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Influence of Transfer Plot Area and Location on Chemical Input Reduction in Agricultural Production: Evidence from China

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Abstract: The development of a farmland transfer market and the spatial characteristics of transfer plots are crucial factors influencing chemical input reduction in agricultural production with relation to the endowment of fragmented agricultural land resources. Through a theoretical discussion, this study analyzed the heterogeneity of transfer plots' spatial characteristics and their effect on the intensity of chemical input in agricultural production in the process of farmland transfer. Plot-level survey data from the Heilongjiang, Henan, Zhejiang, and Sichuan provinces were used for empirical analysis. The results indicated that the values of pesticide and fertilizer input in the large plot group were CNY 10.154 and CNY 8.679 lower than those in the small plot group, respectively. Additionally, compared with non-adjacent plots, the per-unit area input was CNY 2.396 and CNY 6.691 lower in adjacent plots. This indicated that plot area expansion and location adjacence significantly reduced the intensity of pesticide application and fertilizer input in the plots. Simultaneously, location linkage reduced chemical input in agricultural production in small plots; however, the difference was unnoticeable in large plots. This study provides a theoretical basis for promoting farmland integration in China as well as introduces a specialized method for reducing agricultural chemical usage.

Keywords: plot spatial characteristics; chemical input reduction; pesticide input; fertilizer input; farmland transfer; farmland scale management

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1. Introduction

With the deepening of urbanization and the migration of agricultural labor to nonagricultural industries, the transfer of farmland has increased rapidly in China. In 1999, the proportion of farmland transfers was 2.53%. As of 2019, the number of rural households that have transferred farmland out has reached 73.3 million, and the area of farmland transferred has reached 532 million mu (mu is the area unit that is most commonly used in China; 15 mu equals one hectare). The proportions of farmers and arable land in the country were 33.3% and 35.6%, respectively. The rapid increase in agricultural land transfer area has promoted the gradual transformation of China's agricultural production from relying on traditional factors, such as the labor force, to scientific and technological factors, such as chemical fertilizers. Agricultural chemicals, such as pesticides and chemical fertilizers, are gradually being regarded as key factors in achieving grain increases and agricultural economic growth [1]. However, the excessive application of agricultural chemicals is one of the most important issues in agricultural production. China is a major producer and user of agricultural chemicals. According to statistics compiled on Chinese agricultural product costs in 2020, the amount of fertilizer applied per hectare of crops in China in 2019 was 377.2 kg, which was far higher than the world average of 120 kg per hectare. Additionally, pesticide use per hectare of crops was 13.07 kg (reduced purity), which was significantly higher than the world average input of 2.69 kg per hectare. Based on the law of diminishing marginal returns, excessive chemical application not only leads to a reduced utilization rate of input factors and inhibits the improvement of agricultural production efficiency [2], but also causes problems such as agricultural nonpoint source pollution and a decline in farmland quality. Moreover, it reduces the quality of agricultural products and leads to a reduction in their international competitiveness [3]. Currently, the amount of agricultural chemicals applied in China exceeds the optimal range for both economic and environmental efficiency [4,5]. Since 2015, the Chinese government has successively promulgated the "Zero-Growth Action Plan for Chemical Fertilizer Use by 2020", the "14th Five-Year Plan for National Agricultural Green Development" and other programs to reduce the use of agricultural chemicals.

Numerous studies have focused on farmers' pesticide and chemical fertilizer application behaviors, primarily from two specific perspectives. From the perspective of agricultural production, existing studies have focused on the impact of individual and family factors on farmers' chemical application behavior. Individual factors include the age, education, risk preference, and technological awareness of the household head [6]. Family factors include income, assets, and the labor force [7,8]. As for agricultural production conditions, the literature focuses on the effects of land scale, policy subsidies, risk preference, and other factors on farmers' chemical application behavior. It was found that factors such as the farmers' scale of operation [9–11], the stability of farmland rights, and farmland fragmentation characteristics change the economies of scale of farmers' production and reduce their use of agricultural chemicals [12,13]. Technology subsidies, technology extension and training, socialized services, and other factors can lower the threshold for farmers to adopt green fertilization technology and promote fertilizer use reduction [14,15]. Simultaneously, agricultural insurance can affect farmers' production risk preferences and change their pesticide application behavior and fertilizer input intensity [16,17]. From the perspective of chemical characteristics and technology, the efficacy, price, and the mode of pesticide and fertilizer use affect their application and dosages [18]. An important reason for the irrational use of agricultural chemicals is a lack of understanding of their methods and procedures when using them and a lack of mastery of relevant technologies, which may lead to the abuse of chemicals by farmers [19,20]. Additionally, owing to the externality of chemical application, government regulations, environmental regulations, social norms, and community supervision would affect the chemical input mode and application intensity of farmers [21–23].

With the development of a farmland transfer market, the promotion of chemical input reduction remains a scientific problem that requires further exploration. The existing literature has focused on the relationship between a farmer's scale of operation and agricultural reduction. Some investigations have shown that the expansion of farmland scales can help encourage farmers to adopt chemical use reduction technologies, improve chemical utilization efficiency, and achieve agricultural reduction goals [2]. However, some studies have indicated that under the conditions of resource endowment in China, the primary method for farmers to expand the scale of their operations is through land transfer. On the one hand, management rights transferred to farmland are unstable, and farmers may use a large number of chemical inputs to maximize short-term returns [13,24,25]. On the other hand, an increase in farmland size induces the substitution of different factors and stimulates farmers to replace the scarce labor force with chemicals, which is not conducive to agricultural reduction [6,26]. Although studies have examined the multidimensional effects of farmland scale and fragmentation characteristics on the reduction in chemical use in agricultural production [27,28], no studies have paid attention to the effects of transfer plots' spatial characteristics on chemical input reduction in production and its mechanisms. Hence, empirical analyses of this topic remain rare.

From the perspective of the natural attributes of farmlands, we explored the heterogeneity of transfer plot area and location and their effect on the intensity of chemical input in production. An empirical analysis was conducted based on China's plot-level survey data to test the differing intensity of pesticide application and fertilizer input in production on transfer plots, considering plot size and adjacency. The marginal contributions of this research include two aspects: First, through comparative analysis of the differences in agricultural chemical input intensity between different spatial characteristics of plots, the constraints of economic relations, such as farmland transfer and agricultural reduction, were revealed from the perspective of resource endowment. Second, the study constructs an analytical framework to explain the influence of resource endowment constraints on the chemical input reductions in farmland transfer plots. This study will expand and enrich the existing research perspective on chemical input reductions in production.

2. Framework and Hypotheses

With the expansion of farmers' operational scales, labor scarcity among farmers has increased. This change increases the demand for factor replacement in production, which leads to farmers using mechanical labor replacement or labor force-saving technology, making it harder for farmers to tolerate the consumption of ineffective labor. However, the scattered farmland distribution is not convenient for mechanical labor, which proves it inefficient as a substitute for agricultural labor [26,29] or restricts the efficiency of mechanical operations. It also increases the time consumption and transportation cost of transporting the means of production across the land between labor locations. Thus, the scattered distribution of farmlands operated by farmers will seriously hinder possible economies of scale that farmers can achieve in production, including restricting the low efficiency of agricultural chemical input and utilization [30]. Therefore, contiguity at the plot level is conducive to the improvement of low chemical utilization efficiency per unit area of agricultural production, thus reducing agricultural chemical input intensity.

Under the farmland distribution system in China, the expansion of farmers often depends on farmland transfer. Because it is hard for households to form a collective decision to transfer or replace, and partial circulation is common, the transfer market's farmland supply typically presents the characteristic of a random distribution. Thus, the expansion of farmers' operation scale does not mean the expansion of plot area; it may be reflected in the increase in plots number, and the per-area of plots remaining unchanged. In the transfer market, the potential transferable land area differs in size and the location is randomly distributed. The plots that help alleviate fragmentation may have the following characteristics: (1) the transfer plot's area is large, which has advantages in technological substitution and cost allocation; and (2) the transfer plot's location is adjacent to the original plot. As the farmland's location is fixed, the effective cultivation space of the plot can be expanded using a boundary connection or by breaking the ridge when the plot is adjacent [30,31]. Therefore, plots with different spatial characteristics in the farmland transfer market have different effects on the reduction in agricultural chemicals.

First, we analyzed the effect of the transfer plots' area. Specifically, small plots not only increase the time and cost loss of the means of production and cross-plot operation of machinery, but also increase chemical input loss and reduce the ratio between the absorption of chemical factors and the actual input in production. Both lead to a decrease in the utilization efficiency of chemicals and thus reduce the marginal output of the inputs. Moreover, machinery frequently turns and moves in narrow spaces for small plots, which leads to a substantial decline in mechanical efficiency and a sharp increase in the cost of technology replacement. This reduces the possibility of using soil improvement technologies to improve small plots' production and limits the adoption of production technologies related to fertilizer reduction. Therefore, compared to small plots, large plots are more conducive to reducing the intensity of chemical applications in agricultural production.

Second, we analyzed the effect of the transfer plots' location. When a plot is adjacent to original plot, it can expand the space of plots in agricultural production through adjacent borders and breaking plot-ridges. The adjacent plots improved the constraints of the transfer plot area on mechanical substitution and efficiency and saved the cross-plot transportation time and costs of the means of production. This influence was particularly evident when the plot area was small. Therefore, compared to non-adjacent plots, adjacent plots are more conducive to reducing the intensity of chemical applications in agricultural production. Notably, with the plot area expansion, the scale economies in the agricultural production gradually become prominent, and the influence of plot's adjacent location gradually decreases [31]. Thus, the effect of the transfer plot's location on the reduction in agricultural chemicals in the large plot may not be prominent.

Considering the fragmented farmland endowment in China, transferring to larger or adjacent plots can improve the conditions of land fragmentation for farmers. This enhances the convenience of mechanical operation and the potential for labor replacement with technology, and reduces time consumption and transportation costs associated with production means across plots. These two influences help improve the utilization efficiency of chemicals and reduce the application intensity of chemical elements in agricultural production. Based on the above analysis, we formulated the following hypotheses:

Hypothesis 1. *The spatial characteristics of the transferred plots are important factors affecting the reduction in agricultural chemicals. Large or adjacent plots are particularly conducive to reducing the intensity of chemical applications in agricultural production.*

Hypothesis 2. *The transfer plots' adjacent locations had different effects on chemical reduction in different areas. The expansion of the plot area led to an agricultural chemical reduction effect caused by the gradual wear of the adjacent plots.*

3. Materials and Methods

3.1. Model

We analyzed the effect of the transfer plots' area and adjacent characteristics on chemical input reduction in agricultural production using plot-level survey data. The econometric model is designed as follows:

$$chemicals_{ij} = \alpha + \beta_1 Plotarea_{ij} + \beta_2 Link_{ij} + \gamma X_j + \sigma_i + \xi_{ij} \tag{1}$$

In Equation (1), $chemical_{ij}$ represents the chemical inputs transferred by farmer i into the plot j, including primarily pesticide and fertilizer inputs. Considering the significant differences in fertilizer and pesticide application types between regions and crops, we primarily compared the value of chemical inputs. $Plotarea_{ij}$ represents the area of plot j transferred by farmer i. $Link_{ij}$ is a dummy variable for the location of the plots. $Link_{ij} = 1$ represents the plot j adjacent to the original plot of farmer i, and $Link_{ij} = 0$ represents non-adjacent. Variable X_j and σ_i represent a series of control variables at the plot level and household level, respectively. Finally, ξ_{ij} is the random disturbance term.

To further investigate the affection heterogeneity of the transfer plot's location on the chemical input intensity, the intersection cross-term of "plot area group" and "adjacent" was introduced into Equation (1) [31]. Subsequently, we formed the new model:

$$chemicals_{ij} = \alpha + \beta_1 Plotarea\_g_{ij} + \beta_2 Link_{ij} + \beta_3 Plotarea\_g_{ij} \times Link_{ij} + \gamma X_j + \sigma_i + \xi_{ij} \tag{2}$$

In Equation (2), $Plotarea\_g_{ij}$ is a dummy variable that represent the plot area group. Comparing the provincial plot median area, the plots were divided into small group and large groups. Large and small plot groups were assigned 1 and 0, respectively. Parameter β_3 reflects the influence of adjacent plots on the chemical input of a large block group.

3.2. Data Source and Variable Assignment

The data used for econometric analysis are from the "large-scale households' grain production survey" of four provinces in the years 2015 and 2018. Based on the regional distribution as well as economic and agricultural development, Heilongjiang, Henan, Sichuan, and Zhejiang Provinces were selected for surveying. With a multistage sampling method, the households were selected for the survey. For each province, four cities were randomly selected. Subsequently, two towns and 64 households were selected within each city. The survey covered 16 cities (the surveyed cities are Ning'an, Longjiang Tangyuan, and Zhaodong (Heilongjiang provinces); Anyang, Xiayi, Xiping, and Xuchang (Henan province); Linshui, Nanbu, Yanjiang, and Zhongjiang (Sichuan province); and Shengzhou, Wenling, Wuyi, and Xiuzhou (Zhejiang province)) and 1040 households across four provinces in 2015. To avoid the effects of failing to follow-up with farmers, more than 32 farmers were selected in several towns during sampling. The second circle household survey was organized in 2018; however, the sample size was reduced because some farmers were not tracked. In total, 1033 households were included in this study. After sorting the data, there were 1356 plots used for empirical. The samples included 725 plots in 2015 and 631 plots in 2018.

The data and variables used for empirical analysis include the plot information were investigated for spatial characteristics, soil quality, type of grain crops, and chemical inputs. Farmers' details were investigated using information on farmers' families, farmland management, and agricultural machinery ownership. Village details investigated the degree of farmland market development, policy subsidies, farmland property rights, and regional topographic features. All variable assignments and descriptive statistical results of the empirical model are presented in Table 1.

Table 1. Variable definitions and descriptive statistics.

Variable	Variable Assignment	Mean Value	Standard Error
Pesticide	Value of pesticide input per unit area (CNY/mu).	44.65	36.18
Fertilizer	Value of fertilizer input per unit area (CNY/mu).	143.60	50.94
Conversion of Fertilizer	Conversion of fertilizer input per unit area (Kg/mu).	57.10	20.84
Plot Area	Area of transferred plot (mu).	11.48	38.81
Adjacent	Transfer plot's location is adjacent to household's original plot: adjacent = 1, non-adjacent = 0.	0.31	0.46
Soil Quality	Soil quality is good = 1, medium = 2, poor = 3.	1.64	0.64
Irrigation	The plot can be irrigated in production = 1, otherwise = 0.	0.72	0.45
Crop Type	Type of grain planted in autumn on plot: rice = 0, corn = 1.	0.51	0.5
Farmland Area	Total farmland area of the farmer (mu).	126.40	516.30
Age	Age of head of household (year).	53.20	10.64
Education	Years of education for the head of household (year).	6.92	3.14
Farming Experience	Years of farming experience for the head of household (year).	30.48	13.62
Agriculture labors	Number of households labor engaged in agricultural production.	2.03	0.89
Agricultural Disaster Insurance	Farmers have purchased grain disaster insurance = 1, have not = 0.	0.48	0.50
Machine Holding	Value of agriculture machinery holding of household (1000 CNY).	52.77	123.30
Farmland Transfer Rate	Proportion of village farmland transfer (%).	42.06	21.19
Farmland Transfer Subsidy	Subsidies for farmland transfer: yes = 1, no = 0.	0.20	0.40
Farmland Certificate	Farmland certificate have been issued = 1, have not = 0.	0.49	0.50
Village Terrain	Village terrain: plain = 1, hilly = 2, mountainous = 3.	1.53	0.58
Year	Survey year: 2015 = 0, 2018 = 1.	0.47	0.50

Data source: the survey of "large-scale households' grain production" in 2015 and 2018, including 1356 observations.

4. Results and Discussion

4.1. Cross Statistics of Plot Spatial Characteristics and Chemical Inputs in Agricultural Production

This study analyzed the influence of transfer plots' spatial characteristics on agricultural chemical inputs in production. We grouped the plots according to plots' area and location. At the plot-level, the amounts of pesticide and fertilizer input in plots with different areas and locations were grouped statistically, and the difference in the two-groups' *t*-test were conducted. As seen in Table 2, we compared the chemical inputs in different spatial characteristics plots.

Table 2. Cross-statistics of plot spatial characteristics and chemical inputs in agricultural production.

Index Group		**Grouped by Area**			**Grouped by Location**		
		Small Group	**Big Group**	**T-Value of the Two-Sample *t*-Test**	**Non-Adjacent Group**	**Adjacent Group**	**T-Value of the Two-Sample *t*-Test**
Value of pesticide input per unit area (CNY)	Total	49.58	39.69	3.19 ***	46.64	40.18	2.81 ***
	2015	47.17	37.92	2.46 **	44.47	37.39	2.69 ***
	2018	52.15	41.88	2.83 ***	49.26	43.06	2.74 ***
Value of fertilizer input per unit area (CNY)	Total	148.33	138.80	3.45 ***	145.68	138.85	2.28 **
	2015	145.76	138.31	2.10 **	144.39	135.94	2.17 **
	2018	151.06	139.40	2.70 ***	147.25	141.85	1.87 *

Note: * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$. The same as below.

The data show that the input of pesticides and fertilizers per unit area in the agricultural production of the small plot group was higher than that of the large group. Among them, the value of pesticide input per unit area of the small plot group was CNY 9.25 and CNY 10.27 higher than that of the large plot group, respectively. The value of fertilizer input per unit area of the small plot group was CNY 7.45 and CNY 11.66 higher than that of the large plot group, respectively. Furthermore, the differences between the above groups were statistically significant according to the *t*-test. Moreover, the pesticide and fertilizer inputs per unit area in the adjacent plots were significantly lower than those in the non-adjacent plots. Among them, the value of pesticide input per unit area of the adjacent plots was CNY 7.08 and CNY 6.20 lower than that of the non-adjacent plots in 2015 and 2018, respectively. The fertilizer input per unit area of the adjacent plots was CNY 8.45 and CNY 5.40 lower than the non-adjacent plots group in 2015 and 2018. The differences among the above groups were statistically significant at the 10% level or above. The following section further compares the heterogeneity of the agricultural chemical inputs of the different transferred plots with different areas and locations through empirical analysis.

4.2. Effect of Plots' Spatial Characteristics on Agricultural Chemical Input Intensity

Table 3 presents the effect of transfer plots' spatial characteristics on the intensity of the agricultural chemical input. Columns (1) and (3) show the effects of these spatial characteristics on the value of agricultural pesticide input in the plot. Columns (2) and (4) show the effects of these spatial characteristics on the value of agricultural chemical fertilizer input in the plot. The least-squares method was used for robust estimation in all models. The R-squared values of the models were all approximately 0.4. Moreover, the models' goodness-of-fit F-test statistics values indicated that the overall degrees of fit were good.

Table 3. Effect of transfer plots' area and location on the intensity of chemical inputs in agricultural production.

Variables	**Pesticide**	**Fertilizer**	**Pesticide**	**Fertilizer**
	(1)	**(2)**	**(3)**	**(4)**
Plot Area	−0.029 **	−0.119 ***		
	(−2.43)	(−3.05)		
Plot Area Group			−10.154 ***	−8.679 ***
			(−6.26)	(−2.85)

Table 3. *Cont.*

Variables	Pesticide	Fertilizer	Pesticide	Fertilizer
	(1)	(2)	(3)	(4)
Adjacent	−2.064 **	−6.920 **	−2.396 **	−6.691 **
	(2.23)	(−2.41)	(−2.46)	(−2.32)
Soil Quality	0.35	4.199*	0.342	4.133 *
	(−0.32)	(−1.85)	(−0.32)	(−1.82)
Irrigation	−4.169 ***	3.237 *	−4.648 ***	3.214 *
	(−2.68)	(1.87)	(−2.96)	(1.86)
Crop Type	−15.490 ***	29.103 ***	−15.632 ***	29.185 ***
	(−8.41)	(7.01)	(−8.55)	(7.03)
Farmland Area	0.002 ***	0.005 **	0.001 **	0.002 ***
	(2.85)	(2.52)	(1.96)	(2.53)
Age	−0.107	0.350 *	−0.128	0.344 *
	(−0.98)	(1.69)	(−1.22)	(1.65)
Education	0.329	−0.263	0.321	−0.258
	(1.18)	(−0.54)	(1.17)	(−0.53)
Farming Experience	0.023	−0.162	−0.027	−0.213
	(0.28)	(−1.02)	(−0.33)	(−1.34)
Agriculture Labor	1.242	−0.937	1.452 *	−0.721
	(1.61)	(−0.62)	(1.90)	(−0.48)
Agricultural Disaster Insurance	−3.036 *	−1.035 **	−2.962 *	−0.906 **
	(−1.92)	(−2.36)	(−1.89)	(−2.32)
Machine Holding	−0.002	−0.023 **	0.000	−0.025 **
	(−0.40)	(−2.22)	(0.08)	(−2.42)
Farmland Transfer Rate	0.041	0.037	0.032	0.032
	(1.08)	(0.50)	(0.88)	(0.44)
Farmland Certificate	−0.405	0.855	−0.317	0.603
	(−0.18)	(0.23)	(−0.15)	(0.16)
Farmland Transfer Subsidy	5.604 **	4.200	3.972	2.457
	(2.10)	(0.84)	(1.51)	(0.48)
Village Terrain	0.677	2.958	1.256	3.569
	(0.47)	(1.04)	(0.87)	(1.26)
Regional	/	/	/	/
Year	/	/	/	/
Constant	31.103 ***	95.803 ***	38.225 ***	100.890 ***
	(5.00)	(7.58)	(6.12)	(7.81)
Observations	1356	1356	1356	1356
R-squared	0.490	0.388	0.506	0.408
Adjusted R-squared	0.482	0.379	0.498	0.387
The F-value of the Regression Significance Test	65.68	49.85	67.75	52.13

Note: The estimated parameters' *t*-values are in parentheses. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

In Columns (1) and (2), the plot area is expressed as an actual value. The parameter estimates that the values of pesticide and fertilizer inputs will decrease by CNY 0.029 and CNY 0.119, respectively, when the plot area is increased by an additional unit. This was statistically significant at the 5% level. The parameter estimation of plots adjacent to the location indicated that the values of pesticide and fertilizer input per unit area in the adjacent plots were CNY 2.064 and CNY 6.920 lower than those in the non-adjacent plots, respectively, and both were statistically significant. Simultaneously, the plot area in Columns (3) and (4) was represented by grouping dummy variables. Parameter estimation indicated that the values of pesticide and fertilizer input in the large plot group were CNY 10.154 and CNY 8.679 lower than those in the small group, respectively, and both were statistically significant above the 1% level. The parameter estimation of adjacent variable plot locations was consistent with that of the former. The results in Columns (1)–(4)

show that the input intensity of pesticides and fertilizers in agricultural production was lower in large or adjacent transferred plots. These results verified Hypothesis 1.

The parameter estimation of the control variables indicated that an increase in farmers' farmland area increased the per-unit area pesticide and fertilizer input intensity, and the estimated parameters exhibited statistical significance at the 1%. The reason for this being that the expansion of a household's operation scale alters the degree of scarcity of different agricultural production factors, leading to the substitution of chemical input for labor and thus increasing chemical input intensity [11,32,33].

From the variable of type of grain crop planted, the intensity of pesticide input per-unit area of rice was significantly higher than that of corn, whereas the intensity of fertilizer input per-unit area of corn was significantly higher than that of rice, and the estimated parameters were statistically significant at the 1% level. From the perspective of the impact of agricultural disaster insurance, the intensity of pesticide and fertilizer inputs per unit area of land transferred by farmers who purchased agricultural insurance was lower than that of farmers who did not, and the estimated parameters were statistically significant at the 10% level or above. From the perspective of machinery value of household holdings, a higher total value of farm machinery holdings was associated with a lower intensity of fertilizer input into the plot. However, it did not affect the intensity of the pesticide input. This is because the increase in farm machinery holdings is conducive to the adoption of soil protection technologies by farmers, such as deep tillage or straw returning, which is conducive to soil improvement and thus promotes the reduction in fertilizer application.

4.3. Robust Analysis

To test the robustness of the above model's analysis results, we statistically analyzed the influence of the transferred plots' area and location on the chemical input of agricultural production. There were significant differences in the types of pesticides applied in different regions and crops. However, the differences in the components of the different types of pesticides were not suitable for quality comparisons. Therefore, we counted the number of fertilizer applications. Conversion calculations for different fertilizer types were performed for comparison. The effects of the transferred plot area and location on the conversion of agricultural fertilizer input are presented in Table 4. As shown in Column (5), the parameter estimation indicated that the conversion of fertilizer input per unit area of the plot decreased by 0.367 kg when the area of the transfer plot increased by one unit, as represented by the actual value in the plot area. The conversion of fertilizer input to adjacent plots was 1.617 kg lower than that for non-adjacent plots. As shown in Column (6), the plot area was represented by grouping dummy variables, and the parameter estimation indicated that the conversion of fertilizer input in the large plot group was 0.897 kg lower than that in the small plot group. The parameter estimation of adjacent variable plot locations was consistent with that of the former. The estimated results presented in Columns (5) and (6) indicated that the area expansion or location of adjacence of plots had a positive effect on fertilizer input reduction in production.

Table 4. Effect of transfer plots' spatial characteristics on the amount of fertilizer input.

Variables	Conversion of Fertilizer	Conversion of Fertilizer
	(5)	(6)
Plot Area	−0.367 *	
	(−1.79)	
Plot Area Group		−0.897 *
		(−1.75)
Adjacent	−1.617 **	−1.603 **
	(−2.36)	(−2.35)
Soil Quality	0.827	0.811
	(0.96)	(0.94)

Table 4. *Cont.*

Variables	Conversion of Fertilizer	Conversion of Fertilizer
	(5)	(6)
Irrigation	3.344 **	3.395**
	(2.18)	(2.20)
Crop Type	13.210 ***	13.246 ***
	(7.69)	(7.70)
Farmland Area	0.002 ***	0.001 **
	(2.60)	(2.11)
Age	0.113	0.114
	(1.42)	(1.43)
Education	−0.214	−0.212
	(−1.04)	(−1.03)
Farming Experience	−0.101 *	−0.107 *
	(−1.65)	(−1.76)
Agriculture Labor	−0.359	−0.333
	(−0.57)	(−0.53)
Agricultural Disaster Insurance	−2.861 **	−2.840 **
	(−2.38)	(−2.37)
Machine Holding	−0.006	−0.007 *
	(−1.63)	(−1.80)
Farmland Transfer Rate	0.001	0.001
	(0.03)	(0.03)
Farmland Certificate	−0.265	−0.480
	(−0.13)	(−0.24)
Farmland Transfer Subsidy	−0.296	−0.365
	(−0.18)	(−0.22)
Village Terrain	1.715	1.789
	(1.55)	(1.62)
Regional	/	/
Year	/	/
Constant	37.425 ***	37.773 ***
	(7.46)	(7.33)
Observations	1356	1356
R-squared	0.407	0.396
Adjusted R-squared	0.393	0.384
The F-value of the Regression Significance Test	52.84	49.62

Note: The estimated parameters' *t*-values are in parentheses. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

This study further examined the heterogeneity in the effect of transfer plot's spatial characteristics on the chemical input reduction in production. By constructing a cross-term of the plot area group and adjacent, we investigated the difference in the influence of the plots' location on agricultural pesticide and fertilizer input intensities in different groups of plot areas. The parameter estimation results are listed in Table 5. Columns (7)–(9) present the results of the analyses of the influence of the transferred plot location on the pesticide input value, fertilizer input value, and fertilizer conversion amount of different plot groups, respectively. The least-squares method was used for the robust estimation of the models.

Table 5. Difference in the effect of transfer plots' adjacence on agricultural chemical input intensity.

Variables	Pesticide	Fertilizer	Conversion of Fertilizer
	(7)	**(8)**	**(9)**
Plot Area Group	−8.867 ***	−7.557 **	−0.225 **
	(−4.78)	(−2.04)	(−2.16)
Adjacent	−4.351 *	−4.987 **	−0.684 ***
	(1.69)	(−2.18)	(−2.58)
Plot Area Group × Adjacent	−3.966	−3.455	−1.861
	(−1.25)	(−0.60)	(−0.78)
Soil Quality	−0.422	4.064 *	0.774
	(−0.40)	(1.79)	(0.89)
Irrigation	−4.533 ***	3.314	3.449 **
	(−2.90)	(0.89)	(2.24)
Crop Type	−15.399 ***	29.387 ***	13.355 ***
	(−8.46)	(7.03)	(7.76)
Farmland Area	0.001 ***	0.002 **	0.001 **
	(2.47)	(2.15)	(2.17)
Age	−0.126	0.346 *	0.115
	(−1.19)	(1.66)	(1.44)
Education	0.338	−0.243	−0.204
	(1.23)	(−0.50)	(−0.99)
Farming Experience	−0.029	−0.215	−0.108 *
	(−0.35)	(−1.35)	(−1.77)
Agriculture Labor	1.451 *	−0.721	−0.333
	(1.90)	(−0.48)	(−0.53)
Agricultural Disaster Insurance	−3.023 *	−0.960	−2.869 **
	(−1.94)	(−0.33)	(−2.39)
Machine Holding	−0.000	−0.026 **	−0.007 *
	(−0.02)	(−2.44)	(−1.85)
Farmland Transfer Rate	0.034	0.033	0.002
	(0.92)	(0.46)	(0.06)
Farmland Certificate	3.923	2.415	−0.503
	(1.50)	(0.47)	(−0.25)
Farmland Transfer Subsidy	−0.393	0.537	−0.401
	(−0.18)	(0.14)	(−0.25)
Village Terrain	1.190	3.511	1.758
	(0.83)	(1.23)	(1.59)
Regional	/	/	/
Year	/	/	/
Constant	37.344 ***	100.122 ***	37.359 ***
	(5.93)	(7.67)	(7.25)
Observations	1356	1356	1356
R-squared	0.506	0.419	0.407
Adjusted R-squared	0.498	0.403	0.392
The F-value of the Regression Significance Test	65.82	54.57	52.71

Note: The estimated parameters' *t*-values are in parentheses. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

As shown in Column (7) of Table 5, the dummy variable of the "plot area group" was −8.867. This indicated that the per-unit area pesticide input in the large plot group's agricultural production was lower than that in the small plot group by 8.867 CNY/mu and statistically significant at the 1% level. Moreover, the "adjacent" variable's estimated value was −4.351, indicating that the per-unit area pesticide input in the adjacent plots was 4.351 CNY/mu lower than the non-adjacent plots in the small-plot group and the statistically significant at the 10% level. In addition, the estimated value of the cross-term of "plot area group" and plot location "adjacent" was −3.966; however, it was not statistically significant, indicating that no significant difference occurred between the pesticide input per unit area in the agricultural production of the plots, nor with adjacently and non-adjacently located plots in the large-area group.

Similarly, as shown in Columns (8) and (9), the estimated parameters of the variables "plot area group" and "adjacent" were negative and statistically significant at the 5% level or above. However, the cross-term of "plot area group" and "adjacent" were not statistically significant, indicating no significant difference existed between the fertilizer input intensity in the production of the adjacent and non-adjacent plots in the large plot group. These results were consistent with the analysis presented in Column (7), which verify Hypothesis 2. As shown in Columns (7)–(9), the analysis results indicated that the adjacence of plots heterogeneously impacted the chemical input reduction effect of the different area plots. Therefore, the transferred plots' adjacence reduced the chemical input of agricultural production only for the small plot group, whereas the chemical reduction effect for the large plot group was not obvious. This is because the increase in plot area allows for agricultural production with scale economies, and the influence of plot adjacence in alleviating the constraints is gradually weakened.

5. Conclusions

Under fragmented farmland resource endowment, the market development of farmland transfer and resource endowment are important factors affecting the reduction in chemical inputs in agricultural production. This study investigated the effect and heterogeneity of the plot spatial characteristics on the input intensity of agricultural chemicals during farmland transfer. Plot-level survey data from Heilongjiang, Henan, Sichuan and Zhejiang Provinces were used for empirical analysis to examine the differences in the application intensity of pesticide and fertilizer input during agricultural production with different plots areas and locations. Two main conclusions were drawn from this study. First, the transfer plots' spatial characteristics could affect the input intensity of chemicals in production. As shown in the parameter estimation, the values of pesticide and fertilizer input in the large plot group were CNY 10.154 and CNY 8.679 lower than in the small plot group, respectively. Compared to the non-adjacent plots, the per-unit area input was CNY 2.396 and CNY 6.691 lower in the adjacent plots, respectively. The results indicated that, the transfer plots' area expansion and location adjacence could significantly reduce the pesticide application and fertilizer input intensity to the plots. Second, the adjacent location of the transfer plot showed heterogeneity in the decrement effects in different area plots. Regarding both pesticide and fertilizer input values, the parameter estimation of "plot area grouping" and "adjacent" cross-terms revealed no significant difference between adjacent and non-adjacent plots in the large-area group. This indicated that the location connection only reduced the input of agricultural chemicals in the small plot group. However, the "plot adjacent" variable did not significantly reduce the chemical decrement effect in the large plot group. Both hypotheses have been fully verified and accepted.

Beginning with the natural characteristics of agriculture land, we discuss the effect of transfer plots' area and location on chemical input reduction in agricultural production. The policy implications of the research conclusions for agricultural chemical reduction are as follows: First, a unified platform for farmland transfer would be conducive to reduce chemicals input in agricultural production. Centrally transferring spatially scattered farmland through the transfer trading platform can partially weaken the adverse effects of the fixed location of farmland plots in the transfer market, which would improve the utilization efficiency of agricultural chemicals and realize chemical input reduction. Second, plot integration is conducive to agricultural chemical use reduction, thereby leading towards the direction of policy support. Through land integration, small-to-large and short-to-long pieces of land are transformed into flat slopes to strengthen policy support for high-standard farmland construction. This would alleviate the constraints of land characteristics on the use of scale diseconomies of soil protection and improvement technologies. Moreover, this would weaken the adverse impact of land endowment fragmentation on agricultural reduction. Third is a scientific evaluation of the impact of farmland ownership policy on production chemical input reduction in agricultural production. In China, contracted farmland management rights' confirmation and registration have delineated the plots' boundaries, which strengthens the natural properties of farmland's spatial characteristics in institutions. This reduces the possibility of plot integration, which may have adverse influences on the achieving agricultural chemical reduction indirectly. However, the conjecture must be confirmed by further research.

This study has a few limitations. We only consider the area and location of the transferred plots when analyzing their spatial characteristics. Other factors, including the shape, distance, and infrastructure of the transferred plots, are ignored. In the research, we only control the characteristic of the plots' area and location for a simplified setting. Simultaneously, due to limited survey data, when analyzing the influencing factors of chemical application, climate factors, such as rainfall, temperature, and light, were not considered in the model when analyzing the influencing factors of chemical application. The inter-regional differences in climate may lead to bias in the model's estimation results. This study reveals the influence and mechanism of plots' spatial characteristics on chemical input reductions in agricultural production. The effect of fragmented farmland on the efficiency of agricultural chemical use and the estimation of the potential of fragmented farmland integration in agricultural chemical reduction require further attention. These studies will provide a theoretical basis for promoting farmland integration in China. Furthermore, it will also provide a special method for the reduction in agricultural chemicals.

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