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Spatial Characteristics of Transfer Plots and Conservation Tillage Technology Adoption: Evidence from a Survey of Four Provinces in China

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Abstract: Degradation in farmland quality owing to overuse emphasizes the current need for the adoption of protective technologies to ensure food security and sustainable resource utilization. This study employs plot survey data from Heilongjiang, Henan, Zhejiang, and Sichuan provinces in China to investigate how the spatial attributes of transferred plots influence the current adoption of farmland protection methods, such as deep tillage and straw-returning. Findings reveal that larger or interconnected transferred plots significantly increase the likelihood of farmers adopting conservation tillage technologies. However, the influence of the plot's location on technology adoption varies among different plots. As the farmland transfer market expands, the spatial features of these plots emerge as critical determinants in the use of protective technologies. This underscores the pressing need for an integrated farmland transfer trading system and strengthened policy measures promoting land consolidation to foster widespread adoption of these conservation strategies.

Keywords: plot spatial characteristic; conservation tillage technology; deep tillage technology; straw returning to the soil; farmland transfer; farmland scale management

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1. Introduction

Farmland is indispensable for human survival, providing the bedrock for sustainable social development and food security. However, the acceleration of social economic growth, amplified farming frequency, improper chemical use, and excessive industrial waste discharge have exacerbated issues such as cultivated land degradation, soil pollution, and fertility decline [1]. This poses severe threats to both human development and global societal sustainability. Understandably, the challenge of cultivated land protection has garnered attention worldwide, leading to the gradual adoption of conservation tillage technology. This technology, characterized by straw mulching and reduced tillage, not only improves soil quality, but also boosts production, slashes costs, and diminishes consumption [2]. Conservation tillage can reduce the emissions of greenhouse gases from soil and water vapor, which prevents soil erosion by improving the physical and chemical properties of the soil [3]. It reduces the degree of agricultural machinery and equipment required in the field, as well as the need for production materials, such as fuel and labor, and the rolling of soil caused by the use of agricultural machinery [4], which is highly important to farmland ecological restoration [5]. Currently, most nations with a strong agricultural focus actively implement conservation tillage technologies. For example, the proportion of conservation tillage areas in Brazil, Argentina, and Paraguay reached 74.8%, 80%, and 80.1%, respectively, in 2002 [6]. In the United States, conservation tillage accounted for 60% of the total arable land in 2002, and 65% of cornfields in 2016. In 2017, conservation tillage techniques were used in 67% of US wheat fields [7], with conservation tillage in widespread use worldwide as an environmentally friendly technology.

The development of conservation tillage technology is still in its initial stages in China, and further research is required to promote its wider application. In 2011, the Chinese Ministry of Agriculture issued the Code for the Implementation of Conservation Tillage Projects and Key Technical Points of Conservation Tillage to actively promote conservation tillage technology. The document introduced key technical points relating to the application of conservation tillage technology and recommended technical models tailored to different regions in China based on their suitability. In 2021, seven departments in China, including the Ministry of Agriculture and Rural Affairs, the National Development and Reform Commission, and the Ministry of Finance, jointly issued the Implementation Plan for the National Black Land Protection Project (2021–2025), emphasizing the need to "implement multiple modes of conservation farming". Although the state introduced several policies to actively promote it, the conservation tillage area was 8.162 million square hectares in 2019, accounting for only 6.38% of the country's total farmland [5]. As a result, the Chinese government faces significant challenges in fostering the widespread application of conservation tillage technology.

Research on farmland conservation technology adoption has primarily focused on three main aspects. First, scholars have examined the characteristics of conservation tillage technology, noting its long function cycle and slow effects. As a typical intertemporal agricultural technology, conservation tillage can yield economic, social, and ecological benefits through multiple rounds of investment [8–12]. Furthermore, researchers have investigated farmers' levels of adoption and willingness to pay for conservation tillage technology [13,14]. Secondly, studies have explored the factors influencing farmers' decisions to adopt conservation tillage technology. In addition to traditional determinants, such as demographic characteristics, human capital, and social networks [14–18], researchers have also studied the impact of cognition, risk preference, policy mix, and climate on farmers' adoption behavior [19–24]. For instance, farmers' social capital plays a crucial role in disseminating information, reducing technology learning costs, and fostering the "herding effect", thereby lowering transaction costs and the incidence of "free-riding" behavior [25,26].

It is important to note that the promotion of conservation tillage technology involves multiple parties, such as the government, scientific research institutes, and farmers. Farmers have the ability to make independent choices and decisions around agricultural production and management, and are the main decision-makers, participants, and disseminators of agricultural technology adoption. In China, with its longstanding agricultural tradition, small farmers have been a prominent demographic. However, as a result of the rapid development of the cultivated land transfer market, by 2019, more than 40% of small farmers in China had transferred out of cultivated land, with the total scale exceeding one-third of China's cultivated land area. This evolution has brought significant changes to farmers' factor structures and management modes, necessitating a closer examination of its impact on their adoption of protective tillage technology.

Conservation tillage technology has garnered increasing attention from researchers; however, there is still ample room for further exploration in this domain. While previous studies have extensively examined the impact of traditional factors, such as material and human capital, on farmers' adoption of conservation tillage technology, less attention has been given to the influence of reconfigured cultivated land elements and their internal mechanisms. Additionally, the existing research has predominantly focused on investigating the effects of farmers' management scale on their decisions regarding farmland conservation technology adoption and willingness to pay. Yet, a notable gap remains in the empirical analysis of how plot-level farmland characteristics influence farmers' technology adoption choices.

This study focuses on investigating the influence and heterogeneity of spatial characteristics of plots on the adoption of conservation tillage technology in the context of agricultural land transfer. Leveraging plot survey data from Heilongjiang, Henan, Zhejiang, and Sichuan provinces in China, we conduct a comprehensive empirical analysis. We specifically examined differences in deep-plowing technology, straw-returning technology, and technology combinations of transferred plots across various areas and locations. The findings of this study shed light on the intricate relationship between plot spatial features and the adoption of farmland conservation technology in agricultural production. The study's conclusions are of utmost significance as they pave the way for innovative promotional models for conservation tillage technology, fostering sustainable agricultural development, and bolstering national food security.

2. Framework and Hypotheses

2.1. Characteristics of Conservation Tillage Technology

Conservation tillage is a modern tillage technology with straw mulching and deep tillage as its main components. It involves returning crop straw mulching, deep tillage, deep loosening, and a variety of other technical measures. This study investigates the principle of subsoiling and straw returning technology, and the effect of natural disaster risk resistance [27].

(1) Deep tillage technology refers to the use of a tractor traction digging machine as a form of breaking plow. This mechanized plowing technique does not disturb the original soil structure of loose soil. Deep tillage can break the hard plow bottom, deepen the plow layer, reduce soil bulk density, and improve soil permeability, thus enhancing soil water retention and drought and flood resistance, which is conducive to improved crop growth and development and increased yield. According to the Implementation Plan of National Agricultural Machinery Deep Loosening Preparation Operation (2016–2020) issued by the Chinese Ministry of Agriculture in 2017, plots with deep loosening up to 30 cm can store approximately 400 cubic meters more water per hectare than those without it. The average water content during the early season is also increased by approximately 7%, which can extend the drought tolerance of crops by approximately 10 days. The average yields of wheat, corn, and other crops is also increased by approximately 10% (http://www.moa.gov.cn/nybgb/2016/disanqi/201711/t20171127_5920218.htm, accessed on 27 November 2017).

(2) Straw returning technology refers to crop stalks shattered after harvesting crops directly or when heap fermentation is used to cover the surface. The straw can also be further improved by rotary tillage methods used with fertilizers, as these methods cause it to fall into the soil. Straw returning to the field improves water retention and soil fertility, reduces wind and water erosion, and is helpful in improving crop resistance to natural disasters. After seeding, the stubble coverage of surface crops is not less than 30%, which reduces wind and water erosion by 70% [28]. Mulching has been observed to help reduce the ineffective evaporation of soil water by 58% and the water consumption coefficient by 9.75%, while improving water-use efficiency by 12.26% and yield by 4.35% [27].

Deep tillage technology can be used either individually or in combination with complementary conservation tillage technology, such as straw returning. The effect of these technologies in conjunction with one another is better than their use in isolation [29]. The straw-returning method can significantly inhibit soil evaporation and increase soil water content in the topsoil layer. However, the combination of straw returning and subsoiling technology has the best effect on increasing yield. Compared with traditional tillage alone, straw returning to the field used in tandem with deep tillage significantly increased the number of ears, grains per ear, the 100-grain weight of corn, and the biological yield [30,31].

2.2. Farmland Transfer, Plots' Spatial Characteristics and Farmers' Adoption of Conservation Tillage Technology

The rapid development of the farmland transfer market has created favorable conditions for farmers to adopt farmland protection technology. China's per-capita farmland resources are limited and fragmented. The transfer of farmland promotes the redistribution of resources and makes it possible for some farmers to expand their management area. Meanwhile, the reduction in the number of farmers operating farmland can partially alleviate the problem of farmland fragmentation and reduce plot space restrictions in terms of mechanical operation and efficiency. The expansion of farmers' operational scale has several advantages, including facilitating the allocation and internalization of fixed costs in production [32,33]. It enables economies to grow in scale and encourages farmers to make long-term production investments, such as purchasing large-scale agricultural machinery, acquiring advanced production technology, and adopting farmland protection technology. However, the use of agricultural technology or machinery is often limited by the spatial scope of the plots. For example, mechanical operations require a certain amount of space to complete reciprocating and steering movements, making it challenging for machinery to turn and move frequently in narrow spaces. Small plot areas limit the use of machinery and also restrict working efficiency, even if machinery can be used. Expanding plot areas weakens the adverse effects of space on the use of mechanical technology and factor substitution. Therefore, when discussing the impact of the development of the transfer market on farmers' adoption of farmland protection technology, it is necessary to pay attention not only to the scale of farmers' operations but also to the size of the relevant land plots [34].

Under China's farmland resource endowment and distribution system, farmland supply in the transfer market is randomly distributed, and the potential plots to which farmers can transfer differ in size and are located randomly. While farmers realize the expansion of the total area of management through the transfer of farmland, the degree of farmland fragmentation does not necessarily change. The expansion of the management area is only reflected in the increase in the number of management plots; the average area of the land plots themselves does not expand. In the farmland transfer market, land plots that can alleviate fragmentation usually have the following two key attributes. First, a land plot with a large area must have sufficient space for mechanical operations and cost allocation. If the plot area is too small, navigating the machinery in such a narrow space ends up being challenging. This loss of mechanical operation efficiency leads to an increase in the cost of technological substitution, which restricts the possibility of adopting conservation tillage and soil improvement technologies for agricultural production. Second, the location must be connected to the original plot. Owing to the fixed location of the plot in the transfer market, when the transferred plot is connected to the original plot of the farmer, the effective farming space can be expanded using boundary connections and ridge breaking [29]. Thus, the constraints of the transferred plot area can be improved in terms of mechanical substitution and efficiency. In other words, compared with non-connected plots, connected plots in the transfer market can more easily achieve economies of scale in the adoption of farmland protection technology, improving the possibility of farmers adopting cultivated land protection technology. As the plot area expands, the economies of scale available through land use gradually become more prominent. In turn, the influence on land production of whether the location is connected to the original plot of the transferee gradually decreases [35]. As a result, the influence of the location of the transferee on technology adoption on large land areas gradually decreases. Figure 1 presents the analysis framework.

In summary, the fragmented nature of farmland endowment in China means that farmers transferring to plots with different spatial characteristics creates differences in the characteristics of farmers' holding factors, which further affects their adoption of farmland conservation technologies. Specifically, a transfer to large or connected plots can improve the fragmentation conditions of farmers' management plots, as well as the convenience of mechanical operations, and the possibility of substituting mechanical technology for labor. Taken together, this can improve the possibility of farmers adopting farmland protection technology. Thus, the following research hypotheses are proposed.

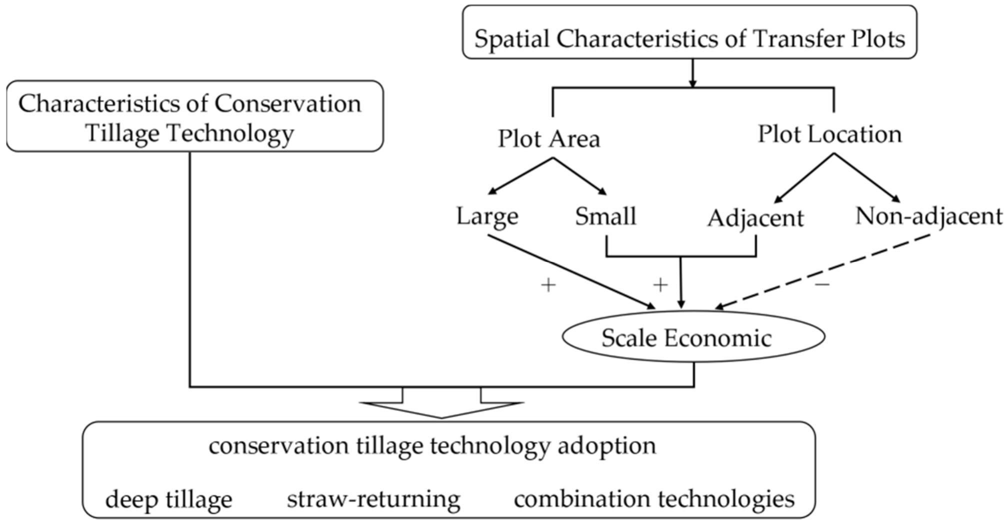

Figure 1. The effect mechanism of the spatial characteristics of plots on the adoption of conservation tillage technology.

Hypothesis 1. *The spatial characteristics of transferred plots are important factors that affect farmers' adoption of farmland protection technologies. Large areas or adjacent transfer plots are particularly conducive to farmers' adoption of farmland protection technologies.*

Hypothesis 2. *The location characteristics of plots have different influences on the adoption of conservation tillage technology in different area. The expansion of plots leads to a gradual decrease in the promotional effect of the adoption of conservation tillage technology due to location connections.*

3. Methods and Dates

3.1. Model

According to the "rational smallholder" farmer behavior theory, the adoption of a certain technology by farmers is based on maximizing the expected utility it brings. When farmers become aware of conservation tillage techniques, they assess the expected utility of using the technology compared to not using it. Based on this evaluation, they decide whether to adopt the technology or not. The expected utility of farmers using farmland protection technology versus those not using it is expressed as follows:

$$E(U_{1ij}) = \alpha_1 + \beta_1 X_{ij} + \xi_{1ij} \quad (1)$$

$$E(U_{0ij}) = \alpha_0 + \eta_0 X_{ij} + \xi_{0ij} \quad (2)$$

In these equations, X_{ij} represents the variables affecting the expected utility from technology adoption. The difference in the expected utility between farmers who adopt the relevant technology and those who do not is as follows: $\Delta E = E(U_{1ij}) - E(U_{0ij}) = \alpha + \beta X_{ij} + \xi_{ij}$. When $\Delta E \geq 0$, farmers will choose to adopt farmland protection technology, and when $\Delta E < 0$, they will not.

To explore the impact of plot spatial characteristics on the adoption of farmland protection technology, we control for the plot area and location characteristics among the factors influencing the expected effects detailed above. We analyze the plot-level data using a probit model constructed as follows:

$$Tech_{ij} = \alpha + \beta_1 Plotarea_{ij} + \beta_2 Link_{ij} + \gamma X_j + \sigma_i + \xi_{ij} \quad (3)$$

In Equation (3), $Tech_{ij}$ represents the farmland protection technology of farmer i that is adopted on plot j through latent variables, mainly including deep tillage technology and straw returning technology. When farmers adopt the relevant technology, $Tech_{ij} = 1$, otherwise it is 0. $Plotarea_{ij}$ represents the area of plot j transferred by farmer i. $Link_{ij}$ is a dummy variable for the location of plot j transferred by farmer i. $Link_{ij} = 1$ represents the plot j adjacent to the original farmland of farmer i; and $Link_{ij} = 0$ represents non-adjacent. Variable X_j are the control variables affecting the input of production chemicals at the plot level, including the soil quality of the plot, irrigation conditions, and the types of crops planted. Variable σ_i are the control variables affecting the input of production chemicals at the household level, including the total area of farmland operated by farmers, characteristics of household owners, available agricultural labor force, and amount of machinery in operation. It also includes the development of the farmland market, policy subsidies, farmland property rights, terrain, and other characteristics of the region where the farmers are located. Finally, ξ_{ij} represents the random disturbance term.

Compared to no adoption of any technology, the use of straw returning to the field or deep tillage technology can help improve the ability of crops to resist natural disaster risks, and the combination of both the technologies has a better effect. To explore and analyze the impact of the spatial characteristics of the transferred plots on the combination of farmland protection technologies, we construct an order probit model as follows:

$$Tech\_z_{ij} = \begin{cases} 0, & None; \\ 1, & Only\ one; \\ 2, & Both; \end{cases} \quad Tech\_z^*_{ij} = \alpha + \beta_1 Plotarea_{ij} + \beta_2 Link_{ij} + \gamma X_j + \sigma_i + \xi_{ij} \tag{4}$$

In Equation (4), $Tech\_z_{ij}$ represents the farmland protection technology combination of farmer i on plot j, after adopting the latent variables. This represents the number or extent to which the conservation tillage technology has been adopted. The other variables are set as described above.

To further investigate the influence of the location of the transferred plots on the adoption of conservation tillage technology for different plot areas, we introduce the intersection term of plot location and plot area grouping into the above model. Subsequently, the following model is formed:

$$Tech_{ij} = \alpha + \beta_1 Plotarea\_g_{ij} + \beta_2 Link_{ij} + \beta_3 Plotarea\_g_{ij} \times Link_{ij} + \gamma X_j + \sigma_i + \xi_{ij} \tag{5}$$

In Equation (5), $Plotarea\_g_{ij}$ is a grouping dummy variable for plot area. The plots are divided into small and large plot groups by comparing the median provincial plot area and sample plot area, in which the large and small plot groups are assigned values of 1 and 0, respectively. Parameter β_3 represents the influence of adjacent groups on the adoption of conservation tillage technology by large block groups. The other control variables are the same as those described above.

3.2. Data and Variables

Data for this econometric analysis were obtained from a large-scale grain production survey in China. In 2015, a rural household survey was implemented using a multistage sampling method. The provinces of Heilongjiang, Henan, Zhejiang, and Sichuan were selected for surveying based on their comprehensive regional distribution, and their relatively advanced economic and agricultural development. Four sample cities were randomly selected in each sample province (The sample of cities are as follows. Ning 'an, Tangyuan, Zhaodong and Longjiang are in Heilongjiang provinces; Xiayi, Anyang, Xiping, Xuchang are in Henan province; Shengzhou, Wuyi, Wenling, Xiuzhou are in Zhejiang province; Zhongjiang, Nanbu, Yanjiang, Linshui are in Sichuan province). Two towns were randomly selected from each city and thirty-two farmers were randomly selected from two villages within each town. The final sample covered 1040 farmers from 32 towns in 16 cities across 4 provinces. A follow-up survey was conducted in 2018. As a number of farmers were not tracked over the time between the original and follow-up survey, the total sample size was reduced to 1033.

The samples analyzed were 1356 plots that were converted into farmland and planted with grain crops, including 725 plots in 2015 and 631 in 2018. The data covered the spatial characteristics of the plots, plot quality, crop planting, and use of cultivated land conservation technology at the plot level. At the farmer level, the data covered household information, cultivated land management, and agricultural machinery ownership. Village-level messages included farmland market development, policy subsidies, property rights, and other regional characteristics. All variable assignments and descriptive statistical results of the empirical model are shown in Table 1.

Table 1. Variable definitions and descriptive statistics.

Variable	Variable Assignment	Obs.	Mean	Std.
Deep tillage technique	Deep tillage technology used in plot production = 1, otherwise = 0	1356	0.390	0.488
Straw returning technology	Straw returning technology used in plot production = 1, otherwise = 0	1356	0.522	0.5
Conservation technology combination	Types of farmland conservation tillage techniques used in plot production.	1356	0.912	0.789
Plotarea	The area of transferred plot (mu).	1356	11.48	38.81
Adjacent	The transferred plot is adjacent to the original land = 1, otherwise = 0.	1356	0.31	0.462
Soil	The soil quality of the transferred plot, 1 = good, 2 = medium, 3 = poor.	1356	1.64	0.644
Irrigation	The transferred plot can be irrigated = 1, otherwise = 0.	1356	0.723	0.448
Kind	Type of grain crops planted in autumn on the transferred plot: 0 = rice, 1 = corn.	1356	0.51	0.5
Area	Total area of farmland planted by farmer (mu).	1356	126.4	516.3
Age	Age of head of household.	1356	53.2	10.64
Edu	Years of education for the head of household.	1356	6.92	3.137
Exp	Years of farming experience for the head of household.	1356	30.48	13.62
Alabor	Amount of labor provided by households engaged in agricultural production.	1356	2.03	0.888
Insurance	Farmers have purchased agricultural disaster insurance = 1, otherwise = 0.	1356	0.48	0.5
Machine	The value of farmer's machinery holding (thousand Yuan).	1356	52.77	123.3
Transfer	Proportion of village farmland transfer (%).	1356	42.06	21.19
Subsidy	Farmer receive subsidies for farmland transfer = 1, otherwise 0.	1356	0.2	0.401
Certificate	The farmland in village has been issued with a title certificate = 1, otherwise = 0.	1356	0.49	0.5
Terrain	Village terrain features, 1 = plain, 2 = hilly, 3 = mountainous.	1356	1.53	0.58
Year	Year dummy variable: 2015 = 0, 2018 = 1.	1356	0.47	0.499

Data source: The author collated the statistics based on the survey data of households on "large-scale grain production" in 2015 and 2018.

4. Results

4.1. Statistical Differences between Transferred Plots' Spatial Characteristics and Conservation Tillage Technology Adoption

This study focused on the effects of the spatial characteristics of plots on the adoption of conservation tillage technology and analyzed the differences in the adoption by farmers on different plots in different areas and locations. Plots were divided into small and large groups by comparing the area with the provincial median of the sample area. They were further divided into non-adjacent and adjacent groups based on whether the location was adjacent to the original farmland of the transferee. At the plot level, the differences in farmers' deep tillage technology, straw returning techniques, and combinations of both technologies were grouped into statistics according to plot area and location, and a two-sample t-test was conducted. Table 2 presents the results of this test.

Table 2. Statistical differences in the influence of transferred plots' area and location on conservation tillage technology adoption.

Index Group		Grouped by Area			Grouped by Location		
		Small Plots	**Big Plots**	**T-Value of the Two-Sample *t*-Test**	**Non-Adjacent**	**Adjacent**	**T-Value of the Two-Sample *t*-Test**
Deep tillage technology	Total	0.293	0.488	7.527 ***	0.361	0.433	2.985 ***
	2015	0.214	0.537	9.503 ***	0.344	0.470	2.816 ***
	2018	0.377	0.427	2.281 **	0.381	0.442	2.145 **
Straw returning technology	Total	0.476	0.568	3.387 ***	0.503	0.565	2.092 **
	2015	0.447	0.557	2.658 ***	0.516	0.58	1.862 *
	2018	0.508	0.582	2.014 **	0.487	0.548	2.044 **
Conservation technology combination	Total	0.769	1.056	6.815 ***	0.864	0.998	2.197 **
	2015	0.661	1.094	4.585 ***	0.860	1.050	1.917 *
	2018	0.885	1.009	2.812 ***	0.868	0.990	1.893 *

Note: * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

The results of the statistical analyses are shown in Table 2. First, the proportions of deep tillage technology adoption in the large plot group in 2015 and 2018 were 32.3% and 5.0% higher, respectively, than those in the small plot group, while the proportions of deep tillage technology adoption in the adjacent plot group in 2015 and 2018 were 12.6% and 6.1% higher, respectively, than those in the non-adjacent plot group. Differences among these groups were considered statistically significant at the 5% or higher level. Second, the proportions of straw returning technology adoption in the large plot group in 2015 and 2018 were 11.0% and 7.4% higher than those in the small plot group, respectively, and the proportions of straw returning technology adoption in the adjacent plot group in 2015 and 2018 were 6.4% and 6.1% higher than those in the non-adjacent plot group, respectively. The differences between groups were statistically significant (>10%). Third, the number of conservation tillage technology combinations adopted by the large plot group in 2015 and 2018 was 0.433 and 0.124 higher than that adopted by the small plot group, and the number of conservation tillage technology combinations adopted by the adjacent plot group in 2015 and 2018 was 0.190 and 0.122 higher, respectively, than that adopted by the non-adjacent plot group. The differences between groups were statistically significant (>10%).

Overall, compared to the small plot group, the proportions of deep tillage technology, straw-returning technology, and technology combination in the large plot group were higher. Compared to non-adjacent plots, the proportions of deep tillage technology, straw returning technology, and technology combinations in connected plots were significantly lower. In the following section, the heterogeneity of conservation tillage technology adoption in the production of plots in different areas and locations is further compared through empirical tests.

4.2. Influence of Transferred Plots' Spatial Characteristics on Conservation Tillage Technology Adoption

The influences of the transferred plot area and location on farmers' adoption of conservation tillage technology are reported in Table 3. Columns (1) and (2) show the influence of the spatial characteristics of the transferred plot on the adoption of deep tillage and straw returning technologies by farmers. The models both provide robust estimates using the maximum likelihood method with the binary selection model. Column (3) shows the impact of the spatial characteristics of the transferred plots on the farmers' adoption of technology combinations; the model is a robust estimation of the ordered probit model and maximum likelihood method. The models' estimation results demonstrate that the goodness-of-fit F-test statistics reached statistical significance at the 1% level, indicating that the overall fit of all models was good, and the explanatory variables of the model had a high degree of interpretation of the explained variables.

Table 3. Influence of transferred plot area and location on conservation tillage technology adoption.

Variables	(1)	(2)	(3)	
	Deep Tillage Technology	**Straw Returning Technology**	**Conservation Technology Combination**	
			None	**Combination**
Plotarea	0.049 **	0.112 ***	−0.050 **	0.077 **
	(2.16)	(3.06)	(2.06)	(2.17)
Link	0.268 *	0.203 *	−0.271 *	0.013
	(1.95)	(1.65)	(−1.87)	(0.08)
Soil	−0.009	−0.060	0.090	0.057
	(−0.09)	(−0.68)	(0.87)	(0.49)
Irrigation	0.223 **	0.544 ***	−0.427 **	0.415 **
	(1.98)	(3.62)	(−2.53)	(1.96)
Kind	0.002 **	−0.322 **	−0.215 *	0.226
	(2.01)	(−2.34)	(−2.35)	(1.26)
Area	0.030 ***	0.031 ***	−0.040 ***	0.029 ***
	(3.66)	(3.28)	(−3.26)	(3.80)
Age	−0.009	0.019 **	−0.012	−0.008
	(−0.91)	(2.30)	(−1.18)	(−0.73)
Edu	0.007	0.023	−0.023	−0.004
	(0.28)	(1.13)	(−0.99)	(−0.15)
Exp	−0.007	−0.013 **	0.016 **	0.009
	(−0.98)	(−2.15)	(2.25)	(1.13)
Alabor	0.139 *	−0.004	−0.025	−0.003
	(1.86)	(−0.06)	(−0.32)	(−0.03)
Insurance	0.326 **	0.128	−0.195	0.230
	(2.35)	(1.06)	(−1.40)	(1.48)
Machine	0.001 **	0.001 **	−0.001 *	0.001 **
	(2.31)	(2.13)	(−1.76)	(1.97)
Transfer	0.002 *	0.004 *	−0.006 *	0.005 **
	(1.75)	(1.92)	(−1.81)	(2.21)
Subsidy	−0.258	−0.061	−0.007	−1.286 ***
	(−1.06)	(−0.39)	(−0.03)	(−4.79)
Certificate	0.465 **	0.248 *	−0.091 *	0.432 **
	(2.44)	(1.90)	(−1.95)	(2.09)
Terrain	−0.174	−0.178	0.070	−0.776 ***
	(−1.27)	(−1.52)	(0.53)	(−4.77)
Regional dummy variable	Control	Control	Control	Control
Year dummy variable	Control	Control	Control	Control
Constant	−0.488	−0.956 *	1.291 **	0.180
	(−0.81)	(−1.74)	(2.04)	(0.26)
Model statistical index	Number of obs = 1356; Wald chi^2 = 219.10; Prob > chi^2 = 0.000; Pseudo R^2 = 0.166	Number of obs = 1356; Wald chi^2 = 197.28; Prob > chi^2 = 0.000; Pseudo R^2 = 0.154	Number of obs = 1356; Wald chi^2 = 266.70; Prob > chi^2 = 0.000; Pseudo R^2 = 0.193	

Notes: The values between parentheses are the z value of the estimated parameters. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

The results of the model parameter estimation show that according to the average area of the plot, the probability of farmers adopting deep tillage technology on the plot increased by 4.9%, the probability of adopting straw-returning technology increased by 11.2%, and the probability of farmers adopting a combination of deep plowing and straw-returning technologies increased by 7.7%. These estimates were statistically significant at the 5% level. This indicates that the expansion of the transferred plot area significantly increased the probability of farmers adopting conservation tillage technology. The parameter estimation of the location characteristics of the transferred plots show that compared with the non-adjacent plots, the probability of farmers on the adjacent transferred plots adopting deep tillage technology increased by 26.8%, the probability of using straw returning technology increased by 20.3%, and the probability of not using any conservation tillage technology decreased by 27.1%. All of the above estimates were statistically significant at the 10% level. Our findings reveal that the location of the transferred plots significantly increased the probability of farmers adopting conservation tillage technology. The results of the two sets of models show that the possibility of using deep tillage or straw returning in agricultural production was greater in plots with large areas or connected locations, which supports Hypothesis 1.

From the perspective of the parameter estimation of the control variables, an increase in the management area had a significant positive impact on the probability of farmers adopting tillage technology, straw-returning technology, and a combination of technologies, with the parameter estimation being statistically significant at the 1% level. This is mainly because the expansion of farmers' management scales helps them share the costs of conservation tillage technology. The unit cost of technology adoption can be reduced to improve the return on technology investment, and the probability of farmers adopting technology can be increased. From the perspective of crop classification, the adoption probability of deep-tillage technology is significantly higher for corn planting plots than it is for rice. Conversely, the adoption probability of straw-returning technology is significantly higher for rice plots than that it is for corn. The parameter estimates are statistically significant at the 5% level, mainly because the differences in crop characteristics produce different technology selections at the production level. The higher the total value of agricultural machinery holdings, the higher the possibility of farmers adopting conservation tillage technology on the transferred plots, with the parameter estimates being statistically significant at 10% or above. This may be owing to the fact that the tillage depth needed for deep-tillage technology and for straw crushing in straw-returning technology require greater machinery power. Thus, the availability of large-sized agricultural machinery is the basis for farmers' adoption of deep-tillage technology and straw-returning technology. From the perspective of transfer market development, farmers in areas with a higher ratio of farmland transfers were more likely to adopt conservation tillage technology. The main reason for this is that the development of the transfer market helps improve the fragmentation of land and mechanization operations, thereby reducing the unit cost of technology adoption and consequently increasing the possibility of farmers' technology adoption.

4.3. Robust Analysis

Owing to the different resource endowments and environmental characteristics of different regions, the spatial characteristics of farmland in the transfer market are systematically different. This may lead to an estimation bias in the model owing to the difference in the use of farmland conservation tillage technology in agricultural production. In this study, the provincial medians of the plot area and the sample plot area were compared and grouped, and the model was estimated using the same method described above to carry out a robustness test. Table 4 documents the influences of the area grouping and location of the transferred plots on deep-tillage technology, straw-returning technology, and the combination of technologies, respectively. The results shown in Columns (4) and (5) were obtained from binary selection models, with those shown in Column (6) based on an ordered selection model. Each of these sets of results adopted a robust estimation using the maximum likelihood method.

Model parameters were estimated, according to the results of Columns (4) and (5) in the plot area. Grouping virtual variable parameter estimation showed that the probability of farmers adopting deep-tillage and straw-returning technology were 50.3% and 14.6% higher, respectively, for the big plot group than for the small plot group. The parameter estimates were statistically significant above the 5% level. The difference in comparison results between the groups in Column (6) shows that the probability of not using any technology in the large plot group was 10.8% lower than that of using a single technology, while the probability of using a combination of deep-tillage and straw-returning technologies was 51.5% higher, and the parameter estimates were statistically significant at the 5% level or above. The estimation results in Columns (4)–(6) further indicate that the expansion of the area or the location of the transferred plot has a significant promotional effect on farmers' adoption of conservation tillage technology.

Table 4. Robust analysis of influence of transferred plot area and location on conservation tillage technology adoption.

Variables	(4)	(5)	(6)	
	Deep Tillage Technology	**Straw Returning Technology**	**Conservation Technology Combination**	
			None	**Combination**
Plotarea group	0.503 ***	0.146 **	−0.108 **	0.515 ***
	(3.86)	(2.19)	(−2.13)	(3.23)
Adjacent	0.188 **	0.208 *	−0.272 *	−0.021
	(2.44)	(1.69)	(−1.88)	(−0.13)
Control variable	Control	Control	Control	Control
Regional dummy variable	Control	Control	Control	Control
Year dummy variable	Control	Control	Control	Control
Constant	−0.533	−1.084 **	1.285 **	−0.308
	(−0.91)	(−1.96)	(2.02)	(−0.43)
Model statistical index	Number of obs = 1356; Wald chi^2 = 166.10; Prob > chi^2 = 0.000; Pseudo R^2 = 0.124	Number of obs = 1356; Wald chi^2 = 181.28; Prob > chi^2 = 0.000; Pseudo R^2 = 0.149	Number of obs = 1356; Wald chi^2 = 271.70; Prob > chi^2 = 0.000; Pseudo R^2 = 0.195	

Notes: The values between parentheses are the z value of the estimated parameters. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

4.4. Heterogeneity Analysis

To further examine the heterogeneity in the influence of transferred plot area and location on conservation tillage technology adoption by farmers, the cross-terms of the constructed plot area grouping variable and plot location were studied in the model. The estimation results for the model parameters are presented in Table 5. In Columns (7)–(9), the interaction term model is used to analyze the influence of the location of the transferred plots on the adoption of deep-tillage, straw-returning, and combination technology for plots of different area groups. A robust estimation of the maximum likelihood method was adopted for all of the models. From the model estimation results, the goodness-of-fit F-test statistics were all large, reaching a significance level of 1%, indicating that the overall fit of all models was good, and the key explanatory variables had a high degree of explanation.

In Column (7), the estimated value of the virtual variable of the plot area grouping was 0.612, which is statistically significant at the 1% level. This indicates that the probability of adopting deep-tillage technology in the large plot group was significantly higher than in the small plot group, by a difference of 61.2%. The estimated value of the parameter of the plot location variable was 0.428 and significant at the 5% level, indicating that in the small plot group, the probability of adopting deep tillage technology in the production of geographically adjacent plots was 42.8% higher than that of non-adjacent plots. The estimated value of the cross-term parameter was −0.370, which was statistically insignificant. This suggests that for the large plot group, the adoption rate of deep tillage technology remained comparable between geographically adjacent and non-adjacent plots. In Column (8), the parameter estimate of the virtual variable of the plot area grouping was 0.373, which was statistically significant at the 5% level. This indicates that the probability of adopting straw returning technology in the large plot group was significantly higher—by a total of 37.3%—than the likelihood of doing so in the small plot group. The estimated value of the parameter of the plot location variable was 0.369, indicating that in the small plot group, the probability of adopting straw returning technology in geographically adjacent plots was 36.9% higher than that in non-adjacent plots, with this statistic being significant at the 5% level. The estimated value of the parameter of the cross-term of the plot area grouping and plot location was −0.536, which was statistically insignificant. This suggests that in the large plot group, the likelihood of adopting straw-returning technology was similar for both geographically adjacent and non-adjacent plots.

Table 5. Difference in the influence of transferred plots' location on conservation tillage technology adoption.

Variables	(7)	(8)	(9)	
	Deep-Tillage Technique	Straw-Returning Technology	Conservation Technology Combination	
			None	Combination
Plotarea group	0.612 ***	0.373 **	−0.040	0.697 ***
	(3.82)	(2.47)	(−0.23)	(3.58)
Adjacent	0.428 **	0.369 **	−0.360 *	0.287 *
	(2.27)	(2.13)	(−1.86)	(1.83)
Plotarea group × Adjacent	−0.370	−0.536	0.216	−0.527
	(−1.42)	(−1.16)	(0.74)	(−1.37)
Control variable	Control	Control	Control	Control
Regional dummy variable	Control	Control	Control	Control
Year dummy variable	Control	Control	Control	Control
Constant	−0.567	−1.609 ***	1.336 **	−0.438
	(−0.96)	(−2.75)	(2.08)	(−0.61)
Model statistical index	Number of obs = 1356; Wald chi^2 = 177.6; Prob > chi^2 = 0.000; Pseudo R^2 = 0.130	Number of obs = 1356; Wald chi^2 = 231.9; Prob > chi^2 = 0.000; Pseudo R^2 = 0.171	Number of obs = 1356; Wald chi^2 = 276.6; Prob > chi^2 = 0.000; Pseudo R^2 = 0.197	

Notes: The values between parentheses are the z value of the estimated parameters. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

In Column (9), the probability of not using any conservation tillage technology was 4% lower on non-adjacent large plots compared to the likelihood of using a single technology. The probability of using a combination of technologies was 69.7% higher, and the parameter estimations were statistically significant at the 1% level. Simultaneously, the probability of not using any conservation technology on the adjacent plots in the small-plot group was 36% lower, whereas the probability of using the combination of technologies was 28.7% higher, and the parameter estimation was statistically significant at the 1% level. However, the parameter estimates for the virtual variable of plot area grouping and the cross-term of plot location were −0.216 and −0.527, respectively, which are not statistically significant. These findings suggest that in the large plot group, the likelihood of using the conservation tillage technology combination was comparable for both geographically adjacent and non-adjacent plots.

These results are consistent with those provided in Columns (7) and (8), indicating that the location of the transferred plot has a heterogeneous effect on the adoption of conservation tillage technology in different plots area. That is, the adjacent location only has a significant promoting effect on the adoption of conservation tillage technology in the small plot group, but not in the large plot group, which verifies Hypothesis 2. The main reason is that the role of the adjacent location in easing the constraints of the spatial characteristics of the land is gradually weakened with the expansion of the plot area.

5. Conclusions

Against the background of the tense relationship between humans and farmland, the quality degradation caused by farmland overuse has become increasingly prominent. The widespread use and popularization of farmland conservation technology is of great significance for ensuring food security and promoting the sustainable utilization of resources. This study explored the influence and heterogeneity of the spatial characteristics of plots on the use of farmland conservation technology in agricultural production and conducted an empirical analysis using plot survey data from Heilongjiang, Henan, Zhejiang, and Sichuan provinces in China. This analysis tested the differences in deep-tillage technology, straw-returning technology, and the combination of technologies adopted by farmers on transferred plots in different areas and locations. Two main conclusions emerge. First, the spatial characteristics of the transferred plots affects the adoption of farmland protection technology in agricultural production. That is, the expansion of the area or location of the transferred plots will significantly increase the probability of adopting deep-tillage technology, straw-returning technology, and a combination of both technologies on the plots. Second, the location of the transfer plot is heterogeneous in promoting the adoption of farmland protection technologies for different plots. Location connection has a significant promotional effect on the adoption of cultivated land protection technology for small plots, but not for large plots.

Starting from the natural properties of cultivated land, this study discusses the influence of the spatial characteristics of plots on the cultivated land protection technology used in agricultural production. The policy implications that emerge from this research are as follows: First, under the condition of existing resource endowment, the government guiding farmers to make transferring a joint decision will help improve resource utilization efficiency and the sustainable development of agriculture. The government's construction of a unified platform for the transfer and trading of agricultural land management rights can help to ease the centralized transfer of spatially scattered land. This in turn can weaken the adverse impact of fixed land location on agricultural production and improve the adoption of cultivated land protection technology, which can further facilitate the sustainable development of agriculture. Second, the policy support for land integration and high-standard farmland construction should be strengthened. By merging smaller plots with larger ones, integrating shorter expanses of land with longer stretches, and implementing slope leveling, one can mitigate the limitations posed by land characteristics on the efficiency of soil protection and enhancement techniques. This approach also diminishes the negative impact of fragmented land allocation on the uptake of farmland conservation methods. Simultaneously, a judicious easing of policy restrictions on farmland contracting and replacement, enabling farmers to consolidate land and eliminate field footpaths, would foster greater adoption and advocacy of farmland conservation techniques among farmers.

It is worth noting this study has certain limitations. When we analyzed the spatial characteristics of transfer plots, we considered only the area and location of plots and ignored some other factors, such as the distance between plots, shape of plots, infrastructure, and so on. In fact, the characteristics of plots in the transfer market are far more complicated than the analysis. We only controlled the influence of plot area and location for simplified setting in the research. This study unveils the impact and mechanisms of a plot's spatial characteristics on the adoption of farmland conservation technology in agricultural production. Therefore, the role of farmland integration in advancing the promotional model of conservation tillage technology warrants further exploration.

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