Research on the Impact of Land Fragmentation and Land Management Scale on the Sustainable Intensification of Cultivated Land Use

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Abstract: Sustainable intensification of cultivated land use (SICLU) plays a crucial role in ensuring China's food and ecological security. Based on survey data from 629 farm households in Jiangxi province, this study employs the super-efficiency SBM model to assess SICLU levels. It analyzes the transmission mechanism through which land fragmentation affects SICLU. Additionally, a moderation effect model is used to examine the moderating role of the land management scale. The results indicate that the overall SICLU level in Jiangxi is relatively low. The study finds an inverted "U" relationship between the land management scale and SICLU, with land fragmentation, farmer age, and the number of laborers engaged in farming significantly impacting SICLU. In contrast, the farmer's education level, health status, agricultural income proportion, village transportation conditions, and village economic level positively influence SICLU. Furthermore, the land management scale significantly moderates the effect of land fragmentation on SICLU; when the land management scale is small, the impact of land fragmentation is more significant, whereas it diminishes as the land management scale increases. Based on these findings, the study suggests promoting fertilizer reduction and efficiency improvements, advancing green and low-carbon agricultural development, enhancing land transfer systems, supporting moderate-scale land management, and accelerating the construction of high-standard farmland.

Keywords: Sustainable Intensification of Cultivated Land Use; Land Fragmentation; Land Management Scale; Food Security; Jiangxi Province

1. Introduction

The United Nations Food and Agriculture Organization and others pointed out in the 2022 State of Food Security and Nutrition in the World that the number of people affected by hunger globally reached 828 million in 2021, underscoring the growing challenges of eradicating hunger and all forms of malnutrition. Although the "Green Revolution" since the mid-20th century has led to a significant increase in global food production, it has come at a high environmental cost. Overusing agricultural chemicals has led to increasingly severe problems such as soil degradation, agricultural non-point source pollution, and a decline in product quality. In 2019, China's cultivated land accounted for only 7% of the World's total arable land. However, its chemical fertilizers and pesticide usage represented 28% and 43% of the global total, respectively, with the per-unit area application of agrochemicals far exceeding the global average. Given the limited potential for agricultural expansion, increasing the intensification of cultivated land use remains a crucial strategy for ensuring national food security in the future, and it is also key to safeguarding both food security and ecological safety.

While intensive land use has significantly contributed to China's food production, it has also caused severe negative impacts on land quality and rural environments. As a sustainable approach that aims to enhance land productivity and protect the ecological environment, SICLU has been widely discussed internationally and offers a possible direction for China's land use transformation, aligning food security with ecological civilization construction. To address the negative impacts of overly intensive traditional agricultural production, the Chinese government has consistently issued central "No. 1 Documents" emphasizing the need to protect

the agricultural ecological environment while ensuring the supply of essential agricultural products, aiming for a "trinity" of land quantity, quality, and ecology. The report of the 20th National Congress of the Communist Party of China also proposed: "We must firmly establish the concept that lucid waters and lush mountains are invaluable assets and accelerate the formation of green and low-carbon production methods." As a sustainable development model that maximizes the benefits of land use while minimizing environmental pollution, SICLU, in light of China's challenging national conditions of a large population and limited land, provides a potential direction for the transformation of land use, the safeguarding of food security, and the promotion of ecological civilization. Its conceptual framework and international experiences offer valuable insights into China's efforts to balance food security and ecological sustainability.

Since the implementation of the household responsibility system in 1978, significant progress has been made in China's agricultural sector. However, alongside rapid agricultural development, issues such as inefficiency in land use, ecological degradation of farmland, and land fragmentation have emerged. The basic national conditions of a large population and limited arable land exacerbate the severity of land fragmentation in China today, highlighting the necessity of improving land management scale and "consolidating small plots into larger ones." Land fragmentation, as a land use pattern in contrast to large-scale farming, has become a primary challenge for agriculture in developing countries. Addressing the tension between rising food demand and resource-environment constraints has been a long-standing government and academic research focus.

In the past, domestic and international scholars mainly focused on farmland ecological efficiency, agricultural sustainable development, and farm sustainability intensification. They were studying SICLU, but there has been relatively little research on this theme. With the introduction of the SICLU concept, scholars have continuously enriched empirical studies on SICLU, addressing issues such as scale selection, content expansion, and method application in SICLU research.

At the macro level, research primarily takes a global or national perspective, forecasting future development trends and food security demands. These studies qualitatively propose regulatory policies and explore ways to resolve the contradictions between the limitations of natural resources and socio-economic development. For example, studies have examined how sustainable intensification can contribute to solving global food demands.

At the meso level, research often focuses on regional or urban scales, using methods such as pattern exploration, case analysis, and effectiveness assessment. Based on horizontal measurement, empirical studies are conducted, leading to targeted regulatory measures. For instance, studies have explored the perceived impact of sustainable intensification of agricultural land on agricultural self-sufficiency in the northwestern region of Ghana.

At the micro level, research primarily focuses on land use behavior, evaluating it based on the activities of farmers, farm owners, or entities such as plots and farms. For example, studies have shown a relationship between SICLU and the livelihood transformation of farmers at the household level.

Regarding evaluation methods, early research mainly used simple ratio methods, which had certain biases when evaluating land use efficiency. In terms of methodology, since the specific calculation methods for SICLU levels have not yet been fully established, many scholars have adopted indicator systems for evaluation. Key measurement methods include the super-efficiency SBM model, energy value analysis, material flow analysis, and DEA models. Among these, the super-efficiency SBM model has been widely applied in assessing agricultural ecological efficiency [1], total factor productivity in agriculture, and other evaluations. In recent years, many scholars have used energy value methods to measure the sustainability intensification level of cultivated land and have incorporated carbon emissions into the SICLU evaluation system.

In terms of research content, with the promotion of the sustainable intensification concept, a large number of theoretical and empirical studies have been conducted internationally; in terms of conceptual understanding, domestic and international scholars have reached a preliminary consensus on the core meaning of SICLU, a sustainable development model aimed at maximizing farmland benefits while minimizing environmental pollution. Regarding research content, current studies on SICLU

mainly focus on conceptual definitions [2], level measurement [3], spatio-temporal evolution analysis [4], and influencing factors, with a continuous expansion of empirical findings. Studies have found that factors such as land tenure security, land fragmentation, and land inflow are related to SICLU levels. These studies offer valuable insights into deepening our understanding of SICLU.

In order to ensure China's food security, numerous scholars have conducted studies on the relationship between land fragmentation and SICLU levels, but no consensus has been reached. Some scholars argue that land fragmentation hurts SICLU levels [5], while others suggest a positive correlation between the two [6]. Additionally, some scholars point out that the relationship is not a simple linear one but follows an inverted "U" shape [7]. Furthermore, other researchers have found that the impact of land fragmentation on SICLU levels varies, primarily due to the moderating role of land management scale. Some scholars have studied the impact of farmland landscape fragmentation on SICLU levels, finding that shape fragmentation suppresses SICLU levels. Other scholars have used the SFA model for measurement and found that the scale of farmland management significantly impacts SICLU levels. Additionally, some scholars believe there is an inverted "U" shaped relationship between farmland management scale and SICLU levels and that farmland fragmentation weakens the positive effect of farmland management scale on SICLU levels.

The existing research provides a solid foundation for this study, but areas still warrant further exploration. The marginal contribution of this paper lies in two aspects: on the one hand, from the research perspective, focusing on farmers as the direct users of land and conducting the study from the micro-level of the farmer enhances the accuracy of SICLU levels and is of significant importance for accelerating the transformation of cultivated land use in Jiangxi province. On the other hand, the carbon emissions generated by land use negatively affect the cultivation process. By incorporating carbon emissions into the evaluation indicator system, this paper optimizes the SICLU evaluation framework, making the measurement results more precise and providing a reference for related research. Therefore, this paper, building on existing research progress, conducts empirical analysis based on survey data from 629 farmers in Jiangxi province and, after rigorous testing of the results, systematically discusses the impact of land fragmentation on SICLU, offering valuable guidance for promoting the transformation of cultivated land use in Jiangxi province.

2. Theoretical Analysis and Research Hypotheses

Intensive land use originated in economics and refers to an agricultural management approach where a large amount of production inputs is concentrated on limited land resources to achieve high output. The theory of intensive land use evolved from the land rent theory proposed by classical economists such as David Ricardo in their studies of agricultural land. It emphasizes the concentration of significant production inputs and labor on a fixed land area, employing advanced technologies and management methods to achieve high yields and income on relatively small land areas. However, the long-standing high-intensity intensive-use model, which heavily relies on commodity markets and external inputs, has primarily focused on increasing output while overlooking the relationship between agricultural production and the ecological environment. This has led to the destruction of the agro-ecosystem structure and threatens food security. Some scholars argue that intensive land use should not be limited to enhancing economic benefits but should also emphasize its social and sustainability benefits, advocating for a comprehensive land-use approach. This view suggests that in pursuing high yields, environmental protection, and ecological balance should also be considered to achieve the sustainable development of agricultural production. As a result, intensive land use needs to focus not only on economic benefits but also on social and environmental benefits, both theoretically and in practice, to ensure that agricultural production achieves high output while maintaining the stability and sustainability of the ecological environment. Building on this, the "sustainable intensification of cultivated land use" concept was proposed, which emphasizes improving land productivity while reducing or eliminating negative environmental impacts, thereby coordinating ecological, economic, and social benefits to maximize comprehensive outcomes.

Building on exploring the relationship between

land management scale and SICLU, some scholars have studied this relationship and concluded that land management scale and SICLU exhibit either a positive "U"-shaped or inverted "U"-shaped relationship. From the perspective of economies of scale, as land management scale increases, the likelihood of farmers adopting new agricultural technologies rises. The development of agricultural machinery can reduce labor input, improve operational efficiency, and unlock the potential for agricultural production. However, excessive investment in agricultural machinery can encourage farmers to substitute labor input with fixed capital, which may lead to increased carbon emissions in agricultural production. Under the assumption that other factors remain constant, this could decrease SICLU levels. From the viewpoint of income focus theory, as the land management scale expands, the proportion of agricultural income to total income increases for farmers. Large-scale farmers, driven by the dual incentives of maximizing profits and increasing risks, tend to focus more on agricultural production inputs. Some farmers may be inclined to reduce chemical inputs to protect land quality, thereby improving SICLU levels. On the other hand, some farmers may increase chemical inputs to achieve higher short-term profits during the contract period. After achieving an optimal land management scale, further expansion may lead to increased costs, resulting in "diseconomies of scale," which could reduce agricultural productivity and hinder improvements in SICLU levels.

Based on this, hypothesis 1 proposes that the impact of the land management scale on SICLU follows an inverted "U" shape.

Land fragmentation affects the desired and undesired outputs by influencing the inputs of land, labor, agricultural chemicals, and machinery, thus impacting the level of SICLU. Land fragmentation increases the labor and agricultural operating costs for farmers, restricting the improvement of agricultural modernization, such as machinery and field irrigation systems. This results in continuous increases in agricultural capital investment and lower per-acre profits for farmers, creating a significant income gap compared to non-agricultural industries. Farmers are more likely to invest heavily in agricultural chemicals to increase output and income to compensate for issues such as low land productivity and labor shortages. Higher levels of land fragmentation reduce the efficiency of machinery use, increase energy consumption from machinery moving between different plots, and raise agricultural carbon emissions, lowering SICLU levels. Additionally, land fragmentation reduces pesticide and fertilizer use efficiency, prompting farmers to increase working capital investments, leading to higher carbon emissions and non-point source pollution, and reducing SICLU levels.

Based on this, hypothesis 2 proposes that fragmentation negatively impacts farmers' SICLU levels.

Since land fragmentation and land management scale interact to influence SICLU levels, the direction of the impact of land fragmentation on SICLU levels differs under varying land management scales. Moderate-scale farming can buffer the negative impact of land fragmentation on SICLU levels. Land fragmentation has a positive impact on the SICLU levels of small-scale farmers, while it negatively impacts the SICLU levels of medium and large-scale farmers.

Based on this, hypothesis 3 proposes that the Land management scale moderates the effect of land fragmentation on SICLU levels.

3. Data Sources, Research Methods, and Variable Selection

3.1 Data Sources

Jiangxi province is a traditional agricultural powerhouse and one of China's key grain-producing regions. In 2023, the grain planting area in Jiangxi was 3,774.3 thousand hectares, with a grain output of 21.98 million tons, representing a 2.2% increase compared to the previous year. At the same time, Jiangxi is rich in geographical resources, with fertile soil, flat terrain, and abundant water sources, providing a solid foundation for cultivated land resources. Using Jiangxi province as a case study, exploring SICLU is of great significance for ensuring food security for China's 1.4 billion people, protecting the ecological environment of the Yangtze River Basin, and promoting the high-quality, green, and low-carbon development of agriculture in Jiangxi.

The data for this study comes from the "China Rural Revitalization (Jiangxi) 'Dual Hundred and Dual Thousand' Data Platform Construction Project," jointly conducted by the Jiangxi Rural

Revitalization Strategy Research Institute and the School of Economics and Management at Jiangxi Agricultural University, between June and July 2023. A sampling survey was conducted on farmers in 11 cities, 24 counties, 72 towns , and 216 villages in Jiangxi province. The sampling method first divided the 24 counties into high, medium, and low economic development areas for stratified sampling. Three towns were selected from each county, three villages from each town, and 10 farmers from each village, resulting in 2,160 questionnaires, of which 2,050 were valid questionnaires. After data cleaning, the necessary indicators for this study were selected, and a final sample of 629 was used for analysis.

3.2 Research Methods

3.2.1 Super-Efficiency SBM Model

In this study, production inputs are represented by labor, land, fertilizer, machinery, and pesticide input. Expected output is represented by rice yield, while unintended output is represented by carbon emissions (Table 1). The carbon emissions in this study specifically include the total carbon emissions generated during rice cultivation from fertilizer, pesticide, and agricultural machinery use (Table 2). These emissions are calculated using the IPCC carbon emission factor method (equation (2)).

$$\min\theta = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{w_i^-}{x_{ik}}}{1-\frac{1}{S_1+S_2}\left(\sum_{r=1}^{S_1}\frac{w_r^g}{y_{rk}^g}+\sum_{k=1}^{S_2}\frac{w_z^b}{y_{zk}^b}\right)}$$

$$x_{ik} \geq \sum_{j=1,\neq k}^{n}\lambda_j x_{ij} - w_i^-, i = 1,2,\cdots,m \quad (1)$$

$$y_{rk}^g \leq \sum_{j=1,\neq k}^{n}\lambda_j y_{rj}^g - w_r^g, r = 1,2,\cdots,S_1$$

$$y_{zk}^b \geq \sum_{j=1,\neq k}^{n}\lambda_j y_{zj}^b - w_z^b, z = 1,2,\cdots,S_2$$

$$E = \sum E_i \sum T_i \times \varepsilon_i \quad (2)$$

In equation (1), θ represents SICLU levels. In equation (2), E represents agricultural carbon emissions.

Table 1. SICLU Level Evaluation Indicator System

Primary Indicators	Secondary Indicators	Tertiary Indicators	Variable Description	Units
Input	Production Input	Labor Input	The amount of family labor input	people
		Cultivated Land Input	Rice planting area	mu
		Fertilizer Input	Fertilizer purchase cost	yuan
		Machinery Input	The costs of owning and renting agricultural machinery such as rice transplanters, plowing machines, and harvesters	yuan
		Pesticide Input	The cost of purchasing pesticides	yuan
Output	Expected Output	Crop Yield	Rice yield	g
	Undesirable Output	Agricultural Carbon Emissions	Total carbon emissions from fertilizers, pesticides, and agricultural machinery	kg

Table 2. Carbon Emission Sources and Carbon Emission Coefficients

Carbon Source	Carbon Emission Coefficient
Fertilizer	0.89kg/kg
Pesticides	4.93kg/kg
Agricultural Machinery	14.67kg/mu
	0.18kg/kw

3.2.2 Tobit Regression Model

To explore the factors influencing SICLU levels, since the efficiency values obtained from the super-efficiency SBM model are all greater than 0, indicating typical merged-type data, and given that the sample data is cross-sectional, a mixed Tobit regression model is employed for estimation. Compared to the OLS regression model, the mixed Tobit regression model can effectively avoid parameter estimation bias and account for the truncation issue in the data, enabling specialized handling of censored data. Therefore, this study adopts the mixed Tobit regression model for analysis. The specific model specification is shown in equation (3).

$$SICLU = \delta_0 + \delta_1 Fra_i + \delta_{2i} control_i + \omega \quad (3)$$

In equation (3), $SICLU$ represents the dependent variable. δ represents the parameters to be estimated. ω represents the error term.

3.3 Variable Selection

The dependent variable in this study is the SICLU level. The evaluation system for the SICLU level consists of production inputs, expected outputs, and unintended outputs, with

specific values calculated using the super-efficiency SBM model. This study selects land fragmentation and land management scale as the core explanatory variables. Land fragmentation is represented by the number of land parcels, with a higher number of parcels indicating a greater degree of land fragmentation. Land management scale is measured by the farmer's rice planting area. The study uses the turning point of land management scale as the grouping criterion, dividing the total sample into two groups: one with a larger land management scale and one with a smaller land management scale. To avoid biases in regression estimates due to omitted variables, this study, in addition to the land fragmentation and land management scale variables, also considers other factors that may affect the SICLU level. Based on previous research, we select seven control variables grouped into three categories: (1) individual characteristics, including the age, education level, and health condition; (2) family characteristics, including the number of agricultural laborers and the proportion of agricultural income; and (3) village characteristics, including the economic level and transportation situation of the village (Table 3).

Table 3. Variable Selection and Descriptive Statistics

Variable	Variable Names		Variable Descriptions	Mean	Standard Deviation
Dependent Variable	SICLU Levels		The values after calculating using the super-efficiency SBM method can be assigned as follows: 1=(0,25]; 2=(0.25,0.5]; 3=(0.5,0.75]; 4=(0.75,1]; 5= greater than 1	1.56	0.86
Core Explanatory Variables	land fragmentation		The number of land parcels operated by the farmer	3.92	2.77
	land management scale		Single-cropping rice planting area	3.42	2.15
Control Variables	Individual Characteristics	Age	age of the household head	52.57	8.78
		Education Level	1=No schooling; 2=Primary school; 3=Middle school; 4=High school (or vocational school); 5=College or above	2.87	0.98
		Health Condition	1=Very unhealthy; 2=Quite unhealthy; 3=Average; 4=Quite healthy; 5=Very healthy	3.74	1.04
	Family Characteristics	Number of Agricultural Laborers	The labor force engaged in agricultural production in the family	1.72	0.80
		Proportion of Agricultural Income	1=0~20%; 2=21~40%; 3=41~60%; 4=61~80%; 5=81~100%	2.46	1.44
	Village Characteristics	Village Economic Level	1=Very poor; 2=Poor; 3=Average; 4=Good; 5=Very good	3.26	0.71
		Village Transportation Condition	1=Very poor; 2=Poor; 3=Average; 4=Good; 5=Very good	3.93	0.86

4. Results Analysis

4.1 Measurement of Farmers' SICLU Levels

Using Matlab 2021a software, this study calculates the SICLU levels of farmers and presents the distribution table (Table 4). The overall SICLU levels of the sampled farmers are relatively low. The SICLU levels of the sample farmers range from 0.1 to 1.39, with an average of 0.27. Only 7.6% of farmers have SICLU levels above 0.5, while more than half of the farmers have SICLU levels below 0.25. Overall, the SICLU levels of the sample farmers are quite low. The primary reason for this is that most of the sampled farmers are older, which has a significant negative impact on SICLU levels. As many elderly farmers tend to have more conservative agricultural production views, and due to their declining physical health, they are more likely to increase the use of fertilizers, pesticides, and other agricultural chemicals to ensure agricultural output, which hinders the improvement of SICLU levels.

Table 4. Distribution of SICLU Levels Among Farmers

SICLU Level Range	(0,0.25]	(0.25,0.5]	(0.5,0.75]	(0.75,1]	>1
Number of Samples	365	215	27	2	20

Percentage(%)	58	34.1	4.2	0.3	3.1

4.2 Analysis of the Factors Affecting SICLU Levels of the Sample Farmers

This study uses Stata 17 software to test for multicollinearity among the explanatory variables. The results show that the maximum value of the variance inflation factor (VIF) is 1.30, the minimum value is 1.02, and the average value is 1.11, all of which are far below the threshold of 10. This indicates that there is no significant multicollinearity among the explanatory variables (Table 5).

Table 5. Tobit Regression Estimation Results for the Total Sample of Farmers

	Model(1)	Model(2)	Model(3)	Model(4)
land fragmentation	-0.062***		-0.031**	-0.068***
	(0.120)		(0.135)	(0.025)
land management scale		0.253***	0.214***	0.226***
		(0.043)	(0.457)	(0.046)
land management scale× land management scale		-0.115***	-0.104***	-0.111***
		(0.004)	(0.004)	(0.003)
land fragmentation× land management scale				-0.108**
				(0.005)
Age	-0.014***	-0.015***	-0.012***	-0.016***
	(0.004)	(0.004)	(0.004)	(0.003)
Education Level	0.062*	0.059*	0.058*	0.060*
	(0.035)	(0.035)	(0.035)	(0.034)
Health Condition	0.025**	0.016**	0.02**	0.023**
	(0.033)	(0.033)	(0.328)	(0.032)
Number of Agricultural Laborers	-0.044***	-0.021***	-0.025***	-0.024***
	(0.042)	(0.041)	(0.041)	(0.041)
Proportion of Agricultural Income	0.046**	0.026**	0.033**	0.031**
	(0.023)	(0.023)	(0.229)	(0.228)
Village Economic Level	0.052*	0.048*	0.043*	0.044*
	(0.048)	(0.048)	(0.475)	(0.047)
Village Transportation Condition	0.009*	0.012*	0.013*	0.010*
	(0.039)	(0.039)	(0.039)	(0.039)
Constant	1.271***	1.610***	1.674***	1.761***
	(0.329)	(0.336)	(0.336)	(0.339)
Log likelihood	-770.249	-760.926	-758.295	-756.810
LR chi2	48.590	67.230	72.490	75.470
Prob > chi2	0.000	0.000	0.000	0.000
Pseudo R^2	0.031	0.042	0.046	0.048
Sample Size	629	629	629	629

According to Model (2), the estimated coefficient for the linear term of land management scale is 0.253, and the estimated coefficient for the quadratic term is -0.115, both of which are statistically significant at the 1% level. This indicates that the relationship between land management scale and SICLU level is not a simple linear one, but rather an inverted "U" shaped relationship. The expansion of land management scale initially leads to an increase in the SICLU level, but after reaching a certain inflection point, the positive effect of land management scale on SICLU level begins to turn into a suppressive effect. This validates Hypothesis 1. The main reason is that the expansion of land management scale promotes a more rational allocation of production resources, facilitates the full utilization of various production factors, and forms a moderate scale of operation, thereby promoting the improvement of SICLU level. However, continuous expansion of land management scale requires additional investment in agricultural production materials, and the high investment leads to high unintended outputs. The accumulation of the "anti-ecological" effects of cultivated land becomes relatively more significant, resulting in a decrease in the SICLU level.

From Models (1), (3), and (4), it can be seen that land fragmentation has a certain negative impact on the SICLU level, meaning that an increase in

the number of plots reduces the SICLU level. The reason is that a higher number of plots indicates a greater degree of land fragmentation, which means a higher spatial dispersion of farmland. On one hand, this increases the difficulty of mechanized farming and raises production costs; on the other hand, it increases the time loss due to the labor force's travel between different plots. Additionally, because of the large number of plots, mechanized operations cannot be carried out effectively, leading to lower land utilization and productivity efficiency. In order to increase yields, farmers tend to increase the use of fertilizers and pesticides to compensate for insufficient labor and mechanical inputs, which leads to increased carbon emissions and a decrease in the SICLU level. This confirms Hypothesis 2. The interaction term between land fragmentation and land management scale has a significant negative effect on the SICLU level, indicating that there is a moderating effect between land fragmentation and land management scale, the specific mechanism of which still requires further investigation.

Among the control variables, the farmer's education level, health status, proportion of agricultural income, village transportation conditions, and village economic level all have a positive impact on the SICLU level. The reason is that as farmers' income continues to grow and their living standards improve, according to Maslow's "Hierarchy of Needs" theory, people will shift from material needs to spiritual needs once their basic material needs are met. Since the 18th National Congress of the Communist Party of China, the "Two Mountains" theory has been deeply rooted in people's hearts. As farmers invest more funds in agricultural production, they are also placing greater emphasis on the protection of natural resources and the environment, which promotes the coordinated development of the agricultural economy and ecological environment, thus benefiting the improvement of the SICLU level. The farmer's age and the number of farm laborers have a negative impact on the SICLU level, suggesting that younger farmers and a reduction in the number of farm laborers are conducive to improving the SICLU level.

4.3 Robustness Test

To further ensure the reliability of the above results, this study uses the "utest" command in Stata to conduct a robustness check on the inverted "U" shaped relationship between land management scale and SICLU level. As shown in Table 6, the slope of the model specified in the robustness check first becomes positive and then negative, indicating the existence of an inverted "U" shaped relationship between land management scale and SICLU level, which is significant at the 1% level (Table 6).

Table 6. Utest Regression Results

Variable	Lower bound	Upper bound
Interval	1	15
Slope	0.234	-0.239
t-value	3.397	-6.571
P>t	0.000	0.000
Overall test of presence of a U shape		
t-value	3.4	
P>t	0.000	

4.4 Grouping Test for Different Land Management Scale Effects on SICLU Level

To further explore the moderating effect of land fragmentation and land management scale on the SICLU level, as well as whether there are heterogeneous impacts, we conduct a subgroup analysis based on the results of the current survey. To assess the moderating effect of the variable, this study uses the inflection point of land management scale as the basis for grouping, dividing the total sample into a "larger land management scale" group and a "smaller land management scale" group. We then regress the samples above and below the inflection point separately.

The specific grouping situation is shown in Table 7. Among the 629 sampled farmers, the number of farmers in the smaller scale group is overwhelmingly larger, with 608 farmers, accounting for 96.67% of the sample. In contrast, only 21 farmers belong to the larger scale group, accounting for 3.33%. This indicates that farmers in the smaller scale group still represent the main force in agricultural production.

Table 7. Classification of Farmers by Land Management Scale

Group	Grouping Criteria(mu)	Sample Size	Proportion(%)
Larger Scale Group	>8.07	21	3.33
Smaller Scale Group	≤8.07	608	96.67

The land management scale has a positive effect on the SICLU level for farmers in the smaller

scale group, which is consistent with the results for the overall sample. This suggests that the land management scale has not yet reached the inflection point of the inverted "U" shaped curve. As land management scale increases, the SICLU level continues to rise. The reason for this is that, with the expansion of land management scale, the allocation of production factors gradually becomes more rational, reducing unnecessary carbon emissions and non-point source pollution, thereby highlighting the scale effect.

Land fragmentation has a negative impact on the SICLU level for farmers in the smaller scale group, which is also consistent with the results for the overall sample. The more plots there are, the greater the degree of land fragmentation, which leads to a lower SICLU level. Specifically, when land management scale is smaller, land fragmentation negatively affects the SICLU level. The main reason is that land fragmentation forces farmers in the smaller scale group to substitute labor input for machinery input. The extensive use of manual labor not only results in low agricultural labor productivity but also leads to inefficient land use. In order to increase output per unit area, farmers tend to overuse chemical products such as fertilizers and pesticides, which leads to increased carbon emissions, thereby hindering the improvement of the SICLU level. This confirms Hypothesis 2.

In the smaller scale group, the interaction term between land fragmentation and land management scale has a significant negative effect on the SICLU level at the 1% level (Table 8). This indicates that smaller land management scale plays an enhancing moderating role in the negative impact of land fragmentation on the SICLU level. In other words, the smaller the land management scale, the greater the impact of land fragmentation on the SICLU level. This confirms Hypothesis 3.

Table 8. Estimation Results of Factors Affecting SICLU Level for Farmers in the Smaller Scale Group

	Model(5)	Model(6)	Model(7)	Model(8)
land fragmentation	-0.064***		-0.039***	-0.115***
	(0.012)		(0.014)	(0.031)
land management scale		0.119***	0.089***	0.169***
		(0.022)	(0.024)	(0.038)
land fragmentation× land management scale				-0.019*** (0.037)
Control Variables	Control	Control	Control	Control
Constant	1.352***	1.446***	1.549***	1.788
	(0.339)	(0.340)	(0.340)	(0.349)
Log likelihood	-751.492	-748.507	-744.807	-741.073
LR chi2	45.56	51.53	58.93	66.40
Prob > chi2	0.000	0.000	0.000	0.000
Pseudo R^2	0.029	0.033	0.038	0.042
Sample Size	608	608	608	0.000

Based on the estimation results for farmers with a smaller land management scale, the land management scale has a positive effect on the SICLU level before reaching the inflection point. After the inflection point, as the land management scale increases, the SICLU level gradually decreases. This confirms that land management scale has a significant negative effect on the SICLU level for farmers in the larger scale group, validating Hypothesis 1 once again.

The reason is that, as rational economic agents, farmers with a larger land management scale, in their pursuit of higher agricultural returns and crop yields, tend to invest large amounts of agricultural chemicals to increase land productivity. This leads to an increase in carbon emissions, thus hindering the improvement of the SICLU level.

In the larger scale group, the interaction term between land fragmentation and land management scale has a significant positive effect on the SICLU level at the 1% level (Table 9). As the land management scale increases, the impact of the interaction term between land fragmentation and land management scale on farmers' SICLU level shifts from negative to positive. This indicates that a larger land management scale plays a reducing moderating role in the negative impact of land fragmentation on the SICLU level. In other words, the larger the land management scale, the smaller the impact of land fragmentation on the SICLU level. This confirms Hypothesis 3.

Table 9. Estimation Results of Factors Affecting SICLU Level for Farmers in the Larger Scale Group

	Model(9)	Model(10)	Model(11)	Model(12)
land fragmentation	-0.159***		-0.029***	-0.278***
	(0.017)		(0.015)	(0.062)
land management scale		-0.103**	-0.134**	0.285***
		(0.049)	(0.049)	(0.052)
land fragmentation× land management scale				0.022*** (0.037)
Control Variables	Control	Control	Control	Control
Constant	0.674***	0.717***	0.659***	0.955***
	(0.738)	(0.902)	(0.959)	(0.917)
Log likelihood	-0.441	1.433	3.189	9.214
LR chi2	23.66	26.61	30.13	42.18
Prob > chi2	0.000	0.000	0.000	0.000
Pseudo R^2	0.096	0.121	0.268	0.276
Sample Size	21	21	21	21

5.Conclusion and Policy Implications

5.1 Conclusions

(1)SICLU Levels of Farmers in Jiangxi Province Need Improvement. The average SICLU level is 0.27, with 58% of farmers' SICLU levels falling below 0.25, and only 7.6% of farmers achieving a SICLU level above 0.5.

(2)Land Management Scale Significantly Affects SICLU Levels. The relationship between land management scale and SICLU levels follows an inverted "U" shape, with the optimal scale being 8.07 mu. Before reaching the optimal scale, SICLU levels increase as land management scale expands; however, once the optimal scale is exceeded, further expansion of land management scale leads to a decrease in SICLU levels. Land Fragmentation has a significant negative impact on SICLU levels. Factors such as farmers' educational level, health status, agricultural income proportion, village transportation conditions, and the economic level of the village positively influence SICLU levels. Conversely, farmers' age, the number of laborers in agriculture, and land fragmentation have a significant negative effect on SICLU levels.

(3)Land Management Scale Moderates the Effect of Land Fragmentation on SICLU Levels. When land management scale is small, land fragmentation has a greater impact on SICLU levels; when land management scale is large, land fragmentation has a lesser impact on SICLU levels.

5.2 Policy Implications

(1)Promote Fertilizer Reduction and Efficiency Improvement, Accelerate Green and Low-Carbon Agricultural Development. Fertilizers play a crucial role in agricultural production, but they are also one of the main sources of carbon emissions in rice production. The government should promote precision fertilization techniques based on local land use conditions, encourage farmers to choose low-carbon fertilizers and pesticides, use organic fertilizers to replace part of the chemical fertilizers, and incorporate straw back into the soil to increase the carbon sequestration capacity of the agricultural ecosystem. These measures will help reduce carbon emissions in agricultural production and promote low-carbon agricultural development.

(2)Improve the Land Transfer System and Promote Moderate-Scale Land Management. As an important factor influencing SICLU levels, the current land management scale of most farmers in Jiangxi Province is below the optimal level. When the land management scale is small, land fragmentation has a larger negative impact on SICLU levels. Expanding the land management scale to a moderate level can enhance SICLU levels. Therefore, on one hand, the government should improve the land transfer system, conduct land consolidation, and build high-standard farmland to form contiguous plots of land. On the other hand, the government should support farmers with development potential by guiding them toward new agricultural business entities, promoting moderate farm scale through cooperatives and service organizations, and increasing support for farmers to help them scale up.

(3)Actively Promote High-Standard Farmland Construction. The report of the 20th National

Congress of the Communist Party of China proposed "gradually converting all permanent basic farmland into high-standard farmland." Taking the construction of high-standard farmland in Jiangxi Province and the joint construction of a green organic agricultural product base with the provincial and ministerial authorities as an opportunity, the government should leverage the synergistic effects of farmland construction projects and property rights reforms. This should be done in coordination with land transfer and farmland remediation efforts to stimulate farmers' intrinsic motivation. By achieving the "consolidation of small fields into larger ones" and reducing land fragmentation, the SICLU levels can be improved.

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