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How Does the Farmland Management Scale Affect Grain Losses at Harvest? Analysis of Mediating Effect of Agricultural Input Based on Harvesting

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Abstract: Previous studies have demonstrated that grain loss in the harvest process accounts for a large loss in all aspects of the grain supply chain. This research extensively discusses the impact of farmland management scale on grain loss in the harvest process based on survey data on farmers' productivity in the Shandong and Hebei provinces of China. The findings revealed that the scale of farmland operation directly influenced the grain loss during harvest and that this effect is greatly reduced as the farmland operation scale increases. This study also constructed an intermediary model, investigated the influence mechanisms, and added agricultural capital as a variable in the harvest link. It was discovered that the scale of agricultural land management has an indirect effect on grain loss in the harvest link via the input of agricultural capital in the harvest link. The increase in agricultural capital investment in the harvest link considerably reduced this effect. In order to decrease grain losses during the harvest process, this paper suggests expanding the size of agricultural enterprises, developing new agricultural corporate organizations, and further playing the role of the rural land market.

Keywords: farmland management scale; agricultural input in harvest link; grain loss in harvest link; intermediary effect analysis

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1. Introduction

Food security is a crucial concern for human life, and it is linked to the steady growth of a nation, society, and economy. Global food security has been endangered by the growth of protectionism in agricultural trade, particularly in light of the novel coronavirus pneumonia epidemic's rapid global spread [1]. In 2020, there will be 720–811 million hungry people in the world as a result of the novel coronavirus pneumonia pandemic, an increase of 161 million from 2019 [2], and the armed conflict between Russia and Ukraine has made the situation even worse. China will be in a tight balance between food supply and demand for a long time [3], so it is particularly important to focus on the food production environment and reduce grain losses.

There are numerous studies now being conducted on the influence of farmers' concurrent business behavior [4,5], farmers' aging [6], land transfer [7,8], agricultural mechanization services [9,10], grain subsidies [11], and other factors on grain production efficiency. However, China's grain output is being constrained by increasing resource, environmental, and factor restrictions [12], such as a decrease in the quantity and quality of farmed land, a scarcity of water resources, and an increase in production and operation expenses [13]. From the perspective of sustainable agricultural production, to understand the need for sustainable agricultural development, one must realize that over the past 40 years, one-third of the world's arable land has been lost. About two-thirds of farmland in the Czech Republic has been affected to some extent [14]. The long-term relationship linking farmland prices, rents, and rates of return has been analyzed. Based on this relationship, it was concluded that recent trends are unlikely to be sustainable [15]. Reduced grain loss is an effective strategy to address grain loss since it is difficult to significantly raise the production efficiency of cultivated land when resources and other factors are limited. However, current research on the behavior of grain loss in the farming production process has yet to receive sufficient attention. As the "separation of three rights" reform of rural land progresses, more farmers are participating in land transfers, and farmland management has become somewhat integrated on a larger scale [16]. The change in harvest mode, labor force structure, and household size caused by the expansion of farmland management scale are progressively emerging as significant factors influencing farmers' resource allocation in agricultural production, thus influencing grain loss during the harvesting process [17]. Therefore, it is of great theoretical and practical significance to study the impact of agricultural land management scale on grain loss in farmers' harvests.

A third or more of the grain produced worldwide is wasted annually, with harvest-to-retail losses accounting for around 14% of the total [18]. Moreover, 2 billion extra people could be nourished if food losses were completely eliminated [19]. China, the greatest grain producer in the world, loses more than 70 billion catties of grain annually [20]. As a result, it has a tough time controlling food losses. Researchers from home and abroad have calculated the degree of harvest loss for various grain types in various locations. Chegere calculated a 2.9% loss in corn harvesting using survey data from 420 households in rural Tanzania that were corn farmers [21]. Kaminski and Christiaensen conducted a survey of maize losses in Malawi and Uganda using a questionnaire, and they measured a maize plant. The loss was 1.4% in Malawi and 5.9% in Uganda based on data from 2932 farmers [22]. Subramanyam et al. surveyed 200 wheat farmers in Ethiopia and derived wheat harvest losses of 6.8% [23]. Bala et al. measured rice harvest session losses of 1.6–1.91% in Bangladesh based on data from 944 rice farmers [24]. In China, Guo Yan et al. estimated maize harvest link losses between 4.76% and 12.41% across five provinces of Heilongjiang, Jilin, Henan, Hebei, and Gansu through a local small-plot field trial method [25]. Additionally, the researcher concluded that maize harvest link losses were 2.74% using a questionnaire survey of 2186 maize farmers in 25 provinces of China [26]. Based on questionnaires from 900 farmers in Henan Province, Song et al. concluded that the loss rate of the wheat harvesting link was 1.6% [27], much higher than the loss rates of other links, such as transportation and storage. Cao et al. found that the average loss rate of wheat harvests was 4.715% based on sample data from 1135 farmers in 16 provinces [28], although the loss rate of wheat in different provinces varied substantially. Based on data from 957 families in 10 provinces across the nation collected by a questionnaire survey, Wu et al. discovered that the average loss rate of rice crops was less than 4% [29]. Through the partial small plot field experiment approach, Huang Dong et al. achieved a rice harvest link loss rate of 1.18–6.55% [30]. As a result, harvest grain losses for different maize varieties vary by region. From the standpoint of grain saving and loss reduction, resolving the loss of grain throughout the harvest process aids in ensuring food security.

This paper studied the impact of agricultural land management scale on grain loss in grain harvesting and its mechanism, with a focus on the intermediary effect of agricultural capital investment in grain harvesting, based on survey data of farmers in Shandong and Hebei and based on measuring the grain loss in the study area. The findings of this paper will contribute to the effective conservation of arable land resources and the promotion of food conservation and loss reduction. The rest of this paper is arranged as follows. A literature review, theoretical analysis, and research hypothesis comprise the second section. The third section comprises the data source, model setting, and variable selection. The analysis of model regression findings makes up the fourth section. The study's conclusion and policy illumination make up the fifth section.

2. Literature Review, Theoretical Analysis and Research Hypothesis

2.1. Literature Review

Initially, grain loss was defined as the portion of food that is safe for human consumption but not consumed due to the disposal, degradation, and infestation of food at any stage, including production [31]. However, this concept has not been broken down into the various linkages of the grain supply chain system, and this issue becomes more complex when grain production and loss are included in the same research context. Based on this, Gustavsson further defined grain losses as all portions initially intended for human consumption but not consumed and divided the food supply chain system into harvesting [32], drying, threshing, storage, transportation, processing, and marketing [33]. In order to more conveniently measure food loss, Buzby et al. of the Economic Research Service of the United States Department of Agriculture defined food loss as the amount of food available for human consumption after harvest but not available for consumption [34]. These include cooking losses, natural shrinkage (e.g., water loss), and losses due to mildew, pests, or climate. Many scholars have adopted this measurement method because the quantitative loss is easier to define and measure than the loss of other measurement methods. For an accurate definition, the Food and Agriculture Organization of the United Nations defines food loss as the unintentional reduction of food quantity or quality before consumption after consultation with experts in this field [35], which considers both quantity and quality factors [36,37]. Current research on harvest losses has focused on Asia and Africa, where major grains such as wheat, corn, and rice are grown. Studies in the Americas and Europe mainly focus on food cold chain transportation, sales losses, and food consumption waste.

The elements that affect grain harvest are numerous and intricate. The primary factor influencing harvest loss during the procedure is harvest time. Grain yields will naturally decrease with early harvest, and the late harvest will readily disappear. Therefore, understanding harvest timing is crucial to minimizing harvest loss [28,29,38,39]. Harvest time is no longer a determinant determined by farmers due to the rise of robotic outsourcing services. From south to north, mechanized outsourcing teams in China will provide harvesting services, and farmers will harvest by the team's arrival time rather than the ideal grain harvesting window. Harvest methods are classified as integrated, segmented, and artificial. In 2020, the mechanization rate of crop farming in China reached 71%, and the combined harvest rate of wheat exceeded 95% [40]. Most academics usually agree that machine harvests lose more crops than manual harvests. In contrast to the meticulous procedure of traditional harvesting, machine harvesting is clumsy and prone to damaging or missing grain [38,41]. Grain varieties differ in how harvesting practices affect harvest loss [42]. Segmented harvesting explicitly minimizes the loss of maize harvest but has no discernible impact on the loss of wheat and rice. This is because the mechanization of wheat and rice started early and developed rapidly, and its combined harvesting technology has reached a high level. The combined harvest method reduces the loss of wheat and rice harvest links and increases the loss of maize harvest links. The reason is that the mechanized harvesting of maize started late, and many mechanical processes cannot avoid reducing grain losses [26]. Mechanical harvesting makes maize grains splash. With the continuous improvement of mechanization, maize harvest losses are also increasing. The choice of harvesting methods is highly related to the endowment of family land. Large-scale farmers and farmers in major grain-producing areas are more willing to choose joint harvesting because of the high cost of hiring workers and the flatness of the land. Small-scale farmers and farmers in mountainous or hilly areas are more willing to choose artificial harvesting or segmented harvesting because of the limitations of resource endowments.

Unusual weather and pests during harvest can exacerbate grain losses and severely reduce yields [28,42,43]. Selecting varieties with good traits can help reduce grain harvest losses [39]. For example, wheat varieties' lodging resistance and other stress resistance characteristics can directly affect harvest losses [28]. In addition, work attitude, hand abundance, and catch-up will also have an impact on the loss. The fineness of harvesting operations also affects harvesting losses. The more positive the harvest attitude, the more delicate the harvest operation, and the lower the loss [28]. Having sufficient labor during harvest is conducive to reducing grain losses [26], especially for rice and maize crops [41]. However, Wu et al. also demonstrated that understaffing may increase grain harvest losses [29], but sufficient staffing does not effectively reduce losses because as the number of laborers increases, the marginal effect of reducing grain harvest losses per unit of labor diminishes.

The existing research mainly focuses on the influencing factors of grain harvest loss. Although a few scholars have paid attention to the impact of farmland management scale on grain loss, the existing research needs to include in-depth mechanism research. From the mechanism perspective, the scale of agricultural land management and the input of agricultural capital in the harvest link are highly correlated and mutually coupled elements in the grain harvest link, which need to be studied within a discussion framework.

2.2. Theoretical Analysis and Research Hypothesis

The impact of farmland management scale on grain loss at harvest may be the combined result of direct and indirect effects. First, the scale of farmland management may directly affect the harvest of grain losses. The scale of farmland management results from the choice of farmers' livelihood capital. The reason is that farmland transfer is the decisive factor in changing the scale of farmland management [44], which promotes the flow of factors between urban and rural areas and the optimal allocation of social resources [8,45]. On the one hand, some farmers transfer a large amount of land from other operators and become large-scale farmers. On the other hand, some farmers transfer part or all of their land out, becoming part-time small-scale farmers or completely transforming into migrant workers [46] and transferring part or all of the agricultural labor force to the non-agricultural sector. In the process, land fragmentation has also improved [47,48]. Addressing land fragmentation can help improve the efficiency of agricultural machinery use [49,50]. From this perspective, large-scale farmers are more willing to accept agricultural skills training to master the grain loss reduction technology in the harvest process and enhance their awareness of grain loss reduction. At the same time, reducing land fragmentation can reduce the loss of grain harvest by increasing the area and reducing the fragmented plots. For small-scale farmers, because the transfer of household labor to urban areas increases the opportunity cost of grain planting when the benefits from reducing grain harvest losses do not compensate for the opportunity costs incurred, farmers' willingness to reduce harvest losses will decline, leading to extensive land management and exacerbating grain losses [30,39]. Based on this, this paper proposes the following hypothesis:

Hypothesis 1. *The farmland operation scale will directly affect grain loss in the harvest stage, and this effect will be significantly inhibited with the expansion of the farmland operation scale.*

Secondly, the scale of agricultural land management may indirectly affect the grain loss in the harvest link by affecting the agricultural input in the harvest link. The input of agricultural means of harvest includes labor, outsourcing services, and household agricultural machinery transportation costs. Due to the limited area of arable land, the land is not the primary source of income for smallholder farmers. For the sake of cost-effectiveness, they may invest more economically in agriculture at harvest time to reduce labor and transportation costs as much as possible, exacerbating food losses. Large-scale farmers, whose agricultural income accounts for a larger proportion of household income, pay more attention to the source of agricultural income and are more inclined to improve the utilization rate of human capital and machinery in the harvest link so as to increase agricultural input in the harvest link and reduce food loss.

Hypothesis 2. *The scale of agricultural land management will indirectly affect the grain loss in the harvest link through the input of agricultural capital in the harvest link, which will be significantly inhibited by the expansion of the input of agricultural capital in the harvest link.*

3. Model Setting, Data Source and Variable Selection

3.1. Model Setting

3.1.1. Econometric Model

The article uses ordinary least squares regression to estimate the value of the dependent variable with the value of all independent variables and least squares to estimate the unknown parameters of the multiple linear regression equation. The basic principle of the OLS regression model is the best-fit straight line, which should minimize the sum of the distances from each point to the straight line, which can also be expressed as the minimum sum of the squares of the distances. The model set in this paper is as follows:

$$Y_{ij} = \alpha + \beta_{ij} X_{ij} + \varepsilon_{ij} \quad (1)$$

Y is the explained variable, representing the loss rate of the jth grain (wheat, maize) harvested by farmer i. Explanatory variables are mainly divided into three categories: one is the core variable of farmland management scale, measured by grain acreage. The second is the harvest's characteristic variables, including the harvest subject, maturity, whether there is bad weather, pests and diseases, fineness, loss cognition, manpower adequacy, harvester operation proficiency, etc. The third is the family's characteristic variables, including gender, age, education years, years of farming, number of technical trainings in one year, family net income (ten thousand yuan), house construction value (ten thousand yuan), etc. α is the intercept term, β is the parameter to be estimated, and ε_{ij} is a random disturbance term.

3.1.2. Mediation Effect Model

In order to investigate the impact of the scale of agricultural land management on the loss of grain harvest through the input of agricultural capital in the harvest link, this paper draws on the existing research results and refers to the intermediary effect test method of Wen Zhonglin and Ye Baojuan et al. (2014) to construct the following econometric model:

$$Y_{ij} = \gamma_0 + \gamma_{ij} Area_{ij} + \sum \gamma_{ij} X_{ij} + \varepsilon_{ij} \quad (2)$$

$$Harv_{ij} = k_0 + k_{ij} Area_{ij} + \sum k_{ij} X_{ij} + \varepsilon_{ij} \quad (3)$$

$$Y_{ij} = \eta_0 + \eta_{ij} Area_{ij} + \gamma_{ij} Harv + \sum \eta_{ij} X_{ij} + \varepsilon_{ij} \quad (4)$$

In Equation (2), Y represents the loss rate of grain harvest; *Area* represents the scale of farmland operation; and *Harv* indicates agricultural inputs in the harvesting process. The explanatory variables X_{ij} are divided into two categories: one is the harvest's characteristic variables, and the other is the family's characteristic variables. γ, k, and η are other parameters to be estimated.

After the γ_{ij} in the baseline regression model passes the significance test, it shows that the scale of farmers' operation does indeed affect the grain loss in the harvest link. At this time, we continue to verify whether the scale of the farmers' operations is significant to the agricultural input in the harvest link. If the K_{ij} passes the significance test, it is necessary to verify that when the scale of farmers' operation and the variable of agricultural input are both included in the regression of grain loss, if η_{ij} and γ_{ij} both pass the significance test, it proves that agricultural input does indeed act as an intermediary variable for the effect of farmland operation scale on grain loss. If η_{ij} is not significant but γ_{ij} is significant, it indicates that the complete mediation effect is significant. If γ_{ij} is not significant but η_{ij} is significant, then the Bootstrap test needs to be introduced to further verify the mediation effect of agricultural input in the harvest link.

3.2. Data Sources

The article uses data obtained from a rural household survey conducted by the research team in Shandong and Hebei in September 2022, and the data were collected using multilevel sampling. First, we targeted Shandong and Hebei, both of which are located in the North China Plain. Second, we randomly selected two to four counties (county-level cities) from each province, including Ningjin and Gaoyi counties in Hebei Province, and Cao County, Yuncheng County, Leling City, and Shouguang City in Shandong Province. Third, three villages were randomly selected from each county. Finally, approximately 15 to 25 households were randomly interviewed in each selected village. Details are shown in Table 1. The interviews covered household demographics, agricultural activities, production operations, and other vital issues related to livelihoods and lifestyles. The study focused on the regional 2021 domain wheat and maize production harvest. The survey collected 413 farmer questionnaires, excluding 27 from non-grain-growing farmers, leaving a valid number of 386 farmer questionnaires. The effective questionnaire rate reached 93.46%.

Table 1. Number of questionnaires by region.

Province	Region	Questionnaire
Hebei	Ningjin County, Gaoyi County	102
Shandong	Cao County, Yuncheng County, Leling City, Shouguang City	284

3.3. Variable Selection and Descriptive Statistics

3.3.1. Explained Variables

In order to quantify the grain loss in the harvest process of farmers, this paper takes the harvest loss rate as the explained variable, which is measured by the formula: grain loss rate = loss amount/(actual yield + loss amount) (%). In order to investigate the heterogeneity of grain loss of different varieties, this paper sets Y as the total grain loss rate, Y1 as the wheat loss rate, and Y2 as the maize loss rate.

3.3.2. Core Explanatory Variables and Mediating Variables

The core explanatory variable of the article is the farmland management scale, measured by grain sown area. Some studies divide farmland operation scale into large-scale farmers and small-scale farmers. However, domestic and foreign scholars have no consistent standards for the classification of scale farmers. For example, the Food and Agriculture Organization of the United Nations (FAO) defines the size of farmers by setting a threshold of 2 square hectares, large-scale farmers above 2 square hectares, and small and medium-sized farmers below 2 square hectares [51]; Chen Chao and others will operate land less than 30 mu of grain farmers as small farmers, 50 mu and above the scale of farmers as large farmers. Because of this, small farmers and large farmers have shown obvious differences in livelihood strategies [52]. Some scholars also set the dividing standard for farmers with scale management as whether their land management area is greater than five times the per capita cultivated land area of the village where they live, in which the farmers with more than five times the per capita cultivated land area of the village where they live are large-scale farmers; otherwise, they are small-scale farmers [53]. However, according to the actual situation of the survey, this paper does not adopt the classification method of large and small farmers because the sample differences in the survey area are large. Some farmers only maintain the land for rations, while others transfer a large amount of land from the village collective or other farmers. If the distribution is forced, the distribution boundaries of large and small farmers are difficult to define, resulting in deviations in the final results.

The intermediary variable of the article is the agricultural input in the harvest process. On the one hand, the larger the scale of agricultural land management, the greater the possibility of land fragmentation improvement, which in turn helps to improve the efficiency of agricultural machinery use and reduce grain losses in the harvesting process. On the other hand, the measures taken by different farmers in the harvesting process are different, and the allocation of resources is also different, which will cause differences in the input of agricultural materials in the harvesting process. Specifically, because the agricultural income of small-scale farmers is more guaranteed, they are willing to invest at a reasonable cost, which will reduce the input of labor, machinery, and other funds in the harvesting process. The more extensive harvesting method may aggravate the grain loss. Large-scale farmers are more willing to increase the input of labor, machinery, and other resources in the harvesting process to minimize the loss of the harvesting process to obtain high agricultural returns.

3.3.3. Control Variables

The control variables include two parts: family characteristic variables and characteristic harvest variables. The characteristic family variables include gender, age, years of education, years of farming, agricultural training, etc. Gender, age, and education level will affect the farmer's year-round planting arrangements and harvesting methods, thus affecting grain harvest losses. Agricultural training reflects the family's emphasis on agriculture and the ability to invest in agricultural production, which affects harvest losses. Household net income and house construction price are variables to measure household assets.

The characteristic harvest variables include the harvest subject, maturity, unusual weather, pests and diseases, planting fineness, loss cognition, workforce sufficiency, harvester operation proficiency, etc. The above variable selection refers to previous studies. The harvest subject and maturity will directly affect the loss during the harvest period, and the expected impact direction is uncertain. The higher the labor abundance, the more sufficient the labor force is at the harvest time, and the expected direction is negative. Unusual weather and pests will increase grain losses during harvest, so the expected impact direction is positive. The influence direction of harvest working attitude is negative.

3.3.4. Descriptive Statistical Analysis

Descriptive statistics of the variables used in the empirical analysis are given in Table 2. Table 2 shows that the mean value of total grain loss is 225.0, the mean value of the wheat loss is 196.1, the mean value of maize loss is 253.8, and the extreme difference in maize loss is the largest, which indicates that maize loss in harvesting is greater than wheat loss. The average land operation scale was 28.94 mu, with a minimum value of 0.5 mu and a maximum value of 1150 mu, which had an enormous difference. The mean value of harvesting subjects was 0.179, the average crop maturity at harvest was 2.293, there was a 33.9% probability of encountering unusual weather at harvest, the average degree of pests and diseases was 1.624, and the average proficiency of harvester operation was 1.883. The results in Table 2 also indicate that the average education level of household heads was 7.212 years, the average age was 58.30 years, the average number of years in farming was 35.09 years, and the average number of education and training received in a year was 1.280.

Table 2. Descriptive statistics.

Variables	Definition	Mean	SD
Grain loss rate (Y)	Grain loss/(actual yield + loss) (%)	225.0	22.84
Wheat loss rate (Y1)	Wheat loss/(actual yield + loss) (%)	196.1	63.99
Maize loss rate (Y2)	Maize loss/(actual yield + loss) (%)	253.8	61.83
Farmland management scale	Grain sown area	28.94	101.4
Harvest subject	Harvest subject (1 for self, 0 otherwise)	0.179	0.384
Maturity	Grain maturity at harvest (1~4, of which 1 is precocious, 4 is overripe	2.293	0.668
Unusual weather	Unusual weather (unusual weather is 1, otherwise 0)	0.339	0.474
Pest and disease	Degree of pests and diseases at harvest (1~5, where 1 is no pests and 5 is serious pests)	1.624	0.835
Planting fineness	Planting fineness (1~5, where 1 is not fine and 5 is fine)	3.301	0.998
Loss cognition	Loss cognition to the head of household (1~5, where 1 is not a serious loss and 5 is a serious loss)	2.650	0.897
Workforce sufficiency	Workforce sufficiency (1~5, where 1 is understaffed and 5 is fully staffed)	3.342	1.008
Harvester operation proficiency	Harvester operation proficiency (1~5, where 1 is insufficient proficiency and 5 is sufficient proficiency)	1.883	0.745
Gender	Gender of head of household; male 1, female 0	0.966	0.181
Age	Age of head of household	58.30	9.733
Education	Years of education of the head of household (years)	7.212	2.589
Farming years	Householder engaged in agricultural production years (years)	35.09	10.72
Agricultural training	The number of trainings in 1 year (times)	1.280	2.569
Family net income	Household annual expenditure-annual income (ten thousand yuan)	6.744	18.78
Housing construction price	Housing construction price (ten thousand yuan)	9.188	9.986

4. Analysis of Model Regression Results

4.1. Basic Regression

In this paper, STATA 17.0 was used for the regression processing of 386 cross-section data from the survey. The regression results are shown in Table 3. Table 3 also shows the effect of each variable on total grain loss, wheat loss, and maize loss at harvest. Table 3 shows that the variance inflation factor VIF is less than 5, so there is no significant covariance among the variables. Table 3 shows the regression results of the model; column (1) shows the effect of each variable on the total grain loss at harvest, and columns (2) and (3) show the effect of each variable on the loss at harvest for wheat and maize, respectively. The results show that there is a significant negative relationship between the farmland management scale on total grain loss at harvesting and also shows a significant negative relationship with the grain loss of wheat and maize crops, with coefficients of −0.065, −0.059, and −0.070 for farmland operation scale, respectively, indicating that for each percentage point increase in the farmland management scale, total grain loss decreases by 0.065 percentage points, and wheat and maize losses decreased by 0.059 and 0.070 percentage points, respectively. The above study shows that an increase in the scale of farming management helps to reduce grain losses at harvest, confirming Hypothesis 1.

Regarding control variables, maturity significantly affected grain loss, with higher crop maturity resulting in higher grain loss. This is because over-maturity of the crop reduces the moisture in the grain, which will lead to natural shedding to the field at harvest, resulting in losses. At the same time, maize, which has a larger cob size compared to wheat, is less affected by this effect and instead reduces losses, but the statistical results were insignificant. The significant positive coefficient of unusual weather indicates that weather conditions affect grain loss at harvest, significantly affecting wheat loss and insignificantly affecting maize loss. Generally, wheat needs to be harvested in unusual weather, and maize can be harvested late. Because wheat is head-heavy, it easily falls over due to natural disasters, and once wheat falls over, this increases the harvesting cost in addition to making it impossible to avoid the grains falling off during harvesting. At the same time, maize can be harvested appropriately late to increase yield and income, and a short period of unusual weather will not cause maize to mold. Pest and disease coefficients were positive but significant for maize and insignificant for wheat. Loss cognition significantly affected wheat losses, indicating that farmers were generally aware of wheat losses and lacked knowledge of maize losses. The coefficient of years of education is significantly positive, indicating that the higher the level of education, the more severe the degree of grain loss, probably because this group of farmers is more focused on non-farm income and less concerned about the loss of income due to grain loss at harvest. Again, the coefficient of age was significantly positive; the older the age, the more severe the grain loss, significantly so in maize. The coefficient of farming years was significantly positive in wheat losses, significantly negative in maize losses, and insignificant in total losses, so its effect on grain losses at harvest could not be determined. The coefficient of the number of agricultural training was significantly negative, indicating that the increase in training had a suppressive effect on the increase in grain losses, with a significant effect on the suppression of wheat losses and a non-significant effect on the suppression of maize losses.

The main conclusions obtained from Table 3 are as follows:

First, the coefficients of the farmland management scale in Y, Y1, and Y2 are all negative, indicating that the larger the scale of farmers, the lower the grain loss rate in the harvesting link, and the loss rate of maize is higher than that of wheat. Expanding farmland management scale helps to reduce grain loss at harvest link to a certain extent, confirming Hypothesis 1.

Second, the factors affecting grain harvesting, such as maturity, unusual weather, and pests and diseases, directly and significantly affect grain loss.

Third, household and individual factors, such as the age of farmers, years of education, years of farming, and the number of times of receiving training in a year, significantly affect grain loss.

Table 3. Regression results of farmland operation scale on grain loss rate.

	(1)	(2)	(3)	(4)
	Y	Y1	Y2	VIF
Farmland management scale	−0.065 ***	−0.059 *	−0.070 **	1.08
	(−5.896)	(−1.793)	(−2.189)	
Harvest subject	3.764	−12.660	19.979	2.8
	(0.804)	(−0.899)	(1.464)	
Maturity	3.266 *	9.407 *	−2.839	1.24
	(1.830)	(1.752)	(−0.545)	
Unusual weather	13.577 ***	19.255 *	8.092	2.23
	(4.022)	(1.896)	(0.822)	
Pests and disease	5.311 **	−0.270	10.843 *	2.95
	(2.410)	(-0.041)	(1.686)	
Planting fineness	1.284	3.667	−1.144	1.44
	(0.994)	(0.944)	(−0.303)	
Loss cognition	1.406	6.888 *	−4.158	1.15
	(1.099)	(1.790)	(−1.114)	
Workforce sufficiency	−0.344	1.872	−2.497	1.29
	(−0.285)	(0.515)	(−0.708)	
Harvester operation proficiency	−0.845	2.674	−4.407	1.24
	(−0.529)	(0.556)	(−0.945)	
Gender	2.089	16.692	−12.408	1.04
	(0.345)	(0.917)	(−0.703)	
Age	0.343 *	-0.857	1.538 **	3.52
	(1.660)	(−1.379)	(2.550)	
Education	1.040 **	0.103	1.971	1.21
	(2.282)	(0.075)	(1.483)	
Farming years	0.066	1.089 *	−0.952 *	3.6
	(0.350)	(1.907)	(−1.720)	
Agricultural training	−1.603 ***	−3.201 *	−0.016	2.09
	(−2.660)	(−1.765)	(−0.009)	
Family net income	0.094	0.212	−0.025	1.09
	(1.580)	(1.183)	(−0.145)	
Housing construction price	0.042	−0.223	0.309	1.15
	(0.366)	(−0.643)	(0.919)	
Cons	169.445 ***	130.424 ***	208.747 ***	
	(11.796)	(3.018)	(4.980)	
Adj R^2	0.752	0.622	0.614	

Note: ***, **, * represent significant at 1%, 5%, and 10% significance levels.

4.2. Decomposition of Factors Influencing Grain Loss at Harvest

Based on the results of the model-based regression, in order to be able to show the influencing factors of grain loss more effectively, this paper divides the factors affecting grain loss into three clusters. The first group is the farmland management scale, including the farmland management scale; the second group is the harvesting characteristics variables, including the harvest subject, maturity, unusual weather, pests and diseases, planting fineness, loss cognition, workforce sufficiency, and harvester operation proficiency variables; the third group is the household characteristics variables, including the gender, age, education, farming years, agricultural training, net family income, and housing construction price variables.

Column (1) of Table 4 indicates total grain loss at harvest, column (2) represents wheat loss at harvest, and column (3) indicates maize loss at harvest. According to the decomposition results of the Shapley value based on R2 in Table 4, we can obtain that the factors affecting total grain loss are group 1, group 2, and group 3 in the order of 39.00%, 35.20%, and 25.80%, respectively, with a cumulative contribution of 100%, which indicates that the farmland management scale plays a dominant role in total grain loss among all the influencing factors. The factors affecting wheat loss were group 2, group 3, and group 1 with 52.12%, 34.68%, and 13.20%, respectively, with a cumulative contribution of 100%, indicating that harvest characteristics variables play a major role in wheat losses. The factors affecting maize harvesting session in order were group 3, group 2, and group 1, with 46.86%, 33.15%, and 20.00%, respectively, with a cumulative contribution of 100%, indicating that household characteristics variables had the greatest effect on maize losses.

Table 4. Decomposition of factors influencing grain loss based on Shapley values.

Factor	(1) Shapley Value (Normalized)	(1) Percent (Normalized)	(2) Shapley Value (Normalized)	(2) Percent (Normalized)	(3) Shapley Value (Normalized)	(3) Percent (Normalized)
Group 1	0.07291	39.00%	0.00821	13.20%	0.01108	20.00%
Group 2	0.06580	35.20%	0.03244	52.12%	0.01837	33.15%
Group 3	0.04823	25.80%	0.02159	34.68%	0.02597	46.86%
TOTAL	0.18694	100.00%	0.06224	100.00%	0.05542	100.00%

Note: Group 1: farmland management scale. Group 2: harvest subject, maturity, unusual weather, pests and diseases, planting fineness, loss cognition, workforce sufficiency, and harvester operation proficiency variables. Group 3: gender, age, education, farming years, agricultural training, family net income, and housing construction price variables.

4.3. Robustness Test

Indicators for evaluating grain loss at the harvesting stage include grain loss rate and amount of grain loss. Considering the different farmland management scales, there may be considerable variability in grain loss rates between operators with large and small farmland management scales. This may lead to a spurious association of farmland management scale on grain loss at the harvest. In order to weaken the influence of different calculation methods of variables on the research findings, this paper adopts the method of replacing the dependent variable for robustness testing. The results in Table 5 show that after replacing the explained variable from the grain loss rate to the determined amount of grain loss, the effects of the farmland management scale on total grain loss, wheat loss and maize loss at the harvesting stage are still significant, indicating that the conclusions of this paper are still robust.

Table 5. Regression robustness.

	(1)	(2)	(3)
	Amount of Grain Loss	**Amount of Wheat Loss**	**Amount of Maize Loss**
Farmland management scale	−0.019 ***	−0.016 ***	−0.021 ***
	(−8.744)	(−3.594)	(−4.482)
Harvest subject	control	control	control
Maturity	control	control	control
Unusual weather	control	control	control
Pests and disease	control	control	control
Planting fineness	control	control	control
Loss cognition	control	control	control
Workforce sufficiency	control	control	control
Harvester operation proficiency	control	control	control
Gender	control	control	control
Age	control	control	control
Education	control	control	control
Farming years	control	control	control
Agricultural training	control	control	control
Family net income	control	control	control
Housing construction price	control	control	control
Cons	17.922 ***	13.223 **	22.610 ***
	(6.427)	(2.200)	(3.730)
Observations	386	386	386
Adj R^2	0.626	0.564	0.532

Note:***, ** represent significant at 1% and 5% significance levels.

5. Intermediary Analysis Based on Grain Farm Inputs at Harvesting Stage

The above study shows that the farmland management scale can suppress grain losses at harvest. The following section will attempt to answer whether farmland management scale can suppress the grain losses of crops by increasing farm inputs. By testing this question, we will investigate the intrinsic link between farmland management scale and grain loss at harvest for each crop.

Table 6 presents the results of the mediation test of farm inputs on the farmland management scale and grain loss at harvest. Column (1) is the regression result of the farmland management scale and farm inputs, column (2) is the regression result of farmland management scale, farm inputs and Y, column (3) is the regression result of the farmland management scale, farm inputs and Y1, and column (4) is the regression result of farmland management scale, farm inputs and Y2. Among them, column (1) indicates that there is a significant positive relationship between the farmland management scale and farm inputs, column (2) indicates that farm inputs significantly suppress total grain losses, and column (3) and column (4) indicate that farm inputs significantly suppress wheat losses and maize losses at harvest, and farm inputs play a relatively vital role in reducing maize losses. Furthermore, the coefficients of operation size in columns (2), (3) and (4) are not significant, indicating that farm inputs play a mediating role, which tentatively proves that Hypothesis 2 is valid.

Table 6. Mediating effect of agricultural input.

Variables	**M (Farm Inputs) (1)**	**Y (2)**	**Y1 (3)**	**Y2 (4)**
Farmland management scale	0.121 ***	−0.013	−0.026	0.001
	(7.328)	(−1.433)	(−0.748)	(0.017)
Farm inputs		−0.430 ***	−0.273 ***	−0.586 ***
Harvest subject	control	control	control	control
Maturity	control	control	control	control
Unusual weather	control	control	control	control
Pests and disease	control	control	control	control
Planting fineness	control	control	control	control
Loss cognition	control	control	control	control
Workforce sufficiency	control	control	control	control
Harvester operation proficiency	control	control	control	control
Gender	control	control	control	control
Age	control	control	control	control
Education	control	control	control	control
Farming years	control	control	control	control
Agricultural training	control	control	control	control
Family net income	control	control	control	control
Housing construction price	control	control	control	control
Cons	230.784 ***	268.567 ***	193.537 ***	343.879 ***
	(10.709)	(21.324)	(3.943)	(7.504)
		−6.674	−2.484	−4.668
Adj R^2	0.542	0.502	0.637	0.406
Observations	386	386	386	386

Note: *** represent significant at 1% significance levels.

The evidence in Table 6 suggests that the scale of farmland management scale can reduce the rate of grain losses by increasing farm inputs. On the one hand, farmers with larger farmland management scales have more significant financial support to invest in more advanced harvesting machinery to meet their needs in the harvesting process and achieve good harvesting, reducing maize losses in the harvesting process. On the other hand, farmers with a larger scale of farmland operations, whose primary source of income is agricultural income, are more concerned about maize harvesting, and higher agricultural inputs make the leading operators broaden their access to information, enhance their ability to resist risks, and reduce the rate of grain loss.

In the mediating effect test regression, the regression coefficient stepwise test method has the problem of low test power. To further verify the robustness of the test results of the mediating mechanism, this paper tested the mediating effect of grain loss using the Sobel test and Bootstrap test. The original hypothesis for both tests is H0: $k_{ij} \times \eta_{ij} = 0$, where k_{ij} is the regression coefficient of farmland management scale on farm inputs, and η_{ij} is the regression coefficient of the farmland management scale on grain loss after adding the mediating variable farm inputs. In the Sobel test, the Z-value of Y in the Sobel test is −6.674, the Z-value of Y1 is −2.484, and the Z-value of Y2 is −4.668. All three values are negative. Additionally, the p-values of Y, Y1 and Y2 are all less than 0.05, and the original hypothesis is rejected at the 5% level, i.e., the mediating effect is tested, and farmland management scale affects grain loss in harvesting through the agricultural input path, thus confirming Hypothesis 2.

In the product of the coefficients test, the confidence interval of the coefficients calculated by the bias-corrected percentile Bootstrap method is more accurate than that obtained by the Sobel method and has higher testing power. Therefore, this method was used to test the mediation robustness further and determine whether the mediation effect exists by the critical value of the confidence level. The number of repeated sampling was set to 500, and the results are shown in Table 7. The indirect effect interval [−0.0010219, −0.000014] and direct effect interval [−0.000234, −0.0000237] did not contain zero, thus rejecting the original hypothesis, and the mediating effect accounted for 80.1%. This further indicates that farm inputs partially mediate the relationship between farmland management scale and grain loss, and Hypothesis 2 is again tested.

Table 7. Bootstrap results.

Influence Path	Effect	Effect Value	Standard Error	95% Confidence Interval Lower Limit	95% Confidence Interval Upper Limit
Farmland management scale→farm inputs→grain losses	Indirect effect	−0.0005179	0.0002571	−0.0010219	−0.000014
Farmland management→grain losses	Direct utility	−0.0001288	0.0000536	−0.000234	−0.0000237

Note: Bootstrap is repeated 500 times.

6. Research Conclusions and Discussion

Academic and policy professionals have recently started to acknowledge the critical role that harvest-related grain losses play in assuring the global food supply and preserving food security. In this paper, we empirically investigate how the extent of field management affects grain loss during harvest. By setting up a mediating variable of farm inputs at the harvesting stage, we seek to analyze how farmland management scale affects the role of grain loss at the harvesting stage and situate our study within the original grain loss study framework.

6.1. Theoretical Contribution

Previous studies mainly focused on exploring the influencing factors of grain harvest link loss. However, they did not conduct an in-depth analysis of the mechanism of action between the farmland operation scale and grain loss in the harvest link. Based on previous studies, this study analyzed the mechanism of the farmland operation scale affecting grain loss in the harvest link. The mediating variable method was used to explore the effect path of the farmland management scale on grain loss. The primary effect analysis revealed that farmland management significantly and adversely impacted crop loss during harvest. In order to better adapt to agricultural production, farmers should level land boundaries and slopes, then integrate the finely fragmented small plots into large flat plots. This would alleviate the finely fragmented land and lay the groundwork for meticulous agricultural production. Grain loss at the harvesting stage would also be alleviated accordingly. The field survey revealed this. The analysis of the intermediary effects demonstrated that as the scale of farmland management was increased, farmers gave more attention to the source of grain income and consequently increased their capital investment in the harvesting process. Grain loss was reduced due to the increased capital investment per unit area.

6.2. Practical Implications

Our research has practical significance for promoting the reduction of food savings. Previous studies have described the influencing factors of grain loss in the harvest process, especially the influence of harvest characteristics on grain loss. Based on the R^2 Shapley value method, this paper explores that the scale of agricultural land management is the critical factor affecting food loss. Therefore, this provides reasonable suggestions for the moderate transfer of land. Specifically, rural land transfer should be continuously promoted to expand the scale of farmland operations to reduce the high grain loss caused by scattered small-scale operations in rural China. Secondly, in response to the problem that some farmers are subjectively unwilling to transfer their contracted land and continue traditional small-scale farming operations, resulting in a high grain loss rate, the rural land resources should be transferred for large-scale operations through the development of new agricultural business entities such as cooperatives and large rural households to reduce the grain loss rate. Finally, the lack of farmers' awareness of grain loss reduction is an essential reason for the high loss rate, so it is necessary to continuously improve farmers' awareness of grain loss reduction to actively pay attention to and implement the behavior necessary to reduce grain losses. Further promotion of the appropriate transfer of agricultural land could further reduce food losses at the harvest stage. In the future, the promotion of rural vitalization should strengthen the construction of rural land marketization and actively create a new type of agricultural management body to assume the responsibility of agricultural production and grain reduction.

6.3. Research Limitations

Although this study provides an in-depth analysis of the effect of farmland operation scale on losses in the grain harvesting chain, there are still several things that could be improved, as follows. First, this study selected six counties in Hebei and Shandong provinces, which are part of the central grain-producing regions, as the sample area, which has a robust national representativeness but is limited by data availability and does not further expand the sample size. Therefore, future studies can consider constructing a large panel data sample further to improve the credibility and generalizability of the findings. However, considering that different farmland operation scales and household income levels may have specific effects on farmers' grain harvesting behavior, future research can further discuss the nonlinear relationship between farmland operation scale and grain harvesting link loss under different groups.

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