Empirical Analysis of the Main Factors Influencing Rice Harvest Losses Based on Sampling Survey Data of 10 Provinces in China

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Abstract

Grain security should be a priority for the Chinese government when managing state affairs. The total rice production needs to remain stable at more than 200 million tons. However, there have been serious rice harvest losses, especially the harvest stage. In this study, the meaning of rice harvest losses was defined based on previous research findings on the definition of grain harvest losses and the realities in China. The current rice harvest losses in different areas in China were analyzed based on sampling survey data from 957 farmers in 10 provinces in China. On this basis, the main factors influencing rice harvest losses and their marginal effects were analyzed using the ordered multinomial logistic model. The survey found that 56.22% of respondents believed that rice harvest losses were 4% or lower in China, though there were differences among the provinces. The proportion of family rice-farming income, size of production area, level of mechanization, timely harvest, and operational meticulousness had negative effects on rice harvest losses. On the other hand, farmers’ experience of employment as migrant workers had a positive effect on rice harvest losses. In addition, bad weather and short handedness during harvest significantly increased rice harvest losses.

Keywords: *rice, harvest losses, ordered multinomial logistic model, marginal effe*ct

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1. Introduction

For 11 years in a row, rain output increased in China and was estimated to be 607.1 million tons in 2014[*]. This was a record high yield, a 0.9% (5.16 million tons) increase over 2013[†]. Another historic breakthrough occurred in 2014 when China's grain output surpassed the previously high level of 600 billion kilograms. The continuous increase in grain output of China not only plays an important role in its own smooth economical operation, but also contributes to world food security. However, studies indicate that China's grain supply will face serious challenges due to tight resources, frequent extreme weather events, population growth, rigid growth of grain demand for feed and processing use, and uncertainty in the world grain market (Aulakh and Regmi, 2013; Li, 2014). The Food and Agriculture Organization of the United Nations (FAO) estimated that the average annual growth rates of grain production and supply/consumer demand would be 1.7% and 1.9%[‡], respectively, between 2013 and 2022 in China representing a gradually widening gap between grain supply and demand (Liu *et al*., 2013). The Development Research Center of the State Council of China reported that China's grain imports exceeded 90 million tons in 2014, accounting for 15% of domestic grain production. This included 19.51 million tons of cereal imports (an increase of 33.8% over 2013), and 71.4 million tons of soybean imports (an increase of 12.7% over 2013)[§]. Grain losses and waste are serious outstanding problems in China's grain security. However, in terms of grain security, China has placed great emphasis on pre-harvest input and management of production factors, while paying seriously insufficient attention to reducing post-harvest grain losses and waste. China's annual post-harvest grain losses are estimated to be 50 billion kilograms. This amount is equivalent to the grain output of 200 million mu of

[*] National Bureau of Statistics of the People's Republic of China: Announcement on grain output in 2014 by the Bureau of Statistics, http://www.stats.gov.cn/tjsj/zxfb/201311/t20131129_475486.html.

[†] National Bureau of Statistics of the People's Republic of China: Announcement on grain output in 2014 by the Bureau of Statistics, http://www.stats.gov.cn/tjsj/zxfb/201311/t20131129_475486.html.

[‡] This grain production and consumption data in China and other data presented in this paper refer to mainland China, excluding Taiwan, Hong Kong, and Macao.

[§] http://news.1nongjing.com/a/201504/83458.html, China Agricultural Outlook Prospect Report (2015-2024), 2015-04-21.

arable land. In addition, China's post-harvest grain loss rate* is approximately 10%, much higher than the world average of 3% to 5% and that of developed countries (Guo *et al*., 2014). Post-harvest grain losses represent a waste of manpower, fresh water, arable land, fertilizers, and other resources expended during grain production (Ridoutt *et al*., 2010; Gustavsson *et al*., 2011). In addition, greenhouse gas emissions, arising from previous production and subsequent waste treatment of lost grain, can exert tremendous pressure on the environment (WRAP, 2011; Dorward, 2012; Kummu *et al*., 2012).

The post-harvest system of grain has a rich meaning. The levels and causes of post-harvest grain losses vary with the different post-harvest stages and grain varieties. In China, the post-harvest period of grain can be generally divided into seven stages, harvest, transport, drying, storage, processing, distribution, and consumption (Cao and Jiang, 1999). As the first stage of the post-harvest period, harvest has a special status in reducing post-harvest grain losses. Rice, for example, is one of the most important grain crops in China, with an output accounting for approximately 33.83% of the domestic grain output in 2013†. Along with the urbanization process, a large number of young farmers have migrated to the cities. As a result, women and older male farmers have become the main labor force for rice production. This situation has not only led to extensive initial post-harvest processing by traditional small-scale farmers, but also has further increased rice harvest losses (Zhang *et al*., 2009). Therefore, an empirical analysis of the key nodes and main influencing factors of rice harvest losses can provide a reference for the government for guiding farmers in controlling post-harvest rice losses.

2. Literature review and concept definition

Post-harvest food losses can be further divided into food losses and food waste. Based on the different factors causing food losses, Aulakh and Regmi (2013) defined those in two ways.

* Post-harvest grain loss rate is the ratio of post-harvest grain losses to total grain output.
† Source: The website of National Bureau of Statistics of China (http://www.stats.gov.cn).

Those based on objective factors (such as natural conditions and technical equipment) were defined as as food losses, and those caused by decision-making mistakes of the supply chain players as food waste. Priefer *et al*. (2013) regarded food waste as a subset of food losses. Food losses include all food that runs off the supply chain, while food waste refers a particular part of food losses caused by human factors. Zhang *et al*. (1998) and Song *et al*. (2015) made no distinction between losses and waste in their analyses of post-harvest food losses in China. They believed that waste fell into the moral category, rather than an economic or technical category, and was just a judgment on post-harvest food losses. Based on the existing literature, the authors believed that food losses referred to a reduction in the quantity and quality of edible food in the post-harvest supply chain, and that losses caused by human factors were called food waste*.

In the early 1990s, Zhejiang Academy of Agricultural Sciences (1991) subdivided the post-harvest grain losses of China into nine sub-systems, i.e., harvest, threshing, transport, cleaning, drying, storage, processing, distribution, and consumption. Teshome *et al*. (1999) divided the post-harvest grain losses of African countries into seven stages, including harvest, transport, drying, threshing, storage, processing, and consumption. However, most researchers divided the post-harvest grain losses based on the conditions of developing countries with a low mechanization level. At present, the mechanization level in rice harvesting has been increasing rapidly in China. According to statistics, 73.59% of rice was harvested by machine in 2012 throughout China (Liu *et al*., 2014). In addition, the area of rice harvested via the combine harvesting method accounts for an increasing proportion of rice planting area. Unlike traditional segment harvesting, reaping and threshing are completed in one operation through the combine harvesting method. Hence, it is difficult to make a strict distinction between the actual losses of reaping and threshing in practice. Therefore, rice harvest losses can be defined as a reduction in quantity or quality of rice due to natural conditions, technical

* As there are no uniform definitions for food losses and food waste, and previous studies did not make a strict distinction between them due to practical factors, grain losses discussed in this paper cover grain waste, in order to improve the comparability between China's grain harvest loss data and those in other countries.

equipment, management skills, and farmers' decision-making from reaping and threshing to bagging (loading).

The main factors influencing rice harvest losses have been analyzed from different angles. Timely harvest is crucial to reducing the loss of rice quantity and quality during a harvest. It has been noted that the period from 10 to 15 days after physical maturity is the best time to harvest rice (Akar *et al*., 2004). Lantin (1999) suggested that premature harvesting led to inclusion of a large amount of immature rice with a high moisture content, while delayed harvesting exposed mature rice to risks of being attacked by insects, birds, animals, and microorganisms; timely harvest not only reduces the impact of bad weather on output, but also decreases the crack ratio[*]. It was also demonstrated that harvesting too early led to a lower grain weight. Timely harvest based on rice maturity and local climatic conditions can not only improve rice yield, but also provide a higher milled rice rate and a better cooking quality (Chen *et al*., 2006). Weather conditions during harvest also have a close relationship with rice harvest losses. Akar *et al*. (2004) indicated that rainy weather during harvest would exacerbate pest problems and premature senescence, resulting in a decreased maturation rate, and thus yield losses. Moreover, prolonged exposure of mature rice to high temperatures and humid environments would increase perishability, resulting in reduced yield and quality of rice (World Bank *et al*., 2011). Continuous rainy weather would not only lead to a sharp drop in the biological production of rice, but also result in mildew of unhusked rice spread on the ground due to untimely sun-drying (Fei *et al*., 2013). Furthermore, stormy weather will increase the lodging area of rice and harvest difficulty, resulting in shattering and pre-harvest sprouting during reaping and threshing, thus increasing harvest losses (Zhang *et al*., 2013).

Rice harvest losses are directly related to field management as well as the meticulousness of farmers' harvesting operations. World Bank *et al*. (2011) found that pre-harvest management and decisions, such as planting density, field management (weeding,

[*] The occurrence of transverse cracks in rice grain is termed "cracking", which not only reduces grain quality, but also increases the broken rice rate in post-harvest processing.

disinsection, fertilization, etc.), and timely harvesting, had an impact on final rice harvest losses. In addition, Hodges and Maritime (2012) believed that non-meticulous harvesting operations would significantly increase the quantity loss of rice during harvest, and that random placement of rice ears would make the rice more vulnerable to microorganisms, thus causing a greater quality loss. Appiah *et al*. (2011) reached a similar conclusion that rice harvest losses in different plots were closely related to field weed control, farmers' harvest experience and skills, and the meticulousness of harvesting operations. Harvesting methods* also influence rice harvest losses. Lantin (1999) indicated that, compared to combine harvesting, segment harvesting involved more stages, and each stage inevitably caused quantity and quality losses of rice. However, Akar *et al*. (2004) pointed out that harvesters might substantially increase the operation speed of machines to increase the harvest area per unit time during combine harvesting, thus increasing the harvest loss rate. Li *et al*. (1991) suggested that due to unreaped rice and harvest shattering losses, rice losses during combine harvesting were much greater than those during segment harvesting. Feng and Sun (2014) also believed that the effect of combine harvesting was susceptible to mechanical properties and operator skills, while segment harvesting allowed more meticulous harvest of lodged rice and provided a threshing efficiency of 99.5%, as well as comprehensive loss rates of 2% or lower.

In addition, the causes of rice harvest losses have also been analyzed from the perspective of economic and social development. Grethe *et al*. (2011) noted that socio-economic factors and agricultural technology were the main causes of rice harvest losses in developing countries. Buchner *et al*. (2012) found that rice losses at the front end of the post-harvest supply chain were significantly higher in developing countries than in developed countries, and that the main reason was related to the fact that small-scale labor-intensive agricultural production in developing countries was inefficient due to the limitation of capital, technology,

* There are two main harvesting methods: combine harvesting and segment harvesting. The latter includes reaping, bundling, stacking, picking, threshing, and cleaning.

and management. Priefer *et al*. (2013) suggested that rice harvest losses were increased by farmers' poor harvesting operation skills, insufficient government management, and a lack of relevant policies. Liu (2014) found that inadequate infrastructure, poor awareness of grain saving and loss reduction, lag in harvesting operation technology, and small-scale scattered production were common factors affecting post-harvest rice losses in China and other developing countries.

The existing research results serve as an important reference for this study. After summarizing and reflecting on the previous research results, the authors found two significant deficiencies in existing studies. First, most existing studies focus on the assessment of rice losses in all post-harvest stages, while rice losses in a particular stage and the influencing factors have rarely been analyzed using quantitative tools. Second, most existing studies focus on post-harvest rice losses in backward developing countries, while rice harvest losses in China during its agricultural transition to modernization have rarely been analyzed. To this end, on the basis of the existing literature, the main factors influencing rice harvest losses and their marginal effects were analyzed using the ordered multinomial logistic model based on sampling survey data from 957 farmers in 10 provinces in China.

3. Survey design and sample analysis

3.1. Survey design

In this study, data were collected using a multi-stage sampling method from 10 provinces/regions in China, including Heilongjiang, Jiangsu, Zhejiang, Guangdong, Hubei, Hunan, Anhui, Jiangxi, Sichuan, and Guangxi. Most of these are major rice producing provinces in China. The rice production of the 10 provinces/regions accounted for 78.96% of the national rice production in 2013[*]. The sampling area not only involves four major regions of China, i.e., the eastern (Jiangsu, Zhejiang, and Guangdong), central (Hubei, Hunan, Anhui,

[*] Calculated based on the relevant data from the China Statistical Yearbook 2014 (National Bureau of Statistics of China, ed., China Statistics Press, 2014).

and Jiangxi), western (Sichuan, and Guangxi), and northeast regions (Heilongjiang), but also stretches across the five major rice areas of China, i.e., the south, central, north, southwest, and northeast regions of China[*]. Therefore, the sampling area is highly representative in terms of spatial distribution. On this basis, five counties were selected from each of these provinces/regions according to rice harvesting methods, topographic features, rice planting proportion, and rural residents' income. Five administrative villages were then randomly selected from each of the selected counties. In the actual survey, house numbers were randomly selected, and then corresponding farmer households were visited by trained investigators. The questionnaire was answered directly by the respondents. The rice harvest loss rate[†] was divided into six levels, "lower than 3%", "3%-4%", "4%-5%", "5%-6%", "6%-7%", and "higher than 7%" based on the existing research results[‡], as well as farmers' feedback from the pre-survey. A total of 1000 copies of the questionnaire was distributed in the above 10 provinces/regions. After careful screening, 957 copies of valid questionnaires were collected, representing a response rate of 95.7%. The survey was carried out in July and August, 2014.

3.2. Sample analysis

3.2.1. Demographics of respondents

Table 1 lists the basic demographics of the respondents. Of the 957 respondents, men comprised a slightly higher proportion (54.96%) than women. Most respondents were aged "46-55 years" and "56-65 years", accounting for 41.27% and 29.68% of the total sample, respectively. In terms of education, family size, and annual household income, most respondents fell into the category of "middle and high school", "3-4", and "60,000 yuan and less", respectively, accounting for 65.20%, 67.71%, and 69.80% of the total sample. In addition, 47.23% of respondents had experience of working in the city.

[*] China generally includes six major rice areas, i.e., the south, central, north, southwest, and northeast single cropping rice areas, and the northwest arid area.

[†] Rice harvest loss rate = rice harvest losses per mu/rice yield per mu.

[‡] A relatively consistent conclusion on rice harvest losses in existing literature is that rice harvest loss rates generally range from 3% to 7%.

3.2.2. Overall estimates of rice harvest loss rate

As shown in Tables 2 and 3, 26.96% and 29.26% of respondents believed that the rice harvest loss rate was “lower than 3%” and “3%-4%”, respectively, 18.29% and 13.06% suggested that it was “4%-5%” and “5%-6%”, respectively, and 5.64% and 6.79% estimated that it was “6%-7%” and “higher than 7%”, respectively. As to the main cause of rice harvest losses, 45.46% of respondents attributed the losses to “changeable weather”, while 19.65%, 18.18%, and 10.55% suggested that it was due to “outdated equipment”, “diseases and pests”, and “shattering during harvest” , respectively.

3.2.3. Estimates of rice harvest loss rates in different regions

As shown in Tables 2 and 3, respondents in different regions had different estimates of rice harvest loss rates. In the survey sample, 50.13% of respondents from the eastern region and 56.71% from the central region believed that the rice harvest loss rates in their regions were “lower than 3%” or “3%-4%”. In the western region, 61.92% of respondents estimated the rice harvest loss rates in their region to be “3%-4%” and “4%-5%”, and 64.93% of respondents from the northeast region estimated the rice harvest loss rate to be “lower than 3%”. In addition, the respondents believed that “changeable weather” was a major factor for rice harvest losses in all regions, followed by “diseases and pests” and “outdated equipment”.

4. Theoretical model and variable settings

4.1. Theoretical model of rice harvest losses

Intuitively, farmers are not pleased to see losses. However, as an economic person, a farmer aims to maximize his/her net income. The reduction of rice harvest losses will inevitably increase costs. If the increase in cost exceeds the increase in income, the net income of the farmer will be reduced. The net income of the farmer can be maximized only when the marginal cost of reducing harvest losses equals the marginal income. In this regard, it is assumed that MC_i is the increase in subjective cost for farmer i to reduce harvest losses.

The judgment of subjective cost is affected by many factors, i.e.,

$$MC_i = \beta X_i + \varepsilon \quad (1)$$

In equation (1), X_i is the vector of factors affecting the subjective cost judgment of farmer i, β is the vector of the coefficient to be estimated, and ε_i is an independent and identically distributed random disturbance. As the farmer aims to maximize net income, the increase in cost for the farmer to reduce harvest losses should theoretically equal the increase in income. Therefore, since it is difficult to observe subjective cost, rice loss Y_i was selected as a display variable and takes on the values in $[1, n]$. Y_i=1 represents "lower than 3%", Y_i=2 represents "3%-4%", Y_i=3 represents "4%-5%", Y_i=4 represents "5%-6%", Y_i=5 represents "6%-7%", and Y_i=6 represents "higher than 7%". A larger value of Y_i indicates a greater loss. The following classification framework was constructed:

$$\begin{cases} Y_i = 1,\ MC_i \le \mu_1 \\ Y_i = 2,\ \mu_1 < MC_i \le \mu_2 \\ \quad \vdots \\ Y_i = n,\ \mu_n < MC_i \end{cases} \quad (2)$$

In equation (2), μ_n is the critical point for changes in the farmer's subjective cost and satisfies $\mu_1 < \mu_2 < \cdots < \mu_n$. As the ordered multinomial logistic model does not require a normal distribution or equal variances, it can be used to assess the relationship between multinomial dependent variables and their influencing factors, and thus to quantitatively assess the factors influencing different levels of rice harvest losses. In general, the distribution function of ε_i is assumed to be $F(x)$, and the probability for the dependent variable Y_i to take each value can then be calculated as below:

$$\begin{cases} p(Y_i = 1) = F(\mu_1 - \beta X_i) \\ p(Y_i = 2) = F(\mu_2 - \beta X_i) - F(\mu_1 - \beta X_i) \\ \quad \vdots \\ p(Y_i = n) = 1 - F(\mu_n - \beta X_i) \end{cases} \tag{3}$$

Since ε_i follows a logistic distribution, then:

$$\begin{aligned} p(Y_i > 0) = F(U_i - \mu_1 > 0) &= F(\varepsilon_i > \mu_1 - \beta X_i) \\ &= 1 - F(\varepsilon_i < \mu_1 - \beta X_i) \\ &= \frac{exp(\beta X_i - \mu_1)}{1 + exp(\beta X_i - \mu_1)} \end{aligned} \tag{4}$$

4.2. Composition and variable selection for rice harvest losses

Rice harvest losses can be subdivided into harvest shattering loss, unreaped loss, windrowing loss, unthreshed loss, spatter loss, and entrainment loss (Li, etc., 1991; Aulakh and Regmi, 2013). Among them, harvest shattering loss, unreaped loss, unthreshed loss, spatter loss, and entrainment loss consist mostly of grain weight losses (volume and quantity losses), and are predominantly affected by the mature period of rice, lodging, field size and shape, harvesting methods, manpower adequacy, and harvesting techniques. The quality loss (reduced nutrition and increased deterioration) during windrowing is closely related with weather conditions during harvest and windrowing duration (see Figure 1).

In fact, there are many factors influencing rice harvest losses, and intensive studies have been carried out from several different perspectives. Table 4 provides a preliminary summary of the main conclusions of these studies.

Based on previous research findings, factors affecting rice harvest losses are summarized as 15 variables in three categories, demographics, production characteristics, and harvesting operation characteristics, as shown in Table 5.

5. Model estimation results and discussion

5.1. Estimation results

In this study, factors affecting rice harvest losses were estimated using SPSS 21.0. The model estimation results are shown in Table 6. Eight independent variables, including employment as migrant workers, proportion of family business income, planting scale, level of mechanization, timely harvest, manpower adequacy, operational meticulousness, and harvest weather, passed the significance test. The production characteristics and harvesting operation characteristics had a greater influence on rice harvest losses.

5.2. Interpretation of estimation results

5.2.1. Influence of demographics

The estimated coefficient of "employment as migrant workers" was 0.386, which was significant at the 0.003 level, indicating that the employment of respondents as migrant workers increased rice harvest losses. This is consistent with the argument of Li (2010) that the transfer of rural labor force to cities and towns has exacerbated the extensive land management. However, this study argues that the increase of rice harvest losses is actually a result of the increased opportunity cost of rice cultivation due to the employment of farmers as migrant workers. When the income obtained by reducing harvest losses is insufficient to make up for the explicit and opportunity costs, the willingness of farmers to reduce harvest losses will be reduced. In addition, the estimated coefficient of the variable "proportion of family business income" was -3.112, which was significant at the 0.000 level, indicating that the rice harvest losses were significantly reduced with the increase in the proportion of family business income. This may be because the higher dependency of family income on rice, the greater the cost of rice harvest losses for farmers, and the higher their willingness to control harvest losses.

5.2.2. Influence of production characteristics

The estimated coefficient of "planting scale" was -0.359, which was significant at the 0.003 level, indicating that rice harvest losses were reduced by the increase of planting scale. This is in agreement with the conclusions of Basavaraja *et al*. (2007). The possible reason for this is that large-scale rice farmers can also effectively reduce the cost of rice harvest losses in the entire production process by using advantages in capital availability and advanced equipment. The analysis of large-scale rice cultivation by Huang *et al*. (2014) indicated that large-scale agricultural operations could reduce land fragmentation and help increase post-harvest working efficiency, thus reducing harvest losses. The estimated coefficient of “mechanization level” was -1.060, and was significant at the 0.020 level, indicating that rice harvest losses were effectively reduced by the increase in harvesting mechanization level. This is similar to the conclusions of Buchner *et al*. (2012). This may be because, with the continuous decrease of mechanized harvesting costs and rapid improvement of technology, farmers can reduce harvest losses at a lower cost by using mechanical harvesting equipment.

5.2.3. Influence of harvesting operation characteristics

The estimated coefficients of “meticulousness level 3” and “timely harvest” were -0.892 and -0.415, respectively, and both were significant at the 0.001 level, indicating rice harvest losses were reduced by timely harvest and meticulous harvesting operations. The willingness of farmers to reduce rice harvest losses depends on their subjective judgment of the costs of loss reduction and the resulting income. The higher the farmers’ subjective judgment of income from reducing rice harvest losses, the higher their motivation to perform timely harvest and improve the meticulousness of harvesting operations, and the smaller the rice harvest losses. In addition, the estimated coefficient of “harvest weather 1” was 1.612, and it was significant at the 0.000 level, indicating that adverse harvest weather significantly increased rice harvest losses. This is in accordance with the findings of Abass *et al*. (2014). This may be because adverse harvest weather increases the rice lodging area, and thereby increases the harvesting difficulty; when the income obtained by reducing harvest losses is insufficient to make up for the costs, farmers will ignore such losses. In addition, the model estimation results of this study reveal that, although “inadequate manpower” may increase rice harvest losses, “adequate manpower” does not effectively reduce the losses. The possible reason for this is that the marginal effect of unit manpower on reducing rice harvest losses will be decreased with the increase in manpower.

5.3. Marginal effect analysis

Although the estimated coefficients in Table 5 reflect the influences of different factors on rice harvest losses, they cannot accurately reflect the degree of influence of these factors. To this end, marginal effects of influencing factors were calculated using critical point estimates and related estimated coefficients to perform further analysis. Since the method of calculating marginal effects for conventional continuous variables does not apply to dummy variables, all other variables were assumed to be zero in the calculation of marginal effect of a single dummy variable (see Greene, 2003), and the following equation was used (Newell and Anderson, 2003):

$$E\left[Y\middle|x_{ik}=1\right]-E\left[Y\middle|x_{ik}=0\right]=F\left(c_n+x_{ik}\right)-F\left(c_n\right) \quad (5)$$

In equation (5), c_n is the critical point, and n = 1, 2, 3, 4, and 5. The results are shown in Table 7.

The following findings were obtained by analyzing the marginal effects of the variables in Table 7.

First, the marginal effect of “employment as migrant workers” was less than zero when Y_i = 0 and Y_i = 1. This indicated that ceteris paribus, there was a higher probability for the rice harvest loss rate to be higher than 4% if farmers had experience as migrant workers. The marginal effects of “meticulousness level 1” and “meticulousness level 3” were also less than zero when Y_i = 0 and Y_i = 1, while that of “meticulousness level 4” was greater than zero when Y_i = 0. This indicated that farmers’ operational meticulousness did not significantly reduce the rice harvest losses, and there was still a high probability for the rice harvest loss rate to be higher than 4%. Only with a high rate of operational meticulousness, can the probability for a rice harvest loss rate higher than 3% be significantly reduced.

Second, the marginal effects of "proportion of family business income", "planting scale", "level of mechanization", "timely harvest", "harvest weather 1", "harvest weather 2", and "manpower adequacy 1", were greater than zero when $Y_i = 0$. This indicated that ceteris paribus, there was a higher probability for the rice harvest loss rate to be lower than 3% for farmers with a high proportion of family business income in total income, large rice planting scale, timely harvest, and a high level of mechanization. Moreover, it is more likely to keep a rice harvest loss rate lower than 3% with favorable harvest weather conditions and appropriately tight manpower, compared with adverse harvest weather conditions and shortage of manpower.

6. Main conclusions

As the first stage of the post-harvest rice processing system, harvest is related to the post-harvest quantity and quality of rice. The current rice harvest losses in different regions in China, as well as the main influencing factors, were analyzed using an ordered multinomial logistic model based on sampling survey data from 957 farmers in 10 provinces/regions in China. Survey results revealed that, compared with the cereal harvest loss rate of around 2% in American and European countries, the rice harvest loss rate in China was not only higher, but also had regional differences. According to statistics, the average rice harvest loss rate in China was 4% or lower. The rice harvest loss rate in the eastern and central regions was close to the national average; that in the western region was generally 3% to 5%, which was higher than the national average, and that in the northeast was generally 3% or lower, representing a lower than average level. Further analysis revealed that the proportion of family business income, rice planting scale, timely harvest, level of mechanization, and operational meticulousness had a negative impact on rice harvest losses, while employment as migrant workers had a positive impact. Moreover, although "inadequate manpower" and adverse weather conditions increased rice harvest losses, "adequate manpower" and favorable weather conditions had no significant impact on the reduction of rice harvest losses.

This study has some notable limitations. For example, quality loss, as part of rice harvest losses, was not fully investigated, as it is difficult to measure by survey. In addition, rice harvest losses of large-scale rice farmers, family farms, and specialized cooperatives for rice production were not investigated, as this survey focused on ordinary farmers. These will be important issues to be investigated in follow-up research.

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Table 1 The basic demographics of respondents

Characteristic	Classification	n	%
Gender	Male	526	54.96
	Female	431	45.04
Age	≤ 35 years	64	6.69
	36 - 45 years	160	16.72
	46 - 55 years	395	41.27
	56 - 65 years	284	29.68
	≥ 66 years	54	5.64
Education	Primary or lower	209	21.84
	Junior high school or lower	369	38.56
	High school or lower (including vocational high school)	255	26.64
	College and above	124	12.96
Family size	1 - 2 members	53	5.54
	3 members	282	29.47
	4 members	366	38.24
	≥ 5 members	256	26.75
Annual household income	≤ 30000 yuan	296	30.93
	30000 - 60000 yuan	372	38.87
	60000 - 100000 yuan	207	21.63
	≥ 100000 yuan	82	8.57
Experience of working in the city	Yes	452	47.23
	No	505	52.77

Table 2 Percentage of respondents selecting each rice harvest loss rate range(%)

Region \ Harvest loss rate	Lower than 3%	3%-4%	4%-5%	5%-6%	6%-7%	Higher than 7%
Nationwide	26.96	29.26	18.29	13.06	5.64	6.79
Eastern region	26.27	23.86	18.50	12.87	6.43	12.07
Central region	24.25	32.46	13.81	16.79	8.21	4.48
Western region	19.25	35.56	26.36	12.97	3.77	2.09
Northeast region	64.93	23.38	6.49	1.30	1.30	2.60

Table 3 Percentage of respondents selecting each rice harvest loss influencing factor(%)

Region \ Influencing factor	Changeable Weather	Outdated Equipment	Inadequate Manpower	Diseases and Pests	Shattering	Others
Nationwide	45.46	19.65	2.82	18.18	10.55	3.34
Eastern region	44.77	21.44	3.49	15.55	11.80	2.95
Central region	47.76	13.06	3.73	23.13	10.45	1.87
Western region	33.89	20.50	4.60	30.55	5.02	5.44
Northeast region	49.35	14.29	1.30	25.97	7.79	1.30

Note: The percentage data for the entire country were calculated by dividing the total sample size by the frequency of each option. The percentage data for each region were calculated by dividing the sample size in that region by the frequency of each option.

Table 4 Typical studies on post-harvest losses and their influencing factors

Literature	Country (region)	Variety	Influencing Factors
Akar *et al.*（2004）	Africa	Rice	Harvest weather, rice varieties with different mature periods, and variety maturity
Basavaraja *et al.*（2007）	India	Rice	Respondents' age and education, rice planting area, and number of family laborers
Zhang *et al.*（2009）	China	Rice	Sources of household income, and proportion of grain income in total household income
Hodges *et al.* （2011）	Southeast Asia	Cereals	Respondents' education, and grain-saving and loss-reducing awareness
Parfitt *et al.* （2010）	EU	Cereals	Rice market price, farmers' skills, power grid installation, and irrigation conditions
Li wei（2010）	China	Rice	Employment of family member(s) as migrant workers or not, and rice harvesting methods
Appiah *et al.* （2011）	Ghana	Rice	Respondents' gender, planting years, family age structure, and level of mechanization of rice harvesting
Gustavsson *et al.*（2011）	Africa	Cereals	Household income, power grid installation and road facilities, and grain-saving awareness
Bokusheva *et al.*（2012）	Central America	Cereals	Farmers' harvesting skills, grain harvesting equipment, and meticulousness of farmers' harvesting operations
Priefer *et al.* （2013）	EU	Cereals	Respondents' age and education, family size, annual household income, farmers' skills, climatic conditions, rural infrastructure
Aulakh and Regmi（2013）	Africa	Cereals	Mechanization level of cereal harvesting, climatic conditions, and harvest weather
Abass *et al.* （2014）	Tanzania	Cereals	Timely harvest or not, harvest weather, farmers' skills, mechanization level of rice harvesting, and grain-saving awareness
Halloran *et al.* （2014）	Denmark	Cereals	Meticulousness of farmers' harvesting operations, and grain-saving and loss-reducing awareness
Guo *et al.*（2014）	China	Rice	Manpower adequacy, rice harvesting equipment, and farmers' harvesting skills
Huang *et al.*（2015）	China	Rice	Acceptance of land transfer or not, and rice harvesting methods

Table 5 Names, meanings, and statistical characteristics of model variables

Variable Name	Variable Meaning	Mean	Standard Deviation
Demographics			
Gender	Male=1; female=0	0.55	0.50
Age	Actual age (years)	51.43	9.72
Education	Specific years of schooling (years)	8.97	3.23
Employment as migrant workers or not	Yes=1; no=0	0.47	0.50
Annual household income	Family net income value (10 thousand)	5.45	3.05
Proportion of family business income	Family business income accounting for the proportion of total household income	0.56	0.20
Production characteristics			
Planting scale	Household per capita rice cultivation area (mu)	4.23	2.38
Level of mechanization	Proportion of mechanically harvested area in the total harvested area	0.59	0.14
Land transfer	Yes=1; no=0	0.51	0.50
Rice prices Satisfaction	Satisfaction =1; Not satisfaction =0	0.63	0.48
Harvesting operation characteristics			
Harvesting methods	Segment harvesting =1; combine harvesting =0	0.47	0.50
Timely harvest or not	Timely harvest =1; Not timely harvest =0	0.45	0.50
Operational meticulousness	Including five categories: very crude, crude, moderate, meticulous, very meticulous (with “very crude” as the reference)	—	—
Operational meticulousness 1	Operational meticulousness is “crude”（yes=1, no=0）	0.20	0.40
Operational meticulousness 2	Operational meticulousness is “moderate,”(yes=1, no=0）	0.42	0.49
Operational meticulousness 3	Operational meticulousness is “meticulous”（yes=1, no=0）	0.21	0.41
Operational meticulousness 4	Operational meticulousness is “very meticulous”（yes=1, no=0）	0.11	0.31
Harvest weather	Including five categories: very adverse, adverse, moderate, favorable, very favorable (with “very adverse” as the reference)	—	—
Harvest weather 1	Harvest weather is “adverse”（yes=1, no=0）	0.29	0.45
Harvest weather 2	Harvest weather is “moderate”（yes=1, no=0）	0.31	0.46
Harvest weather 3	Harvest weather is “favorable”（yes=1, no=0）	0.24	0.42
Harvest weather 4	Harvest weather is “very favorable”（yes=1, no=0）	0.06	0.23
Manpower adequacy	Including five categories: very inadequate, inadequate, moderate, adequate, very adequate (with “very inadequate” as the reference)	—	—

Manpower adequacy 1	Manpower adequacy is “inadequate”（yes=1, no=0）	0.17	0.38
Manpower adequacy 2	Manpower adequacy is “moderate”（yes=1, no=0）	0.43	0.50
Manpower adequacy 3	Manpower adequacy is “adequate”（yes=1, no=0）	0.22	0.42
Manpower adequacy 4	Manpower adequacy is “very adequate”（yes=1, no=0）	0.09	0.29

Table 6 Model estimation results of main factors influencing rice harvest losses

Variable	Coefficient	Standard Error	Wald Value	*P* Value
Gender	0.093	0.125	0.552	0.458
Age	-0.004	0.008	0.213	0.644
Education	0.001	0.019	0.002	0.967
Employment as migrant workers or not	0.386***	0.130	8.808	0.003
Annual household income	0.020	0.020	0.911	0.340
Proportion of family business income	-3.112***	0.364	73.166	0.000
Planting scale	-0.359***	0.039	82.857	0.000
Level of mechanization	-1.060**	0.455	5.422	0.020
Rice price satisfaction	-0.019	0.128	0.021	0.884
Land transfer	0.084	0.131	0.413	0.520
Harvesting methods	0.072	0.124	0.334	0.563
Timely harvest or not	-0.415***	0.127	10.647	0.001
Manpower adequacy 1	0.769***	0.265	8.413	0.004
Manpower adequacy 2	0.344	0.240	2.058	0.151
Manpower adequacy 3	-0.245	0.258	0.902	0.342
Manpower adequacy 4	-0.368	0.303	1.470	0.225
Operational meticulousness 1	0.946***	0.262	13.063	0.000
Operational meticulousness 2	0.159	0.244	0.423	0.515
Operational meticulousness 3	-0.892***	0.265	11.347	0.001
Operational meticulousness 4	-1.077***	0.303	12.627	0.000
Harvest weather 1	1.612***	0.241	44.692	0.000
Harvest weather 2	0.711***	0.239	8.883	0.003
Harvest weather 3	-0.106	0.252	0.179	0.673
Harvest weather 4	-0.563	0.397	2.016	0.156
Critical point				
Critical point 1 μ_1	-0.763	0.672	1.288	0.256
Critical point 2 μ_2	1.110*	0.672	2.732	0.098
Critical point 3 μ_3	2.579***	0.675	14.587	0.000
Critical point 4 μ_4	4.069***	0.687	35.118	0.000
Critical point 5 μ_5	5.066***	0.699	52.485	0.000
Nagelkerke R^2		0.524		
Cox & Snell R^2		0.505		
χ^2 test		672.035***		

Note: * represent p< 0.1, ** represent p< 0.05, *** represent p<0.01.

Table 7 Marginal effects of significant independent variable on rice harvest losses (ceteris paribus)

Significant Independent Variable	Y_i =0	Y_i =1	Y_i =2	Y_i =3	Y_i =4	Y_i =5
Employment as migrant workers or not	-0.0773	-0.0013	0.0488	0.0222	0.0048	0.0029
Proportion of family business income	0.5949	-0.3614	-0.1663	-0.0511	-0.0101	-0.0060
Planting scale	0.0824	-0.0216	-0.0406	-0.0152	-0.0031	-0.0019
Level of mechanization	0.2557	-0.1103	-0.1005	-0.0340	-0.0068	-0.0041
Timely harvest or not	0.0959	-0.0267	-0.0463	-0.0172	-0.0035	-0.0021
Manpower adequacy 1	0.1690	-0.0605	-0.0740	-0.0261	-0.0053	-0.0032
Operational meticulousness 1	-0.1403	-0.0274	0.0976	0.0514	0.0116	0.0072
Operational meticulousness 3	-0.1647	-0.0465	0.1183	0.0676	0.0156	0.0097
Operational meticulousness 4	0.2142	-0.0853	-0.0885	-0.0305	-0.0062	-0.0037
Harvest weather 1	0.2599	-0.1129	-0.1016	-0.0343	-0.0069	-0.0041
Harvest weather 2	0.3824	-0.1962	-0.1306	-0.0422	-0.0084	-0.0050

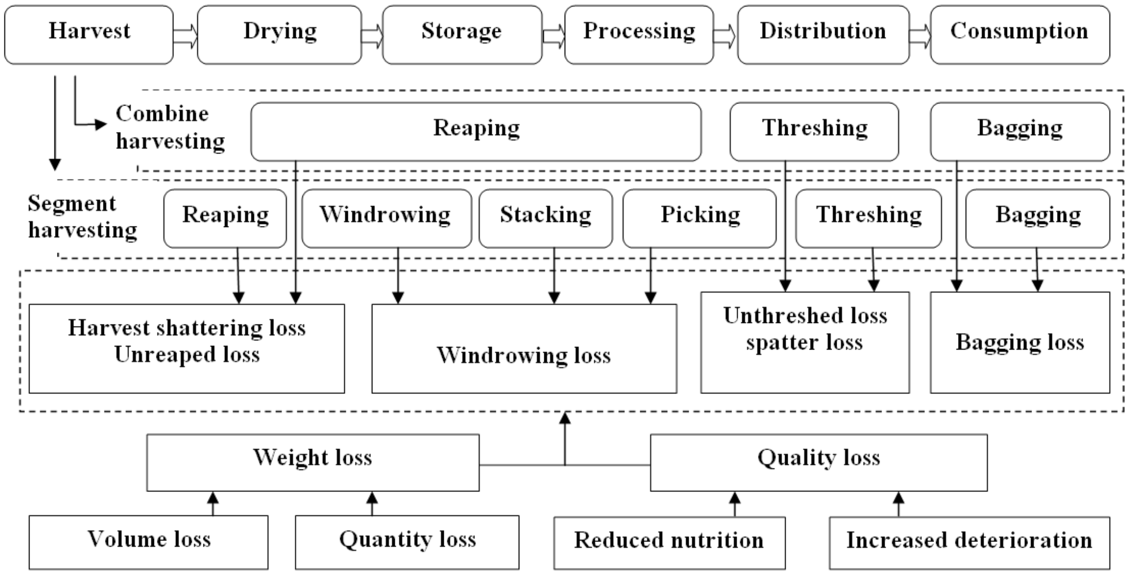

Figure 1. Composition of rice harvest losses