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Impact of rice harvest loss by mechanization or outsourcing: Comparison of specialized and part-time farmers

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Abstract: One-third of the world's food is lost and wasted each year, making reducing food loss and waste one of the promising ways to ensure global food security. This study conducts a comparative analysis of the differences among the factors affecting rice harvest loss of specialized and part-time farmers. Data collected from 1 106 farmers in China were analysed using Tobit regression. The results indicated the following: *i*) The average rice harvest loss rate of part-time farmers is higher than that of specialized farmers. *ii*) Among the variables considered, most factors not only increase the loss of part-time and non-rice specialized farmers but also reduce the loss of rice specialized farmers. *iii*) The use of combine harvesters and the purchase of outsourcing services increases the loss of part-time and non-rice specialized farmers but can reduce the loss of rice specialized farmers. *iv*) In addition to weather and pests, planting area, terrain conditions, operating attitude, and labour shortage also affect the loss. These findings are valuable to understand how the loss occurs and the differences between specialized and part-time farmers, which will help develop targeted interventions to reduce the loss.

Keywords: food loss; mechanical harvesting; outsourcing service; part-time farming; professional farmer

The hot debate on the article "Who will feed China" in the 1990s shows the importance of China's food security (Brown 1994). As the huge food loss and waste are being noticed, reduction in food loss and waste is regarded as a promising measure to achieve food security (Kummu et al. 2012), which can not only increase the amount of food available for consumption, but also reduce the waste of land, water, and other resources embedded in food (Bellù 2016; Muth et al. 2019). Loss and waste occur in the whole food supply chain from farm to fork. Moreover, in developing countries, upstream stages account for a greater percentage of losses (Gustavsson et al. 2011), leading to a loss of income to farmers and threatening their food security (Coker and Ninalowo 2016), especially in those countries facing a food shortage.

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As the staple food for the Chinese, rice should be guaranteed "absolute security". To calculate the magnitude of rice harvest loss in China, our team launched a nationwide survey in 2016 and 2017. The harvest loss rate of rice in 2016 was on average 3.65%. The causes of harvest loss include not only weather and insect disease but also humans (Kiaya 2014; Fenn and Laycock 2017). Some studies have identified harvest loss factors, but they often regarded all farmers as homogeneous, or examined them by farm scale (Li et al. 2019).

Moreover, it is important to examine the factors of harvest loss by classifying farmers into specialized farmers (whose major income is from agriculture) and part-time farmers (whose major income is from non-agricultural sources). Part-time farming refers to the transfer of labours originally in farm production to non-farm sectors to maximize the utility of households (Yang and Li 2018), which is becoming more common (Qian 2008) and will persist for a long time in China (Liao 2012). Table 1 describes the losses of specialized and part-time farmers based on our research in the next section. The losses of specialized and part-time farmers account for almost the same proportion of the total loss, while the loss per unit area of part-time farmers is 1.5 times that of specialized farmers. Identifying factors that cause higher losses of part-time farmers or reduce the losses of specialized farmers helps in understanding the occurrence of loss and developing targeted interventions. However, existing research has rarely examined the issue from this point of view.

Much research on part-time farming focused on its possible negative impact on agricultural production. Azam and Gubert (2006) argued that the remittance from non-farm labour would allow farm labour to take a free ride, weaken their production enthusiasm, and cause their low efficiency. This may lead to different effects of machinery, outsourcing services, and other factors affecting harvest loss on specialized and part-time farmers. Similarly, among specialized farmers, there may be differences between farmers whose major source of agricultural income is rice and other farmers.

Various factors affect harvest loss. Most of the factors related to production and household characteristics, such as weather and land conditions, are difficult to control or cannot be changed in a short period of time. In contrast, farmers have a certain choice in the use of agricultural machinery, which is booming in China. Therefore, this study focuses on agricultural machinery and examines factors that increase part-time farmers' harvest loss and factors that reduce the harvest loss of specialized farmers (both rice specialized farmers and others), to support the development of targeted interventions.

METHODOLOGY AND DATA

Data. Primary data on harvest losses, production, and household information of 1 106 households in 19 provinces were derived from the dataset of a national survey conducted by China Agricultural University (CAU) jointly with Research Center for Rural Economy (RCRE) of Ministry of Agriculture and Rural Affairs of China in 2016 (CAU and RCRE 2016). The sample size is distributed in proportion according to the rice planting area of each province.

The surveyed provinces cover three rice advantageous producing areas in the Northeast Plain, Southeast Coast, and the Yangtze River Basin. Their total rice production accounted for 98% of that in China in 2016.

The harvest loss studied here refers to losses that occur in the whole harvest process, from the field to the storage, including during reaping, threshing, winnowing, and field transportation, which are estimated by farmers. Although the reliability of farmers' self-reports has been questioned, they are still considered to be the best available current data (Sheahan and Barrett 2017). The absolute amount of losses is directly related to the planting area, which is not convenient for comparison among farmers. Therefore, the loss rate is used here to measure the loss, which is the ratio of the total losses (sum of four stages' losses) to the sum of the total losses and rice production.

Table 1. Rice harvest loss of specialized and part-time farmers

	Harvest loss (kg)	Ratio to total loss (%)	Planting area (ha)	Harvest loss per area (kg/ha)
Specialized farmer (n = 479)	45 552.8	50.4	221.7	205.5
Part-time farmer (n = 627)	44 856.4	49.6	145.8	307.6
Total (n = 1 106)	90 409.2	100.0	367.5	246.0

Source: Own calculation based on CAU and RCRE database (CAU and RCRE 2016)

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Table 2. Definition and *F-incs* (farm income/total income) for each farmer classification

Classification		Definition	*F-incs* (%)
Specialized farmer	(1) Rice farmer I	*F-incs* > 2/3 and the largest income crop is rice	85.86
	(2) Rice farmer II	*F-incs* > 1/2 and the largest income crop is rice	76.70
	(3) Non-rice farmer	*F-incs* > 1/2 and the largest income crop is not rice	77.20
Part-time farmer	(4) Part-time farmer	*F-incs* ≤ 1/2	24.48

In this study, the proportion of rural household management income is used to represent the proportion of farm income
Source: Own calculation based on CAU and RCRE database (CAU and RCRE 2016)

Methodology. In the existing literature, the proportion of farm income or the days of non-farm employment were often used to define different farming types. This study regards the households whose farm income accounted for more than half of the total income as specialized farmers, others as part-time farmers. To spread risks and meet diversified household consumption needs, farmers often choose to cultivate multiple crops. More production materials are invested in crop that accounts for the largest share of agricultural income because of their limited resources and time. Therefore, specialized farmers are further divided into two groups: farmers whose largest farm income comes from rice are regarded as rice specialized farmers II, others as non-rice specialized farmers. For further comparison, rice specialized farmers with farm income share of more than two-thirds are regarded as rice specialized farmers I. Table 2 shows the classification of farmers. If sorted according to their proportion of rice-related farm income, their order is as follow: rice specialized farmer I > rice specialized farmer II > non-rice specialized farmer > part-time farmer.

Next, a multiple regression equation was established to examine the factors affecting harvest losses, as used by Basavaraja et al. (2007). The multiple regression equation is specified as (1).

$$HLR = \beta + \beta\,(Com) + \beta\,(Ser) + \beta\,(Com \times Ser) + \\ + \beta\,(Win) + \beta\,(Tra) + \beta\,(P) + \beta\,(H) + \\ + \beta\,(R) + \sigma \quad (1)$$

where: *HLR* – harvest loss rate; *Com* – a dummy variable of 1 if combine harvesting is used, otherwise 0; *Ser* – a dummy variable of 1 if farmer purchased outsourcing services, otherwise 0; *Win* – a dummy variable of 1 if mechanical winnowing is used, otherwise 0; *Tra* – a dummy variable of 1 if mechanical transportation is used, otherwise 0. In addition to the mechanical variables that we are more concerned with in this study, variables about production and household that may affect the loss are included based on previous studies: *P* – production and harvesting conditions that comprise *Wea* (bad weather), *Pest*, *Area*, *Yield*, *Terrain* (flat terrain of farmland), *Distance* (distance from field to storage), *Attitude* (serious working attitude), *Labour* (labour shortage), *Saving* (pick up rice after harvesting), *Maturity* (rice is just mature when harvesting), and *Price* (sale price of rice); *H* – household and individual characteristics that include *Gender, Age*, *Edu* (school year), *Training*, *T-inc* (total income), and *R-incs* (rice income share); *R* – regional dummy variable.

Considering that outsourcing service usually occurs during combine harvesting, the cross-term of *Com* and *Ser* is introduced in the model. Then $\beta_1 + \beta_3$ represents the marginal effect of combine harvesting on the loss rate when purchasing outsourcing services, and $\beta_2 + \beta_3$ is the marginal effect of outsourcing service on the loss rate of rice harvested by combine harvesters. Since the *HLR* is between 0 and 1 and some farmers estimate the *HLR* to be 0, a Tobit model is used for regression (Tobin 1958). Stata 15.0 software is used to estimate the above model.

The meaning and definitions of variables used in the empirical analysis are listed in Table 3. The average *HLR* increases from rice specialized farmers to part-time farmers: part-time farmers have the highest loss rate (4.09%), and rice specialized farmers I have the lowest loss rate (2.8%). The highest proportion of combine harvesting and outsourcing services is for rice specialized farmers I, and the lowest is for non-rice specialized farmers. The production and harvesting conditions of rice specialized farmers are obviously better than those of other farmers, mainly reflected in area, yield, and the terrain of the plots and fields' distance to the storage places. The average farmed area of part-time farmers (0.23 ha) is less than half that of rice specialized farmers I (0.59 ha). Interestingly, the farmers with the lowest yield, worst terrain, and farthest distance from plots to storage places are not part-time farmers but instead non-rice specialized farmers. This

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Table 3. Sample descriptive statistics

Variable	Definition	Specialized farmer			Part-time farmer
		rice farmer I	rice farmer II	non-rice farmer	
HLR	harvest loss rate	2.80	2.89	3.39	4.09
Com	dummy = 1 if using combine harvesters, 0 otherwise	0.63	0.62	0.24	0.45
Ser	dummy = 1 if farmers buy outsourcing service at reaping and threshing stage, 0 otherwise	0.72	0.70	0.34	0.60
Win	dummy = 1 if winnowing rice by machine, 0 otherwise	0.43	0.44	0.60	0.55
Tra	dummy = 1 if transporting rice by machine, 0 otherwise	0.80	0.76	0.66	0.52
***P* – Production and harvesting conditions**					
Wea[1]	dummy = 1 if the weather is bad when harvest, 0 otherwise	0.19	0.19	0.17	0.14
Pest	pest conditions when harvest: no pest = 1, slight pests = 2, general or serious pests = 3	1.79	1.81	1.80	1.87
Area	planting area (ha)	0.59	0.55	0.31	0.23
Yield	yield (100 kg/ha)	82.53	85.23	67.62	81.70
Terrain	dummy = 1 if the terrain of plot is flat, 0 otherwise	0.84	0.83	0.67	0.74
Distance	distance between field and storage (km)	0.59	0.62	0.92	0.59
Attitude	dummy = 1 if the harvest attitude of operators is serious, 0 otherwise	0.22	0.23	0.24	0.23
Labour	dummy = 1 if farmers report a lack of labour when harvest, 0 otherwise	0.23	0.22	0.26	0.31
Saving	dummy = 1 if farmers pick up rice left in the field after harvest, 0 otherwise	0.15	0.18	0.21	0.14
Maturity	dummy = 1 if harvest when rice is mature, 0 otherwise	0.94	0.94	0.93	0.95
Price	the sale price of rice (USD/kg)	0.44	0.44	0.46	0.45
***H* – Household and individual characteristics**					
Gender	gender of household head (male = 1, female = 0)	0.89	0.90	0.75	0.85
Age	age of household head	52.33	53.49	51.04	55.28
Edu	school year of household head (years)	7.15	6.97	6.86	7.06
Train	dummy = 1 if household head had agricultural training, 0 otherwise	0.05	0.08	0.11	0.10
T-inc	total income (thousand USD)	12.44	11.10	9.99	10.54
R-incs	rice income as a percentage of total income (%)	33.31	31.07	12.33	9.34
n	number of samples	202	305	174	627

[1]The questionnaire contains types of weather, such as normal weather, strong wind, heavy rain; if the answer includes options other than normal weather, it is considered that bad weather was encountered during the harvest; some other variables about production and harvesting are also reported by farmers based on their observations during harvest, such as *Attitude* (options include serious, fair, and not serious) and *Labour* (options include lack, fair, and adequate); in the large sample, we believe that the judgment made by farmers is credible

Source: Own calculation based on CAU and RCRE database (CAU and RCRE 2016)

may be due to the fact that non-rice specialized farmers invest more means of production into their main crops. Moreover, the proportion of rice income of rice specialized farmers I is about 3.6 times that of part-time farmers.

RESULTS

The Tobit regression results are listed in Table 4. Overall, most factors that affect the loss of part-time farmers are positive, while rice specialized farmers

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Table 4. Tobit regression results

Variable	Specialized farmer			Part-time farmer
	rice farmer I	rice farmer II	non-rice farmer	
Com	1.708 (0.88)	1.595 (0.84)	−1.288 (−1.10)	−0.601 (−0.92)
Ser	0.170 (0.16)	0.084 (0.09)	2.744*** (3.32)	−0.279 (−0.57)
Com × *Ser*	−3.415* (−1.73)	−2.829 (−1.45)	1.558 (1.25)	1.418* (1.87)
Win	1.033* (1.88)	0.902* (1.94)	1.636*** (2.76)	1.043*** (3.65)
Tra	0.433 (0.63)	−0.401 (−0.81)	−2.887*** (−4.56)	−0.922*** (−2.88)
***P* – Production and harvesting conditions**				
Wea	0.490 (0.49)	−0.094 (−0.14)	3.588*** (6.41)	1.806*** (3.07)
Pest = 2	0.745* (1.67)	1.117*** (3.00)	1.385*** (2.68)	0.939*** (2.70)
Pest = 3	2.399*** (2.91)	2.360*** (4.27)	2.651*** (3.81)	2.757*** (6.10)
Area	−0.905* (−1.69)	−0.817* (−1.86)	−4.985*** (−3.57)	−4.206*** (−3.94)
Yield	0.004 (0.47)	−0.002 (−0.23)	−0.007 (−0.59)	−0.011* (−1.76)
Terrain	0.692 (1.06)	0.214 (0.40)	−1.295** (−2.49)	0.105 (0.27)
Distance	0.410 (0.88)	0.271 (0.94)	−0.520* (−1.86)	0.096 (0.36)
Attitude	−1.847*** (−3.10)	−1.185** (−2.37)	−0.142 (−0.26)	−1.574*** (−4.01)
Labour	−0.231 (−0.43)	0.594 (1.22)	0.682 (1.35)	0.582* (1.87)
Saving	0.541 (0.95)	0.420 (0.87)	−0.376 (−0.67)	1.427*** (3.66)
Maturity	−0.094 (−0.12)	−0.558 (−0.73)	0.209 (0.22)	0.412 (0.57)
Price	−12.355* (−1.75)	−0.914 (−0.14)	−10.404** (−2.47)	0.791 (0.26)
***H* – Household and individual characteristics**				
Gender	−0.948 (−1.10)	−0.709 (−1.05)	0.366 (0.80)	0.031 (0.08)
Age	−0.002 (−0.08)	0.009 (0.40)	−0.026 (−1.15)	0.026 (1.60)
Edu	−0.129 (−1.34)	−0.041 (−0.49)	−0.117 (−1.17)	0.037 (0.56)
Train	0.025 (0.03)	−0.023 (−0.04)	−0.159 (−0.24)	0.853 (1.61)
T-inc	0.002 (0.06)	0.021 (0.92)	0.031 (1.32)	0.006 (0.23)
R-incs	−0.015* (−1.95)	−0.008 (−0.93)	−0.021 (−0.99)	−0.002 (−0.08)
Cons	9.805** (2.55)	4.653 (1.35)	14.265*** (4.46)	1.773 (0.84)
Region control	yes	yes	yes	yes
Pseudo R^2	0.083	0.065	0.141	0.049
n	202	305	174	627
$\beta_1 + \beta_3$	−1.708** (−2.10)	−1.234* (−1.75)	0.270 (0.31)	0.817** (2.01)
$\beta_2 + \beta_3$	−3.245* (−1.72)	−2.745 (−1.49)	4.302*** (3.56)	1.140* (1.84)

***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; *t*-statistics are in parentheses; $\beta_1 + \beta_3$ and $\beta_2 + \beta_3$ are calculated after the regression

Age – age of household head; *Area* – planting area; *Attitude* – serious working attitude; *Com* –combine harvesting; *Cons* – constants; *Distance* – distance from field to storage; *Edu* – school year of household head; *Gender* – gender of household head; *H* – household and individual characteristics; *HLR* – harvest loss rate; *Labour* – labour shortage; *Maturity* – rice is just mature when harvesting; *P* – production and harvesting conditions; *Pest* – pest conditions when harvest; *Price* – sale price of rice; *Pseudo* R^2 – pseudo *R* squared; *R* – regional dummy variable; *Region* – regional control and sample is divided into three regions: the Yangtze River Basin, the Northeast Plain, and the Southeast Coast; *R-incs* – rice income share; *Saving* – pick up rice after harvesting; *Ser* –outsourcing services; *Terrain* – flat terrain of farmland; *T-inc* – total income; *Tra* –mechanical transportation; *Train* – agricultural training; *Wea* – bad weather; *Win* – mechanical winnowing; *Yield* – yield

Source: Own calculation based on CAU and RCRE database (CAU and RCRE 2016)

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are the least affected, followed by non-rice specialized farmers.

Most mechanical factors (including $\beta_1 + \beta_3$ and $\beta_2 + \beta_3$) are positive for part-time farmers and non-rice specialized farmers, while most of them are negative for rice specialized farmers. *Com* × *Ser* is significantly negative for rice specialized farmers I and significantly positive for part-time farmers, which shows that the two variables influence each other on the loss. Specifically, *Com* is not significant, and *Ser* is only significantly positive for non-rice specialized farmers. However, the coefficients of $\beta_1 + \beta_3$ – which indicate the marginal effect of combine harvesting on the loss rate when purchasing outsourcing services – are significantly negative for rice specialized farmers I and II, while those for part-time farmers are significantly positive. The parameters of $\beta_2 + \beta_3$ – which indicate the marginal effect of outsourcing service on the loss rate of rice harvested by combine harvesters – are significantly positive for both part-time farmers and non-rice specialized farmers. And the coefficients become significantly negative from rice specialized farmers I and II. Besides, *Win* is positive for all groups, and *Tra* is significantly negative except for rice specialized farmers.

Most production or household factors are positive for part-time farmers, and negative for specialized farmers. *Wea* and *Pest* show positive effects on losses. The effects of *Area* on non-rice specialized farmers and part-time farmers are much greater than those on rice specialized farmers I and II, although they are all negative. In non-rice specialized farmers, the parameters of *Terrain*, *Distance*, and *Price* are negative, while that of *Attitude*, which is significantly negative in both rice specialized farmers I and II and part-time farmers, is not significant, although still negative. *Labour* has a positive effect on only part-time farmers. Besides, *Price* and *R-incs* become significantly negative from rice specialized farmers II to I.

DISCUSSION

Except for mechanical winnowing, other mechanical variables reduce rice specialized farmers' losses; except for mechanical transportation, other mechanical variables increase losses of both non-rice specialized farmers and part-time farmers.

No matter the group, there is no difference in combine harvesting and segmented harvesting if the farmers undertake harvesting work themselves. However, it is different under outsourcing services. From part-time farmers to rice specialized farmers I, the impact of combine harvesting on the losses gradually changed from increasing losses to reducing losses. Combine harvesting increases the losses of part-time farmers but reduces those of rice specialized farmers I and II, and the effect on rice specialized farmers I is larger ($\beta_1 + \beta_3$). The reason may be that a small area brings great difficulties for mechanical operations, making greater losses inevitable. Table 3 shows that the rice planting area of rice specialized farmers I and II is larger than that for non-rice specialized farmers and part-time farmers. Similarly, in the case of combine harvesting, outsourcing services increase the losses of non-rice specialized farmers and part-time farmers, but reduce those of rice specialized farmers I ($\beta_2 + \beta_3$). As mentioned above, non-rice specialized farmers and part-time farmers allocate more labour into other crops or non-farm employment. Their extensive management gives service providers the chance to conduct rough harvesting and increase losses, even if the combine harvester from outsourcing service providers may be more advanced. The fine management of rice specialized farmers could avoid the moral hazard of service providers and then benefit from their advanced combine harvesters. Moreover, the effect of outsourcing service on non-rice specialized farmers is far greater than that on part-time farmers. And for non-rice specialized farmers, outsourcing is significantly positive in not only combine harvesting, but also segmented harvesting. This might be related to the fact that non-rice specialized farmers invest more in the production of the largest income crop, which forms a certain competitive relationship with rice planting, leading to their casual management of rice. It can also be seen from Table 3 that the proportion of combine harvesting and outsourcing service of non-rice specialized farmers is the lowest, about half that of part-time farmers.

Besides, mechanical transportation is smoother and faster than human handling, which reduces the losses of non-rice specialized farmers and part-time farmers. However, this has no such effect on rice specialized farmers, probably because the proportion of mechanical transportation of rice specialized farmers itself is already very high.

Most production or household factors help specialized farmers reduce their losses, while most of these factors increase the losses of part-time farmers. Pests bring losses to all farmers, while bad weather only increases the losses of non-rice specialized farmers and part-time farmers. This shows that rice special-

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ized farmers can better cope with weather changes. Other remaining production or household factors also helps reduce specialized farmers' losses. A large area provides conditions for mechanical harvesting, which can reduce losses. However, the farmed area of rice specialized farmers is larger than that of other farmers, leading to a smaller impact of the area. Farmland with flat terrain can facilitate harvesting operations and reduce the losses of non-rice specialized farmers. Contrary to intuition, longer distances reduce losses of non-rice specialized farmers. It may be because the possibility of farmers using mechanical transportation will increase when the distance is long enough, thereby reducing the loss. Table 3 shows that the distance between non-rice specialized farmers' rice planting land and storage is much greater than that of other farmers[1]. Moreover, a serious working attitude helps to reduce losses, but its impact on non-rice specialized farmers is not significant. The increase in rice profit brought about by the rise in rice price induces non-rice specialized farmers to allocate more means of production and time to rice production, thus reducing losses. The coefficients of *Price* and *R-incs* become significantly negative from rice specialized farmers II to rice specialized farmers I. This may imply that rice specialized farmers I are not so sensitive to the price and income stimulus as they have already invested more resources and management in rice production than in other crops. Only if the importance of agriculture (*F-incs*) is further enhanced will they respond to the increase of rice price and proportion of rice income and reduce losses. For part-time farmers, in addition to bad weather and pests, labour shortage also has significant effects on rice harvest losses. Part-time farmers usually allocate younger and stronger labour to non-farm sectors, leaving the older or female labour to undertake farm work, causing their most severe labour shortage and oldest labour force, as shown in Table 3.

CONCLUSION

This study's most significant contribution to existing research is that it examines the factors influencing rice harvest loss by classifying farmers into part-time and specialized farmers. We find that part-time farmers and non-rice specialized farmers have higher average loss rate and poorer production or harvesting conditions, such as smaller farmland, uneven land, and lower mechanical utilization. Tobit regression is used to analyse the factors influencing losses. The losses of part-time farmers are increased by most factors, such as outsourcing services (especially outsourcing service by combine harvesting), combine harvesting, mechanical winnowing, bad weather, pests and labour shortage. For specialized farmers, factors that increase losses reduced, while those that reduce losses increased. Specifically, for non-rice specialized farmers, flat terrain, long distance, and high price of rice reduce losses. For rice specialized farmers, besides the price and the income proportion of rice, combine harvesting and outsourcing services also reduce the loss, which are completely opposite to their effects on non-rice specialized farmers and part-time farmers.

The above influencing factors indicate different interventions. Strengthening the forecast and management of weather and pests – which are important factors affecting harvest loss – could reduce the losses of all farmers. For rice specialized farmers, promoting mechanical harvesting and outsourcing services in places where conditions permit and ensure rice income could further reduce harvest loss. For part-time farmers and non-rice specialized farmers, losses can be reduced by developing harvesters suitable for small farmlands and by regulating the operation of outsourcing services.

This study focuses on rice harvest losses. But the occurrence of harvest losses is a complex problem, and the characteristics of losses vary with regions and varieties, which requires more research in the future.

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[1]China's household responsibility system takes into account factors such as the family labour, the fertility of land, and the topography when allocating the farmland equally. Therefore, a household usually owns multiple farmlands.

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