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Can farmland ownership confirmation promote farmers' adoption of conservation tillage techniques: empirical evidence from the Yellow River Basin in China

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Introduction: Cultivated land is the basic resource for human survival, and the quality of arable land affects the level of food supply. Previous studies have shown that farmland ownership confirmation will promote farmers' cultivated land quality protection behaviour, but it is unclear whether it will promote farmers' choice of conservation tillage techniques.

Methods: This paper uses sample data of farmers in the Yellow River Basin in China's key agricultural regions to analyse the impact of the new round of farmland tenure confirmation on farmers' choice of conservation tillage techniques.

Results: The results show that farmland ownership confirmation can significantly promote the adoption of conservation tillage technology by farmers. Resource allocation plays a significant intermediary role in the impact of farmland ownership confirmation on farmers' adoption of conservation tillage techniques. The study found that farmers with different family situations have different levels of adoption of conservation tillage technology after farmland ownership is confirmed. Farmers with higher education levels, smaller arable land areas, and less arable land are more likely to adopt those techniques. This study shows that the new round of farmland title confirmation has had a positive effect on the spread and application of agricultural technology in rural areas.

Discussion: Further improving the farmland ownership policy can not only improve the efficiency of agricultural production, but also promote the sustainable development of agriculture, which is of great research significance for guaranteeing national food security.

KEYWORDS

farmland ownership confirmation, conservation tillage, straw retention, PSM, Yellow River Basin

1 Introduction

In recent years, China's agriculture has gradually shifted from increasing production to improving quality. Being the basis of agricultural production, the quality of cultivated land is not only related to the sustainability of agricultural development but also ensures China's food security. The protection of cultivated land quality is the key focus of the document issued by the Central People's Government of the People's Republic of China, with special plans, such as the National Agricultural Sustainable Development Plan (2015–2030), issued to promote the improvement of cultivated land quality. However, due to the excessive use of chemical fertilisers and pesticides, the geological quantity of cultivated land in China has decreased significantly (Karimi et al., 2023). The implementation of conservation tillage technology can protect wild animals and plants, improve soil tillability, increase soil organic matter, retain water in the soil, improve water quality, and purify the air and other environmentally friendly characteristics (Mellon Bedi et al., 2022; Cooper et al., 2020; Aryal et al., 2021). This is an effective measure to protect cultivated land and improve its quality.

Conservation tillage technology is a modern farming technology system emphasising covering the surface with straw, no low-tillage sowing, deep loosening, and comprehensive control of diseases, insect pests, and weeds. Conservation tillage technology is continuously developing. After the 1980s, a complete technical model emerged, which has been gradually implemented in various countries (Zhang et al., 2021). Compared with the previous tillage method, the conservation tillage technology focuses on protecting the cultivated land according to local conditions. In the farming process, the straw of corn, rice, and wheat crops is directly returned to the field through no-tillage and reduced tillage methods increasing soil fertility and improving the quality of cultivated land (Gebhardt et al., 1985; Liu et al., 2019). With the continuous progress of agricultural technology and the increasing protection of cultivated land quality, by 2018, conservation tillage technology was utilised for 124 million mu of cultivated land, accounting for 6.13% of the total cultivated land area in China. However, the implementation of conservation tillage in China is affected by factors, such as land fragmentation, business scale, and farmers' cognition. Its adoption is in its infancy, far below the 40–70% levels in developed countries, such as the United States and Australia.

Although China introduced the conservation tillage technology in the 1960s and began to conduct experiments and demonstrations, its current adoption in rural areas remains poor. Domestic and foreign scholars have mainly analysed the factors influencing farmers' choice of conservation tillage technology from the aspects of farming type, family management characteristics, information acquisition, technology cognition, economic returns, and government regulation (Crystal-Ornelas et al., 2021; Ricart et al., 2023; Damalas, 2021). For instance, some scholars administered a questionnaire survey to farmers in the Shandong, Hubei, Hebei, and Anhui Provinces, finding that middle-aged farmers often regard agriculture as their main occupation and are more willing to adopt conservation tillage techniques to improve long-term land benefits (Zhang et al., 2020). Other scholars showed that holding agricultural technology exhibitions and encouraging information exchange among farmers are key factors for farmers to choose conservation tillage techniques (Damba et al., 2020).

Property rights protection of cultivated land is the basis of its quality assurance. According to classical institutional economics, the reform of modern agricultural land property rights clarifies those rights, protects agricultural land rights and interests, and increases the holding period, which can effectively stimulate farmers' investment in and protection of farmland (Qian et al., 2020). Therefore, land registration and certification are closely related to farmers' adopting conservation farming technologies. Some scholars have reported the impact of land registration and certification on the protection of farmland quality. Mogesetal's field survey in Ethiopia found that farmers with land property rights had a higher awareness of soil and water conservation technology (Moges and Taye, 2017). However, in some countries or regions, land registration and certification have no significant impact on farmers' cultivated land quality protection behaviour. For instance, two scholars conducted a survey of the middle and lower reaches of the Yangtze River and found that the impact of land registration and certification on farmers' adoption of straw-returning technology was not significant (Zhou and Wang, 2019). A rural areas study in the highlands of Peru revealed that land registration and certification had a limited impact on the investment of local farmers and protection of cultivated land (Navarro-Castañeda et al., 2021). Moreover, the scholar argued that the impact of the improvement of tenure security on agricultural productive investment of farmers, such as soil improvement, was uncertain (Jiao, 2018). Since 2013, a new round of confirmation, registration, and certification of rural land contractual management rights has been carried out in China. At present, there is no conclusive evidence of the impact of the new round of land registration and certification on farmers' production and cultivated land protection behaviour.

In summary, previous research has examined factors influencing farmers' adoption of the conservation tillage technology, suggesting areas that require improvement. First, research has focused on the impact of land registration and certification in terms of the economic benefits for farmers (Gao X. et al., 2021), whereas few studies have examined whether land registration and certification affect farmers' adoption of conservation tillage techniques. This study focused on the ecological effects of land registration and certification, investigating the impact of the new round of land registration and certification on farmers' adoption of straw-returning technology. Second, since the reform and its economic opening up, China's policies and society have undergone drastic changes, and the behavioural intentions of farmers are very different. Therefore, this study evaluates the impact of land registration and certification on farmers' adoption of conservation tillage techniques, before analysing further whether land registration and certification results in differences in the adoption of such techniques by farmers with different household conditions. Regarding the adoption of the conservation tillage technology, compared with the single-temporal agricultural technology, the improvement of the quality of farming due to returning straw to the field is observed in subsequent periods, meaning that farmers cannot immediately acquire the benefits. Therefore, concerns could arise when selecting inter-temporal agricultural technology. This study investigated straw retention to aid the future development of the research system of farmland quality protection. Moreover, previous studies failed to solve the endogenous problems that may exist in farmers' adoption of conservation tillage technology, and the accuracy and reliability of the estimated results were low. This study used the propensity score matching method, which can effectively reduce sample selection error and endogenous problems, to produce externally effective research results.

Our study complements earlier research on the following three points: First, most current research on the confirmation of farmland rights does not pay attention to the time when farmers' farmland rights are confirmed. After 2013, China conducted a new round of farmland rights confirmation which has a larger scope, while farmers are also issued land title confirmation certificates, which can serve as a stronger motivation for land protection. Accordingly, this paper examines the impact of farmland title confirmation on farmers' adoption of conservation tillage techniques, increasing the accuracy of current research. Second, with the economic and social development, differences have arisen in the family conditions of farmers. This study explores the similarities and differences in the adoption of conservation tillage techniques by farmers with different family conditions after the confirmation of farmland rights. Finally, straw-returning technology is a kind of conservation tillage technology for which farmers will have special concerns, as it improves the quality of cultivated land slowly. Although returning straw to fields can effectively increase soil organic matter content and thereby improve the soil, it is a long-term process. Farmers cannot significantly improve the quality of planted crops quickly after using this technology, and the yield of economic benefits from such cultivated land will take longer. The adoption of straw retention can therefore serve to better examine whether farmers care more about the land once their farmland title is confirmed by choosing this technology to improve the quality of cultivated land.

2 Theoretical analysis and research hypothesis

2.1 Impact of land registration and certification on farmers' adoption of conservation farming techniques: a combined effect

The essence of land registration and certification is that farmland property rights are formally recognised by law, which legally guarantees the land rights. When farmland is not confirmed, the stability of land rights is insufficient, farmers lack awareness of farmland protection and tend to perform predatory management, leading to low adoption of conservation tillage techniques (Wang et al., 2020). The farmland ownership confirmation can stimulate farmers' investment in farmland and increase the amount of organic fertiliser they use (Huang and Luo, 2020). Agricultural land titling has been widely promoted in many countries and regions, such as Ethiopia, the UK, Russia, and Peru. Scholars have found that when farmers perceive their farmland property rights as unstable, they reduce agricultural investments, such as land levelling, to improve the quality of cultivated land (Ma et al., 2015). Others have argued that the effect of increased security of land rights on farmers' productive agricultural investments, such as soil improvement, is uncertain. However, some countries and regions have not achieved the expected results of land registration and certification (Jiao, 2018). For instance, a study of random villages in Zambia, where land registration and certification were carried out, found that the process did not lead to increased investment and conservation of land (Huntington and Shenoy, 2021). However, more studies have shown that land registration and certification can reduce the instability of land rights and enhance farmers' protection of the ecological quality of agricultural land (Qian et al., 2021), help farmers focus on soil quality improvement (Navarro-Castañeda et al., 2021), motivate them to apply more organic fertilisers (Zhou et al., 2022), reduce the application of chemical fertilisers and pesticides (Zheng et al., 2023) and improve the selection of new agricultural technologies (Wen et al., 2020).

Institutional economics suggest that land registration and certification give farmers legal recognition of their land property rights, which can fully protect their land rights and interests and stimulate farmers to change their predatory production methods and choose ones that cause less damage to cultivated land (Qian et al., 2019). Clear and stable land property rights prevent farmers from concerns about losing their land and motivate them to protect it. Therefore, once the land rights are confirmed, farmers feel confident in investing in and protecting the land and improving the quality of farmland (Gao X. W. et al., 2021). However, from the perspective of individual farmers, farmland titling increased their land tenure stability expectations. Studies have demonstrated that farmland titling significantly increases farmers' land tenure stability expectations (Qin et al., 2020) and promotes farmers' arable land quality conservation behaviour.

Based on this, we proposed the following hypothesis:

> *H1*: The new round of land registration and certification has a positive impact on farmers' adoption of conservation tillage techniques.
>
> *H2*: The new round of farmland rights confirmation has a positive impact on farmers' adoption of conservation tillage techniques by changing farmers' allocation of farmland resources.

2.2 The impact of farmland titling on farmers' adoption of conservation farming techniques: a heterogeneous effect

In actual farming operations, the impact of land registration and certification on farmers' adoption of conservation tillage techniques can differ, usually due to differences in farmers' personal factors and family conditions (Wang et al., 2021). Farmers' adoption of conservation tillage techniques is often affected by factors, including farmers' own education level, the degree of fragmentation of the cultivated land they own, and the scale of crop planting (Ruzzante et al., 2021; Theis et al., 2018). Therefore, the adoption of conservation tillage technologies after land registration and certification is likely to differ between farmers.

More educated farmers have a better understanding of property rights, can confidently invest in their farmland after registration and certification, and understand the need for ecological protection of their farmland. Farmers tend to adopt new technologies considering profit maximisation. Finely fragmented farmland could negatively impact output (Sun et al., 2018), increasing labour time and costs, while also not being conducive to farmers' adoption of conservation tillage technologies after land registration and certification. Regarding arable land area, large-scale farmers already have a high adoption rate of conservation tillage technology for gaining the scale effect before farmland titling (Feng et al., 2018). Small-scale farmers take more care of their farmland and are willing to adopt quality conservation measures and increase adoption of conservation tillage technology based on long-term awareness after land registration and certification, as their rights and interests are guaranteed and operational risks are reduced.

Therefore, we proposed the following hypothesis:

> *H3*: Families with educated heads of household are more inclined to adopt conservation tillage techniques after land ownership is confirmed.

H4: Families with small amounts of cultivated land are more inclined to adopt conservation tillage technology after confirming their farmland rights.

H5: Families with less cultivated land fragmentation are more inclined to adopt conservation tillage techniques after confirming their land ownership.

This study constructed a theoretical analysis framework for the adoption of conservation tillage techniques by farmers on agricultural land titling (see Figure 1).

3 Materials and methods

3.1 Data sources and sample characteristics

This study used data from a questionnaire survey conducted by the School of Economics and Management of the Northwest Agriculture and Forestry University in August 2020. The survey covered the Yellow River Basin in the six provinces of Qinghai, Ningxia, Shanxi, Shaanxi, and Inner Mongolia (Figure 2). Using a combination of random sampling and stratified sampling, the survey randomly selected 13 counties based on economic development status and arable land, with three townships (towns) per county randomly selected for good, medium, and poor economic development, and three administrative villages per township randomly selected for good, medium, and poor economic development. The main contents of the questionnaire included: basic information on farmer' households, household assets, household income and expenditure, agricultural production and operation, and village rules. The survey data were collected via questionnaires by investigators who interacted one-on-one with farmers. A total of 2,362 questionnaires were obtained. As this study focused on the straw-handling methods of cereal and oil crop growers, we screened samples that did not grow straw crops, samples with inconsistent information, and samples with missing key information. Finally, 830 valid samples were obtained after screening and sorting.

The basic characteristics of the interviewed farmers are shown in Table 1. Most participants were older, with 71.54% of them being over 50 years old. Moreover, education level was generally low, with 85.36% of the farmers having a junior high school or lower education. The overall health condition was high, with 72.77% of the farmers in good health. The majority (59.88%) of the family farming area was concentrated in less than 15 mu. The total household income was less than 60,000 yuan for 65.3% of the participants. The basic characteristics of the sample farmers were in line with the real situation of China's rural areas at this stage and could be considered representative.

3.2 Variable selection

(1) Explained variables. We selected straw retention to represent conservation tillage technology. Straw retention was defined as the behaviour of farmers who use the straw return technology when handling straw during the grain growth process.
(2) Key explanatory variables: Agricultural land confirmation rights. The farmland ownership confirmation directly affects the protection of farmers' land rights and interests and behaviour towards farmland governance (Li, 2018; Ye et al., 2018). We used 2013 as the starting point of the new round of land registration and certification.
(3) Mediating variables: Resource allocation. Resource allocation was used as a mediating variable and was defined as the amount of labour input per acre.
(4) Control variables. Referring to existing studies (Wen et al., 2020; Zheng et al., 2023; Hasan et al., 2023), we introduced three control variables: individual, family, and regional characteristics of household heads. Individual characteristics included the age, education level, and health status of the household head. Household characteristics comprised the presence of village cadres among relatives and friends, area of cultivated land, number of cultivated plots, amount of non-farm employment, and total household income. Regional characteristics were the distance from the residence to the road, technical support, industrial organisation, credit policy, and government regulation. Table 2 presents the definitions and descriptions of each variable.

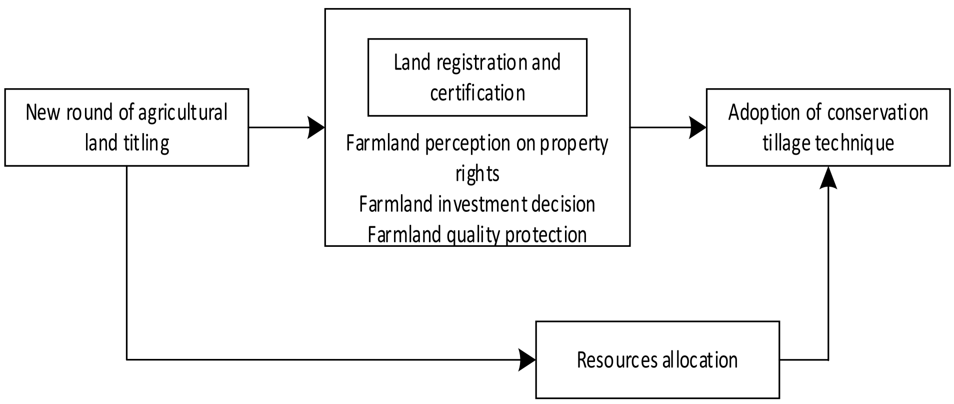

FIGURE 1
Logical framework.

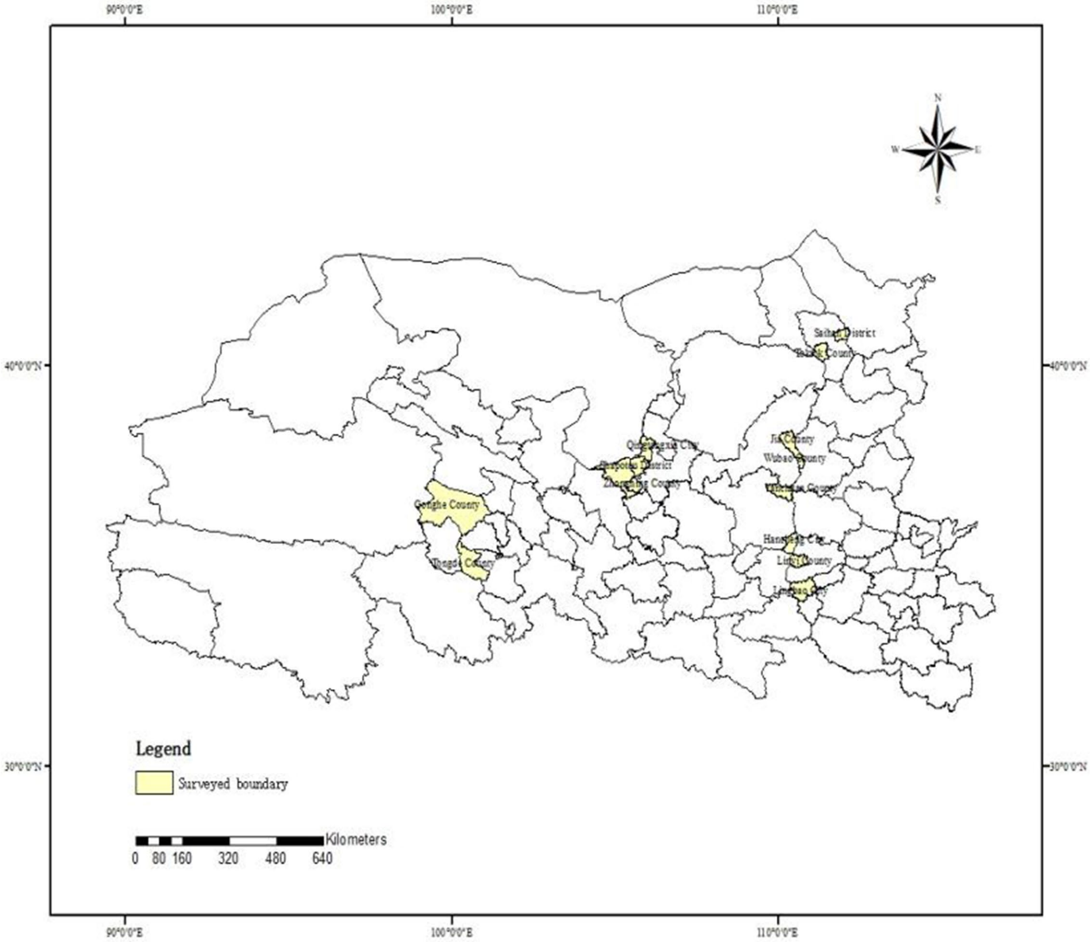

FIGURE 2
Distribution of the 6 focus provinces in China.

3.3 Model setting

To investigate the impact of the new round of land registration and certification on farmers' adoption of conservation farming techniques, we simultaneously compared the impact of titling on the adoption of those techniques by the same farmers. As farmland can only be in a confirmed or unconfirmed state, data from both states cannot be observed at the same time, which creates a problem of missing data. Therefore, this study used the Propensity Score Matching (PSM) method based on a counterfactual framework to estimate the factors influencing farmers' adoption of conservation tillage technologies and compared the impact of titled versus un-titled farmland and the new round of land registration and certification on farmers' adoption of conservation tillage technologies by using the average treatment effect in the propensity score matching method. Specifically, we used appropriate control variables to match a characteristic-balanced unconfirmed household for each confirmed household to ensure that the two sample households were as balanced as possible. The propensity score value of each sample farmer was estimated, and the likelihood of land registration and certification of farm households was estimated using a binary logit regression, as shown in Equation 1.

$$P(Xi) = P(D_i = 1|X_i) \tag{1}$$

Then, we used the propensity score matching method to analyse the data before matching each farmland-accredited household with balanced characteristics according to the propensity score and conducting a balance test between the two groups to ensure accuracy. The average treatment effect of farmland titling on the adoption of conservation farming technologies was obtained by calculating the difference in the adoption of conservation farming technologies between the treatment and control groups, as shown in Equation 2.

$$ATT = E(y_{1i}|D_i = 1) - E(y_{0i}|D_i = 1) \tag{2}$$

Where $D_i = \{0, 1\}$ denotes whether the farmland is confirmed, y_i represents whether farmers adopt conservation tillage techniques, y_{1i} denotes whether farmers who have confirmed farmland adopt conservation tillage techniques, and y_{0i} denotes whether farmers who have not confirmed farmland adopt conservation tillage techniques. To ensure the validity of the sample and the robustness of the matching results, multiple matching methods were used. Kernel (using the

TABLE 1 Sample characteristics.

Characteristics	Classification	Number of samples	Percentage/%	Characteristics	Classification	Number of samples	Percentage/%
Gender	Male	789	95.06%	Health status	Unhealthy	104	12.53%
	Female	29	3.49%		Fair	122	14.70%
Age	40 years old and below	66	7.95%		Healthy	604	72.77%
	(40, 50)	171	20.60%	Arable land area	5 acres and below	144	17.35%
	(50, 60)	256	30.84%		(5, 10)	228	27.47%
	60 years old and above	337	40.60%		(10, 15)	125	15.06%
Years of education	6 years and below	359	43.25%		More than 15 acres	333	40.12%
	(6, 9)	346	41.69%	Total household income	30,000 yuan and below	351	42.29%
	(9, 12)	111	13.37%		(3, 6)	191	23.01%
	More than 12 years	14	1.69%		60,000 yuan or more	288	34.70%

default kernel function with bandwidth), k-nearest neighbour (where k = 4), and radius matching (where $\mathcal{E} = 0.01$) were selected to estimate the average treatment effect.

4 Results and discussion

4.1 Equation estimation for land registration and certification

Although the new round of land confirmation, registration, and certification is a policy arrangement led by the state, land registration and certification are not completely random (Chen et al., 2018). Promoting land registration and certification usually begins with the normal farmers' families and testing it out on a pilot basis before gradually extending the scope. This means that the farmland ownership confirmation is not random. The results of the logit equation estimation showed that the propensity score of land registration and certification, age of the household head, education level, and degree of cultivated land fragmentation had significant effects on land registration and certification. The age variable was significant at the 1% level for land registration and certification, suggesting that older farmers were more likely to focus on security issues and, therefore, valued the security that comes with land property rights (Sun et al., 2023). Literacy was significant at the 1% level for land registration and certification, most likely because farmers with higher educational levels had a clearer understanding of property rights. The degree of cultivated land fragmentation was significant at the 1% level. Under the premise of voluntary farmer participation, certification could consolidate scattered plots and reduce the degree of cultivated land fragmentation; therefore, farmers with a high degree of cultivated land fragmentation were more willing to have their farmland confirmed to facilitate agricultural production and operation (Table 3).

4.2 Common support domain and balance tests

To ensure accuracy in the propensity score matching, samples outside the range of values common to the treatment and control groups were excluded. However, excluding a large number of samples was considered a match failure. Thus, it was important to choose the appropriate matching method and cover as much of the sample as possible within the range of the common support domain. To examine the common support domain of treatment and control group farmers, probability density plots of propensity scores (Treated and Untreated, respectively) before and after matching are presented separately (Figure 3). The kernel density functions of the samples in the treatment and control groups converged after matching, indicating that a better matching effect was achieved.

To improve the reliability of the matching results, Table 4 presents the variance changes in the control variables after the balance test. The standard bias for most variables was substantially reduced after matching. The standard bias of the control variables after matching was <10%. In particular, the variables of age of the household head, education level, and the degree of cultivated land

TABLE 2 Definition and descriptive statistics of variables.

Variable	Variable description	Mean	Standard deviation
Explained variables			
Conservation tillage technology adoption behaviour	Using straw return technology; 1 = yes, 0 = no	0.481	0.500
Core explanatory variables			
land registration and certification	Whether the agricultural land is confirmed; 1 = yes; 0 = n	0.911	0.285
Intermediary variables			
Resource allocation	Labour input per acre	0.19	0.256
Control variables			
Age of household head	Actual age	57.018	10.888
Education level of the household head	Actual years of schooling	6.830	3.681
Health status of household head	1 = unhealthy (having a disease); 2 = general; 3 = healthy	2.602	0.701
Non-farm employment	Actual non-farm employment	0.688	0.879
Social interaction	Presence of village cadres among relatives and friends	0.212	0.409
Arable land area	Acres of farmland area of a farm household (1 after logarithmic processing)	27.554	114.233
Degree of cultivated land fragmentation	Plots of farmland operated by households in 2019: higher number of blocks indicates higher degree of fragmentation	1.911	0.606
Household income level	Total annual household income (Yuan)	61,185.5	104,383.3
Distance from residence to road	Distance between a household's residence in a village and nearest road at or above the county level (Li)	2.172	8.082
Technical support	Number of contacts with agricultural technicians in 2019	1.664	10.997
Industrial organisation	Belonging to an industrial organisation; 1 = yes; 0 = no	0.051	0.219
Government regulation	Government supervision of agricultural product cultivation; 1 = yes; 0 = no	0.517	0.500

TABLE 3 Logit estimates on the propensity scores.

Variable	Coefficient	S.E.	Z-value
Age of household head	0.044***	0.012	3.550
Education level of household head	0.112***	0.036	3.120
Health status of household head	−0.07	0.208	−0.330
Non-agricultural employment	−0.226	0.138	−1.630
Social Interaction	−0.012	0.329	−0.020
Arable land area	−0.001	0.003	−0.350
Degree of cultivated land fragmentation	0.609***	0.218	2.800
Household income level	0	0	1.570
Distance from residence to road	0.006	0.026	0.250
Technical support	0.004	0.021	0.190
Industrial organisation	−0.672	0.531	−1.250
Government regulation	−0.378	0.263	−1.410
Log likelihood	−231.3648		
LR chi2	36.24		
Pseudo R2	0.0726		

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

fragmentation were significant before matching, and the t-values of all control variables were less than the critical value of 1.96 after matching. Therefore, the covariates selected for matching were suitable, and the differences in the characteristic variables between the two groups were eliminated. Therefore, the sample matching passed the balance test.

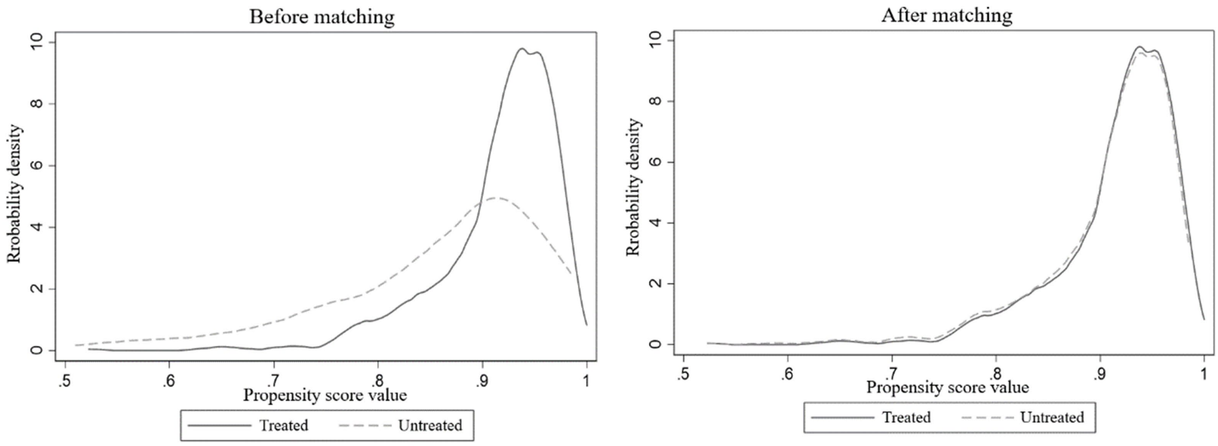

FIGURE 3
Probability density of the propensity scores of farmers with land registration and certification before and after kernel matching.

TABLE 4 Balance tests of propensity score matching.

Variable	Matching type	Treated	Untreated	Standard bias (%)	Decrease in absolute value of standard error (%)	t-value
Age of household head	Before matching	57.368	53.446	35	74.8	2.97***
	After matching	57.367	56.396	8.8		1.74*
Education level of household head	Before matching	6.927	5.838	27.5	84.8	2.44**
	After matching	6.877	6.697	4.2		0.82
Health status of household head	Before matching	2.594	2.689	−14	73.9	−1.12
	After matching	2.589	2.617	−3.6		−0.67
Non-agricultural employment	Before matching	0.673	0.838	−18.2	81.5	−1.54
	After matching	0.677	0.708	−3.4		−0.68
Social Interaction	Before matching	0.214	0.189	6.2	−8.4	0.50
	After matching	0.209	0.184	6.8		1.32
Arable land area	Before matching	27.986	23.136	5.1	51.8	0.35
	After matching	23.729	25.476	−2.5		−0.86
Degree of cultivated land fragmentation	Before matching	1.930	1.718	30.5	90.8	2.89***
	After matching	1.920	1.936	−2.8		−0.53
Household income level	Before matching	62,186	50,961	13	95.4	0.88
	After matching	56,030	55,771	0.6		0.17
Distance from residence to road	Before matching	2.207	1.815	5.5	12.1	0.40
	After matching	1.961	1.634	4.8		1.39
Technical support	Before matching	1.685	1.446	2.9	10.8	0.18
	After matching	1.666	1.456	2.6		0.50
Industrial organisation	Before matching	0.049	0.068	−7.9	3.6	−0.70
	After matching	0.048	0.063	−7.6		−1.49
Government regulation	Before matching	0.509	0.595	−17.2	79.0	−1.40
	After matching	0.512	0.496	3.6		0.69

These results were obtained with kernel matching (using the default kernel function with a bandwidth). The results of k-nearest neighbour matching (k = 4), radius calliper matching, local linear regression matching, and martingale matching were similar to these results. Regarding the common range of values, 819 samples were matched in 830 groups, and 11 groups were matched outside the common range of values.

4.3 Analysis of the impact of land registration and certification on farmers' adoption of conservation tillage techniques

As shown in Table 5, the mean treatment effects of the impact of land registration and certification on farmers' adoption of conservation tillage techniques were obtained after applying kernel, k-nearest neighbour (k = 4), radius calliper, local linear regression, and martingale matching. These effects were significant at the 5% level for all five matching methods, four of which had significant treatment effects at the 1% level. Assuming that farmers did not participate in land registration and certification, the likelihood of adopting conservation tillage techniques ranged from 27.9 to 33.9%. Farmers in the treatment group were 49.1–49.3% more likely to adopt conservation tillage techniques, with a 15.2–21.4% increase in ATT values and an average treatment effect mean of 18.58%. Land registration and certification had a significant positive effect on the adoption of conservation tillage techniques by farmers (Zhang and Zhang, 2023). One possible reason could be that clear and stable land ownership stimulated farmers to take better care of their farmland and be willing to invest in it, thus influencing them to adopt conservation tillage techniques.

Therefore, H1 was confirmed.

4.4 Robustness tests

The PSM method can only deal with the sample selection bias caused by observable variables; unobservable factors pose the problem of hidden bias. To test the robustness of the research results, this study adopted a double robust model to analyse the effect of land registration and certification on farmers' adoption of conservation tillage techniques. We used regression-adjusted, inverse probability weighting, as well as inverse probability weighting regression-adjusted empirical methods for robustness testing.

Table 6 illustrates the ATT based on RA, IPW, and IPWRA. The estimation results of the three regression adjustment methods, inverse probability weighting, and inverse probability weighting regression adjustment were relatively similar. The new round of land registration and certification significantly increased farmers' adoption of conservation tillage techniques. Regarding ATT values, the mean treatment effects of the three methods were 17.6, 23.6, and 19.6%, respectively, with a mean treatment effect of 20.3%; all were significant at the 1% level. The PSM estimation results were robust; thus, the findings of this study were valid.

4.5 Mesomeric effect of land registration and certification

This study demonstrated that the new round of land registration and certification had a positive impact on farmers' adoption of conservation tillage techniques. However, the pathway of how land registration and certification specifically affected the adoption of those techniques requires further investigation. The above analysis argued that land registration and certification affect farmers' adoption of conservation tillage technologies mainly through resource allocation. Drawing on previous research (Wen et al., 2022), the mesomeric effect was tested using the test path.

A bias-corrected non-parametric percentile bootstrap approach was adopted to perform robustness tests on the mesomeric effect of resource allocation. If the confidence interval did not contain 0, the mesomeric effect was present and significant. As shown in Table 7, the benchmark test results were robust. In particular, the 95% confidence interval of resource allocation did not contain 0, indicating that the mesomeric effect of resource allocation was significant. In addition, the ratio of the mesomeric effect to the total effect was 17.61%, implying that approximately 17.61% of land registration and certification were achieved through the mesomeric effect of resource allocation on technology adoption. This demonstrated the presence of a mesomeric path of land registration and certification-resource allocation to conservation tillage technology adoption.

Therefore, H2 was confirmed.

4.6 Impact of land registration and certification on the adoption of conservation tillage techniques by farmers with different capital endowments

The PSM method was used to measure the effect of land registration and certification on farmers' adoption of conservation

TABLE 5 Average treatment effect of farmland ownership confirmation on farmers adopting conservation tillage technology.

Matching method	Treated	Untreated	ATT	T-value
Kernel	0.492	0.316	0.175*** (0.063)	2.58
K-nearest neighbour (k = 4)	0.493	0.301	0.192*** (0.068)	2.65
Radius calliper	0.493	0.296	0.197*** (0.061)	2.75
Local linear regression	0.492	0.279	0.213** (0.057)	2.47
Martingale	0.491	0.339	0.152*** (0.057)	2.58

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively, with standard errors in parentheses.

TABLE 6 Average treatment effect of land registration and certification on farmers adopting conservation tillage technology in double robust model.

Variable	ATT		
Land registration and certification	RA	IPW	IPWRA
	0.176***(0.057)	0.236*** (0.057)	0.196*** (0.052)

*, **, and *** indicate significance at the 10, 5, and 1% levels, respectively, with standard errors in parentheses.

TABLE 7 Tests for mesomeric effect of resource allocation.

Intervening variable	Effect	Efficacy value	S.E.	95% confidence interval		Relative Effect Value
				Lower limit	Upper limit	
Resources allocation	Direct effect	0.117	0.013	0.001	0.227	17.61
	Indirect effects	0.025	0.062	0.003	0.055	

tillage techniques. Nevertheless, this impact only reflected the mean value of the change in ATT after land registration and certification. Differences in conservation tillage technology adoption among farmers with different capital endowments were not evident. As the effects of urbanisation and industrialisation gradually spread to the countryside, the differentiation of farm household groups widened. Following previous studies reporting divisions in farmers' education levels (Song et al., 2021; Yue et al., 2021), we distinguished the educational level of the household head into two categories: elementary school and below and junior high school and above. We distinguished the arable land area into two categories, as well: less than 10 mu and 10 mu and above. The degree of cultivated land fragmentation was grouped by mean value as the cut-off line. In addition, to further analyse the effect of land registration and certification on the adoption of conservation tillage techniques by farmers with different endowments, five matching methods were used to estimate the average treatment effect: kernel (using the default kernel function with bandwidth), k-nearest neighbour (where k = 4), radius (where $\mathcal{E}$ = 0.01), local linear regression, and martingale matching. The differences in the average treatment effects estimated by these five matching methods were small, indicating that the results of the propensity score matching were robust (Table 8).

(1) The results of the subgroup estimation based on the education level of the household head showed that in the lower education level subgroup, farmers' participation in land registration and certification had a positive effect on ATT; however, the results were not significant. Moreover, land registration and certification had a significant positive effect on the adoption of conservation tillage techniques among the subgroups with higher education of the household head (Avemegah et al., 2024). The farmers' probability of adopting conservation tillage techniques increased by 20.74% on average after land registration and certification. Thus, H3 was confirmed.
(2) The results of the subgroup estimation based on arable land area showed that land registration and certification positively influenced farmers' adoption of conservation tillage techniques in the subgroup with arable land areas above 10 acres; however, the results were not significant. Land registration and certification had a significant positive effect on the adoption of conservation tillage techniques among the subgroups with arable areas of 10 acres or less. The probability of farmers adopting conservation tillage techniques increased by an average of 15.76% after land registration and certification. Thus, H4 was confirmed.
(3) The results of group estimation based on the degree of cultivated land fragmentation showed that land registration and certification had a positive effect on farmers' adoption of conservation tillage techniques when the degree of cultivated land fragmentation was greater than the mean value. However, the results were not significant. Land registration and certification had a significantly positive effect on the adoption of conservation tillage techniques when the degree of cultivated land fragmentation was less than the mean value. The farmers' probability of adopting conservation tillage techniques increased by 25.42% on average after land registration and certification. Thus, H5 was confirmed.

5 Conclusion and policy implications

This research selected 830 sample data points from the Yellow River Basin and empirically tested the impact of the new round of land registration and certification on farmers' adoption of conservation tillage techniques using PSM. Our study found that the new round of farmland ownership confirmation has promoted the adoption of conservation tillage technology by encouraging farmers to increase the resource input in their farmlands, therefore improving its quality, especially among farmers whose land ownership has been confirmed. Moreover, land registration and certification influenced farmers' adoption of conservation tillage techniques through the mesomeric effect of resource allocation. Furthermore, the effect of the new round of land registration and certification on farmers' adoption of conservation tillage techniques could not be generalised, and its impact on farmers' adoption of conservation tillage techniques was heterogeneous, based on their individual family situation. Among farmers with confirmed farmland, the adoption was more pronounced among household heads with an education level of junior high school or above, as well as ones with cultivated land area below 10 mu, and ones without finely fragmented cultivated land.

These results suggest that the new round of land registration and certification secured farmers' land property rights legally, which alleviated farmers' concerns about the high risk, long lead time, and slow results of choosing conservation tillage techniques. Local governments should promote conservation tillage techniques by improving publicity and organising demonstrations to improve the quality of farmland and sustainable use of farmland resources. Moreover, to address the differences in endowments that already exist among farm households, conservation tillage techniques should be promoted and disseminated in a targeted manner. Therefore, demonstrations and dissemination in villages should strengthen the precise supply of information. Interventions should focus on farmers with higher education, smaller arable land areas, and less cultivated land fragmentation and guide them to choose conservation tillage techniques first, which would encourage other farmers to participate. Furthermore, the choice of conservation tillage technique has a positive effect on green agricultural production (Zhang et al., 2024). To increase the adoption of these techniques among farmers requires

TABLE 8 Average treatment effect of farmland ownership confirmation on the adoption of conservation tillage techniques by farmers with different capital endowments.

Variable	Project	Treated	Untreated	ATT
Education level of household head	Elementary school and below	0.432	0.338	0.094 (0.099)
		0.432	0.258	0.175 (0.115)
		0.434	0.272	0.162 (0.122)
		0.432	0.285	0.147 (0.125)
		0.438	0.429	0.009 (0.094)
	Junior high school and above	0.531	0.367	0.164 (0.111)
		0.53	0.329	0.201* (0.103)
		0.534	0.311	0.223* (0.117)
		0.531	0.32	0.210 (0.135)
		0.528	0.29	0.239*** (0.084)
Arable land area	10 acres and below	0.406	0.248	0.158* (0.085)
		0.406	0.207	0.199** (0.093)
		0.408	0.209	0.199** (0.099)
		0.406	0.225	0.181* (0.103)
		0.406	0.354	0.051 (0.081)
	More than 10 acres	0.569	0.476	0.093 (0.112)
		0.569	0.359	0.210* (0.125)
		0.564	0.359	0.205 (0.131)
		0.569	0.45	0.119 (0.138)
		0.554	0.417	0.137 (0.096)
Degree of cultivated land fragmentation	Less than or equal to the mean	0.547	0.281	0.266*** (0.088)
		0.547	0.285	0.262*** (0.089)
		0.536	0.285	0.251*** (0.092)
		0.547	0.275	0.272** (0.108)
		0.556	0.336	0.220*** (0.072)
	Larger than average	0.413	0.325	0.087 (0.158)
		0.413	0.263	0.150 (0.167)
		0.404	0.289	0.115 (0.173)
		0.413	0.257	0.156 (0.184)
		0.405	0.344	0.061 (0.141)

Standard errors are in parentheses.

not only creating a positive market circumstance to guarantee the economic effectiveness of green production farmers but also improving farmers' technical cognition. This would help them understand better that the adoption of technologies, such as straw turnover, can protect and enhance the quality of cultivated land after confirmation. This can provide inter-temporal economic benefits for better promotion of conservation tillage techniques.

6 Limitations and future research

The use of questionnaires to obtain primary data for farmers' self-reports may suffer from problems such as recall bias and hindsight bias. This study used questionnaires as the main method of obtaining primary data, and although it was able to effectively collect a large amount of self-reported information from farmers, the limitations of this method deserve to be explored in depth. It is recommended that subsequent studies incorporate more objective indicators in the evaluation process to make up for the shortcomings of the questionnaire survey and improve the accuracy of the study.

There are many types of conservation tillage techniques. This paper only examined whether farmers adopt the technology of returning straw to the field after farmland ownership confirmation. Whether the confirmation of agricultural land rights can also spur the adoption of different types of conservation tillage techniques with higher costs to farmers should be a direction for future research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZL: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. QY: Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

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