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# Does Farmland Transfer Contribute to Reduction of Chemical Fertilizer Use? Evidence from Heilongjiang Province, China

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**Abstract:** Promoting the reduction of chemical fertilizers is an important measure to promote the green and sustainable development of agriculture. Farmland transfer is a new way to minimize the need of chemical fertilizers. However, there is debate over this causality. This paper examines the relationship between farmland transfer and chemical fertilizer reduction. After the theoretical analysis, based on the data of 442 corn farmers in Heilongjiang Province, the study employed the endogenous switching probit model to empirically test the effect of farmland transfer on the reduction of chemical fertilizer. The study finds that in the survey area, the overall actual chemical fertilizer application rate was 12.12 kg/mu higher than the economic optimal application rate, which had more room for chemical fertilizer reduction. Moreover, farmland transfer-in reduced the chemical fertilizer application during corn production. If farmland transfer-in farmers decided not to transfer into the farmland, the chemical fertilizer reduction treatment effect would decrease, while it would increase if farmland non-transfer-in farmers decided to transfer into the farmland. Finally, the chemical fertilizer reduction treatment effect would decrease if farmers who had transferred into farmland concentratedly chose to transfer into farmland dispersedly, while it would increase if farmers who had transferred into farmland dispersedly chose to transfer into farmland concentratedly. These findings can provide experience for achieving more effective farmland transfer and chemical fertilizer reduction.

**Keywords:** farmland transfer; chemical fertilizer reduction; corn growers; Heilongjiang province



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## 1. Introduction

Chemical fertilizers have long played a significant role in China's grain production and agricultural development. However, excessive and inefficient chemical fertilizer application has also had a severely negative impact on environment [1–4]. Moreover, it should be noted that China's chemical fertilizer inputs have entered the stage of diminishing marginal returns [5] and increased chemical fertilizer application can no longer ensure a sustainable increase in grain production. Instead, it may result in soil consolidation, acidification, and water pollution [6–9], endangering food security and the sustainability of agricultural development [10–12]. Therefore, the Chinese government proposed a "zero growth" action plan for chemical fertilizers and has already implemented some measures to promote chemical fertilizer reduction. However, chemical fertilizer reduction is a complex and long-term process. At present, the intensity of chemical fertilizer application in China still exceeds the internationally recognized upper limit of environmental safety in chemical fertilizer application, and the utilization efficiency is much lower than that of developed countries in Europe and the United States [13–16]. How to continue to encourage chemical fertilizer reduction in the future to achieve cleaner output is an essential topic that requires immediate attention for the green and sustainable development of Chinese agriculture.

In fact, the allocation of production elements like chemical fertilizer is an endogenous reflection of changes in important endowment resources like land, meaning that chemical fertilizer inputs are inextricably linked to the scale of farmland [17,18]. In recent years, more and more academics have conducted extensive discussions on the relationship between farmland transfer and chemical fertilizer reduction. Most studies have shown that the expansion of farmland management scale under farmland transfer has a significant negative correlation with chemical fertilizer application, mainly because farmland transfer helps to play the scale management effect and effectively reduces the cost of farmers' acquisition of "new technology and new knowledge", which awakens farmers' ecological consciousness and motivates them to adopt clean production methods, thereby reducing the use of chemical fertilizers [19–23]. However, other studies indicate that the increasing scale of farmland through farmland transfer may push farmers to apply more chemical fertilizer in pursuit of higher yields [24]. At the same time, the time and management costs, as well as the moral hazard and adverse selection of hired workers, may lead to an increase in chemical fertilizer use [25]. That is, large-scale agricultural production may cause environmental pollution and inefficiency [26–28].

Throughout the studies on farmland transfer and chemical fertilizer reduction, we found that the total effect of farmland transfer on chemical fertilizer reduction did not form a consistent conclusion. The reason may be that homogenization treats the connotations of farmers' scale operation and plot scale operation. In actuality, the location of the transferred farmland is different, resulting in different economic scale. In other words, the impact of applying chemical fertilizer will vary depending on whether the farmland rented is adjacent to one another. The land was still fragmented as a result of the dispersive transfer, which makes it challenging to meet the investment threshold for large and medium-sized machinery and advanced technology. Additionally, the corresponding time and financial costs are on the rise, which could encourage farmers to apply excessive chemical fertilizer [29]. Contrarily, if farmers transfer into farmland concentratedly, that will make the transferred farmland adjacent, increasing both the scale of the operation and the size of the plots, which in turn increases the economies of scale impact and reduces the need for chemical fertilizer [30].

Through the above analysis, we found that the spatial difference of farmland transfer has different effects on fertilizer reduction. Unfortunately, previous studies have mainly focused on the impacts of farmland transfer scale on fertilizer reduction, we believe that it is necessary to further explore the internal relationship between farmland transfer and fertilizer reduction from the perspective of spatial differences in farmland transfer, especially to analyze the effect of concentrated transfer of farmland and dispersed transfer of farmland to fertilizer reduction. Secondly, in terms of research methods, since decisions on farmland transfer and fertilizer application are often affected by some unobservable factors at the same time, there may be problems of "simultaneous decision" and "self-selection" that may cause deviations in estimated results. To overcome this defect, we intentionally correct the problem by the endogenous switching probit model to obtain more robust estimation results.

Therefore, in this paper, based on microscopic research, we analyze the impact of farmland transfer on fertilizer reduction in maize production from both theoretical and empirical perspectives, and compare the effects of farmland centralized transfer and farmland decentralized transfer on fertilizer reduction. The results of this study will provide empirical evidence on how the government can promote and support the achievement of more effective farmland transfer and fertilizer reduction, and contribute to green and sustainable agricultural development globally, especially in developing countries.

The paper is organized as follows. Section 2 theoretically analyzes the mechanism of the impact of farmland circulation on fertilizer reduction. Section 3 presents the data sources and econometric methods. Section 4 presents the empirical results and analysis. Section 5 focuses on discussion. Section 6 presents conclusions and implication.

## 2. Theoretical Analysis and Hypothesis

The allocation of production factors such as chemical fertilizer is an endogenous reflection of changes in key endowment resources, and changes in operation scale and plot size induced by farmland transfer will largely affect farmers' chemical fertilizer input behavior [17,18]. However, the relationship between farmland transfer and chemical fertilizer reduction does not form a consistent conclusion, probably because of the homogeneous treatment of the connotations of farmers' scale operation and plot scale operation. In fact, the different locations of the transferred farmland result in different economies of scale.

Specifically, if the transferred farmland is not adjacent to the farmer's existing farmland, it only indicates that the number of plots managed by farmers has increased, but the size of these plots has not increased [29,30]. Farmland fragmentation akin to that of traditional small farmers may still occur if there are too many plots or if they are too far apart from one another. On the one hand, excessively finely fragmented plots will spatially make it more difficult for large and medium-sized farm machinery to operate, which in turn will reduce the standardization and specialization of mechanical chemical fertilizer application operations and will not only make no contribution to improving chemical fertilizer reduction technology but also incur high time and economic costs. On the other hand, for some farmers to manage non-adjacent farmland, the demand for labor will increase, and the resulting moral hazard and supervision costs may also increase farmers' motivation to increase chemical fertilizer application. It is difficult for farmers to change the spatial distribution of farmland in the short term, and they generally readjust the resource elements they own and reduce high costs such as hired workers, large and medium-sized machinery and new technologies by increasing the amount of chemical fertilizers. Therefore, we believe that if farmland transfer fails to eliminate fragmentation, it will not only exacerbate the loss of production efficiency but also weaken the chemical fertilizer reduction effect of farmland economy of scale.

If the transferred farmland is adjacent to the farmer's existing farmland, or if the transferred farmlands are already adjacent, it can obtain economies of scale on plots by eliminating ridges, dead ends, and compartment ditches. Firstly, the concentrated transfer of farmland achieves the operational space and investment threshold for large and medium-sized machinery and advanced agricultural technology. The deep application method under advanced technology and large machinery can reduce the amount of chemical fertilizer and improve the absorption and conversion rate while improving the application standard and traceability, which is more conducive to the reduction of chemical fertilizer [30–32]. Second, the concentrated transfer of farmland may induce farmers to shift from diversified cropping patterns to more monoculture and specialized cropping patterns. In terms of human capital accumulation effects, horizontal specialization can reduce farmers' time costs and improve their ability to learn specialized planting techniques, especially their ability to learn and apply chemical fertilizer reduction and efficiency technologies. In terms of human capital spillover effects, knowledge, technology, and ability have spillover effects, and the imitation and diffusion of chemical fertilizer reduction technologies among farmers also promotes the diffusion and application of chemical fertilizer reduction technologies to a certain extent [33]. In addition, the concentrated transfer of farmland can reduce the cost of production materials conversion between plots, reduce the apportionment cost per unit area, and encourage farmers to purchase productive service items such as mechanization and chemical fertilizer application. This will further promote the development of the agricultural socialized service market and the deepening of vertical division of labor, thereby promoting the application of specialized and precise chemical fertilizer reduction technology services and enable farmers to obtain the service-scale economy of chemical fertilizer reduction [34–37].

Accordingly, we have the following hypothesis:

**Hypothesis 1.** *Farmland transfer-in has a positive effect on chemical fertilizer reduction.*

**Hypothesis 2.** *Compared with farmland transferred dispersedly, the farmland transferred concentratedly is more helpful for the farmers to reduce the application of chemical fertilizers.*

## 3. Data and Methods

### *3.1. Data Collection*

Data were gathered during a field survey in Heilongjiang province, China, in 2021. The research region was chosen for two major reasons. First, Heilongjiang province, a significant grain-producing region in China, is situated in one of the "three prime maize belts" of the world. In 2020, Heilongjiang Province accounted for 13.28% and 13.99% of China's total maize sown area and production, respectively, significantly contributing to the country's food security. However, the high maize yields rely on high levels of fertilizer inputs, posing a serious threat to the quality of the black land and the ecological environment. After 2015, fertilizer application in Heilongjiang province began to show a downward trend, probably due to the fertilizer reduction initiative implemented by the Chinese government. It is noticed that the development of agricultural land transfer in Heilongjiang Province is rapid, with the proportion of agricultural land transfer and the scale of continuous agricultural land transfer much higher than the Chinese average level. Large-scale operation under agricultural land transfer has facilitated Heilongjiang Province to take the lead in promoting large and medium-sized mechanization, agricultural production services and other agricultural modernization projects. It also provides good conditions for achieving chemical fertilizer reduction. Thus, Heilongjiang province provides a very typical example that can provide China and other developing countries with experience in fertilizer reduction (Figure 1).

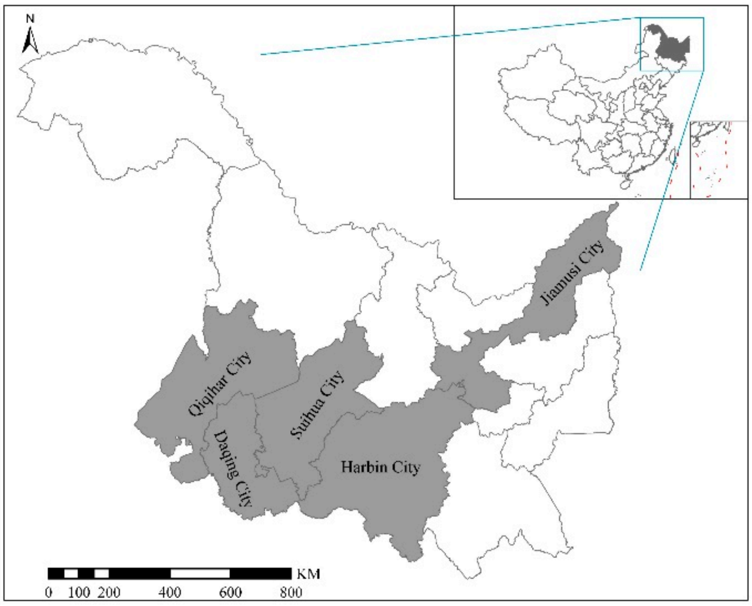


**Figure 1.** Map of the surveyed area.

To obtain data, we conducted a field survey of maize farmers in Heilongjiang Province from June to September 2021 based on a three-stage random sampling method, and the research process was divided into two phases.

Phase I: Pre-study was launched in June 2021. The research team conducted in-depth interviews with 15 randomly selected farmers in Acheng District, Harbin City, and made adjustments to the interview content and specific questions to improve the shortcomings of the questionnaire on the basis of sorting out the interview content and summarizing experiences.

Phase II: The formal research was launched from July to September 2021. To guarantee the scientific nature of sample selection, a three-stage random sampling was mainly adopted, in which five prefecture-level cities were randomly selected in Heilongjiang province, including Harbin, Qiqihar, Daqing, Jiamusi and Suihua; then, four counties were randomly selected in each prefecture-level city, and two to three villages were randomly selected in each county, and 10 farmers were randomly selected in each village for the questionnaire survey.

Considering the age and educational differences of farmers, the questionnaires were conducted in a one-on-one interview mode. In addition, a reward and punishment mechanism was set up to review and select the quality of questionnaires, to ensure the scientific nature of the questionnaire data. A total of 460 questionnaires were distributed in the survey. After excluding questionnaires with incomplete or missing data, logical contradictions, and irregularities, a total of 442 valid questionnaires were finally obtained, with a sampling efficiency of 96.09%.

### *3.2. Econometric Methods*

#### 3.2.1. Chemical Fertilizer Economic Optimal Application Amount

It is difficult to know whether farmers have reduced the amount of chemical fertilizer application, because the farmer's own answer is subjective and arbitrary. Therefore, in order to more accurately judge whether farmers have reduced fertilizer use, this paper, based on sorting out the views of the rational smallholder school represented by Schultz, tries to estimate the economic optimal chemical fertilizer application by farmers, and to measure whether farmers reduce chemical fertilizer application by comparing the difference between the economic optimal chemical fertilizer application and the actual chemical fertilizer application by farmers. Referring to the past research [38–40], we took corn yield as the dependent variable and chemical fertilizer input, labor input, machinery input and seed input as independent variables, the C-D production function model was constructed to estimate the output elasticity of chemical fertilizers. The C-D production function was set as follows:

$$\begin{aligned} \ln yield = \alpha_0 + \beta_1 \ln(fertilizer) + \beta_2 \ln(labor) \\ + \beta_3 \ln(machine) + \beta_4 \ln(seed) + \varepsilon \end{aligned} \quad (1)$$

In the Equation (1), yield denotes the average corn yield per mu of the farmer, fertilizer denotes the average chemical fertilizer input per mu of the farmer, labor, machine and seed denote the average input per mu of labor, machinery and seed, $\alpha$ and $\beta$ denote the parameters to be estimated, and $\varepsilon$ denotes the random error term.

Based on profit maximization theory, it is known that if farmers want to maximize profit, they should choose a production point where marginal benefit and marginal cost are equal, at which point the marginal benefit of chemical fertilizer on maize yield is equal to the ratio of chemical fertilizer price and maize price. As follows:

$$\frac{\partial yield}{\partial fertilizer} = \frac{p_{fertilizer}}{p_{yield}} \quad (2)$$

Meanwhile, based on the chemical fertilizer output elasticity $\beta_1$ measured in Equation (1), the marginal return of chemical fertilizer to maize yield is:

$$\frac{\partial yield}{\partial fertilizer} = \beta_1 \times \frac{yield}{fertilizer} \quad (3)$$

Using the profit maximization Equations (2) and (3), the average economic optimal chemical fertilizer application rate per mu can be obtained (4):

$$fertilizer_{optimal} = \frac{\beta_1 \times yield}{p_{fertilizer}/p_{yield}} \quad (4)$$

#### 3.2.2. Endogenous Switching Probit Model

Since the decision on farmland transfer and the decision on chemical fertilizer application are often affected by some unobservable factors at the same time, there may be problems of "simultaneous decision" and "self-selection", which may lead to biased estimation results. In order to overcome this shortcoming, this paper uses the endogenous switching probit model to correct this problem. The model measures the average processing effect by constructing a counterfactual scenario, and then corrects the selection bias caused by unobservable or observable variables, that is, overcomes the biased estimation problem caused by the "self-selection" of the sample, so as to obtain a more robust estimation result [41–43].

Firstly, the influence model of farmers' decision to transfer into farmland is constructed, and the decision to transfer into farmland is a binary choice variable. It is assumed that the potential benefit to be gained from the transfer of farmland by farmer (i) is $D^*_{ia}$, and the potential benefits for farmers who have not transferred into farmland is $D^*_{in}$, and then the condition for farmers to transfer into farmland is $D^*_{ia} - D^*_{in} = D^*_i > 0$, which means that farmers can get a higher return if they transfer into farmland. $D^*_i$ is the latent variable that cannot be observed directly. Then, the decision model for whether a farmer transfers into farmland is:

$$D_{\mathrm{i}} = \begin{pmatrix} 1, & D^*_{\mathrm{i}} > 0 \\ 0, & D^*_i \leq 0 \end{pmatrix} \quad (5)$$

In Equation (5), $D_i$ is the farmer's decision whether to transfer into farmland or not. When $D_i = 1$, it means that the farmer transferred into farmland, and when $D_i = 0$, it means that the farmer did not transfer into farmland. Therefore, the following model can be constructed for the effect of transferring into farmland on farmers' chemical fertilizer inputs.

$$Y_i = \alpha_i D_i + \sum_{j=1}^{n} \beta_j X_{ij} + \varepsilon_i \quad (6)$$

In Equation (6), $Y_i$ is the probability of reduced chemical fertilizer application, and $X_{ij}$ is the specific variables such as personal characteristics, household characteristics and production and operation characteristics that affect the chemical fertilizer input. $\alpha_i$ and $\beta_i$ are both the coefficient to be estimated. $\varepsilon_i$ is the random error term. Farmland transfer-in is the result of farmers' self-selection based on expected return analysis and is influenced by other factors which may also affect chemical fertilizer application, and thus generate sample selectivity bias. Therefore, the parameters $\alpha_i$ in model (6) can't accurately reflect the effect of farmland transfer-in on chemical fertilizer reduction.

We chose the endogenous switching probit model (ESP) to scientifically assess the impact of farmland transfer on chemical fertilizer reduction while constructing a counterfactual analytical framework to address issues such as information omissions [44,45].

The ESP model is divided into two stages, the first stage focuses on measuring the probability of farmers transferring into farmland, and the second stage focuses on constructing a decision equation for farmers to reduce chemical fertilizer. The specific equations are as follows:

Select Equation (whether farmers will transfer into farmland):

$$D_i = \gamma Z_i + \delta I_i + \mu_i \quad (7)$$

Result Equation (1) (treatment group, chemical fertilizer reduction equation for farmland transfer-in groups):

$$Y_{ia} = \beta'_a X_{ia} + \varepsilon_{ia} \quad (8)$$

Result Equation (2) (control group, chemical fertilizer reduction equation for farmland non-transfer-in groups):

$$Y_{in} = \beta'_n X_{in} + \varepsilon_{in} \quad (9)$$

In Equation (7), $D_i$ is a binary variable, indicating whether the farmer transfers into farmland, $Z_i$ refers to the influencing factors that affect whether the farmer transfers into farmland, $I_i$ is the identification variable, which is represented by whether the neighbor transfers into farmland; $\mu_i$ is the error term, $\gamma$ and $\delta$ indicate the parameter to be estimated; in Equations (8) and (9), $Y_{ia}$ and $Y_{in}$ are the chemical fertilizer reduction behavior of the farmland transfer-in group and the farmland non-transfer-in group, $X_{ia}$ and $X_{in}$ are the factors that affect farmers' chemical fertilizer reduction. $\varepsilon_{ia}$ and $\varepsilon_{in}$ are the error terms. $\beta'_a$ and $\beta'_n$ indicate the parameter to be estimated.

The estimation results of the ESP model show the probability of chemical fertilizer reduction by farmers under the true scenario, and further calculate the expected value of the reduction in chemical fertilizer application by farmers in the counterfactual scenario. Comparing the two, the average treatment effect of farmland transfer-in on the reduction of chemical fertilizer application can be obtained.

$$E[Y_{ia}/D_i = 1] = \beta'_a X_{ia} + \sigma_{\mu a}\lambda_{ia} \tag{10}$$

$$E[Y_{in}/D_i = 0] = \beta'_n X_{in} + \sigma_{\mu n}\lambda_{in} \tag{11}$$

$$E[Y_{in}/D_i = 1] = \beta'_n X_{ia} + \sigma_{\mu n}\lambda_{ia} \tag{12}$$

$$E[Y_{ia}/D_i = 0] = \beta'_a X_{in} + \sigma_{\mu a}\lambda_{in} \tag{13}$$

Equations (10)–(13) are the probability of chemical fertilizer reduction under the four scenarios: farmland transfer-in farmers, farmland non-transfer-in farmers, assumed farmland transfer-in farmers decided not to transfer into farmland, and assumed farmland non-transfer-in farmers decided to transfer into farmland, and thus estimate the average treatment effect of farmland transfer-in on the reduction of chemical fertilizer.

Therefore, the average treatment effect (*ATT*) of farmland transfer-in on the effect of chemical fertilizer reduction, can be expressed as:

$$ATT_i = E[Y_{ia}/T_i = 1] - E[Y_{in}/T_i = 1] = \left(\beta'_a - \beta'_n\right)X_{ia} + \left(\sigma_{\mu a} - \sigma_{\mu n}\right)\lambda_{ia} \tag{14}$$

Correspondingly, the average treatment effect (*ATU*) of farmland non-transfer-in on the effect of chemical fertilizer reduction, can be expressed as:

$$ATU_i = E[Y_{ia}/T_i = 0] - E[Y_{in}/T_i = 0] = \left(\beta'_a - \beta'_n\right)X_{in} + \left(\sigma_{\mu a} - \sigma_{\mu n}\right)\lambda_{in} \tag{15}$$

In summary, this study used the mean of $ATT_i$ and $ATU_i$ to measure the average treatment effect of farmland transfer on chemical fertilizer reduction.

In addition, we applied the endogenous switching probit model, under the counterfactual framework, to further analyze the treatment effects of concentrated and non-concentrated farmland transfer-in on the reduction of chemical fertilizer. Referring to the above studies and models, $A_i$ indicates whether the farmland transfer-in is concentrated, and whether transferring farmland through land transfer intermediary service organizations ($T_i$) was chosen as the identifying variable.

### *3.3. Variable Description*

Dependent variable. "Chemical fertilizer reduction" was used as the dependent variable, specifically to measure whether farmers reduced chemical fertilizer by comparing the economic optimal chemical fertilizer application rate with the actual chemical fertilizer application rate, and the actual chemical fertilizer application rate below the economic optimal chemical fertilizer application rate was defined as chemical fertilizer reduction. Table 1 shows that the probability of chemical fertilizer reduction for the surveyed farmers was 0.22.

Independent variable. "Farmland transfer-in" and "farmland concentrated transfer-in" were used as independent variables. Specifically, the first independent variable is the behavior of farmers transferring into farmland; the second independent variable is the behavior of farmers transferring into farmland in a concentrated manner, including farmers transferring into farmland adjacent to existing farmland, or the transferred-in farmlands are adjacent to one another. Table 1 shows that the probability of the surveyed farmers transferring into farmland is 0.56, and the probability of farmland concentrated transfer-in is 0.20.

**Table 1.** Descriptive statistics of variables.

| Variables Category | Variables | Definition | Mean | S. D |
|---|---|---|---|---|
| Input and output variables | Corn yield | kg/mu | 674.25 | 82.97 |
| | Chemical fertilizer input | kg/mu | 59.38 | 13.70 |
| | Labor input | Workdays/mu | 22.05 | 9.29 |
| | Mechanical input | Yuan/mu | 92.50 | 22.28 |
| | Seed input | Yuan/mu | 59.96 | 8.39 |
| Dependent variables | Chemical fertilizer reduction | Yes = 1, No = 0 | 0.22 | 0.41 |
| Independent variables | Farmland transfer-in | Yes = 1, No = 0 | 0.56 | 0.50 |
| | Farmland concentrated transfer-in | Yes = 1, No = 0 | 0.20 | 0.40 |
| Controlled variables | Age | Actual age in 2021 | 54.08 | 11.93 |
| | Gender | Male = 1; Female = 0 | 0.79 | 0.41 |
| | Education level | Years spent in school | 7.43 | 3.29 |
| | Risk appetite level | Strongly dislike = 1, Strongly prefer = 7 | 3.46 | 1.55 |
| | Household income level | Total family income (million yuan) | 6.80 | 3.78 |
| | Main business of household | Agriculture = 1, Other = 0 | 0.70 | 0.46 |
| | Chemical fertilizer application technology training | Yes = 1, No = 0 | 0.34 | 0.48 |
| | Farmland size | farmland area (mu) | 89.13 | 45.72 |
| | Farmland quality | Very poor = 1, Very good = 7 | 4.84 | 1.36 |
| Identifying variables | Neighbors transfer into farmland | Yes = 1, No = 0 | 0.47 | 0.50 |
| | Transfer into farmland through intermediaries | Yes = 1, No = 0 | 0.32 | 0.47 |

Controlled variable. The chemical fertilizer input behavior of maize growers will be influenced by other factors besides farmland transfer, and this paper mainly selected control variables from the following perspectives. In terms of personal characteristics of production decision-makers, age, gender, education level, and risk appetite level were selected; in terms of household characteristics, household income level, main business of household and chemical fertilizer application technology training were selected; in terms of production and operation characteristics, farmland size and farmland quality were selected.

Identifying variable. The identifying variables should meet the two conditions of relevance and exogeneity. In this study, whether neighbors transferred into farmland and whether farmers transferred into farmland through intermediaries were selected as identifying variables. Among them, whether neighbors transfer into farmland only affects farmers' behavior of transferring into farmland but not directly affects chemical fertilizer input behavior; whether farmers transfer into farmland through intermediaries only affects whether farmers will transfer into farmland concentratedly but not directly affects chemical fertilizer input behavior; land transfer intermediary organizations, such as village and community organizations and other land transfer service agencies, have the ability to collect information, supervise and coordinate, and are important for matching supply and demand for farmland transfer. They play an important role in matching supply and demand for farmland and in the realization of continuous agricultural land transfer. Table 1 shows that among the surveyed farmers, the average probability of neighbors transferring to farmland is 0.47, and the probability of transferring farmland through intermediaries is 0.32.

# 4. Empirical Results

## 4.1. Chemical Fertilizer Economic Optimal Application Amount

The results of estimating Equation (1) using Stata software and ordinary least squares robustness regression are shown in Table 2.

**Table 2.** C-D production function estimation results.

| Variables | Corn Yield | |
|---|---|---|
| | Coefficient | Standard Error |
| Chemical fertilizer input | 0.098 ** | 0.045 |
| Labor input | 0.053 * | 0.028 |
| Mechanical input | 0.023 ** | 0.011 |
| Seed input | 0.036 | 0.031 |
| Constant | 6.532 *** | 0.303 |
| Observations | 442 | |
| $R^2$ | 0.742 | |

Note: ***, **, and * indicate that it is significant at the 1%, 5%, and 10% levels.

According to the Equation (4), the economic optimal chemical fertilizer application rate of farmers can be calculated, as shown in Table 3. The calculation results show that the average optimal economic chemical fertilizer application rate of 442 households is 47.25 kg/mu, but the actual application rate is 59.38 kg/mu, and the actual chemical fertilizer application rate is 12.12 kg/mu higher than the economic optimal application rate on the whole. According to the analysis of the research results, it can be seen that among 442 farmers, the number of farmers who exceeded the economic optimal chemical fertilizer application amount was as high as 345, accounting for 78.05% of the total sample, and only 97 farmers did not exceed the economic optimal chemical fertilizer application amount, accounting for 21.95% of the total sample number. Therefore, it can be seen that most of the farmers in the survey area have an over-application of chemical fertilizers.

**Table 3.** Calculation results of economic optimal chemical fertilizer application amount.

| Actual Amount of Chemical Fertilizer (kg/mu) | Optimal Amount of Chemical Fertilizer (kg/mu) | Excessive Amount of Chemical Fertilizer (kg/mu) | Percentage of Farmers Who Over-Fertilize (%) |
|---|---|---|---|
| 59.38 | 47.25 | 12.13 | 78.05 |

## 4.2. Impact of Farmland Transfer on Chemical Fertilizer Reduction

The effects of "farmland transfer-in" and "farmland concentrated transfer-in" on chemical fertilizer reduction separately were studied in this paper.

First, a full-sample regression was performed on 442 farmer households to investigate the effect of farmland transfer on the reduction of chemical fertilizer. From the estimation results of the farmland transfer selection model, age, gender, education level, risk appetite level, main business of household, and farmland size had significant effects on farmers' decision on farmland transfer. Among them, age had a negative effect on farmland transfer-in, while gender, education, risk appetite level, main business of household, and farmland size had a positive effect on farmland transfer-in. From the estimation results of the chemical fertilizer reduction application outcome equation, age, risk appetite level, household income level, and chemical fertilizer application technology training had significant effects on the chemical fertilizer reduction application behavior of farmers. Among them, age and household income level were negatively correlated with chemical fertilizer reduction, and risk appetite level and chemical fertilizer application technology training were positively correlated with chemical fertilizer reduction.

Second, the sample of 248 farmers who transferred into farmland was regressed and the impact of concentrated farmland transfer-in on the reduction of fertilizer application was examined. In terms of the selection equation, age, gender, household income level, main business of household, and farmland size all had significant effects on whether farmers concentrated transferred into farmland. Age had a negative effect on the choice of concentrated transferring into farmland, and gender, household income level, main business of household, and farmland size had a positive effect on farmland transfer-in concentration. In terms of the outcome equation, education level, risk appetite level, and chemical fertilizer application technology training had significant effects on chemical fertilizer reduction, while age had significant effects on chemical fertilizer reduction for farmers who transferred into farmland concentratedly. Specifically, age had a negative effect on the level of chemical fertilizer reduction for farmers who transferred into farmland concentratedly. Education level, risk appetite level and chemical fertilizer application technology training had a greater effect on the level of chemical fertilizer application reduction for farmers who transferred into farmland concentratedly, and a lesser effect for farmers who didn't transfer into farmland concentratedly (Table 4).

To further examine the effect of farmland transfer-in on chemical fertilizer reduction, the endogenous switching probit model was applied to further analyze the level of chemical fertilizer reduction in a counterfactual framework under four scenarios: farmland transfer-in farmers, farmland non-transfer-in farmers, assumed farmland transfer-in farmers who decided not to transfer into farmland, and assumed farmland non-transfer-in farmers who decided to transfer into farmland. The results are shown in Table 5. Farmland transfer has a significant positive treatment effect on chemical fertilizer reduction.

The results of ATT estimation showed that if farmland transfer-in farmers decide not to transfer into farmland, the chemical fertilizer reduction level would be reduced by 18.644%. The ATU estimation showed that if farmland non-transfer-in farmers decide to transfer into farmland, the chemical fertilizer reduction level would be increased by 26.519%. Therefore, farmland transfer-in can significantly increase the level of chemical fertilizer reduction.

Similarly, we applied the endogenous switching probit model, under the counterfactual framework, to further analyze the treatment effects of concentrated and non-concentrated farmland transfer-in on the reduction of chemical fertilizer. Table 6 shows the fertilizer reduction application levels under four scenarios: farmland concentrated transfer-in farmers, farmland non-concentrated transfer-in farmers, assumed farmland concentrated transfer-in farmers who decided not to transfer into farmland concentratedly, and assumed farmland non-concentrated transfer-in farmers who decided to transfer into farmland concentratedly.

We discovered that if farmland concentrated transfer-in farmers decide not to transfer into farmland concentratedly, the chemical fertilizer reduction treatment effect would be reduced by 18.790%. In addition, if farmland non-concentrated transfer-in farmers decide to transfer into farmland concentratedly, the treatment effect would increase by 18.487%. It can be seen that concentrated farmland transfer-in has a significant promoting effect on the reduction of chemical fertilizer.

**Table 4.** Determinants of farmland transfer and chemical fertilizer reduction.

| Variables | Select Equation (Whether to Transfer into Farmland) | Result Equation (Whether to Reduce Chemical Fertilizer) | | Select Equation (Whether to Transfer into Farmland Concentratedly) | Result Equation (Whether to Reduce Chemical Fertilizer) | |
|---|---|---|---|---|---|---|
| | | Farmland Transfer-in | Farmland Non-Transfer-in | | Farmland Concentrated Transfer-in | Farmland Non-Concentrated Transfer-in |
| Age | −0.021 ** (0.010) | −0.006 ** (0.003) | −0.013 ** (0.005) | −0.062 * (0.032) | −0.023 * (0.014) | −0.045 (0.033) |
| Gender | 0.060 * (0.033) | 0.038 (0.027) | 0.021 (0.016) | 0.038 * (0.021) | 0.056 (0.038) | 0.050 (0.039) |
| Education level | 0.048 * (0.026) | 0.073 (0.055) | 0.052 (0.035) | 0.145 (0.122) | 0.083 ** (0.040) | 0.041 * (0.022) |
| Risk appetite level | 0.039 ** (0.017) | 0.096 * (0.053) | 0.074 * (0.040) | 0.072 (0.048) | 0.034 ** (0.016) | 0.029 ** (0.013) |
| Household income level | −0.074 (0.055) | −0.019 * (0.011) | −0.023 * (0.013) | 0.053 ** (0.023) | −0.036 (0.030) | 0.024 (0.017) |
| Main business of household | 0.035 *** (0.013) | −0.162 (0.115) | −0.082 (0.064) | 0.068 *** (0.025) | −0.061 (0.050) | −0.032 (0.021) |
| Chemical fertilizer application technology training | 0.008 (0.006) | 0.158 ** (0.067) | 0.073 *** (0.026) | 0.012 (0.009) | 0.043 ** (0.019) | 0.029 ** (0.013) |
| Farmland size | 0.052 * (0.027) | 0.036 (0.024) | 0.105 (0.083) | 0.051 * (0.027) | 0.063 (0.045) | 0.103 (0.078) |
| Farmland quality | 0.072 (0.050) | 0.372 (0.313) | 0.273 (0.226) | 0.301 (0.251) | 0.141 (0.101) | 0.083 (0.068) |
| Neighbors transfer into farmland/Transfer into farmland through intermediaries | 0.593 *** (0.201) | — | — | 0.487 *** (0.158) | — | — |
| Constant | −3.826 *** (1.263) | 0.376 *** (0.129) | 0.269 *** (0.097) | −4.632 *** (1.544) | 0.438 *** (0.164) | 0.386 *** (0.133) |
| $\rho_1$ | | −0.736 ** (0.353) | | | −0.703 * (0.405) | |
| $\rho_0$ | | −0.825 * (0.426) | | | −0.791 * (0.418) | |
| Goodness-of-fit test | | 253.621 *** | | | 238.631 *** | |
| Log likelihood | | −753.621 | | | −642.392 | |
| Observations | | 442 | | | 248 | |

Note: ***, **, and * indicate significant at the 1%, 5%, and 10% levels.

**Table 5.** Estimates of the effect of transferring into farmland on chemical fertilizer reduction.

| Result Variables | Farmer Type and Treatment Effects | Decision type | | Average Treatment Effect | Change (%) |
|---|---|---|---|---|---|
| | | Farmland Transfer-in | Farmland Non-Transfer-in | | |
| Chemical fertilizer reduction | Farmland transfer-in (ATT) | 0.236 | 0.192 | 0.044 | 18.644 |
| | Farmland non-transfer-in (ATU) | 0.229 | 0.181 | 0.048 | 26.519 |

**Table 6.** Estimates of the effect of concentrated transferring into farmland on chemical fertilizer reduction.

| Result Variables | Farmer Type and Treatment Effects | Decision Type | | Average Treatment Effect | Change (%) |
|---|---|---|---|---|---|
| | | Farmland Concentrated Transfer-in | Farmland Non-Concentrated Transfer-in | | |
| Chemical fertilizer reduction | Farmland concentrated transfer-in (ATT) | 0.314 | 0.255 | 0.059 | 18.790 |
| | Farmland non-concentrated transfer-in (ATU) | 0.282 | 0.238 | 0.044 | 18.487 |

## 5. Discussion

Farmland transfer is one of the key ways to promote chemical fertilizer reduction. Based on the theoretical basis of elucidating the intrinsic linkage between farmland transfer and chemical fertilizer reduction, the survey data of 442 corn growers in Heilongjiang Province was used, and the endogenous switching probit model was adopted. Then the effects of transferring into farmland and concentrated transferring into farmland on the reduction of chemical fertilizer were quantitatively analyzed.

Our study clearly shows that farmland transfer-in has a positive effect on chemical fertilizer reduction. This is partly explained by the findings of Ju et al. [19], Zhao et al. [20] and Hu et al. [21] that increasing the size of farmland will greatly reduce the use of chemical fertilizers in agricultural production. One possible explanation is that farmland transfer helps to play the scale management effect and effectively reduces the cost of farmers' acquisition of "new technology and new knowledge", which awakens farmers' ecological consciousness and motivates them to adopt clean production methods, thereby reducing the use of chemical fertilizers.

On the other hand, we also found that compared with farmland transferred dispersedly, the farmland transferred concentratedly is more helpful for the farmers to reduce the application of chemical fertilizers. This finding is the same as the study by Liang et al. [29] and Liang et al. [31]. The possible reason is that the concentrated circulation makes the transferred farmland adjacent, which can not only expand the scale of operation, but also expand the scale of the plot, and then realize the effect of economies of scale through horizontal specialization and deepening vertical division of labor to achieve fertilizer reduction. However, the scattered transfer of agricultural land did not change the size of the plot, and the plot was still in a finely divided state. The increase in time cost and economic cost may lead farmers to apply more chemical fertilizers.

In conclusion, farmland transfer can reduce the amount of chemical fertilizers applied in the process of corn production, but the effect of dispersed transfer to farmland and concentrated transfer to farmland are different. For farmers who transferred into farmland in a decentralized form, they spend more time and money managing the fragmented farmland, which may stimulate them to apply more fertilizers. For the farmers who transferred into the farmland in a centralized way, the application amount of chemical fertilizer was reduced by exerting economies of scale.

The main contributions of this paper are: First, in view of the inconsistent conclusions of existing studies, the intrinsic association between farmland transfer and chemical fertilizer reduction was re-examined, and furthermore compares and analyzes the effects of concentrated transfer of farmland and dispersed transfer of farmland to fertilizer reduction, this provides a new perspective on the fertilizer reduction effect of farmland transfer. Secondly, since the decision on farmland transfer and the decision on chemical fertilizer application may be affected by some unobservable factors at the same time, there may be a problem of "simultaneous decision" and "self-selection", resulting in biased estimation results. We solve this problem perfectly by using an endogenous switching probability model and obtain more robust estimation results.

Finally, it should be pointed out that this research can be further improved upon in the following two aspects in the future: First, this study mainly focuses on corn growers and does not study the behavior of farmers who grow other types of crops in the application of chemical fertilizers in farmland transfer. In view of the differences in the application of chemical fertilizers between commercial crops and food crops, it is necessary to compare and analyze commercial and food crops in the future. Secondly, only taking Heilongjiang Province as the research area, the research results and countermeasures are more applicable to some major grain producing areas with large scale agricultural operations and high levels of farmland transfer. As a result, future research must consider the aforementioned factors in order to conduct more beneficial investigations into issues such as farmland transfer and fertilizer reduction.

## 6. Conclusions and Implication

This study estimated the effect of farmland transfer on fertilizer reduction. The results showed that farmland transfer could reduce fertilizer application in maize production. In addition, the effects of concentrated transfer to farmland and dispersed transfer to farmland on fertilizer reduction were further analyzed. It was found that farmland concentrated transfer-in farmers were more likely to reduce fertilizer application compared with those who transferred to farmland in a scattered manner.

The results of this study have important implications for more effective realization of farmland transfer and chemical fertilizer reduction. Based on the above analysis, this paper proposes the following suggestions. First, the orderly transfer of farmland management rights should be guided continuously. The government should standardize farmland transfer procedures, increase farmers' willingness and motivation to participate in farmland transfer, dispel farmers' farmland transfer concerns, let farmland transfer drive chemical fertilizer reduction, and promote green and sustainable agricultural development. Second, an information service platform for farmland transfer should be established to strengthen the management, guidance and service of farmland transfer, effectively coordinate and communicate the needs and conflicts of farmland transfer, so as to enhance the effect of farmland transfer on chemical fertilizer reduction. Third, through comprehensive improvement of farmland, a favorable external environment for the continuous circulation of farmland and the reduction of chemical fertilizers should be created by implementing comprehensive measures such as land leveling, soil improvement and agricultural water conservancy construction so as to alleviate the problem of natural fragmentation of farmland. Finally, the scale operation mode should be innovated and improved by means of cooperating with farmers, guiding the appropriate agglomeration of land and providing social services. Simultaneously, convenient conditions for fertilizer reduction should be provided through strengthening the agricultural socialization service system for small farmers, creating a supportive environment, and promoting the scale of agricultural productive services.

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