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The Impact and Driving Mechanism of the "Three Rights Separation" Reform on the Ecological Efficiency of Cultivated Land Use: A Case Study of China

Weijuan Li [1,2], Jinyong Guo [2,*] and Tian Xie [3]

[1] School of Economics and Management, Chinese and Law, Shandong Institute of Petroleum and Chemical Technology, Dongying 257061, China; 000301@sdipct.edu.cn
[2] School of Economics and Management, Jiangxi Agricultural University, Nanchang 330045, China
[3] School of Environment, Beijing Normal University, Beijing 100875, China; tianxie@bnu.edu.cn
* Correspondence: jinyongguo@jxau.edu.cn

Abstract

Balancing food security with ecological sustainability is a critical challenge for global agricultural development. This research explores how China's "three rights separation" reform influences the ecological efficiency of cultivated land use. This institutional innovation separates ownership, contract, and management rights to improve land resource allocation. Utilizing panel data from China spanning from 2005 to 2023, this study employs a super-efficiency SBM model to evaluate ecological efficiency, a continuous difference-in-differences (DID) framework to identify the causal effects of the reform, and a mediation effect model to explore the underlying transmission mechanisms. The results show that the "three rights separation" reform significantly improves the ecological efficiency of cultivated land use, with a regression coefficient of 0.632 that is statistically significant at the 1% level. The findings remain robust across multiple robustness tests. Mechanism analysis reveals distinct hierarchical transmission pathways through the promotion of non-agricultural labor transfer, the optimization of planting structure, and the advancement of agricultural technological progress. Among these pathways, agricultural technological progress emerges as the primary driver. Furthermore, heterogeneity analysis indicates that the positive impact of the reform is more pronounced in non-major grain-producing regions, as well as areas characterized by higher levels of mechanization and land transfer. These results suggest that further deepening land tenure reform is essential, with careful consideration of regional disparities and the mediating role of labor factors, land resource allocation, and technological progress.

Keywords: "three rights separation" reform; ecological efficiency of cultivated land use; continuous difference-in-differences model; mediating effect

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1. Introduction

As a core component of land resources, cultivated land is widely regarded as the "lifeblood of food production" and serves as the basis for achieving sustainable agriculture. However, efforts to increase food production have been accompanied by challenges in cultivated land utilization. Land degradation has emerged as a global challenge [1]. Attaching importance to the circular economy and environmental protection factors contributes greatly to the sustainable development of agriculture [2,3]. Balancing increasing food demand with resource and environmental constraints has therefore become a critical issue.

Improving the efficient utilization of cultivated land is essential for guaranteeing food security and agricultural sustainable development [4].

Sustained, high-intensity land use has enabled China to feed 22.15% of the global population while occupying only 7.61% of the world's cultivated land [5,6]. Despite continuous growth in grain output in recent years, significant regional disparities persist in staple food self-sufficiency [7]. In addition, the excessive application of chemical inputs along with the excessive consumption of water and soil resources has led to pronounced agricultural pollution [8]. According to the 2024 "China Ecological and Environmental Status Bulletin", agricultural non-point source emissions of total nitrogen and phosphorus accounted for 58.2% and 64.7%, respectively, increasing by 1.7 and 2.3 percentage points compared to 2020. The deterioration of soil quality and declining cultivated land productivity have gradually become prominent ecological concerns, posing substantial threats to food security and sustainable land use. In response to these issues, China has introduced a series of policies, emphasizing the protection of land. The Central Document No. 1 of 2026 emphasized that "production capacity, ecological protection, and increasing production and income should all be pursued simultaneously". The concept of ecological efficiency in cultivated land utilization aims to reconcile economic development with environmental protection through the optimized allocation of production factors. It serves as an important indicator of sustainable land management and rational utilization [9,10].

The optimization of agricultural property rights systems and the protection of cultivated land ecology have become important issues confronted by global agricultural development. A review of international land reform practices shows that some countries have carried out radical property rights restructuring centered on land privatization. While this approach has improved agricultural operational efficiency to a certain extent, it has also led to a series of problems, such as loss of land and infringement of the rights of small-scale farmers. China's "three rights separation" reform is a typical progressive model of agricultural property rights reform. By maintaining the inviolability of the collective ownership of land, the reform separates ownership, contract rights, and management rights while refining their respective powers and functions. Numerous studies have identified several determinants of cultivated land ecological efficiency, including labor force, natural resource endowments, and policy frameworks. At the labor level, factors such as rural labor transfer [11], population aging [12], and farmers' production behavior play important roles. At the resource and policy levels, key influences include comprehensive land consolidation [13], cultivated land operation scale [14], and land transfer systems [15]. Additional factors include natural conditions, urbanization, industrialization, education, and agricultural service systems [16–18]. Among them, land-related policies provide critical institutional guidance and represent a major determinant of ecological efficiency outcomes.

In 2014, China formally proposed the "three rights separation" system, which distinguishes ownership, contract right, and management right. In February 2026, China further emphasized the 30-year extension of the second-round rural land contracts and standardizing the transfer of land management rights. This reform is beneficial for resolving the longstanding issues related to ambiguous property rights and inefficient factor mobility. It is widely regarded as an important institutional innovation that provides a foundation for improving the ecological efficiency of farmland utilization. Despite its importance, how the "three rights separation" reform affects land utilization remains unknown. Existing studies on the effects of the reform in China have mainly focused on outcomes such as farmers' income [19], agricultural new-quality productive force [20], land transfer [21] and total factor productivity of grain [22]. In the broader context of agricultural land systems, related research has examined impacts on farmers' income [23], economic efficiency [24], output efficiency [25], agricultural pollution [26], and grain system resilience. For example,

the reform constitutes an important institutional measure for allocating land resources [27]. Research on land use has largely focused on efficiency measurement and the identification of influencing factors, with technological progress widely considered as the main driving force [28]. While these studies provide a useful foundation, empirical evidence on the direct relationship between the "three rights separation" reform and ecological efficiency remain limited, and the underlying mechanisms require further investigation. This gap highlights the need for further empirical research and motivates the present study.

From a theoretical perspective, the "three rights separation" reform aims to clarify the interrelationships among ownership, contract rights, and management rights, restructure the agricultural property rights system, and improve the efficiency of land factor allocation. In theory, this reform is expected to contribute to the improvement of the ecological efficiency of land use. However, existing literature has not systematically expounded the internal transmission mechanism, and there is insufficient research on the differential effects across different regions. Such research gaps highlight the necessity and value of this further study. Using panel data from 30 provinces in China from 2005 to 2023, this study employs the Super-SBM model, a continuous DID model, and a mediation effect model to explore the impact and driving mechanisms of "three rights separation" reform on cultivated land's ecological efficiency.

The contributions of the research are reflected in the following aspects: First, it incorporates land tenure reform and ecological efficiency into a unified analytical framework, thereby extending the theoretical understanding of the relationship between institutional land reform and sustainable land use. Second, it empirically investigates the mechanisms including non-agricultural labor transfer, planting structure, and technological progress, conceptualizing these pathways within a labor–land–technology framework. Third, it conducts heterogeneity analysis across levels of regional mechanization, land transfer intensity, and functional grain production areas to explore how the effects of land reform vary under different scenarios. This study verifies the actual effects of China's "three rights separation" reform, enriching the relevant theories on agricultural property rights and resource ecological efficiency. It provides practical references for promoting the ecological protection of cultivated land. The "three rights separation" is an efficient path to achieve scale operation and ecological improvement. As a gradual property rights reform model, the reform experience and effect verification in China can provide references for developing countries' economies dominated by small-scale agriculture, and regions facing acute land–human constraints.

2. Theoretical Analysis

2.1. Impact of the "Three Rights Separation" Reform on the Ecological Efficiency of Cultivated Land Use

Understanding the "three rights separation" reform from a theoretical perspective can clarify property rights and optimize resource allocation efficiency. Specifically, the reform delineates land ownership, contract rights, and management rights, thereby reducing transaction costs and risks, establishing an institutional foundation for cultivated land transfer and scale operation.

First, from the perspective of sustainable agriculture, greater stability in land contract rights strengthens farmers' incentives for long-term investment in land [29]. The issuance and certification of land contracts and management rights enhance tenure security, activate the potential of land as a production factor [30], and encourage farmers to adopt practices that support ecological protection. Second, from the perspective of factor allocation theory, the reform has liberated management rights and has facilitated the efficient flow of land resources. Excessive input of cultivated land production factors and redundancy of undesirable outputs constitute the core cause of the loss in cultivated land ecological utilization

efficiency. The "three rights separation" reform can effectively alleviate the misallocation of agricultural production factors including land, labor, capital, and technology. It guides fragmented and scattered cultivated land to concentrated order among high-efficiency operators, promotes the optimal restructuring of farmland resources and appropriate scale operation, and further facilitates the cultivation of new professional farmers. Professional farmers are more inclined to adopt environmentally friendly technologies, improving ecological efficiency.

However, due to the differences in resource endowments and production functional positioning among various regions, the effects of the "three rights separation" reform on ecological efficiency may exhibit regional heterogeneity.

Hypothesis 1: *The "three rights separation" reform improves the ecological efficiency of cultivated land use.*

Hypothesis 2: *The impact of the "three rights separation" reform is heterogeneous across regions.*

2.2. Impact Mechanisms of the "Three Rights Separation" Reform on the Ecological Efficiency of Cultivated Land Use

This study identifies non-agricultural transfer, the optimization of planting structure, and the advancement of agricultural technology as the transmission channels through which the "three rights separation" reform exerts an influence on the ecological efficiency of cultivated land use. First, non-agricultural transfer plays a fundamental role in the optimal allocation of cultivated land production factors. It reshapes the human–land ratio relationship, forces the circulation of fragmented cultivated land, and promotes the rematching of labor and land factors. By activating the land management right, the "three rights separation" reform facilitates the outflow of agricultural labor, thereby ameliorating the extensive farming mode dominated by small-scale farmers. Second, the optimization of planting structure constitutes a key reflection at the cultivated land utilization structure level. Land circulation promotes scaled and intensive farming, facilitating the adjustment of crop planting structure. With more farmers opting for grain cultivation, the mode of cultivated land use has been greatly optimized. Third, agricultural technological progress transforms the farming operation modes and factor input patterns of cultivated land, serving as the endogenous driving force for the transformation and upgrading of cultivated land utilization patterns. Stabilizing property rights expectations encourages relevant entities to adopt green agricultural technologies, thereby enhancing the efficiency of resource utilization. Three hierarchical pathways focus on labor endowment, land allocation, and agricultural technology separately. These three mechanisms reveal how the "three rights separation" reform acts on cultivated land.

2.2.1. Promoting Non-Agricultural Labor Transfer

Previous studies have argued that rural labor transfer may trigger land abandonment. Against the backdrop of China's "three rights separation reform", the transfer of land management rights has accelerated land scale management and fostered the development of new agricultural business entities. This process effectively mitigates the land idleness and abandonment caused by population outmigration. Non-agricultural transfer creates favorable conditions for large-scale cultivated land utilization and the optimal allocation of agricultural production factors. Under the traditional agricultural property rights system, farmers are reluctant to completely abandon agricultural production due to concerns about the instability of their contracting rights and the lack of security in land transfer income. As a result, they often adopt a dual-employment model of "part-time farming and part-time work", which leads to a tendency of loose management in the use of culti-

vated land. The "three rights separation" reform establishes the concurrent existence of ownership, contract rights, and management rights in rural land systems. Contract rights safeguard farmers' basic entitlements, thereby reducing the perceived risks of participating in non-agricultural employment. The orderly transfer of land management rights enables farmers to entrust their land to new agricultural business entities for unified management. This not only enables the realization of moderate-scale operations but also ensures that farmers "lose their land use but retain land rights". This reconfiguration of rights and capabilities alleviates constraints on labor mobility, promoting the reallocation of rural labor to non-agricultural sectors.

The reallocation of labor reduces agricultural labor redundancy and improves the precision and standardization of farming practices. Moreover, the transfer of rural labor promotes the formation of new agricultural business entities, which are better positioned to adopt agricultural machinery and specialized production methods. The substitution of traditional labor with modern technologies strengthens both scale efficiency and technical efficiency, thus improving ecological efficiency. With the continuous advancement of non-agricultural labor force transfer, a large number of scattered and fragmented farmlands have been concentrated through the process of land transfer into the hands of new agricultural business entities. This is conducive to achieving contiguous and large-scale agricultural land management. New agricultural business entities have stronger capital investment capabilities and a greater willingness to adopt technologies, which can promote agricultural production to shift from a "labor-intensive" model to a "high-efficiency and green" model. Labor migration to urban areas often increases household income and supports greater investment in education [31,32], which strengthens farmers' capacity and willingness to adopt new agricultural technologies. Therefore, "three rights separation" reform facilitates non-agricultural labor transfer, promotes the optimal allocation of factor inputs in cultivated land use, and further improves cultivated land ecological efficiency. This mechanism serves as a vital embodiment of factor allocation theory.

2.2.2. Optimizing Planting Structure

By clarifying property rights, the reform ensures that the contracted farmers can effectively use and transfer their land, laying the groundwork for large-scale operations. For small-scale farmers, income derived from the transfer of operating rights reduces reliance on short-term, high-yield production strategies. Given that grain crops are generally more compatible with mechanized production than cash crops, adjustments in planting structure toward grain cultivation can promote scale economies and achieve contiguous land management. This grain-oriented transformation enhances the specialization and division of labor, generating both economic and ecological benefits. Increased grain cultivation contributes to reduced agricultural pollution and improved ecological efficiency [33,34]. The trend towards grain-based planting structures has led to higher levels of mechanization, scale, and standardization in grain production, facilitating the unified adoption of technologies. That is, compared to the scattered cultivation of economic crops, grain crops are more capable of achieving reduced resource input, maximized utilization efficiency, and the widespread application of green technologies. Grain-oriented scale operations allow for "standardized green production" which is harder to achieve with fragmented cash-crop plots. Therefore, by promoting a transition toward grain-based planting structures, the "three rights separation" reform can enhance ecological efficiency of cultivated land use.

2.2.3. Promoting Agricultural Technological Progress

Technological progress is a key driving force for enhancing ecological efficiency [35]. The tripartite division of land ownership rights aims to stabilize contract rights, liberalize

management rights, and clarify ownership rights. This approach, at the institutional level, resolves the constraints of "not willing to invest in technology" and "not daring to invest in technology" under the traditional agricultural property rights structure, promoting the adoption and upgrading of agricultural technologies. This practice reduces environmental pollution resulting from one-sided short-term profit-seeking. It also creates an institutional foundation for agricultural technology research. By stabilizing expectations regarding land management through the liberalization of management rights, the reform reduces the risks associated with technological investment. This motivates agricultural operators to increase investments in agricultural technological innovation so as to promote technological progress.

The advancement of agricultural technology can enhance labor productivity and reduce resource waste. Technological progress promotes the transformation of cultivated land use methods towards more intensive and sustainable land use practices, as well as the expansion of large-scale and specialized agricultural production [36]. Under the scale operation model, agricultural business entities have an increased demand for agricultural machinery investment, which reduces the wasteful nature of manual operations. Moreover, scale operation significantly reduces the technical application cost per unit of land, achieving a positive linkage between agricultural machinery investment and the ecological efficiency of land use. Furthermore, the adoption of intelligent agricultural equipment enables the precise regulation of fertilizer and pesticide application during cultivation, thereby curbing undesirable outputs including agricultural carbon emissions. The adoption of modern agricultural technologies enhances production efficiency while mitigating environmental impacts, thereby contributing to improved ecological efficiency.

The three transmission pathways are not mutually independent but closely interconnected. From the empirical research perspective, this paper examines the mediating roles of labor non-agricultural transfer, planting structure optimization and agricultural technological progress separately. Independent testing for each channel can accurately identify the effect magnitude and influence the direction of every mechanism. On this basis, targeted policy recommendations can be proposed accordingly.

Hypothesis 3a: *The "three rights separation" reform improves the ecological efficiency of cultivated lands by promoting non-agricultural labor transfer.*

Hypothesis 3b: *The "three rights separation" reform improves the ecological efficiency of cultivated lands by optimizing planting structure.*

Hypothesis 3c: *The "three rights separation" reform improves the ecological efficiency of cultivated lands by promoting agricultural technological progress.*

Based on the above analysis, this paper constructs the mechanism framework of the "three rights separation" reform on the ecological efficiency of cultivated land use, as shown in Figure 1.

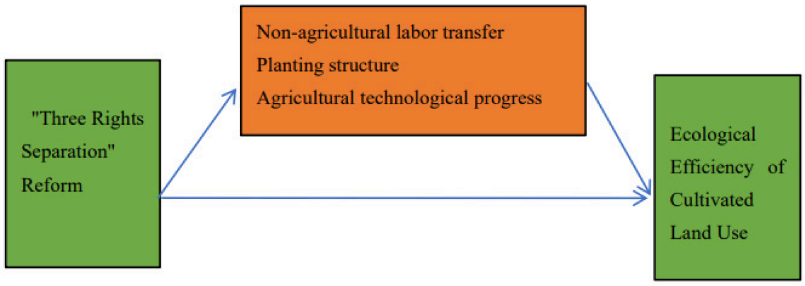


Figure 1. Mechanism of the "Three Rights Separation" Reform on the Ecological Efficiency of Cultivated Land Use.

3. Materials and Methods

3.1. Model Specification

3.1.1. Super Efficiency SBM Model

Accurate measurement of the dependent variable is essential. The Slacks-Based Measure (SBM) model, originally proposed by Tone [37], addresses the limitations of the traditional radial data envelopment analysis (DEA) models by explicitly incorporating slack variables into efficiency evaluation. Given this advantage, the SBM model has been widely applied in efficiency studies [38,39]. This method provides a more accurate and comprehensive approach. It can obtain a value greater than one from the frontier surface to further compare the decision-making units and has become a commonly used model for evaluating ecological efficiency.

3.1.2. Continuous Difference-in-Differences Model

The traditional difference-in-differences (DID) approach mainly determines the average treatment effect of a policy but does not account for variation in policy intensity. To address this limitation, the study adopts the continuous DID framework, treating the "three rights separation" reform as a quasi-natural experiment [40,41]. The intensity of policy implementation is measured by the number of land contract and management right certificates issued. The continuous measure is interacted with a policy dummy variable to construct the core explanatory variable. The model is specified as follows:

$$Land_{it} = \alpha + qLMC_{it} \times Post_t + \gamma Controls_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (1)$$

where $Land_{it}$ represents the ecological efficiency of cultivated land use in province i in year t; LMC_{it} is the number of land contract and management right certificates issued in province i in year t, capturing policy intensity; $Post_t$ is a dummy variable equal to 1 from 2014 onward and 0 otherwise; $LMC_{it} \times Post_t$ is the core explanatory variable; q represents the impact after the policy implementation; $Controls_{it}$ is the set of control variables; μ_i and λ_i represent the fixed effects of provinces and time, ε_{it} is the random disturbance term; α is the constant term; γ is the influence coefficient of the control variables.

3.1.3. Parallel Trend Test and Dynamic Effect Analysis of Policies

Before conducting the regression analysis using the continuous DID method, a parallel trend test is required. This test ensures that prior to the policy intervention, the provinces followed a consistent temporal trend without significant differences. Specifically, before the policy's implementation, the coefficient should not be significant; however, after implementation, this coefficient should gradually become significant and positive. To conduct the parallel trend test and dynamic effect analysis, this paper constructs the following model:

$$\begin{aligned} Land_{it} = a + \sum_{t=1}^{9} q_{pre}(LMC_{it} * D_{pre}) + q_{current}(LMC_{it} * D_{current}) + \\ \sum_{t=1}^{9} q_{post}(LMC_{it} * D_{post}) + \gamma Controls_{it} + \mu_i + \lambda_i + \varepsilon_{it} \end{aligned} \quad (2)$$

where D_{pre}, $D_{current}$, D_{post} represent the dummy variables for the years before, during, and after the implementation of the "three rights separation" reform (2005–2013, 2014, and 2015–2023), and q_{pre}, $q_{current}$, and q_{post} are the corresponding estimated coefficients for each period.

3.1.4. Mediating Effect Model

$$Land_{it} = \alpha + qLMC_{it} \times Post_t + \gamma Controls_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (3)$$

$$M_{it} = \alpha + q1LMC_{it} \times Post_t + \gamma Controls_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (4)$$

$$Land_{it} = c_0 + c_1LMC_{it} \times Post_t + c_2M_{it} + c_3Controls_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (5)$$

where M_{it} represents the mediating variables, including non-agricultural labor transfer, planting structure, and agricultural technological progress.

3.2. Variable Explanation

(1) Dependent Variable

The index system is constructed to measure the dependent variable [42], as shown in Table 1. The super-efficiency SBM model is implemented using the Dearun software (v3.2.0.5) to calculate ECL. Carbon emissions are estimated based on the carbon emission coefficients.

Table 1. Index System for Ecological Efficiency of Cultivated Land Use.

Primary Indicator	Secondary Indicator	Variable Description
Input	Land	Crop sown area
	Labor	Agricultural labor force
	Machinery	Total power of agricultural machinery
	Fertilizer	Quantity of chemical fertilizers applied (pure amount)
	Pesticide	Pesticides used
	Plastic Film	Agricultural plastic film used
	Irrigation	Effective irrigated area
Desired Output	Economic Output	Total agricultural output value
	Social Output	Total grain output
Undesired Output	Carbon Emissions	Total carbon emissions from cultivated land use

(2) Explanatory Variable

The "three rights separation" reform is proxied by the number of land contract and management right certificates issued in each province (unit: billions), which reflects the intensity of policy implementation. This variable interacts with the policy implementation dummy to construct the core explanatory variable [41].

(3) Mediating variables

① Non-agricultural labor transfer (NLT), measured as the ratio of employment in secondary and tertiary industries to total employment.

② Planting structure (PS), measured by the proportion of grain sown area to total crop sown area.

③ Agricultural technological progress (ATP), proxied by the number of agricultural patents authorized. Patent authorization is a crucial stage in the process of technological innovation from research and development to application. It indicates that a technical solution possesses novelty, creativity and practicality, and is one of the commonly used proxy variables in the academic field for measuring technological progress. Agricultural technological progress is calculated as the total number of regional patent authorizations multiplied by the share of agricultural output value in regional GDP.

(4) Control Variables

The following control variables are included:

① Disaster rate, measured as the ratio of affected crop area to total sown area.

② Fertilizer usage, measured as the logarithm of fertilizer application.

③ Agricultural development status, represented by the proportion of primary industry value-added in regional GDP.

④ Agricultural structure, indicated by the share of planting industry output value within the total output value of agriculture, forestry, animal husbandry, and fishery.

⑤ Rural population aging, measured by the rural dependency ratio.

⑥ Local economic development level, represented by the per capita gross domestic product (unit: ten thousand yuan).

⑦ Rural population size, measured as total rural population (unit: ten thousand people).

3.3. Data Sources and Descriptive Analysis

The dataset comprises panel data for 30 provinces in China spanning from 2005 to 2023. Data are obtained from the "China Statistical Yearbook", "China Agricultural Machinery Industry Yearbook", "China Rural Statistical Yearbook", "China Population and Employment Statistical Yearbook", "China Business Management Statistical Yearbook", "China Rural Policy and Reform Statistical Yearbook", and the EPS database. Missing values for individual indicators are filled via linear trend extrapolation. Table 2 provides detailed descriptive statistical results.

Table 2. Descriptive Statistical Analysis.

Variable	Variable Name	Mean	Standard Deviation
Dependent variable:	Ecological efficiency of cultivated land use	0.572	0.232
Independent variable	"Three rights separation" reform	0.036	0.050
Mediating variable:	Non-agricultural labor force transfer	0.667	0.149
	Planting structure	0.652	0.138
	Agricultural technological progress	0.314	0.432
Control variables:	Disaster rate	0.179	0.144
	Fertilizer usage	4.775	1.127
	Agricultural development status	10.47	5.687
	Agricultural structure	0.526	0.0860
	Rural population aging	0.182	0.078
	Local economic development level	5.081	3.311
	Rural population size	0.205	0.143

4. Results

4.1. Analysis of Baseline Regression Results

Columns (1) to (3) of Table 3 show the baseline regression results, with control variables introduced sequentially. The regression outcomes show that the coefficients of the "three rights separation" reform are steadily positive and significant at the 1% threshold in all models. In addition, the goodness-of-fit (R^2) increases as control variables are added, indicating improved model explanatory power and supporting the robustness of the results. After controlling for relevant variables, a one-unit increase in the intensity of the "three rights separation" reform is associated with a 0.632-unit increase in the ecological efficiency of cultivated land use. From a policy perspective, this empirical result validates the scientific nature of the "three rights separation" reform. It provides practical evidence for further intensifying reform efforts and expanding the coverage of land contract management right certification. The finding suggests that the "three rights separation" reform significantly enhanced ecological efficiency of cultivated land use, thereby supporting Hypothesis H1.

Table 3. Baseline Regression Results.

Variable	(1)	(2)	(3)
"Three Rights Separation" Reform	0.500 ***	0.685 ***	0.632 ***
	(2.81)	(3.63)	(2.92)

Table 3. *Cont.*

Variable	(1)	(2)	(3)
Disaster rate		−0.095 **	−0.105 **
		(−2.11)	(−2.27)
Fertilizer usage		−0.099 **	−0.022
		(−2.27)	(−0.46)
Agricultural development status		0.010 **	0.012 ***
		(2.44)	(2.91)
Agricultural structure		0.300 **	0.309 **
		(2.03)	(2.06)
Rural population aging			−0.301
			(−1.39)
Local economic development level			0.017 ***
			(2.91)
Rural population size			−0.340
			(−1.37)
Provincial fixed	YES	YES	YES
Year fixed	YES	YES	YES
Constant term	0.554 ***	0.779 ***	0.425
	(82.09)	(3.46)	(1.58)
N	570	570	570
R^2	0.824	0.834	0.838
F	7.898	5.982	5.062

t statistics in parentheses ** $p < 0.05$, *** $p < 0.01$. (The following table is the same).

4.2. Analysis of Robustness Test

4.2.1. Parallel Trend Test and Dynamic Effect Analysis

The validity of the DID approach depends on the parallel trend assumption. With 2014 designated as the policy launching year, the one year prior to reform adoption was selected as the benchmark group and excluded from regression to eliminate multicollinearity. Figure 2 presents the dynamic effects. The dotted lines represent the 95% confidence intervals. Before the introduction of the policy shock, all estimated coefficients fail to pass the significance test, with confidence intervals covering zero value, indicating no systematic differences across provinces before the reform. The above estimations conform to the prerequisite of parallel trends.

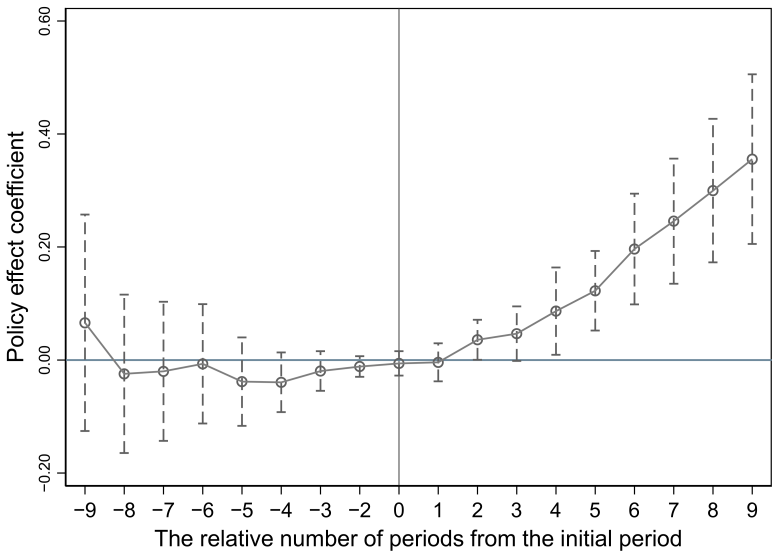


Figure 2. Parallel Trend Test.

The confidence intervals of the estimated coefficients no longer include zero after two years of the implementation of the policy, and the coefficients become significantly positive and exhibit an increasing trend over time. This pattern suggests that the "three rights separation" reform has a sustained and strengthening effect on land use. As the policy continues to be implemented, its impact becomes increasingly pronounced.

Based on the results reported in Table 4, the dynamic effects are further examined. Before the policy, the estimated coefficients are generally negative and not statistically significant, indicating the absence of systematic pre-policy effects. In the second year following implementation, the coefficients become significantly positive, suggesting a lagged policy effect, with the promoting impact becoming increasingly pronounced over time.

Table 4. Dynamic Impact.

Interaction Term	Estimated Coefficient	T-Value
pre_9	0.066	(0.70)
pre_8	−0.024	(−0.36)
pre_7	−0.020	(−0.33)
pre_6	−0.007	(−0.13)
pre_5	−0.038	(−1.00)
pre_4	−0.039	(−1.53)
pre_3	−0.020	(−1.14)
pre_2	−0.012	(−1.29)
current	−0.006	(−0.57)
post_1	−0.004	(−0.25)
post_2	0.036 **	(2.07)
post_3	0.047 *	(1.98)
post_4	0.087 **	(2.29)
post_5	0.123 ***	(3.56)
post_6	0.197 ***	(4.10)
post_7	0.246 ***	(4.54)
post_8	0.300 ***	(4.83)
post_9	0.355 ***	(4.84)

Note: Control variables and the years and provinces have all been controlled. *t* statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

This lagged effect may be attributed to several factors. First, there is an inherent delay between policy design and effective implementation. During 2014–2015, the reform was mainly carried out through local pilot projects and exploratory initiatives. In 2016, the "Opinions on Improving the System of Rural Land Ownership, Contracting Rights and Operating Rights Separation" was promulgated, clarifying the institutional framework, rights boundaries, and implementation pathways, thereby strengthening policy intensity and stabilizing expectations regarding management and contract rights. Second, the reconfiguration of production factors induced by the reform, including land transfer and the expansion of scale operations, requires time to take effect. Similarly, the diffusion and adoption of advanced agricultural technologies by operating entities occur gradually. These processes contribute to the observed lagged and strengthening impact of the "three rights separation" reform on the ecological efficiency of cultivated land use.

4.2.2. Analysis of Placebo Test

To rule out random confounding factors and verify result robustness, this study conducts a placebo test with 500 instances of random sampling. The results of the placebo test are shown in Figure 3. The vertical dashed line on the right side of the figure represents the true estimated coefficient of the baseline regression, while the horizontal dashed line indicates the 10% statistical significance level. The simulated coefficients follow an approximate

normal distribution centered around zero, and the vast majority of them fail to pass the significance test at the 10% level. Meanwhile, the main body of the coefficient distribution in the placebo test are far lower than the benchmark coefficient of 0.632. It is verified that the promotional effect of the "three rights separation" reform on cultivated land ecological efficiency stems from the policy itself rather than accidental random interference. The baseline regression findings are reliable and robust.

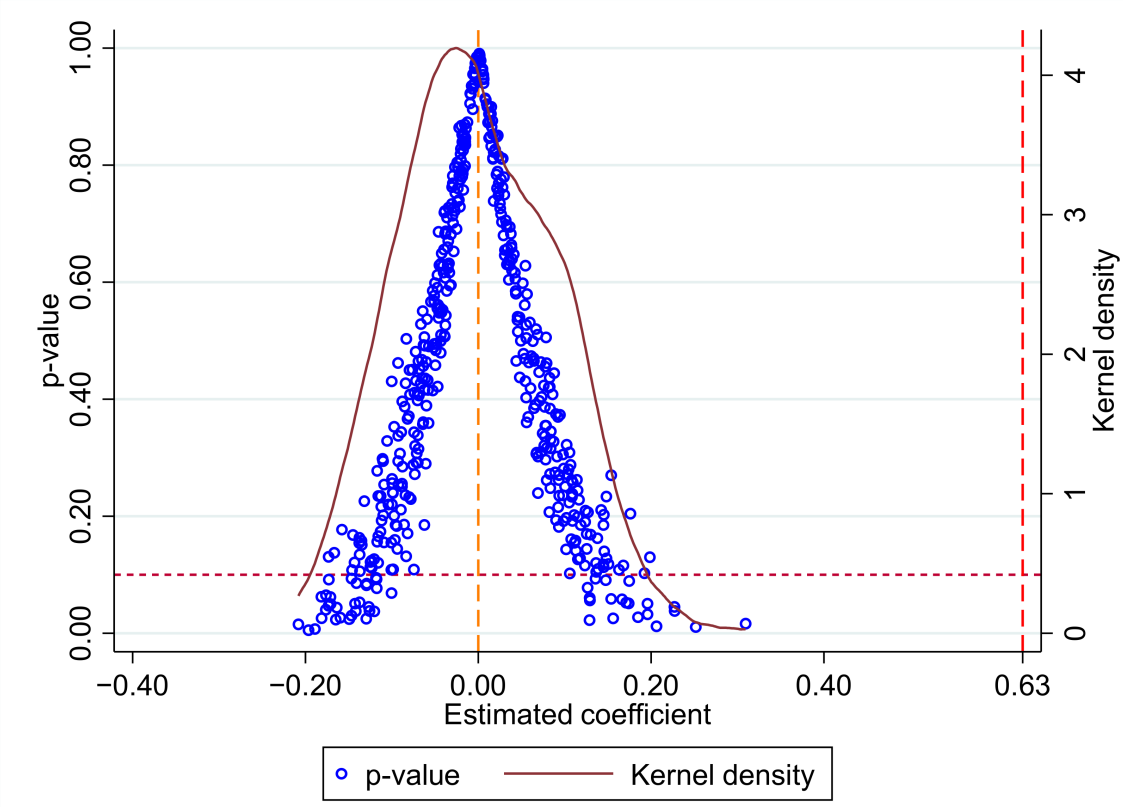


Figure 3. Placebo Test.

4.2.3. Other Robustness Tests

Additional tests were conducted to further validate the baseline results, as shown in Table 5.

Table 5. Results of Robustness test.

Variable	(1) Using 90% of the Samples	(2) Replacing Explanatory Variable	(3) Truncation 1%	(4) Adjusting Period	(5) Excluding Municipalities
"Three Rights Separation" Reform	0.696 ***	0.637 ***	0.676 ***	0.562 ***	0.580 **
	(3.38)	(3.10)	(3.16)	(2.64)	(2.50)
Control variables	YES	YES	YES	YES	YES
Provincial fixed	YES	YES	YES	YES	YES
Year fixed	YES	YES	YES	YES	YES
Constant term	0.554 **	0.424	0.385	0.363	−0.138
	(2.07)	(1.57)	(1.39)	(1.02)	(−0.47)
N	513	570	570	390	494
R^2	0.857	0.839	0.839	0.794	0.852
F	5.134	5.154	5.912	5.244	9.550

t statistics in parentheses ** $p < 0.05$, *** $p < 0.01$.

First, to address potential sample selection bias, 90% of the sample was randomly selected for re-estimation. The regression coefficient remains positive (0.696) and exhibits remarkable statistical significance at the 1% level.

Second, to mitigate potential measurement errors, the core explanatory variable was redefined. The number of land contract and management right certificates was replaced with the number of household contracted management contracts., and the interaction term with the dummy variable was reconstructed. The estimated regression coefficient remains positive (0.637) and exhibits remarkable statistical significance at the 1% level.

Third, to reduce the influence of outliers, variables were winsorized at the 1% level, and the regression was re-estimated. The results remain robust, with a positive coefficient of 0.676 and exhibit remarkable statistical significance at the 1% level.

Fourth, to control for potential interference from other policies, such as the Rural Revitalization Strategy proposed in 2017, the sample period was truncated by excluding observations from 2018 onward. The estimated coefficient remains positive (0.562) and statistically significant at the 1% level.

Fifth, to account for potential bias arising from regional heterogeneity, four special regions (Beijing, Shanghai, Tianjin, and Chongqing), directly under the Central Government, were excluded from the sample. The estimated coefficient remains positive (0.580) and statistically significant at the 5% level.

Overall, the results indicate that the "three rights separation" reform promotes the ecological efficiency of cultivated land use, confirming the robustness of the baseline findings.

4.3. Heterogeneity Analysis

(1) Heterogeneity by grain production function

To examine whether the impact of the "three rights separation" reform varies across functional zones, a heterogeneity test was conducted based on the classification of grain production functions. In both grain-producing and non-grain-producing regions, the coefficients are significantly positive at the 5% level. In non-grain-producing regions, the estimated coefficient is 0.953, which is greater than that of the grain-producing regions, indicating a stronger promoting effect.

A possible explanation is that the grain-producing regions are primarily tasked with ensuring national food security, leading them to prioritize grain output and stable production. The level of large-scale agricultural land management in this region is already at a relatively high level. As a result, the improvement in ecological efficiency from the reform is relatively limited. Non-grain-producing regions face less pressure to maintain grain output. The process of land management rights transfer has become more smooth. There is a large potential for improving the scale and concentration level of land management, which can effectively encourage agricultural business entities to actively adopt environmentally friendly production models.

(2) Heterogeneity by level of mechanization

Investment in agricultural machinery can reduce production costs and substitute for labor inputs in agricultural production. A heterogeneity test based on the mean value of regional mechanical cultivation rates was conducted, with the results summarized in columns (3)–(4) of Table 6. In regions with higher levels of mechanization, the impact coefficient of the "three rights separation" reform is 0.783 and statistically significant at the 1% level. In contrast, in regions with lower mechanization levels, the impact coefficient (0.317) is not statistically significant.

Table 6. Results of Heterogeneity Analysis.

Variable	(1) Major Grain-Producing	(2) Non-Major Grain-Producing	(3) Low Mechanization	(4) High Mechanization	(5) Low Land Transfer	(6) High Land Transfer
"Three Rights Separation" Reform	0.592 **	0.953 **	0.317	0.783 ***	0.486	2.034 ***
	(2.17)	(2.46)	(0.90)	(2.86)	(1.30)	(4.51)
Control variables	YES	YES	YES	YES	YES	YES
Provincial fixed	YES	YES	YES	YES	YES	YES
Year fixed	YES	YES	YES	YES	YES	YES
Constant term	0.221	0.605	2.946 ***	0.083	0.069	1.587 ***
	(0.46)	(1.63)	(4.70)	(0.25)	(0.19)	(3.01)
N	247	323	210	360	322	248
R^2	0.905	0.814	0.858	0.877	0.821	0.865
F	9.688	2.296	8.490	5.266	4.063	4.581

t statistics in parentheses ** $p < 0.05$, *** $p < 0.01$.

A possible reason is that the "three rights separation" reform promotes large-scale land operations. Expanded scaled agricultural production facilitates the high-efficiency utilization of machinery, providing essential technical support for scale economies and enhancing the substitution effect of capital for labor. In addition, the utilization of intelligent agricultural machinery realizes precise fertilization and pesticide application, thereby curbing agricultural carbon emissions and improving land ecological efficiency.

So, across regions with varying levels of agricultural mechanization, the effects of scale economies and factor substitution associated with the transfer of management rights exhibit significant heterogeneity. In regions with lower mechanization, the positive effect of the "three rights separation" reform on improving ecological efficiency is weakened, thereby constraining the effective realization of policy benefits.

(3) Heterogeneity based on land transfer level

Differences in land transfer levels directly affect the scale of land operations and the degree of factor allocation optimization. A heterogeneity test was conducted based on the mean value of regional land transfer rates, with the results shown in columns (5)–(6). In regions with higher land transfer rates, the "three rights separation" reform significantly improves the ecological efficiency of land use, with an estimated coefficient of 2.034 that is statistically significant at the 1% level. In regions with lower land transfer rates, the promoting effect is not statistically significant.

In regions with high levels of land transfer, the regression coefficient is significantly larger. The possible explanation is that when land transfer activity is relatively developed, the transmission chain from property rights restructuring to the realization of economic and ecological outcomes operates more effectively, generating an expanding effect of the institutional reform. Higher levels of land transfer improve the realization of the policy benefits of the "three rights separation" reform by enabling land consolidation and large-scale operations. In comparison, in regions with limited land transfer, fragmented land operations remain predominant, restricting the effective release of policy benefits and limiting improvements in ecological efficiency. This result also indicates that a well-developed rural land transfer market is an essential foundation for fully leveraging the effectiveness of the "three rights separation" reform policy. A certain scale of regional land transfer is essential to fully release the reform's resource allocation benefits and ecological gains.

As demonstrated by the above analysis, the "three rights separation" reform exerts differentiated influence on the ecological efficiency of cultivated land use. The positive promotion effect is more prominent in non-grain-producing areas and regions with higher mechanization levels and land transfer rates, which confirms Hypothesis H2.

4.4. Mediation Effect Analysis

To further examine the influencing mechanisms, the mediation effect model was employed, and the corresponding results are presented in Table 7. The estimated coefficients of columns (1), (3), and (5) stand at 0.138, 0.317, and 3.600, respectively. All coefficients are positive and statistically significant at the 5% or 1% levels. These findings indicate that the "three rights separation" reform has accelerated the non-agricultural labor transfer, the optimization of planting structure, and agricultural technological progress.

Table 7. Results of Mediating Effect.

Variable	(1) NLT	(2) ECL	(3) PS	(4) ECL	(5) ATP	(6) ECL
"Three Rights Separation" Reform	0.138 **	0.591 ***	0.317 ***	0.513 **	3.600 ***	0.342
	(2.46)	(2.72)	(4.22)	(2.43)	(6.03)	(1.62)
NLT		0.297 **				
		(2.16)				
PS				0.375 **		
				(2.29)		
ATP						0.081 ***
						(4.84)
Control variables	YES	YES	YES	YES	YES	YES
Provincial fixed	YES	YES	YES	YES	YES	YES
Year fixed	YES	YES	YES	YES	YES	YES
Constant term	0.620 ***	0.241	0.941 ***	0.072	−0.503	0.465 *
	(10.61)	(0.84)	(9.39)	(0.22)	(−1.33)	(1.75)
N	570	570	570	570	570	570
R^2	0.963	0.840	0.947	0.841	0.843	0.842
F	26.090	5.683	31.263	4.634	35.116	8.126

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

As indicated by column (2), non-agricultural labor transfer exerts a prominently positive impact on cultivated land ecological efficiency at the 5% statistical threshold. After including this mediating variable, the coefficient of the "three rights separation" reform decreased from 0.632 to 0.591, remaining statistically significant at the 1% level. This indicates that the non-agricultural transfer of labor plays a partial mediating role. Similarly, the results in column (4) show that the estimated coefficient of planting structure is positive and remains statistically significant at the 5% level. After including this variable, the coefficient of the reform decreased to 0.513, significant at the 5% level. Such outcomes verify that planting structure serves as a partial intermediary variable in the influencing path.

In comparison, the results in column (6) show that agricultural technological progress had a positive and statistically significant effect on ecological efficiency at the 1% level. After incorporating this variable, the coefficient of the reform decreased to 0.342 and became statistically not significant. Agricultural technological progress plays a full mediating role. These results support Hypothesis H3a–H3c.

5. Discussion

5.1. Main Findings and Literature Comparison

Land is the foundation of people's livelihood and national food security. The rationality of land reform systems directly influences the allocation of agricultural land resources and cultivated land utilization patterns. Existing studies on land system reform mainly focus on its unilateral impacts on farmers' income, agricultural productivity, and ecological compensation standard [43–45], while neglecting the coordinated development of agricultural economic benefits and ecological conservation. Rural land system reform has fundamentally reshaped the traditional mode of cultivated land utilization. This paper comprehensively explores how farmland institutional adjustments act on the ecological efficiency of cultivated land use, as well as their corresponding influencing pathways and

practical effects. Compared with existing studies, this research emphasizes the importance of ecological efficiency by considering both grain production and the ecological protection of cultivated land. Against the backdrop of scarce arable land resources and worsening environmental pollution, prioritizing the ecological efficiency of cultivated land utilization is more aligned with the requirements of sustainable agricultural development. By combining a continuous DID model with a mediation effect model, the analysis confirms that the "three rights separation" reform significantly enhances ecological efficiency in China. In addition, a series of tests, including balance trend and placebo tests, were conducted to verify the robustness of the conclusion that the "three rights separation" reform improves ecological efficiency of cultivated land use.

Compared with major grain-producing regions, non-grain areas feature diversified crop layouts and fewer grain production restrictions. The institutional dividends of the "three rights separation" reform optimize factor allocation and enable more flexible farming management. Regions with advanced mechanization and active land transfer are conducive to large-scale and consolidated cultivation, resulting in the higher production efficiency of farmers. Accordingly, the institutional effects of the "three rights separation" reform can be further strengthened.

This study further identifies the mediating effect of non-agricultural labor transfer, planting structure optimization, and agricultural technological progress, highlighting the importance of guiding the labor reallocation, promoting grain-oriented cultivation, and advancing agricultural technology. By clarifying these mechanisms, this research offers deeper insight into the mechanisms through which rural land institutional reforms affect cultivated land.

5.2. Limitations and Future Research Directions

There exist certain shortcomings throughout this research. Firstly, constrained by data constraints, the analysis relies mainly on macro-level panel data and does not incorporate micro-level evidence. In addition, this article did not consider the spatial impact between regions, such as whether the "three rights separation" reform will affect land use in neighboring areas, which also needs to be explored. Also, the sample is limited to China and does not include cross-country comparisons.

Future research can address these limitations in several ways. One direction is to incorporate micro-level data at the farmer or household level to provide more detailed evidence on the underlying mechanisms. Future studies could employ spatial econometric models to explore spillover effects. Another direction is to expand the sample to include multiple countries or regions, allowing for comparative analysis.

6. Conclusions

6.1. Main Conclusions

This study employed the super-efficiency SBM model, a continuous DID model, and a mediation effect model to systematically analyze the driving mechanisms and effects of the "three rights separation" reform on the ecological efficiency of cultivated land use. The primary research findings are summarized below:

First, the "three rights separation" reform significantly improves the ecological efficiency of cultivated land use, and the results remain robust across multiple tests. The dynamic analysis shows that the effect exhibits a certain lag, becoming increasingly pronounced after 2016, with a positive and gradually strengthening impact.

Second, the impact of the reform on ecological efficiency exhibits significant heterogeneity. The promoting effect is more pronounced in non-grain-producing areas, regions with higher levels of mechanization, and areas with higher land transfer rates.

Third, the mechanism analysis shows that the reform improves ecological efficiency through the non-agricultural labor transfer, optimization of planting structure, and agricultural technological progress. Among them, non-agricultural labor transfer and the planting structure play a partial mediating role, while agricultural technological progress plays a complete mediating role. This indicates that technological progress is the core transmission channel for the ecological effect of the tripartite land ownership system.

6.2. Recommendations

First, the implementation of the "three rights separation" reform should be further strengthened, and rural land system reforms should be deepened to enhance policy effectiveness. The reform clarifies property rights and stabilizes expectations, thereby supporting the efficient allocation of land, labor, and capital. It also promotes rural land transfer, which helps alleviate land–labor conflicts, improves the allocation of land resources, and supports moderate-scale operations, thereby enhancing the ecological efficiency of cultivated land use. However, due to significant regional differences in labor–land relationships, land transfer should not be imposed on farmers and should rely primarily on market mechanisms, with government regulation playing a complementary role. The "enhancement of the voluntary and compensated exit mechanism for farmers' land contract rights, homestead land usage rights, and collective income distribution rights upon urban settlement" proposed in the 15th Five-Year Plan (2025) can reduce concerns over land tenure during labor transfer and promote land circulation.

Second, the non-agricultural transfer of labor and the adjustment of planting structures should be guided to optimize factor allocation and enable large-scale land operations. Rural labor transfer constitutes a rational household decision intended to optimize resource allocation. Farmland fragmentation greatly constrains the growth of cultivated land ecological utilization efficiency. Reliable off-farm employment serves as a crucial prerequisite for developing moderate-scale agricultural production. Accordingly, the orderly guiding of surplus rural labor into non-agricultural sectors can effectively alleviate land fragmentation. This process further facilitates farmland consolidation and paves the way for large-scale agricultural management. Land transfer can also support large-scale land management, but the effects of labor transfer on land transfer are gradual and cumulative, becoming significant only when labor transfer reaches a critical threshold. Accordingly, this paper puts forward targeted policy measures to guide orderly labor transfer. Policies should combine market employment opportunities with farmers' intentions, strengthen vocational training to enhance labor competitiveness, and promote industrialization and urbanization to absorb surplus agricultural labor. At the same time, planting structures should shift toward grain production and use crop rotation or green fallow, supported by soil testing and formula fertilization technologies, to balance food security with ecological protection.

Third, investment and publicity in agricultural technological innovation and machinery should be strengthened to enhance technological contributions to ecological efficiency. Greater financial support should be provided for the R&D of environmentally friendly agricultural technologies, as well as technology-intensive agricultural machinery. In 2024, China issued the "Implementation Plan for Promoting Equipment Upgrading in the Industrial Sector", which focuses on digital transformation and green upgrading. The action to replace outdated and inefficient production equipment in the agricultural machinery industry was listed as a key task. This policy orientation is conducive to promoting the continuous increase in advanced production capacity and improving the utilization of cultivated land. The modernization of facility agriculture and the development of suitable agricultural machinery can reduce input redundancy, improve factor allocation efficiency, and lower ecological pollution. The underutilization of machinery is mainly due to farmers'

limited understanding of its functions. Many farmers perceive that the machinery is not suitable for small plots, and its operation is relatively cumbersome. The demand for the use of mechanical equipment by farmers can be stimulated through publicity, incentives, or subsidies for advanced technologies. So, it is necessary to enhance regular information exchange about agricultural machinery and appropriately increase the subsidy standards for machinery. For example, public outreach activities led by village officials, including demonstration programs and technical lectures highlighting advantages such as labor savings, cost efficiency, and yield enhancement can further promote the adoption of modern agricultural machinery.

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