

Article

Expounding the Effect of Harvest Management on Rice (*Oryza sativa* L.) Yield and Latent Loss Based on the Accurate Measurement of Grain Data

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Abstract: Due to the impact of global environment and climate change, determining how to ensure food production and reduce food loss has become an important research topic for many countries, especially developing countries, and can provide key information for China's grain harvest management. This article mainly examines the impact of harvesting period on rice yield, the existence of latent losses, and their management value. From 2019 to 2022, our team conducted experiments on the growth curve of rice grains, plants, and populations to investigate the existence of latent losses by establishing the relationship between the standard moisture weight and the days after heading. The results showed that the weight of the rice gradually decreased as the harvest time was delayed, and there were latent losses, of which the dry matter loss was about 3.5%. With the addition of grain shattering loss, the latent loss rate was about 7.0%. In summary, if rice management is strengthened, including harvesting at the optimal time, 4.67% of the loss can be recovered. The timing of the harvest significantly impacts rice yield. Understanding the process and causes of new types of rice losses, increasing the basis for judging the timely harvest period, and providing the best management measures can prevent the post-harvest losses caused by traditional methods and increase the amount of fertile land available.

Keywords: latent loss; rice; post-harvest stage; loss reduction; food loss



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1. Introduction

Rice, as one of the three major food crops in the world, feeds nearly half of the world's population and is the largest grain consumed [1], especially in low-income and middle-low-income countries [2]. Due to the impact of global climate change [3–5] and the international political situation [6–8], the consumption of food per capita is gradually decreasing. Therefore, it is necessary and strategic to ensure and increase food production, and manage and reduce food losses [9,10].

Since 2015, the FAO has undertaken numerous case studies that have shown that the harvest appears to be a common critical point for losses for all types of food crop species in the world [11]. As the beginning of the post-harvest system for grain [12], the loss of the grain harvest directly affects the quantity and quality of the grain supply [13,14]. A reduction in grain losses is equal to a direct increase in the amount of available grain, and, at the same time, it also avoids the unnecessary expenditure of grain production factors and means of production [15,16]. From an economic point of view, Shadrack shows that harvesting and post-harvest activities account for 21% of the total production cost and nearly 20% of the total loss of grain [17]. In developing countries, and sometimes not only these countries, food may be lost due to premature harvesting, where the motivation is that food is in short supply or farmers are in urgent need of funds, which directly leads to a loss in the nutritional and economic value of food [18–20]. According to the

Ministry of Agriculture's statistics, the fixed loss rate of grain during harvesting is 5.5%, including 1.5% for harvesting, 2% for threshing, and 2% for drying. Take rice planting nationwide as an example, at present, the unit area yield of rice per ha in China is about 6379 kg. Based on this loss rate, about 351 kg of grain will be wasted per ha [21]. For a big agricultural country like China, this overall base loss is undoubtedly very large. This figure is estimated according to conventional climatic conditions. If extreme climatic conditions are encountered, the grain loss will be higher in order to gather the grain quickly during harvest.

Although different scholars have extensively discussed and studied the post-harvest losses of grain, they mainly focus on its characteristics and evaluation methods [22–25], and pay less attention to the post-harvest latent losses and the possibility of participating in timely rice harvest determination. In 2019, we conducted a 5 T management experiment on the harvesting and storage of three high-quality rice varieties [26]. Our experimental results showed that the dry matter of the rice grains reached its peak on a certain day of the rice maturity period and began to decrease over time, which we call latent loss. Latent losses mainly refer to indirect quantitative losses in the post-production chain that can have an obvious negative impact on the quality of the grain itself, including losses resulting from metabolic consumption of the grain, grain shattering, etc. Grain shattering loss refers to the natural separation of seeds from the mother after they reach physiological maturity. This part of the loss is generally constrained by research methods, the technical level, and social value standards, and is not easily measured. In order to prove that the existence of latent losses is not due to errors, we selected representative rice varieties from Jilin Province for repeated experiments in 2020, and obtained confirmation of the latent losses in the dry matter of rice grains [27]. However, since the research subjects were all rice grains, they are not representative of all grain harvests. Therefore, while summarizing previous experiments, this article focuses on the post-harvest stage of grain; selecting representative rice varieties; using different sampling methods such as rice grains, individuals, and populations; implementing a fixed sampling period (once a day); designing relevant experiments; establishing a standard moisture weight model for rice; calculating its latent loss rate; analyzing key loss points in the harvest process; and studying the existence and management value of latent losses. The aim is to generate widespread attention, provide a new path for grain loss management, and provide guidance and a reference for the post-harvest losses of grain at home and abroad [28].

2. Materials and Methods

2.1. Plot Location and Test Materials

This experiment was conducted from 2019 to 2022, and rice was used as the research material. The experimental sites and rice varieties are listed in Table 1. The experimental conditions were basically the same in each year, and the experimental field had a deep soil layer, which was a moderately fertile meadow-type rice soil, with a PH value of approximately 7. Convenient irrigation and drainage, good water and fertilizer conservation and permeability, and the management measures used during the grain growth period were the same as those of the local production, and the pesticide and chemical fertilizer dosage and time of use were the same, without adverse stress; all other conditions were basically the same.

2.2. Data Processing

Due to the problems of insufficient detection accuracy and long sampling and detection times (about 7 days) in previous research, as well as the relatively low level of latent loss and many interference factors, it is difficult to accurately detect the quantitative and changing problem of latent loss (including damage) at each stage of the grain harvest, which has caused latent loss to be revealed only recently.

By analyzing the data, the optimal harvest date for each variety was determined, and then a standard moisture weight model was established. Based on the average harvest day

of rice, a linear or nonlinear regression model was used to calculate the latent loss and loss rate of dry matter. The various indicators were measured and calculated as follows.

Table 1. Rice varieties and plot location.

Plot Location	Longitude	Latitude	Date	Variety
Jilin City, Jilin Province	126.37	44.02	11 September 2019–11 October 2019	Jijing 816, Wuyoudao 4 Jijing 511, Jijing 816, Jinongda 667, Qinglin 611, Tianlong 619, Wokeshou 1, Fangyuan 77, Zhongke 804, Zhongkefa 5, Daohuaxiang 9, Wuyoudao 4, Longyang 13, Zaoxiang 7, Longyang 16, Songjing 29, Longyang 7, DF416, Jijing 561
			5 September 2020–17 October 2020	Songjing 16, Jihong 6
			19 September 2020–16 October 2020 8 September 2021–28 October 2021 10 September 2022–20 October 2022	Jihong 6, Chaojidao Jihong 6
Changchun City, Jilin Province	125.74	44.08	20 September 2022–10 October 2022	Changjing 729, Nongjing 306, Deyu 317, Tongke 28
Gongzhuling City, Jilin Province	124.75	43.47	12 September 2019–9 October 2019	Jijing 528
Baicheng City, Jilin Province	122.53	45.35	10 September 2022–20 October 2022	Jihong 6, Daohuaxiang 2
Jiamusi City, Heilongjiang Province	130.37	46.79	27 September 2020–18 October 2020 23 August 2021–12 October 2021	Xinfeng 6, Longdun 1614 Xinfeng 6
Wuchang City, Heilongjiang Province	127.36	45.03	15 September 2020–12 October 2020 1 September 2021–30 October 2021 10 September 2022–20 October 2022	Daohuaxiang 2 Daohuaxiang 2 Daohuaxiang 2, Zhongkefa 5
Panjin City, Liaoning Province	122.07	40.75	15 September 2021–31 October 2021 10 September 2022–20 October 2022	Yanfeng 47, Qiaoyuxietian Tianlong 619
Mishan City, Heilongjiang Province	131.85	45.53	20 September 2022–25 October 2022	Qijing 10
Yancheng City, Jiangsu Province	120.15	33.40	15 September 2022–10 October 2022	Ningxiangjing 9
Nanchang, Jiangxi Province	115.97	28.79	20 September 2022–31 October 2022	Yexiangyoulisi

2.2.1. Determination of the Standard Moisture Weight

The moisture content of rice (W_{H_2O}) was determined using the national standard GB/T 20264-2006 [29]. For the determination of the dry matter weight (M), refer to the Experimental Design section for details. Finally, the dry weight was converted into the standard moisture (15% w.b.) weight, and its moisture content was 15.0%.

2.2.2. Determination of the Sample's Optimal Harvest Days

During data processing, the maximum and the minimum values of the standard moisture weight data of each rice variety were determined, and if the value was at either end of all the data, the value was omitted; if it was not at the ends, averaging was performed and the rest of the data were filled in accordingly. Finally, all the data were processed to obtain the standard moisture weight homogenization data of the different rice varieties. In order to analyze the direct influence of the standard moisture weight and the number of days between rice heading and harvest, linear and nonlinear regression analyses were carried out on the obtained data, and finally the model with the highest adjusted R^2 value was selected. The optimal harvest day is the day when the rice weight reaches its maximum during rice growth.

2.2.3. Latent Dry Matter Loss and the Loss Rate

The latent loss of dry matter (Δm) was defined as the weight change value between the standard moisture weight of rice on its optimal harvest day (m_0) and its standard moisture weight on the average harvest day (m_1) of the experimental area. The formula is as follows (1):

$$\Delta m = m_0 - m_1 \quad (1)$$

The latent loss rate of dry matter (URL) is defined as a ratio of the latent loss of dry matter to the standard moisture weight of rice on its optimal harvest date. The formula is as follows (2):

$$\text{URL} = (m_0 - m_1) \div m_0 \times 100\% \quad (2)$$

2.3. Experimental Design

We attempted to investigate the latent loss of rice through different rice research units, such as grains, plants, and populations, using the thousand-grain weight method, hundred-spike method, unit area method, and fixed area tracking method. We studied the impact of the harvest period on rice yield, provided a basis for determining the timely harvest period of rice, and provided a reference for farmers and researchers in grain conservation and loss reduction. The specific operation of each method is as follows.

2.3.1. The Method Used to Determine the Thousand-Grain Weight of Rice

In the rice experimental field, the middle 10 m $\times$ 10 m plot with flat, square, and uniform fertility was selected as the experimental area. According to a 5-point sampling method, 15~20 plants were sampled at each point, and marginal effects were avoided as much as possible. Samples with uniform and full grains were selected for subsequent experiments. Forty days after heading, the samples were sampled every day for about thirty days. After threshing and hulling, the dry matter weight of 1000 grains and the moisture of brown rice were measured, and a regression equation between the standard moisture weight of 1000 grains and the number of days after heading was established.

The method for calculating the dry matter weight of 1000 grains is as follows: firstly, measure the water content (W_{H_2O}) of brown rice grains; then, randomly sample 500 brown rice grains using the quartering method, put forward broken grains, weigh them (m_t), record the number of whole grains (N), and calculate the dry matter weight of 1000 grains (M) with an accuracy of 0.0001 g [30]. All test results need to be repeated three times to obtain their average.

$$M = m_t \times 2 \times (100 - W_{H_2O}) \div N \quad (3)$$

Finally, the dry weight of 1000 grains were converted into the standard moisture (15% w.b.) weight of 1000 grains, and their moisture content was 15.0%.

2.3.2. Unit Area Determination Method

After harvesting about 3 m² of rice each time, the actual area was measured with a meter ruler. After transporting the harvested rice back to the experimental site, it was immediately threshed by hand. During threshing, there should be no crushing or weight loss. After threshing, the moisture and weight of the wet grain were recorded and its dry matter weight per unit area was calculated. A change model of the rice yield was established, using the standard moisture weight of the rice and the number of days after headings.

The method for calculating the dry matter weight of rice per unit area is as follows: firstly; measure the moisture content (W_{H_2O}), the row spacing (a), and the hole spacing (b) of the harvesting area; and then calculate the dry matter weight per unit area (M). All the test results needed to be repeated three times to obtain their average.

$$M = m_t \div ab \times 10^4 \times (100 - W_{H_2O}) \quad (4)$$

Finally, the dry weight of the unit area was converted into the standard moisture weight of the unit area, and its moisture content was 15.0%.

2.3.3. One-Hundred-Spike Weight Determination Method

A 10 m long ridge of rice with uniform growth was selected for harvesting each time. After the harvested rice was transported back to the test site, 100 spikes of rice were randomly selected for collection, and their weight and moisture content were measured to calculate the dry matter weight of 100 spikes and the regression equation of the relationship between the 100-spike standard moisture weight and days after heading was established.

The method for calculating the dry matter weight of 100 spikes is as follows: firstly, measure the water content (W_{H_2O}), randomly sample 100 spikes of rice, pay attention to the completeness of sampling, and weigh (m_t) to calculate the dry matter weight (M) of 100 spikes, with an accuracy of 0.0001 g. All test results needed to be repeated three times to obtain their average.

$$M = m_t \times (100 - W_{H_2O}) \quad (5)$$

Finally, the dry weight of 100 spikes was converted into the standard moisture weight of 100 spikes, and their moisture content was 15.0%.

2.3.4. Fixed Area Tracking Method

After obtaining the satellite signal and setting the measurement parameters, the actual area of the rice experimental plot was measured using a GPS area-measuring tool (China), and the measured area was divided into two equal parts as much as possible according to the actual planting terrain. After mechanically harvesting one part at a time, according to the time frames of timely harvesting and natural harvesting, the grain yield of each part was measured. The measured results were converted into the change model of rice yield per mu, according to the standard moisture content of the rice.

2.3.5. Shattering Weight Determination Method

In this experiment, three representative one-square-meter ranges in the same paddy field were selected for each variety to avoid boundary effects. After the experiment began, the fallen grains were picked up from three rice fields every day, and they were picked up from the periphery of each one-meter-square rice field to avoid rice falling due to human factors. Fallen grains were picked up and put in a self-sealed bag, and the variety and time were marked. Then, we used scissors to take samples from the same variety of rice for moisture measurement. We took the packed samples back to the laboratory for moisture measurement and weighing. Moisture measurement was carried out on three parallel samples, and we measured the weight of the fallen grains. The calculation formula of the shattering loss rate was as follows:

$$SRL = m_s \div [(m_1 \div 10 \div 667) \times 1000] \quad (6)$$

In the formula, SRL is the rice grain loss rate (%); m_s is the weight of falling grains per square meter (g); and m_1 represents the yield of rice per mu (kg).

3. Results

3.1. Determination Results of 1000-Grain Weight

3.1.1. Experiments in 2019

In 2019, the growth curves of three rice varieties were measured at the rice experimental bases in Jilin City, Jilin Province, and Gongzhuling City, Jilin Province, using the 1000-grain weight method. To preprocess the data after establishing the best harvest date, it is necessary to convert the 1000-grain weight of rice dry matter into its 1000-grain standard moisture weight and establish a linear regression model of the 1000-grain weight's standard moisture. The results showed that, with the change in the curve, the 1000-grain dry matter weight of the rice decreased, as shown in Figure 1. That is to say, if the rice was not

harvested at the right time, the yield would decrease rather than increase with the increase in days after heading, and it was estimated that a delayed harvest would produce a 3.47% latent loss of dry matter.

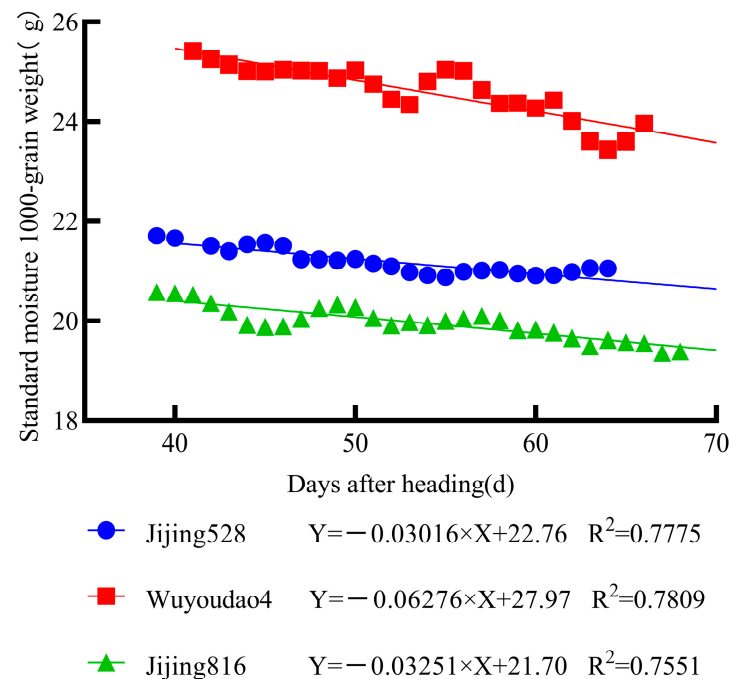


Figure 1. Relationship between 1000-grain standard moisture weight of rice and days after heading in 2019.

3.1.2. Experiments in 2020

In 2020, the latent loss of the dry matter of rice was tested at the rice experimental base in Jilin City, Jilin Province, and 18 rice varieties were tested. The rice used in the test comprised representative varieties of those grown in Jilin Province, covering round and long grains, late maturity, and middle maturity. In this experiment, the 1000-grain weight method was also used to sample and measure the rice. The regression curves and correlation coefficients (R^2) of the 18 rice varieties were obtained by establishing a 1000-grain standard moisture weight model for rice, as shown in Table 2. From the results of the regression curve and correlation coefficient analysis, the first-order coefficient of the regression curve of the 18 rice varieties is negative, and 12 of them have R^2 values greater than 0.5, which further explains that the dry matter weight decreases gradually with the increase in rice growth time. Furthermore, there is a latent loss of dry matter and, when rice is not harvested at the best time, this loss can reach 3.53%.

Table 2. Regression curve model and correlation coefficient of rice's 1000-grain standard moisture weight in 2020.

Variety	Regression Equation	R^2	Variety	Regression Equation	R^2
Jijing 816	$y = -0.0372 \times X + 22.390$	0.6850	Zhongke 804	$y = -0.0344 \times X + 26.035$	0.6178
Wuyoudao 4	$y = -0.0347 \times X + 27.865$	0.7502	Jinongda 667	$y = -0.0295 \times X + 21.654$	0.3805
Longyang 16	$y = -0.0320 \times X + 24.502$	0.6337	Wokeshou 1	$y = -0.0216 \times X + 25.358$	0.3345
Songjing 29	$y = -0.0182 \times X + 24.218$	0.4218	Tianlong 619	$y = -0.0324 \times X + 30.183$	0.6548
Longyang 7	$y = -0.0274 \times X + 25.038$	0.5872	Jijing 511	$y = -0.0273 \times X + 21.822$	0.8062
Fangyuan 77	$y = -0.0234 \times X + 27.997$	0.2620	DF 416	$y = -0.0545 \times X + 30.121$	0.8323
Jijing 561	$y = -0.0370 \times X + 25.728$	0.9489	Qinglin 611	$y = -0.0317 \times X + 25.020$	0.6190
Longyang 13	$y = -0.0333 \times X + 25.580$	0.7035	Daohuaxiang 9	$y = -0.0133 \times X + 25.084$	0.3448
Zhongkefa 5	$y = -0.0595 \times X + 29.708$	0.3984	Zaoxiang 7	$y = -0.0371 \times X + 27.337$	0.6381

3.2. Determination Results of Unit Area Method

3.2.1. Experiments in 2020

In 2020, the management system of the 5 T Smart Farm collected the harvest data of six rice varieties using the unit area method. After harvesting about 3 m² of rice each time, the actual area was verified. According to our experience, the suitable harvest period of rice is generally 45~55 days after heading. After linear fitting, the overall yield showed a downward trend from 55 d to 75 d after heading, which showed that a delayed harvest would lead to latent losses, and the result reached a significant 7.16%. Figure 2 shows the relationship between the yield of rice varieties and the days after heading in 2020. That is to say, according to the existing field harvesting methods and the annual rice yield in Jilin Province, the rice yield was 478,000 t with this latent loss.

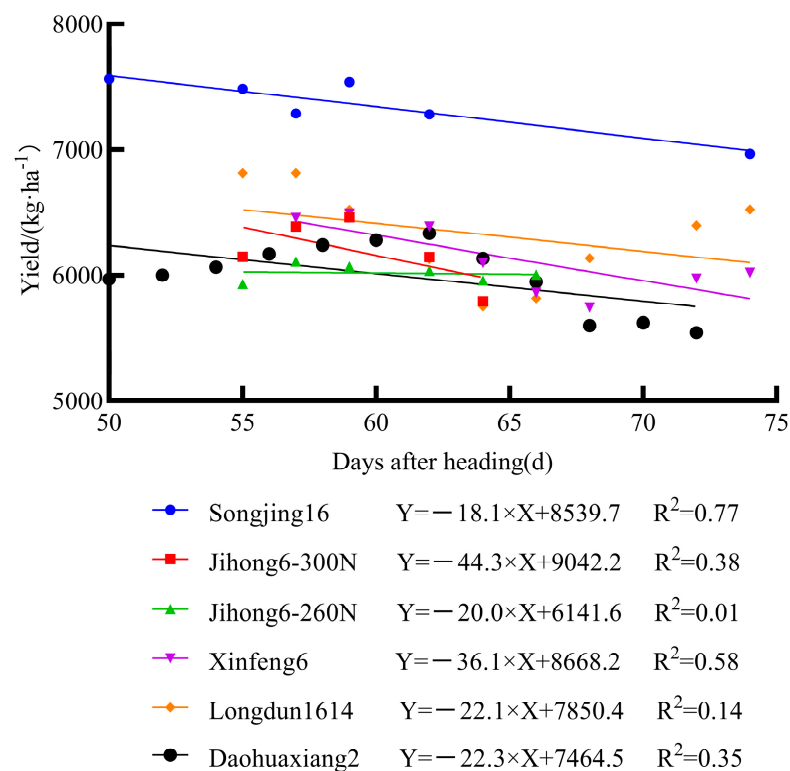


Figure 2. Relationship between rice yield and days after heading in 2020.

3.2.2. Experiments in 2021

In 2021, varieties of rice with and without fragrance were selected in a northern experimental area and a total of six varieties were tested. Due to relatively sufficient preparation work, samples were taken around one week before the estimated timely harvesting period, and the experiment lasted for about 50 days, until the farmers finished harvesting. The start time varied according to the actual environment, such as the climatic conditions in various places. Using the unit area method, the collected rice was threshed manually; the rice grains were not broken and there was no weight loss during the process. By establishing a model for the unit area weight of the standard moisture content in rice, regression curves and correlation coefficients (R^2) were obtained for the six rice varieties, as shown in Figure 3. From the results of the regression curve and correlation coefficient analysis, it can be seen that the coefficients of the rice regression curve are all negative, and the R^2 values are all greater than 0.5, indicating that the total yield will gradually decrease with the increase in rice growth time. After calculation, it was concluded that the final yield experienced a significant 7.05% latent loss.

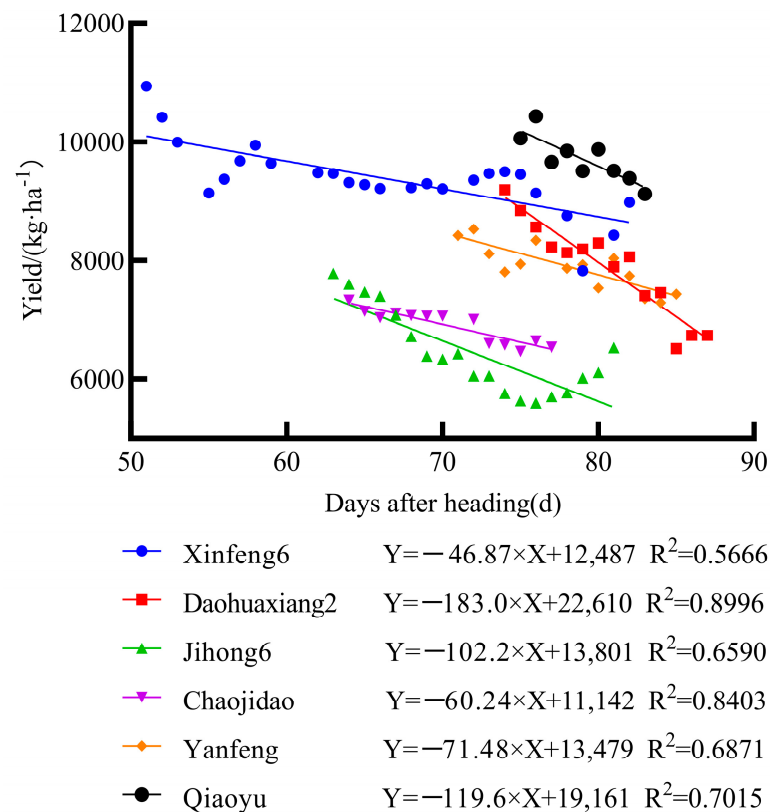


Figure 3. Relationship between rice yield and days after heading in 2021.

3.3. Determination of the Results of the 100-Spike Weight Method

In 2022, a population-latent loss test of four rice varieties was carried out at the Jiutai District experimental site of Changchun City, Jilin Province. Although the latent loss of the rice population was explored using the unit area method, considering the influence of growth characteristics and the yield of the rice population, the 100-spike weight method was used to detect the yield, and a regression equation of the 100-spike standard moisture weight and days after heading was established. From the analysis of the varieties' regression curves and correlation coefficients, it can be seen that the first-order coefficients of the different samples are all negative, indicating a downward trend in the curve. The R^2 values are 0.6833, 0.6717, 0.8331, and 0.9576, respectively, indicating a good fit and reliable trend line. In other words, if rice is not harvested at the appropriate time, as the number of days after heading increases, the weight will decrease rather than increase. Based on the best harvest date of 55 days after heading, harvesting beyond this date is regarded as incurring a loss, and the average loss rate of four of the tested varieties of rice is 11.41%, as shown in Figure 4.

3.4. Determination of the Results of the Fixed Area Tracking Method

In 2022, fresh-cutting experiments were carried out on seven rice varieties at eight bases of seven factories across five northern and southern provinces (Jilin, Heilongjiang, Liaoning, Jiangsu, and Jiangxi), with an experimental area of about 2000 mu. The measured results were converted into the change model of rice yield per mu according to the standard moisture content of the rice, as shown in Figure 5. After this multi-sector experiment, the yield loss rate of delayed harvesting was 1.66–7.88%, and the average latent loss rate reached 5%. Based on the annual rice output and the existing 5,785,100 hectares of cultivated land for rice in Jilin Province in 2022, if the fresh-cutting method is widely adopted, the loss of about 2.04 million tons of rice can be reduced, which is equivalent to an increase of 289,000 hectares of cultivated land.

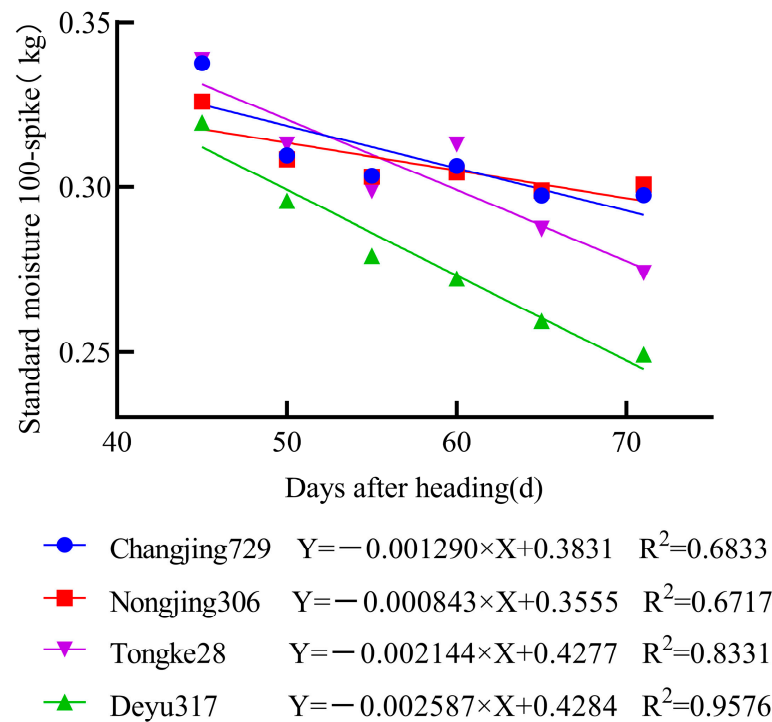


Figure 4. Relationship between 100-spike standard moisture weight of rice and days after heading in 2022.

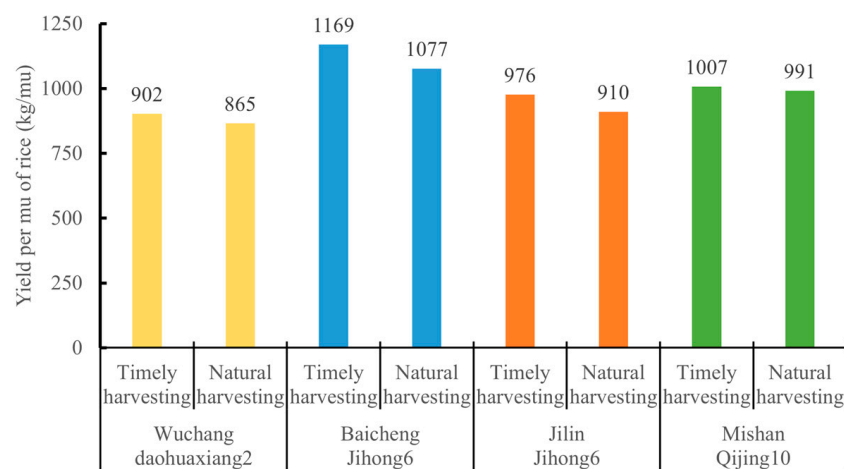


Figure 5. Rice yield per mu in 2022.

3.5. Determination of the Results of the Shattering Weight Method

In 2020, in order to verify the yield loss caused by natural grain shattering and collision grain shattering during rice harvesting, the grain shattering loss rate of four varieties of rice with a delayed harvest was measured in four areas of Jilin Province. The experimental results show that there is a loss in falling grain during harvest, as well as the latent loss in dry matter, with an average loss rate of 3.02%. Combined with the dry matter loss and grain loss, in 2020, the latent loss rate caused by the delayed harvest reached 6.55%.

In 2021, in order to verify the existence of post-harvest grain losses, an experiment was carried out to determine the loss rate of post-harvest grain loss in Jilin city, Jilin Province. In this experiment, representative varieties of the rice grown in Jilin Province were selected—Jijing 811, Zhongkefa 5, and Daohuaxiang 9—and three areas of 1 m² were selected for the observation of grain shattering. According to the local harvesting habits at the experimental site, the starting date for calculating the grain loss of delayed rice harvesting is 55 days after

heading, and the grain loss rate generated at the end of rice harvesting was thus calculated; the daily grain loss was summed to create a fitting curve, and the average natural loss rate of three varieties of rice was 0.93%. The reason why this numerical value is lower than that of the falling grain loss rate measured in 2020 is because the time period measured across in 2020 was longer than that in 2021, while, at the same time, the area experienced the challenge of changing conditions such as heavy snow; thus, more seeds fell and more fallen grains were picked up, and the measured value was larger, as shown in Figure 6. To summarize, there was a loss of falling seeds during harvest. When rice is immature, the connection strength of fruit stalks is high, and a large external force is required to make grains fall. As rice matures, the plant's activity decreases, the connection strength of the fruit stalks is low, and the external force required to generate grain falling is small, so there is a greater loss of falling seeds in the field.



Figure 6. Grain shattering conditions: (a) grain shattering in 2020; (b) grain shattering in 2021.

In conclusion, we calculated the latent loss rates of rice calculated using different research methods, as shown in Table 3.

Table 3. Summary of experiments on the latent loss of rice.

Year	Experimental Method	Fallen Grain Loss Rate	Dry Matter Loss Rate	Latent Loss Rate
2019	1000-grain weight determination method		3.47%	
2020	1000-grain weight determination method		3.53%	
	Shattering weight determination method Unit area determination method	3.02%		7.16%
2021	Shattering weight determination method	0.93%		
	Unit area determination method			7.05%
2022	100-spike weight determination method			11.41%
	Fixed area tracking method			around 5%

4. Discussion

4.1. The Latent Loss of Rice Exists

When considering different years and temperatures, the latent loss rates and research methods vary, but it can essentially be determined that there are various latent losses in rice harvesting. In 2019 and 2020, the thousand-grain weight measurement method was used to focus on the weight changes of the grains themselves, including the loss of dry matter in rice. The latent loss rate of dry matter in rice grains was measured to be around 3%. In 2020 and 2021, the unit area measurement method was used; although there is a possibility of rice seed scattering during manual harvesting, this process is controllable when using this method. By accurately measuring factors such as the sampling area and sampling weight of rice, the latent loss rate of rice was accurately measured to be around 7%; however, due

to the complexity of the unit area method, the hundred-spike measurement method was used to explore the latent losses of rice in 2022. However, due to the large difference in the number of grains per spike, although homogenization was performed, the results were more random, with latent losses of about 11%. It is on this basis that the research scope was expanded, and a fixed area tracking method was adopted to conduct research on the latent losses of rice at eight research bases across the country. This research method requires a large amount of manpower and mechanical harvesting, and the harvested area and weight of rice cannot be accurately measured. The obtained result is an estimated value, but the experimental scope is large. National harvest experimental data can be filled in, and the latent losses of rice were measured to be about 5%. In addition to the latent loss of dry matter in rice, there are other forms of latent loss. Part of the reason for rice loss is that the higher the maturity of rice, the more mature the grains are, and the easier it is for them to fall off the plant; during mechanical harvesting, rice seeds do not directly fall onto the cutting table after collision [31–34]. Our experimental analysis shows that, in addition to dry matter loss, the rice grain shattering loss rate during the harvesting stage is about 3%.

In summary, although the rice varieties and planting years were different during the trial period, the results indicate that latent losses do exist and can occur in erroneous operations such as overdue harvesting in the rice harvesting chain. What can be determined at this point is that the loss of dry matter is about 3.5%, and, combined with the grain shattering loss, the final latent loss rate is around 7.0%.

4.2. Latent Loss and Optimal Harvest Days

In many studies on grain growth, the weight curve of rice shows a rapid and then slow increase until it remains stable at a certain value, without any latent loss of weight [35–37]. This phenomenon does not match our experimental results, because the sampling time in the literature is too long, the sampling varieties are too few, and the relatively small amount of dry matter loss is covered up because of randomness. Therefore, an experiment was designed to explore the latent losses of rice by studying the changes that occur across different research units, such as rice grains, plants, and populations, with an increasing heading time. Estimating latent losses requires two time points: one is the optimal harvest period for rice, and the other is the date of the actual harvest operation. Ensuring the optimal harvest period for rice is an effective operation to ensure high yield and quality of rice. Rice should be harvested in a timely manner, with the optimal harvest period ranging from 45 to 55 days after heading [38]; during this period, the grain loss caused by delayed harvesting and mechanical harvesting can be reduced. Ultimately, the number of days after heading is used as the main judgment method for timely harvesting of experimental varieties, and is simple and easy to operate.

4.3. Value of Latent Loss Management

In this experiment, we selectively monitored and controlled the technical status of different rice varieties during their harvest period based on real-world conditions, studied field operation problems, and analyzed the latent losses and management value of the rice harvest process based on experience gained from relevant regional production practices.

Based on China's annual rice production of 210 million tons and a latent loss rate of 7%, this proposed harvesting method could recover two-thirds of China's rice loss, reducing the loss of dry matter and grain shattering during the harvest period. We determined that timely field management can reduce the loss rate by 4.67% and the loss of post-harvest rice by 9.8 million tons. Based on the minimum rice purchase price of 2.62 CNY/kg this year [39], the loss value of the rice harvest reached CNY 25.69 billion. New drying equipment is priced at CNY 5 million, and 5138 drying machines could also be purchased for that amount of money. According to the estimated annual drying of 12,000 tons of rice per facility, 61.66 million tons of rice could be dried annually. A drying facility with a processing capacity of approximately 246.64 million tons can be built within four years, which is approximately equivalent to the weight of China's annual rice production. Essentially,

our method can prevent grain from falling to the ground, ensure appropriate processing moisture, and ensure the quality of rice for consumption. It would only take four years to reach the investment's breakeven point while demonstrating the value of managing latent losses after rice production.

5. Conclusions

Reducing food losses is a long-term and arduous task. In the fields of food and agriculture, latent loss is still a new concept, and research on it has just begun. From 2019 to 2022, under the research conditions of short and continuous sampling intervals and large-scale sampling detection, latent loss experiments were conducted in multiple regions on several varieties of rice. The research results show that the average latent loss rate of the rice harvest is about 7%, and timely harvesting can restore two-thirds of the rice loss, i.e., about 4.67%, which is equivalent to 9.8 million tons of rice and one-fifth of the annual rice yield of Jilin Province. Our experimental results fully demonstrate the existence of latent losses in the grain harvesting process, and to some extent prove that delaying harvesting will reduce the total rice yield, rather than increase it. We propose a new perspective on food loss management, aimed at avoiding the losses caused by incorrect methods and improper management. If timely harvesting and supportive management operations can be promoted, the latent losses of rice can be mitigated every year; the amount of tangible fertile land can be increased; agricultural production methods and habits can be further improved; and high-quality food engineering, farmland protection, and agricultural development can be promoted, thereby achieving rural revitalization.

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