and a concave screen, including impact threshing, combing brushing threshing, rolling threshing and kneading threshing. From the book Agricultural Machinery Design Manual (Volume 2) [46], the cylinder can be divided into a nail tooth type, striped rod type, double cylinder type and an axial flow type. According to the difference of threshing elements, it can be divided into a nail tooth type, striped rod type, bow tooth type, plate tooth type, tooth plate type, etc., as well as the combination of different threshing elements.

As the core component of harvester, the threshing cylinder is the research focus of scholars at home and abroad, and the relevant achievements are abundant. The research mainly focuses on optimizing structural parameters or proposing new structures to reduce crushing rate, improve cleanliness, reduce power consumption, and improve efficiency. In recent years, researchers have also carried out key research in many aspects such as anti-
blocking and performance detection in terms of intelligent regulation, and adopted various technical means such as three-dimensional design, dynamic simulation, and finite element simulation, which promotes the improvement of working efficiency and intelligence level of the threshing and separating device.

In recent years, some researchers have studied the differences between ratoon rice and common rice in the first harvest, such as green stalk, lush leaves, and high moisture content. In order to solve the threshing problem of ratoon rice, Lu [47] designed a small horizontal-axial threshing and separating device, which can meet the threshing needs of ratoon rice and first-season rice at the same time. Li [48] designed a longitudinal axial flow threshing and separating device to adapt to the strong, green, and wet ratoon rice in the first harvest. The results show the optimal parameters of the threshing and separating device: the threshing drum speed is 760 r/min, the guide angle of the guide plate is 19°, and the concave plate screen grid axial spacing is 19 mm. Li et al. [49] proposed an integrated device for threshing, smashing, and scattering of ratoon rice with a simple structure and low power consumption.

4.3.2. Cleaning

As an important part of the cleaning system of the grain combine harvester, the cleaning device directly affects the working performance of the whole machine and the harvest quality of grain. According to the working principle, the cleaning system can be divided into air flow type and air screen type cleaning devices [50]. The air flow cleaning device adopts a pure air flow device in structure, and realizes the cleaning process by using the aerodynamic characteristics of the cleaning effluent. It has the advantages of simple structure, small volume, low power consumption, working stability and high reliability. However, due to its volume and power consumption, it is mainly used for miniature harvesters. The air screen cleaning device uses the cooperation of the fan and cleaning screen for cleaning, which is mainly composed of a fan, vibrating screen, frame, and transmission system. Medium and large combine harvesters basically adopt an air screen cleaning device, which has high cleaning performance and good cleaning effect.

The cleaning device is used together with the threshing and separating device to separate and clean the grains on the ear head. In recent years, research on the air flow cleaning system been mainly regarding the structure of the separating cylinder, the wind speed of the impurity suction fan and the air flow field of the impurity suction pipe to improve the cleaning effect [51,52]. The air screen cleaning system is studied from the aspects of volute structure, impeller form and multi air duct of the agricultural centrifugal fan, screen surface structure, shape, material, and motion form of the cleaning screen [53,54]. Through numerical simulation and coupling, dynamic simulation and finite element simulation, the cleanliness of grain and the intelligence level of the whole machine are improved.

In terms of ratoon rice, Wang [55] improved the cleaning device of WORLD 4LZ-3.0E rice combine harvester, taking a six-blade centrifugal fan as the cleaning fan and shutter screen, and a flat plate structure without stamping as the upper screen of vibrating screen. They used CFD (Computational Fluid Dynamics) software to simulate and compare the air flow field in the cleaning device, and the optimal opening of the screen was obtained. The grain impurity content was 1.52% and the loss rate was 1.11%, which is suitable for the harvest of ratoon rice.

4.4. Threshing and Cleaning Straw Disposal

There are many ways to dispose of rice straw, such as returning it to the field, collecting it to make into compost, making feed and converting it into energy. The straw disposal by the harvester mainly includes direct discharge, smashing and scattering, and baling as shown in Figure 12. The straw directly discharged without smashing will be scattered disorderly on the stubble of ratoon rice, which will seriously affect the re-germination of the head. After being smashed, there will be two forms of scattering for the straw according to the actual demand: even scattering and directional scattering. Even scattering is the main
scattering method for the harvester equipped with the straw disposal device at present. It will still cover the stubble of ratoon rice to a certain extent, but it will not affect the germination of the ratoon rice head when the straw smashing is relatively thorough and the covering is thin. The directional scattering is mainly to scatter the smashed straw to the rolling area, so as to completely cover little rice stubble in the stubble area, and will not affect its regeneration and germination. Some models with a self-propelled medium and large harvesters are equipped with a straw baling device, but no ratoon rice harvester has tried it at present.

Figure 12. Ways of straw disposal and effect. (a) Straw directly discharged and placed disorderly; (b) straw smashed and scattered evenly; (c) straw smashed and scattered directionally; (d) straw baling.

4.4.1. Straw Smashing and Scattering

Harvesting crops and smashing straw are important parts before returning the straw to the field. The straw smashing and scattering device matched with the harvester is a research hotspot of agricultural machinery companies at home and abroad in recent years. Direct harvesting and smashing of the harvester is also a field returning technology vigorously promoted by the government and easily accepted by farmers. The straw smashing and scattering device matched with the harvester is mostly used on the longitudinal axial flow combine harvester. The straw smashing and scattering device is connected to the tail body of the harvester through a hinge. The belt drive obtains power to drive the knife roller to rotate at high speed. The straw is smashed under the action of a moving knife with or without fixed knife support.

The combine harvesters produced by large foreign agricultural machinery companies are equipped with supporting straw smashing and scattering devices, which have a high degree of direct return of straw to the field. Among them, the combine harvesters in European and American countries have a complex structure, large volume, and wide cutting width. Longitudinal axial flow is mostly used for threshing, and the scattering range is wide. Common models such as the CASE 4077 combine harvester [56] are equipped with a straw smasher at the tail, with 28 moving knives arranged in a double helix and 25 fixed knives, with excellent smashing performance. At the same time, it is equipped with a horizontal double disc spreader with wide scattering range and high evenness. Its structure is shown in Figure 13.
Figure 13. Straw smashing and scattering device of CASE 4000 series axial flow harvesters. (a) CASE 4007 combine harvester; (b) straw smashing roller; (c) scattering device.

Japanese brands such as Kubota and Yangmar provide optional straw smashers. As shown in Figure 14, the moving blades are straight blades, and are mostly double helix or symmetrical staggered arranged. During harvest, the fixed blade can be disassembled according to the smashing requirements, and different smashing effects and power consumption can be obtained according to the reserved fixed blade number [57]. This kind of straw smasher is no longer equipped with a special scattering device. Under the combined action of the centrifugal force generated by the high-speed rotating knife and the air flow in the smashing room, the straw can be directly thrown out for a long distance, and the straw can be evenly scattered under the action of the straw deflector and the guide plate.

Figure 14. Straw smashing and scattering device of Kubota harvester. (a) Straw deflector; (b) straw smashing roller.

Chinese brands such as WORLD and Lovol also provide optional straw smashers according to the national requirements for returning smashed straw to the field, and their structural forms are basically the same as that of Kubota in Japan. The form and arrangement of moving knives are different in many models. As shown in Figure 15, the ASHNA series harvesters [58] produced by the Lovol company have a double blade flail knife, which is arranged in a staggered manner. The scattering width and distance are also controlled by the tail plate and angle adjustable deflector.

Figure 15. Lovol ASHNA harvester. (a) Straw deflector; (b) flail knife.
Due to the thickness and evenness of straw scattering and covering, a number of studies have been carried out with common straw smashing and returning machines on the qualified rate of smashing length, scattering evenness and width as the performance indexes. The straw smashing and returning machine is often used as the reference for the structure improvement and parameter optimization of the straw smashing and scattering device supporting the harvester. Since the straw smashing length is required to be less than 150 mm during the harvest of common rice and there is no corresponding requirement for the straw scattering range, the existing harvesting models basically scatter the straw evenly, and the relevant research is basically focused on the straw smashing part. Therefore, there are few studies on the throwing performance of stubble.

Thakur et al. [59] developed a straw smashing device matched with the harvester. The smashing performance is the best when the moisture content of the straw is 70%, the operating speed of it is 0.56 m/s and the rotating speed of knife roller is 1500 r/min. Schillinger et al. [60] installed a high-pressure fan on the harvester to improve the scattering evenness. The wind power is transmitted by the harvester through belt drive, and its wind force is acted on the outlet by a hose, which can adjust the air flow direction and speed according to the actual situation. Veikle [61] conducted a test with the type of smasher, straw moisture content and straw amount as factors and the energy consumption of the harvester as indicator. It was found that the moisture content was reduced from 25% to 7%, and the energy consumption was reduced by 0.14 kW. Taking the cutter roller speed, straw quantity and cutter type as factors and the energy consumption as indicators, Korn et al. [62] carried out a test and found that the installation of fixed cutter can improve the qualified rate of straw length, but the energy consumption increases. With the increase of cutter roller speed within an appropriate range, the energy consumption also increases. Lisowski et al. [63] used Fluent software to analyze the movement process of the straw at the straw outlet of the cylinder, and studied the relationship between the blade roller speed of the smasher and the straw scattering speed. Virk [64] installed an auxiliary straw smashing on the header of the combine harvester. The operating speed of the machine was 0.5 m/s, the smashing efficiency was 0.23 hm²/h, and the length of 44.3% straw after smashing was less than 400 mm.

Chen et al. [65] designed a 1JHSX-34 double shaft straw smasher, which can be directly connected with the straw scattering outlet at the tail of the harvester. Two straw smashing knife rollers are installed in the smashing room. The rotation speed of the knife roller is 2800 r/min, and the rotation direction is opposite during operation. The moving knife is a disc-blade. The rotation speed difference between the two shafts due to the gear transmission can make the straw be cut for many times and then scattered. Lu et al. [66] designed a rice and wheat straw scattering and returning machine matched with the semi-feeding combine harvester. The straw scattered by the harvester is smashed by the smashing device and then scattered into the field under the action of the scattering auger. Chen et al. [67] improved an L-shaped cutter for the smashing device of corn harvester, and carried out stress analysis and strength check on the blade. Wang et al. [68] designed a straw smashing device installed under the header of corn harvester. The qualified rate of straw smashing length could reach 90.21% and the breakage rate could exceed 85.38%. Wu et al. [69] designed a rice straw smashing and returning device, which was connected to the tail of the harvester to complete the whole process. Through hob cutting, the straw was smashed under the combined action of fixed knife and hob, and then transported to the shaking plate by the horizontal auger, which fell evenly onto the field under the action of the shaking plate.

4.4.2. Straw Baling

If the harvester is equipped with a straw baling device, it can cut down works and labor intensity. For the first harvest of ratoon rice, if the straw is directly baled during harvest and the bales can be put at the side of the field every time when the harvester...
walks, the coverage of straw on rice stubble can be completely avoided in theory, and the straw can be used as processing feed and energy conversion.

At present, most of the grain harvesters on the market only have the function of harvest, and the traction or self-propelled straw baler can only bale the straw. The grain harvester and baler are required to work on the ground, respectively, to complete harvest and baling. There are many operation steps, high labor intensity, and repeated rolling damage done to the field. It is especially unsuitable for the harvest of first season ratoon rice.

As shown in Figure 16, the integrated harvester integrates the function of harvesting and baling to realize the harvesting and baling at one time. The baling mainly includes three operation links: feeding, compression and knotting. It is installed behind the discharge outlet of the threshing device at the tail of the harvester, and the crop straw discharged by the threshing device can be baled regularly.

![Figure 16. WORLD 9YFL-2300 all-in-one machine for harvesting and baling.](image)

Huang et al. [70] developed the 4LYZ-3K corn combine harvesting both straw and spike, which can complete the ear harvest, straw cutting, feeding, chopping, scattering, and baling at one time. It effectively improves the utilization rate of corn straw, reduces the working intensity and the working steps, and the baling rate of straw can reach more than 96%. Yan et al. [71] developed a crawler harvester and baler based on the crawler harvester, which can complete the harvesting and baling operation at one time, and the regular baling rate can reach 96%. For the rice fields with unsatisfactory harvesting conditions in South China, it can effectively solve the problems of secondary laying down and straw collection, storage and transportation, and shorten the working time and increase the income of the owners. Zhang et al. [72] developed a straw baling device for a highland barley combine harvester, with a bale forming rate of 98.3%, a baling passing rate of 94.7%, a bale falling resistance rate of 90%, an overall operating efficiency of 0.4 hm²/h and an average bale area of 0.8 m × 0.6 m with an average bale density of 124 kg/m³. Wu [73] developed a matching baler for the wheat combine harvester, with a bale forming rate of 99.5%, a regular bale rate of 96%, a bale density of 120 kg/m³ and a bale falling resistance rate of 95%. On the basis of the existing round baler, Jin et al. [74] improved and designed the corresponding working units of the round baler and the combine, and developed the rear non-landing baler of the combine, with a baling rate of 98% and a regular baling rate of 95%. The 4LZ-4.0 rice and wheat combine harvesting and baling compound operation machine developed by Li et al. [75] realized the crop harvesting and straw baling in the process of rice and wheat combine harvesting at one time. Based on the wheel combine harvester, a feeding mechanism was designed at the straw outlet under the threshing cylinder, with a baling rate of 98.3% and a bale area of 0.4 m × 0.5 m, with bale density 190–200 kg/m³.

At present, the synchronous baling technology of rice straw collected by a machine has been applied to many models. When applying this technology to the harvester in the first season of ratoon rice, to avoid the secondary or even multiple rolling of rice stubble caused by picking up the related machines, it is necessary to reasonably plan the size of the straw stack by referring to the size of the field, the orientation of the tractor track and the amount of the straw. If the baled place of the straw stack is closer to the ridge and tractor
road, the transportation distance could be reduced, the repeated rolling of rice stubble could be reduced, and the work efficiency could be improved.

4.5. Stubble Management

The rolling caused by mechanical harvest is inevitable. While taking a series of measures to reduce the rolling rate, how to improve the survival rate and regeneration ability of rice stubble in the rolling area is also an important question to promote the yield increase in ratoon season. The double-channel feeding ratoon rice harvester designed by Huazhong Agricultural University smashes the straw and scatters it into the rolling area. It is a solution to abandon the stubble in rolling rice to make way for the better growth of the stubble area. Some researchers use a stubble righting device to straighten the rolled rice pile, which can increase the regeneration capacity of rice stubble in the rolling area to a certain extent.

Xu et al. [76] put forward an automatic stubble righting and dredging device for ratoon rice in the form of a patent, which can realize stubble righting and dredging during the first harvest and improve the yield of ratoon rice. Lin et al. [77] proposed a stubble righting device for ratoon rice, which is used together with the harvester. The flexible righting wheel mechanism is adopted to straighten the stubble without damaging the rice stubble. At the same time, the profiling structure is adopted to ensure the working effect of the righting device.

Zhang [78] developed a double-layer chain toothed claw stubble righting device for ratoon rice, which can lift the rolled rice pile, with a simple and compact structure and convenient disassembly and assembly. As shown in Figure 17, the device is mainly composed of chain row devices, a tooth claw righter, righting top plate, arc top plate, chain row connecting devices, chain row hanging device, chain, and U-shaped fixed plate. The toothed claw righter moves along the chain track. When the toothed claw righter reaches the arc top plate at the bottom, it contacts the arc baffle, keeps the toothed claw righter open, and rights the rolled ratoon rice stubble at a certain penetration angle perpendicular to the chain movement direction. The success rate of righting is up to 91.17%, which improves the survival rate of rolled rice stubble.

The survival rate of rice stubble after righting is improved. Based on the principle of lightweight and reducing the rolling degree of rice stubble, the use of righting device is another technology to improve the yield of ratoon rice in ratoon season. This measure is applicable to the field where the straw is baled after mechanized harvest or evenly scattered after straw smashing. If the straw is directionally scattered and rolled in the area after smashing, the amount of straw in this area is too large and it is difficult to straighten the

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5. Application of Lightweight Technology

The lightweight design of a ratoon rice harvester can reduce the mechanical damage to rice stubble and reduce the degree of rolling. Xiong [79] proposed an amphibious miniature harvester, which is suitable for small terraces in hilly and mountainous areas. The whole machine is light and is also suitable for the first harvest of ratoon rice. Xu et al. [80] proposed a ratoon rice combine harvester, which can harvest the ear head separately so as to reduce the structural size of working parts and realize the lightweightness of the whole machine. Li et al. [81] proposed a double inlet cyclone cleaning device and ratoon rice combine harvester, which uses air cleaning to reduce the volume of the cleaning device and reduce the weight of the whole machine. It can be seen that reducing the weight of working parts by adjusting the structure of the working parts of the harvester or changing the harvesting, threshing and cleaning methods, so as to achieve the goal of lightweightness of the whole machine, is an important developing direction of mechanized harvesting technology in the first season of ratoon rice.

Lightweight technology has been applied in the field of construction machinery and automobile manufacturing for many years. In recent years, with the development of large-scale, intelligent and high-end agricultural machinery, lightweight technology has become a strong support for manufacturing high-end agricultural equipment. The lightweight design of mechanical equipment is generally carried out from three aspects: structural lightweight, material lightweight and process lightweight. Structural lightweight includes size optimization, shape optimization, topology optimization and multidisciplinary design optimization (MDO); material lightweight mainly includes high-strength steel, aluminum alloy, magnesium alloy, titanium alloy, plastic and composite materials; process lightweight includes laser welding, hot stamping, hydroforming and casting. Material lightweight and process lightweight are widely used in the automotive field, but agricultural machinery, especially harvesters, rarely use aluminum alloy or light composite materials because of their complex structure, huge volume, and large cost constraints.

Jiao [82] designed a lightweight JN4LZ crawler combine based on HyperWorks software, and optimized the topology and size of the body by using the Optistruct module. Finally, while meeting the requirements of strength and stiffness, the weight of the machine can reduce by 119 kg. Zang [83] carried out the lightweight design of the thresher frame of a grain combine harvester based on ANSYS Workbench software, and adopted the topology optimization method on the basis of static analysis, which can reduce the weight of the frame by 20%. Feng et al. [84] established the finite element model of the chassis frame of a small harvester. The size was optimized based on ISIGHT software, and the weight of the frame decreased by 22.9%. Zhou [85] analyzed the fatigue life of the chassis frame of a corn harvester based on ANSYS Workbench software. According to the analysis results, the key components of the frame were designed by the shape optimization method, and the weight could be reduced by 24%. Yan et al. [86] conducted static analysis on the frame of the grain thresher based on ANSYS Workbench and carried out topology optimization design on its structure. The improved frame can reduce weight by 10.98% on the basis of satisfying structural usability and material mechanical properties. Li et al. [87] conducted modal test verification and theoretical analysis on the header frame of the WORLD 4LZ-2.5B crawler combine harvester based on UG software, analyzed the characteristics of external excitation frequency among which the natural frequency of the header frame can avoid the range of external excitation frequency, and carried out structural optimization and test on the frame structure, with a weight reduction range of 14.02%. Long et al. [88] established the finite element model of an articulated rhombic chassis frame meeting the assembly layout and actual driving requirements, analyzed the stress distribution of the frame under various typical working conditions, and proved that the weight of the frame can be reduced by
nearly 60 kg after lightweight design. Based on ProE and ANSYS Workbench software, Sun et al. [89] used structural optimization and material replacement methods to carry out lightweight design for the header of a rice harvester. After optimization, the mass of the header was reduced by 49.872 kg compared with the original header, and the fuel economy was higher. Ma et al. [90] analyzed the strength and hardness of the axle housing of a wheel combine harvester based on ANSYS, and optimized the section shape and size of the axle housing, which could reduce the weight of the axle housing by 17.8%. Li et al. [91] optimized the size to achieve the lightweight quality of the frame of a soybean harvester by checking and calculating the strength of the frame under different working conditions, taking the natural frequency of the frame and the maximum allowable stress of the material when the dynamic load coefficient was 2.5 as the constraint, and the minimum mass of the frame as the goal. After optimization, the mass of the chassis frame was reduced by 16%.

Obviously, the research on lightweight of harvesting machinery mainly focuses on structural optimization design, which is also the main technical means suitable for lightweight design in the field of agricultural equipment at this stage. Based on the finite element simulation technology, the lightweight design of agricultural machinery is carried out by using the structural optimization method, which has strong operability and saves the production cost. With the continuous development of agricultural equipment, the application of lightweight materials and lightweight technology in the lightweight field of agricultural machinery will be studied step by step in the future. Learning from the research achievements in the field of automobile lightweight, combined with the actual operating environment and requirements of agricultural equipment, exploring the lightweight technology development of agricultural machinery from the aspects of structure, materials and technology is not only the development trend in the future, but also an important direction of the research on the first season mechanical harvesting technology of ratoon rice.

6. Application of Intelligent Harvesting Technology of Ratoon Rice

The intelligent development of ratoon rice harvester can learn from the technical application of existing ordinary rice harvesters and other agricultural machinery, especially John Deere in the United States, Case New Holland in the United States, CLASS in Germany, Massey Fawkson in the United Kingdom, and other large European and American agricultural machinery companies, are relatively comprehensive in the automatic control and monitoring system. Indeed, 3S, sensing and detection, automatic control and information processing technologies have promoted the development of intelligent agricultural machinery and equipment, and the intelligent harvester is also one of the development directions. The intelligent harvester mainly includes performance monitoring and fault diagnosis of working parts, real-time detection of grain quality such as impurity content, breakage rate and loss rate, and automatic navigation technology. Intelligent harvester integrating automatic navigation, fault monitoring, information detection and other technologies have become the development direction of efficient rice harvest and an important technical means to realize the low rolling harvest of ratoon rice.

6.1. Performance Monitoring and Fault Diagnosis

The development of intelligent harvesting technology is an important basis for promoting the precision harvest of ratoon rice. The basic requirement for precision harvesting is to harvest timely according to crop maturity, to automatically adjust the harvester walking speed, header height, threshing drum speed and cleaning working parameters according to crop growth and yield, and to monitor, display and alarm the working conditions of various components, which can effectively solve the problems that parameter adjustment depends on experience, manual adjustment, and inconvenient operation [92]. At present, the harvesters at home and abroad generally use electronic and hydraulic technology to realize the above functions.

Foreign grain harvesters have been quite satisfactory in performance monitoring, fault diagnosis and intelligent regulation. A variety of sensors are arranged in each link and
part of the harvester to collect data such as speed, vibration, torque, temperature, and grain humidity and density. The data are fused and analyzed through the fault diagnosis system to judge the load and blockage degree of each working part, and send corresponding early warning information. Then, the grain harvester is intelligently regulated by the intelligent control element. The harvester can automatically adjust the harvesting height of the header, drum speed, cleaning wind force and angle. When the threshing torque increases, the walking speed of the harvester can be reduced in real time. With the improvement of intelligent detection, automatic regulation and intelligent fault diagnosis technology, grain harvesters are developing to have more intelligence, automation, and modernization.

John Deere 70 series STS harvester [93] can automatically adjust the parameters of the threshing cylinder and cleaning parts according to the type of harvested crops and the actual harvest operation, and the flexible profiling header can adjust the stubble height according to the field environmental conditions. Case IH series harvester [94] is equipped with the APS intelligent system, with accurate positioning, real-time parameter adjustment and real-time monitoring of various components by touch screen with low labor intensity. The New Holland CR series harvester [95] is equipped with a super large header and a new floating operation system, which can automatically adjust the stubble height; the feeding amount monitoring system uses an ultrasonic filter to monitor the feeding amount and adjusts it in real time through an overload back spitting device. The double axial flow drum threshing system and automatic leveling cleaning system are adopted to improve the threshing and cleaning effect; its pulsating straw disposal system can improve the quality of straw scattering.

There are several grain harvesters in China with good product quality, such as WORLD, Lovol Ceres and Zoomlion, but there is still a big gap compared with foreign intelligent monitoring equipment. Wei et al. [96] designed a set of mechanical header profiling structure, which touches the ground through the mechanical structure and obtains the fluctuation by the angle sensor. It detects the expansion and contraction of the header oil cylinder through the displacement sensor, so as to control the header for ground profiling. Li et al. [97] designed a set of measurement system to detect the rotating parts of the harvester, which can prevent the rotating parts from blocking and reduce the failure rate. Zhao et al. [98] designed a measurement system for the feeding amount in a threshing cylinder based on the thin-film sensor to study the relationship between the feeding amount, drum speed and the resistance signal collected by the thin-film sensor arranged between the contact surface between the drum top cover and the edge of the lower cover plate of the cylinder, which can be used for real-time monitoring of the feeding amount of the grain harvester. Liao et al. [99] used the method of unilateral infrared reflection to detect the crop height, and the expansion amount of the oil cylinder could be detected by the displacement sensor to obtain the header height. Zhuang et al. [100] adopted the header height control strategy based on robust feedback linearization to adjust the header fluctuation height. Chen et al. [101] designed the parameter key adjustment device of the header of the rice harvester, established the automatic control model of the reel speed, and realized the automatic control of the reel speed combined with the fuzzy PID (Proportion Integration Differentiation) control algorithm. Chen et al. [102] also designed a combine harvester monitoring system based on PLC (Programmable Logic Controller) and touch screen. The PLC main controller processed the data collected by the sensor. The touch screen displayed the harvester operation status, fault alarm point, rotating speed and walking speed trend chart of each component, and the fuzzy PID control algorithm was used to reduce the pulse step deviation of stepping motor and to improve the stability of operation speed and the accuracy of speed control. Xi et al. [103] proposed a combined harvester operation fault monitoring and diagnosis method (SDAE-BP) based on the fusion of stacked denoising autoencoder (SDAE) and the back propagation neural network (BP). The speed sensor collects the speed of each part of the harvester and takes it as the system input information, and uses SDAE to extract the deep-seated characteristics of the input signal. The working state of the combine harvester is identified by the BP neural network.
to realize the fault monitoring of the combine harvester. Xu [104] combined the BP neural network (BPNN) with D-S (Dempster-Shafer) Evidential Theory to establish the harvester blockage fault diagnosis algorithm model. By using the BP neural network to analyze the speed information of each part of the harvester and fusing the information at different times through Dempster synthesis rules, the final probability distribution of each working condition was obtained, and blockage fault diagnosis was realized.

Intelligent fault diagnosis technology requires the integration and combination of multiple fault diagnosis methods. Multi-sensor information integration technology is an important means to improve the comprehensive performance of the fault diagnosis system. The characteristics of each sensor are different. The information data collected by various sensors are integrated and analyzed to establish an effective fault detection model and prediction model for timely feedback and adjustment [105].

6.2. Detection of Grain Quality

Impurity content, breakage rate and loss rate are the main indexes to test the harvest performance of harvester, and they are also important standards to evaluate grain quality. The loss of grain can be reduced by using detection technology to quickly identify complete grains, broken grains, impurities, and losses, and timely adjust the operation status of machines.

Operation errors of harvester, improper parameter setting or poor rotation of working parts will lead to the increase of impurity content and crushing rate, which requires real-time monitoring to provide effective control basis for the manipulator, improve grain quality and operation efficiency. Most of the research on impurity content and breakage rate is based on image processing. The “grain quality camera” from CLAAS [106] can directly capture the grain image in the threshing process, analyze the content of impurities such as straw and broken grains in the image, and display detailed information on the display screen, which can effectively evaluate the grain quality in real time and optimize the regulation of the threshing and cleaning process. Pourreza et al. [107] collected gray images of wheat seeds, extracted texture features, and classified the features with linear judgment analysis classifier. The resolution accuracy of impurities and broken wheat reached 98.15%. Craessaerts et al. [108] established a nonlinear prediction model of grain impurity content by using fuzzy theory based on the influencing factors such as fan speed and upper screen load impurity content. Wallays et al. [109] used machine vision to online detect the impurity content of wheat during the working process of the harvester, combined five bands within the range of 400–900 nm through genetic algorithm, and classified a single pixel in the image as wheat grain or impurity. Chen et al. [110] used the multi-scale Retinex algorithm with color restoration to enhance the collected rice original image, set thresholds for the hue and saturation channels of HSV color model for image segmentation, and obtained the classification and recognition results in combination with shape features. The recognition rates of straw impurities, fine branch impurities and broken grains were 86.92%, 85.07% and 84.74%, respectively. Using the K-means algorithm, Chen [111] roughly extracted broken grains and miscellaneous grains, finely segmented them by the watershed algorithm, extracted the eigenvalues of miscellaneous grains and grains, and input them into the BP neural network model to identify miscellaneous grains, broken grains, and intact grains. Su [112] established the machine vision static detection hardware system and recognition model for grain and impurity recognition, and the overall recognition rate could reach 90%.

During mechanical harvesting of ratoon rice, the loss mainly happens in threshing, entrainment, and cleaning losses. During operation, the losses can be reduced by adjusting the operation speed, header height and reel speed, but the requirements for the manipulator are high and the information acquisition is unstable. Therefore, it is necessary to detect the loss in the harvest process in real time to guide the manipulator or control system to adjust the harvest state in time.

John Deere 70 series STS harvester has two harvest modes: minimum harvest loss and maximum harvest efficiency. At the same time, the intelligent detection system can monitor
and record the humidity and yield information of grain in real time, which is convenient for the generation of yield distribution map. Li et al. [113] took YT-5 piezoelectric ceramics as sensitive elements to design the cleaning loss monitoring sensor of the combine harvester. The secondary instrument can calculate the real-time cleaning loss rate according to the amount of cleaning loss grains monitored by the sensor relying on the grain cleaning loss monitoring model, walking speed, and cutting width of the combine harvester, the yield per unit area of rice and the quality of 1000 grains. It also has the function of over standard alarm for cleaning loss. Liang et al. [114] studied the distribution law of cleaning loss grains at the rear of the tail screen of the cleaning screen, and established a mathematical model between the amount of cleaning loss grains and the amount of grains in different areas at the tail of the cleaning screen. The maximum relative error of grain cleaning loss monitoring was 3.26%. Wang et al. [115] designed a corn harvester grain cleaning loss monitoring device composed of an impact sensor, signal processing circuit and installation device, and used support vector machine multi classification algorithm to extract corn grain impact signals to realize real-time monitoring of corn grain loss. Zhang et al. [116] developed an online monitoring system of cleaning loss rate based on a piezoelectric ceramic sensor, which realizes the real-time monitoring of grain loss rate during the working process of the combine harvester, and the measurement error was less than 4.1%. Jiang et al. [117] constructed a multivariate nonlinear prediction model for cleaning loss rate of the rice and wheat combine harvester, and the prediction result of the model was close to the actual cleaning loss rate.

The development of machine vision and digital sensing technology provides technical support for the research and development of intelligent detection equipment for a rice harvester. However, different from industrial production detection, intelligent detection equipment of a rice harvester, especially a ratoon rice harvester, has higher and more complex requirements. At present, it is necessary to further explore the general detection model of breakage rate, impurity content and loss rate based on sensing information, and strengthen its application in a ratoon rice harvester to further improve the total yield in both the first and the second season.

6.3. Automatic Navigation Technology

The GNSS-based automatic navigation system is the most mature and widely used automatic navigation technology. The technology integrates high-precision satellite positioning, agricultural machinery attitude detection, steering precision control, obstacle identification and autonomous obstacle avoidance, operation path planning and other technologies, and combines with modern agricultural technology to implement accurate timing, positioning, and quantitative control for harvester operation, so as to achieve the goal of harvesting rice with high efficiency and high quality.

The harvesters of John Deere, CASE, New Holland, Fendt, CLAAS and other companies are basically equipped with navigation systems with high navigation accuracy. For example, the navigation accuracy of John Deere 70 series STS harvesters can reach 0.33 m. Kurita et al. [118] carried GNSS positioning and GPS compass on the crawler harvester to obtain the absolute position and direction of the vehicle. The lateral error of navigation harvesting operation was 0.04 m, and the steering angle error was only 2.6°. Zhao [119] developed a three-dimensional laser information acquisition device to conduct a three-dimensional measurement on the measured target and automatically adjust the deviation angle between the initial installation position of the laser scanner and the driving direction of the harvester, which can improve the navigation accuracy. Zhang et al. [120] integrated predictive control theory with a fuzzy pure tracking model and designed a pre-adaptive path tracking model harvester RAC navigation system. Through the built-in harvester kinematics model, the tracking results are predicted before tracking, and the tracking amount is corrected in advance to improve the tracking accuracy. According to the BeiDou positioning and farmland shape information, Sun [121] established the path planning model of the auxiliary navigation system, and realized the global path planning of
the auxiliary navigation operation. Guan [122] proposed a 2R-G-B image graying algorithm suitable for harvesting navigation, which was suitable for extracting the boundary between harvested and non-harvested areas of rice. Ding et al. [123] constructed the visual navigation control system of a wheeled grain combine harvester and designed the straight-line detection algorithm of a grain harvest boundary to identify the boundary between the harvested area and non-harvested area in a rice field to obtain the forward-looking target path of harvester visual navigation operation.

The application of automatic navigation technology can effectively reduce the labor intensity of drivers and reduce the loss caused by mechanical harvest. Taking low rolling rate and low rolling degree as the optimization goal, setting a reasonable operation route and combining with automatic navigation technology can further reduce the production reduction in regeneration season caused by rolling. Although automatic navigation technology has been gradually applied to large-scale agricultural production, the practicability, adaptability, and reliability of intelligent harvesting of ratoon rice still need to be further studied.

The development of mechanized harvesting technology for the first season of ratoon rice depends on a variety of technologies such as sensing and detection, automatic control and information processing, navigation technology, decision analysis, hydraulic and electric control. The application of these technologies to agricultural machinery and equipment is still under development in China, and the research process should be accelerated to meet the needs of the development of agricultural modernization.

7. Analysis on Technical Difficulties and Development Trend of First Season Harvest of Ratoon Rice

As the country that pays the highest attention to the specialized harvesting machinery for ratoon rice in the world, China meets more challenges in the planting area of ratoon rice in its south with more rain and deep mud feet in paddy fields. So, the harvesting agronomic requirements are more complex than common rice. It is particularly important to develop a specialized harvester for the first season of ratoon rice suitable for the national conditions of China’s ratoon rice planting areas, so as to break through the difficulties of high rolling rate, heavy rolling and low efficiency in the first season of ratoon rice. At the same time, it should cooperate with agricultural information, automatic driving navigation and other technologies to become an important part of agricultural modernization.

7.1. Difficulties and Problems in Mechanical Harvesting of Ratoon Rice in the First Season

(1) Mismatch between agricultural machinery and agronomy.

If the appropriate plant row spacing is set during the planting of ratoon rice to adapt to the mechanical harvest, that is, the mechanized harvest row planting is reserved, the rolling damage to the rice pile caused by the mechanical harvest in the first season can be avoided, the “zero rolling of the rice pile” in the first season can be realized, the field ventilation and light transmission conditions can be improved, the occurrence of diseases and pests can be reduced, and the marginal effect can be promoted.

However, the mismatch between the planting row spacing, plant spacing of the existing transplanting and sowing machines, the walking gauge and walking wheel width of plant protection machines and harvesters seriously affects the rolling effect. To reduce the rolling rate of ratoon rice during harvest and reduce the rolling by plant protection machinery, it is necessary to ensure that the gauge of the harvester and plant protection machine is an integral multiple of plant row spacing, so as to realize walking along the rows. At the same time, if the width of the walking wheel of the harvester and plant protection machine is less than the plant row spacing, the rolling of the root of rice stubble can be avoided while walking along the rows. Therefore, from the perspective of agronomy, unifying the planting mode of ratoon rice and strengthening the matching of machine parameters in the links of seed, management and harvest of ratoon rice are important ways to improve the benefits of ratoon rice.
When transplanting, sowing and disorderly throwing seedlings artificially, the plant row spacing of rice stubble is not fixed, and the density of rice is not consistent. The operation track of machine plug-in and machine broadcast is closely related to the driver’s driving technology and operation proficiency. These conditions cause irregular planting track of ratoon rice, and will also affect the rolling effect of plant protection and the harvest process. Therefore, strengthening automatic driving, navigation technology and intelligent application can better realize the integration of agricultural machinery and agronomy, improve the planting effect, and improve the harvest level of ratoon rice.

(2) Inadequacy drying of the field.
Generally speaking, before the first harvest of ratoon rice, it is necessary to drain and dry the field to make the paddy soil hard and solid for the field operation of harvester. Heavy sun drying in the middle and late stage of first season grouting can significantly increase soil hardness, alleviate the rolling damage of first season mechanical harvest to rice piles, and improve the yield of regeneration season in the rolling area, so as to reduce the yield loss of ratoon season caused by first season mechanical harvest. In recent years, the first season harvest in the southern ratoon rice planting area often encountered rainy days, which made it difficult to dry the field, the paddy field became wet and soft, and it was easy for the harvester to sink, which required high trafficability of the harvester. Therefore, the design of ratoon rice harvester must take into account the chassis trafficability and weight reduction of the whole machine while reducing the rolling rate.

(3) Wet and thick straw and large feeding amount.
In the first season of ratoon rice, the best harvest time is when 90% of the grain is yellow. At this time, the straw is still green and the moisture content is high. Because of the strong regeneration ability of ratoon rice, its stem is relatively strong, so it is required that the harvesting, transportation, and cleaning effect of thresher can perform well in facing with the negative operation requirements of large machine operation load and easy winding. There is plenty of rain in the south. If the rice field is poorly managed and there are many weeds, it will be easy for the reel to be entangled with weeds and straw when working, which makes it difficult for the reel to rotate and increases the difficulty of feeding to a certain extent. As the speed of the harvester is accelerated, the feeding amount is increasing. When the rated feeding amount is reached or even exceeded, it will often cause blockage of the conveying channel and bring damage to the harvester.

(4) The contradiction between low rolling rate, low rolling degree and lightweight.
In order to reduce the rolling area of the first harvest of ratoon rice on the rice stubble, it is necessary to increase the ratio of the cutting width of the harvester to the width of the walking wheel (track), that is to increase the header width on the basis of ensuring the complete working links of the machines and tools, which means to increase the weight of the harvester at the same time. In order to reduce the rolling degree of rice stubble and improve the recovery capacity of rolled rice stubble in the rolling area, it is necessary to reduce the grounding specific pressure, which can be realized by lightning and reducing the weight of the whole machine and reducing the size of the grounding wheel (track) of the harvester. How to find the optimal matching parameters between these two contradiction points is the design difficulty of the specialized harvester for the first season of ratoon rice.

(5) Unreasonable design of harvesting route.
The rotary harvesting path is mostly adopted for the mechanized harvesting of ratoon rice. When the warehouse is full, it returns to the grain unloading point for unloading. When the warehouse is far from the grain unloading point, it causes secondary rolling or even multiple rolling on the rice stubble in the process of leaving for the unloading point and returning to the paddy field to start harvesting, which deepens the rolling degree of the stubble, and even produces a new rolling area and increases the rolling rate.

7.2. Development Trend of Machinery Harvesting in the First Season of Ratoon Rice

(1) To promote large scale planting and popularization of ratoon rice to achieve high efficiency and low rolling harvest.
With the shortage of rural labor force and the rapid development of agricultural modernization, appropriate scale operation of agriculture has become an urgent requirement and inevitable trend to promote the transformation and upgrading from traditional agriculture to modern agriculture. Universities, research institutes and enterprises that have developed harvesting harvesters for the first season of ratoon rice provide large-scale farmers or cooperatives with specialized harvesters for the first season of ratoon rice with low rolling rate, low rolling degree and high efficiency through experimental demonstration. At the same time, they train farmers to carry out machinery harvesting work, so as to achieve efficiency and income.

(2) To develop specialized harvester for the first season of ratoon rice, to reduce the rolling rate and degree during the first season harvest, to ensure the secondary germination and tillering of ratoon rice stubble, and to improve the yield of ratoon rice.

Large-scale first season harvester for ratoon rice can be developed for large-scale planting areas of ratoon rice by increasing the cutting width and narrowing the track width. A small-scale first season harvester for ratoon rice with less feeding and a narrower cutting width can be developed for small-scale planting areas and terraced fields of ratoon rice.

(3) To carry out research on supporting devices and technologies for the first season harvester of ratoon rice.

In view of the wet, thick and strong straw with high moisture content during the first harvest of ratoon rice, the research on the cylinder and cleaning device which is more suitable for the threshing of ratoon rice is conducive to improve the threshing and cleaning effect of ratoon rice, reduce the size of threshing and cleaning devices and reduce the weight when feeding amount is also guaranteed. Combined with the requirements of stubble in the first season of ratoon rice and the biological parameter characteristics of plant and rice, the structural parameters of working parts such as header need to be optimized and the whole machine needs to lightweight. According to the agronomic requirements of straw management, the straw management device matched with the harvester should be equipped by taking scattering evenness, directional scattering after smashing and straw baling into consideration, which is conducive to reducing the coverage of stubble, enhancing the growth, and improving the yield in the second season.

(4) To carry out research on operation path planning with low rolling rate and low rolling degree as the optimization goal.

The agronomic requirements of machinery harvesting of ratoon rice in the first season are complex. According to the planting mode of ratoon rice, it is better for the harvester to walk along the rows when harvesting. For the same harvester, the grounding specific pressure only changes with the amount of grain in its grain bin, so reducing the repeated rolling area is the main way to reduce the rolling degree of rice stubble. Therefore, to carry out the research on the harvesting path planning of the first season of ratoon rice with the comprehensive rolling rate and repeated rolling area as the evaluation indicators, and design the harvesting path planning software, can not only provide the path reference for the manual driving mode, but also provide the necessary path basis for the automatic navigation driving of the harvester.

(5) To develop ratoon rice industry based on multi-disciplinary integration and multi technology integration.

It is necessary to select ratoon rice varieties with strong regeneration ability and adapt to regional ecological conditions, to standardize the planting mode in various regions, to unify the technical parameters of mechanical planting, plant protection and harvest, and to adjust the field environment timely before harvest in order to improve the yield of ratoon rice. With the comprehensive application of agricultural sensor technology, fine operation technology, intelligent equipment and Internet of things technology in the control mode of harvesting machinery equipment, feeding amount detection, performance monitoring, fault monitoring, smashing rate, impurity content and loss rate detection of each link, the work efficiency and planting benefit have been effectively improved. The deep integration of agricultural machinery, agronomy and agricultural information
technology can effectively improve the intelligence level of harvesting machinery for ratoon rice and reduce the rolling rate and grain loss.


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