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Farmers' Livelihood Differentiation and Pesticide Application: Empirical Evidence from a Causal Mediation Analysis

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Abstract: As agriculture is becoming a less reliable source of income, many farmers are turning to other industries to supplement their lackluster profits from farming in a process known as farmers' livelihood differentiation. Despite the existence of a voluminous literature on farmers' livelihood differentiation, little is known about its effect on agricultural production behavior. To fill this knowledge gap, this study uses rice planting data from 537 Chinese farm households to analyze how farmers' livelihood differentiation affects pesticide application among rural farmers in China. This study not only examines the effects of farmers' livelihood differentiation on farmers' pesticide application, but also underscores the potential pathways behind the effects of farmers' livelihood differentiation according to land resource endowment via a causal mediation analysis. The results showed that (1) farmers' livelihood differentiation had a direct effect on the amount of pesticide use. Compared to the full-time agricultural households, regular part-time farmers and ir-regular part-time farmers generally tend to use lower levels of pesticides. (2) The mediating effect of farmers' livelihood differentiation on pesticide use was through land resource endowment. Compared to the full-time agricultural households, ir-regular part-time farmers reduce their pesticide use through maintaining better land resource endowment, while regular part-time farmers increase their pesticide application by maintaining poor land resource endowment. These results may provide important implications for policymakers to improve cultivated land protection policies and encourage the use of soil testing technology to determine the formulation of the fertilizer used in the agricultural ecological environment.

Keywords: pesticide overuse; farmers' livelihood differentiation; land resource endowment; Chinese farm households

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1. Introduction

The application of agricultural chemical inputs is essential to China's food security. However, despite bringing economic benefits, the extensive use of agricultural chemicals has negative impacts. The usage of fertilizers and pesticides has increased dramatically in the past 20 years. In China, the amount of pesticide per hectare was 2.5 times higher than the world average in 2013 [1]. In 2017, the unit used for the chemical fertilizers were 352.27 kg/ha (calculated based on data from the China Agriculture Yearbook 2018), exceeding the upper limit of safe use of 225 kg/ha proposed to prevent water pollution. The issue of agricultural nonpoint source pollution is becoming more and more serious due to the over usage of chemical fertilizers and pesticides. The agricultural ecological environment and sustainable food production are facing serious threats to their stability.

Facing the above environmental problems, many studies have proposed methods to reduce pesticide residue [2–14]: at the macro level, previous proposals include channel sales management [2], new agricultural operation organization [3,4], social norms [5], the social service market [6,7], and agricultural support policy [8,10]; at the micro level, especially regarding the production characteristics of farmers, previous proposals have included planting area scale [11], controlling the risk aversion of farmers [12,13], technical training for farmers [14], and many other ways to reduce the chemical inputs in agriculture.

However, if we consider pesticide overuse in China, several problems still exist in a variety of different aspects. Firstly, from the time dimension, although factors that have positive effects on pesticide reduction, such as farmers' education levels, agricultural technology, and public policy, have been on the rise, pesticide overuse has continued to increase since the 1950s. Secondly, from the region dimension, China has demonstrated more severe pesticide overuse than neighboring countries in the last ten years.

In the past 30 years, compared to other countries, the most significant change in China's agricultural process is that many rural laborers have flocked to larger cities, leading to decreased farm labor; as such, farmers are no longer a homogeneous group of peasants toiling in the field. Agricultural income decreased from 75.02% of the average farmer's net income in 1985 to 26.3% in 2011 [7]. In 2016, only 12.8% of farming households had more agricultural income than nonagricultural income, and the proportion of farm households with nonagricultural income accounting for more than 80% of their overall income was as high as 64% (Data from the Ministry of Agriculture and Rural Affairs of The People's Republic of China about the observation data about 20,000 households in 355 counties in 31 provinces (ccnu.edu.cn)).

Consequently, many farmers no longer live on agriculture alone. They are turning to other industries to supplement their lackluster profits from farming in a process known as farmer livelihood differentiation. We cannot ignore the change in agricultural management objectives under role differentiation nor the changes in the allocation of agricultural production factors, such as land and planting methods. To the best of our knowledge, few studies have investigated the mechanism of the multiple factor linkage environment of pesticide application from the perspective of combining agronomy and economics to deal with the problem of pesticide overuse.

Some scholars have paid attention to the causal relationship between farmers' livelihood differentiation and the use of agriculture chemicals [15–17]. Xia Qiu et al. (2018) and Zhang, Yali et al. (2021) believe that farmers' livelihood differentiation and the crowding-out effect of part-time farmers would increase pesticide use and aggravate the problem of agricultural nonpoint source pollution. On the other hand, LV Xinye et al. (2018) hold different views: that part-time employment of farmers increases farmers' personal knowledge accumulation, improves the safety awareness of agricultural products, and reduces agricultural nonpoint source pollution. Therefore, it is still controversial as to whether farmers' livelihood differentiation has a positive or negative effect on pesticide use. Although the diversity of income sources may change the purchasing power of pesticides and the attitude toward yield loss, it cannot fully explain the motivation behind pesticide overuse. In fact, the essence of pesticide application is to prevent or control plant diseases and the damage caused by pests. There are still some unexplained logical links connecting "purchase" and "overuse"; so, what happened on farms that has resulted in pesticide overuse?

To answer the above questions, this paper focuses on explaining the path of pesticide overuse. Under the hypothesis of "farmers as economically rational people" and based on the micro survey of 40 villages in Fujian Province, this paper provides an objective and reasonable explanation for pesticide overuse and discusses the treatment of pesticide overuse from the causal relationship among farmers' livelihood differentiation, land resource endowment (land resource endowment is an indicator of land productivity that refers to the land function of production materials, including land fertility, land topography, and the convenience of mechanical access), and pesticide use to facilitate the protection and sustainable development of the agricultural ecological environment.

The remainder of the study is arranged as follows: Section 2 is a theoretical analysis on the behavior of pesticide overuse. Section 3 introduces the data source and model settings. Section 4 includes the analysis of the empirical results. Section 5 provides a discussion on the results and policy recommendations.

2. Theoretical Analysis

With the development of urbanization, farming is no longer the main source of income for rice farmers. Schultz and Popkin, who study the behavior of farmers, believe that the behavior of small farmers is affected by personal income or family welfare, follows the rational calculation of cost and benefit, and seeks the maximization of benefit or utility. With the deepening of the farmers' livelihood differentiation, agricultural operators have changed to encompass structures such as family farmers, co-operative collective organizations, part-time farmers, and other production units. They may face different production risks, including variations in frequency and intensity of rainfall, temperature fluctuations, crop diseases, and marketing risks [18], so their coping strategies will be different. Finally, the difference in livelihood changes the expectation of income. The purpose of grain production has been profoundly changed, and the resulting difference in farmers' resource endowment will bring about changes in the mode of production. Moreover, from the agronomic and pathologic perspective, the increased application of pesticides means that the epidemic risk and damage degree of crop diseases and insect pests increase, so the allocation of field habitat resources, such as land fertility and topography, become the external key factors that affect crop disease resistance. Hence, it is necessary to explain the farmer behavior of excessive pesticide application from the dual perspectives of economic rationality theory and agronomic knowledge.

Some scholars categorize farmers according to factors such as the degree of part-time work, the intergenerational division of labor, and land and capital use [19–21]; some divide farmers into the categories of survival, functional, production, and life according to the labor mobility characteristics [22]; and some divide farmers into the categories of withdrawal, self-supporting, part-time, and development types based on the intensity of agricultural factor input and the degree of agricultural operation specialization [23].

Regardless of the classification criteria, all farmers aim to reduce labor [24]. The impact of the time management of part-time farmers on the chemical factor input needs to be considered [25]. In order to analyze the behavior path of pesticide overuse based on farmers' livelihood differentiation and to clarify the behavioral motivation of different farmer groups, this paper divides farmers into full-time agricultural households, regular part-time farmers, and ir-regular part-time farmers. Considering the causal relationship between production factor management and pesticide investment in rice planting, this paper analyzed three scenarios (as shown in Figure 1).

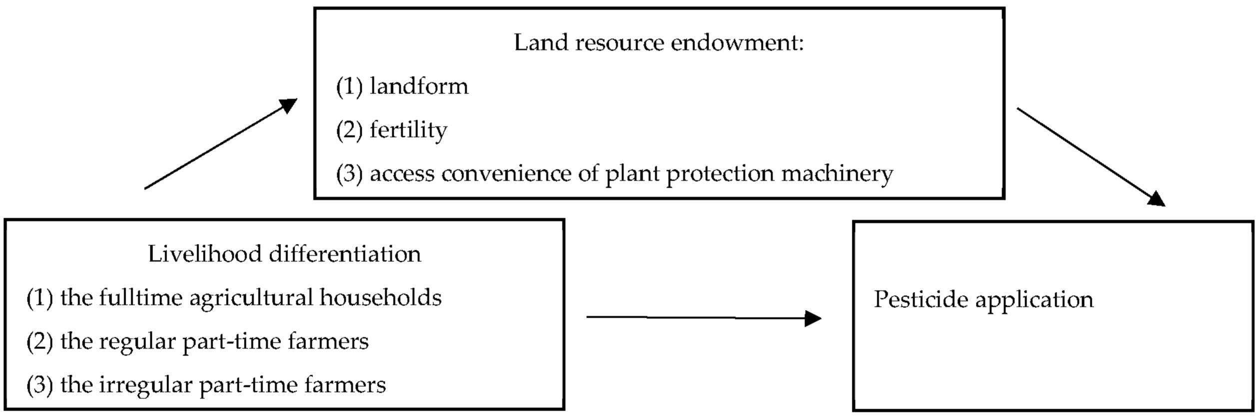

Figure 1. Theoretical analysis framework of pesticide overuse behavior.

Scenario 1: Pesticide application path of the full-time agricultural households. From an economic rationality perspective, full-time agricultural households spend all of their working time on agricultural land management, and as rice planting income accounts for a large proportion of their household income, they hope to maximize the income from rice planting, causing them to be more sensitive to the losses caused by diseases and pests than part-time farmers. Consequently, they are more likely to overuse pesticides to avoid diseases and insect pests. Moreover, due to the lack of labor time management, some part-time farmers have to sublet their secondary land to full-time agricultural households who are enthusiastic towards farming and demonstrate time flexibility through the exchange of human demands or by caring for the land at a low price. Full-time agricultural households receive this secondary land, which helps them to realize the economy of planting scale. However, the above behaviors have reduced the average land quality level of full-time agricultural households.

Although we can control pesticide input by introducing modern production factors to supplement the short board of soil fertility, low land quality will still reduce the resistance of rice to diseases and pests. Additionally, terrain conditions will also affect the factor substitution difficulty and the degree of machinery substitutions for human resources in the process of agricultural production [26], eventually leading to the weakening of the promotion effect of other production factors on production in mountainous areas and the strengthening of the demand for chemical elements, such as pesticides.

Scenario 2: Pesticide application path of regular part-time farmers.

Representing the "rational economic man", regular part-time farmers need to strike a balance between part-time work and farming. Compared to full-time agricultural households, they do not necessarily pursue the maximization of agricultural income but pay more attention to the maximization of the overall income of the family. On the one hand, income diversity determines that these farmers are less sensitive to rice yield and the damage caused by pests than full-time agricultural households. Therefore, their willingness to overuse pesticides is relatively lower than that of full-time agricultural households. Moreover, regular part-time work means a stable nonagricultural income, so the survival value of the land they hold, which relies on land planting to ensure survival, is diminished. Furthermore, regular part-time farming increases the predictability of the commuting time between the part-time job site and the field, and the time cost and labor cost of part-time work strictly achieve the "economy" of prevention and control costs, so the amount of pesticide application is relatively small. On the other hand, regular part-time farmers incur losses in their farming time to a certain extent, which may affect farming processes, such as baking the field and stacking organic fertilizer, meaning that regular part-time farmers may hold poor land planting conditions, which further affects pesticide application. Compared to full-time agricultural households, the amount of pesticide application by regular part-time farmers is reduced as a whole, but poor land resources will weaken the performance of pesticide reduction.

Scenario 3: Pesticide application path of ir-regular part-time farmers.

Ir-regular part-time farmers are farmers who do not have a stable part-time income, which makes field management time more difficult to control. Despite the land production value continuing to decline, it remains the main social and spiritual source of security for part-time farmers [24,27]. Here, farmers show a higher level of "Economic Rationality"; they have multiple dependences and multidimensional value evaluations on the land [28]. Ir-regular part-time farmers may also face more survival pressure, so they are not willing to give up rice production completely. To reduce the intensity of agricultural production over time and maximize the labor allocation efficiency, these farmers may choose to retain high-quality farmland with a low land slope and sublet the farmland with ordinary or slightly poorer conditions to other farmers. In this case, high land resource endowment further reduces pesticide use. According to the principle of agricultural pathology, the occurrence of rice diseases is the result of the combined action of the rice itself, environmental conditions (climate and soil), human activities, and pathogens [29]. High-quality farmland can provide a good growth environment for rice planting, which can increase the resistance of rice to diseases and reduce pesticide application. Moreover, the share of rice planting income in the household income decreases due to nonagricultural employment, leading part-time farmers to focus more on the overall household income. The instability of the ir-regular, part-time business increases the labor costs and time costs of field management, and it is easy to miss the best pesticide time or even miss it entirely. Moreover, few of these farmers sell commercial grain and are less sensitive to yield loss. Therefore, the probability of ir-regular part-time farmers overusing pesticides is small.

Based on the above analysis, this paper puts forward the following two hypotheses:

Hypothesis 1 (H1). *Farmer livelihood differentiation directly affects pesticide application. Compared to full-time agricultural households, the pesticide application of part-time farmers is relatively lower*.

Hypothesis 2 (H2). *Farmer livelihood differentiation will change the quality level of the land resource endowment and affect pesticide application according to the level of land resource endowment*.

3. Research Methods

3.1. Data Source

From 2018 to 2019, surveys on rice control were conducted in 10 counties in Fujian Province. The main contents of the questionnaire include questions related to the farmers' characteristics, the farmland production and management characteristics, and the control of diseases and insects. According to the main rice-producing areas recorded in the "Fujian Statistical Yearbook" and the "Implementation Opinions on Rice Production Functional Areas", we selected 40 villages from the 10 counties that were surveyed and visited 12–15 households per village, on average. Out of the 600 questionnaires, 537 responses were received after data cleaning, achieving an 89.5% response rate.

3.2. Model Setting

The conceptualization of mediation analysis was proposed by Baron and Kenny's causal stepwise regression method in 1986. The mediation analysis has been widely used in psychology and consumer research. However, the disadvantage of this method is that it observes the significant changes of the direct effect by controlling the intermediary variable rather than by directly measuring the significance of the intermediary effect. Therefore, Zhao et al. (2010) further improved the test procedure of the mediation effect, which has been widely referred to by foreign scholars in recent years. The advantage of using causal mediation analysis is that it can clearly establish mediation on the explained variables and help to clarify the relationship among farmers' livelihood differentiation, pesticide application, and the land resource endowment.

In the theoretical analysis framework, farmers' livelihood differentiation affects the land resource endowment (including land fertility, topography, and the degree of convenience of mechanical access) and then affects the pesticide application behavior. The regression model constructed is as follows:

$$M_{\mathrm{i}} = \eta_1 + aF + \beta_1 \chi_{\mathrm{i}} + \varepsilon_1 \quad (1)$$

$$Y_{\mathrm{i}} = \eta_2 + cF + \beta_2 \chi_{\mathrm{i}} + \varepsilon_2 \quad (2)$$

$$Y_{\mathrm{i}} = \eta_3 + c'F + bM + \beta_3 \chi_{\mathrm{i}} + \varepsilon_3 \quad (3)$$

In Formulas (1)–(3), "M_{i}" represents the land resource endowment condition; "Y_{i}" represents the amount of pesticide application; "F" represents farmer livelihood differentiation; "χ_{i}" represents the vector of control variables; "a" represents the influence coefficient of farmers' livelihood differentiation on the intermediary variable (land resource endowment); "c" represents the direct influence coefficient of farmers' livelihood differentiation on pesticide application behavior; "c'" represents the indirect influence coefficient of farmers' livelihood differentiation on pesticide application behavior; "b" represents the influence of the land resource endowment conditions as an intermediary variable on pesticide application behavior; "β_1"represents the influence coefficient of the control variables on land resource endowment; "β_2" and "β_3"represent the influence coefficient of the control variables on pesticide application behavior; "η_1", "η_2", and "η_3"represent constants; and "ε_1",

"ε_2", and "ε_3" represent random error terms. We used the mediation effect test procedure of Zhao et al. [30] because the independent variable in this paper is a multicategory independent variable, and we use the Bootstrap method proposed by Hayes and Preacher [31] to test the mediation effect of the multicategory independent variables. The specific steps are outlined as follows:

(1) Test the significance of the mediation path a*b. If the significance is significant, it indicates the presence of the mediating effect; otherwise, it does not exist;
(2) If the mediation effect exists, then test the significance of "c'". If it is not significant, it means that the variable is the only intermediary variable; if it is significant, go to step (3);
(3) Calculate the product of $a \times b \times c'$. If $a \times b \times c' > 0$, it indicates complementary mediation; if $a \times b \times c' < 0$, it indicates competitive mediation.

3.3. Selection and Description of Model Variables

3.3.1. Dependent Variables

As a dependent variable (We recorded pesticide application with the help of the Fujian Provincial Plant Protection Station staff. Although pesticide include powders and granules, the main pesticides in Fujian Province are liquid buprofezin, abamectin, etc.), the amount of pesticide application reflects the farmers' pesticide application behavior. Considering the price differences in pesticides in various regions, the research team worked with the Fujian Plant Protection and Quarantine Station, and with the help of technicians from plant protection stations in various regions, we attempted to use the amount of pesticide input before dilution as the amount of pesticide application.

3.3.2. Independent Variables

The paper uses farmers' livelihood differentiation as the independent variables and divided the farm households into full-time agricultural households, regular part-time farmers, and ir-regular part-time farmers. Additionally, the classification standard of regular part-time or not is based on "whether the time (month) of part-time job is fixed" in the questionnaire.

3.3.3. Intermediary Variables

The paper uses land resource endowment as the intermediary variable. According to the land topography, land fertility, and the convenience of mechanical access, we scored the land resource endowment of different plots. This was based on the question from the questionnaire of "Field Topography: Mountain land = 1, Plain = 2, Low-lying land = 3; Land fertility: Poor = 1, General = 2, Rich = 3; Difficulty degree of working land conditions for plant protection machinery: Difficult = 1, General = 2, Easy = 3". The higher the score, the better the land resource endowment. In the rice planting technology of agronomy, poor land indicates poor rice growing conditions. Similarly, the topography can also affect the environmental conditions required for rice planting because rice needs sufficient water from the panicle differentiation stage to the heading stage. If rice is planted in mountainous or hilly areas, due to the high slope of the terrain, the water storage capacity is lower after rainfall, which is not conducive to the development of spikelets and will increase the empty shell rate. In comparison, the land conditions of depressions or plains will be more ideal. In addition, the inconvenience of control machinery entering the field will increase the difficulty of the control operations in paddy field management.

3.3.4. Control Variables

Referring to previous studies [27,32], we selected age, farming experience, family labor force, whether to join a co-operative, etc., as control variables to reflect the characteristics of the farmers, the farmers' family, and the farmers' production and operation conditions. Table 1 presents a description and the descriptive analysis of the variables.

Table 1. Description and descriptive analysis of the variables.

Variable	Variable Description and Assignment	Mean	Std Dev
Pesticide application (Y)	Pesticide Application Per Mu (mL/mu)	270.01	221.80
Farmers' livelihood differentiation (F)	The full-time agricultural households = 1; the regular part-time farmers = 2; the ir-regular part-time farmers = 3	2.05	0.80
Land resources endowment (M)	Assign a comprehensive score of three levels from 1 to 3 for field fertility, field topography, and the convenience of mechanical access.	6.25	1.19
Age (X1)	Actual age of the decision maker (unit: year)	52.12	9.82
Farming Experience (X2)	Decision maker's years of farming (unit: year)	29.93	12.89
Member of a co-operative (X3)	Un-cooperative member = 0, co-operative member = 1	0.38	0.49
Social Network (X4)	Number of friends or acquaintances	6.69	17.45
Agricultural labor force (X5)	Amount of labor input per unit area	0.86	1.56
Regional variables (X6)	Southern Fujian = 1, Northern Fujian = 2, Western Fujian = 3	2.09	0.88

One mu equals 1/15 ha.

4. Results

Stata was used to calculate the regression results for pesticide application behavior based on the mediation effect analysis. The variance inflation factor (VIF) of the continuous variables in the model range from 1.03 to 3.62, and the average value of VIF is equal to 1.79, indicating that there is no obvious multicollinearity in the model.

Then, the MEDIATE plug-in compiled by Hayes and Preacher [31] was used to code the independent variables as dummy variables, and the group of the full-time agricultural households was used as the reference group. Then, we took age, farming experience, whether to join a co-operative, social network, family labor force, and region as control variables and tested the mediating effect of land resource endowment on the relationship between farmers' livelihood differentiation and pesticide application. According to Zhao et al. [30] and Legate et al. [33], regarding the mediating effect analysis process of multicategory independent variables, we performed the bootstrap method to test the mediation effect (set self-sampling 5000 times). The data results are reported as follows:

In terms of the mediation effect, the significance of the indirect effect is important [30]. First, as shown in Table 2, the bootstrap analysis is within the 95% confidence interval. On the one hand, taking the full-time agricultural households as the reference level, the confidence interval of the relative mediation effect of the regular part-time farmers is (0.5926, 16.5889), and excluding 0, it shows that the relative mediation effect is significant and that the mediation effect value of $a \times b = 7.292$ (as shown in Table 3, $a = -0.278$, $b = -26.231$). On the other hand, taking the full-time agricultural households as the reference level, the confidence interval of the relative mediation effect of the ir-regular part-time farmers is (−16.9150, −0.6940), excluding 0, indicating that the relative mediation effect is significant, with the mediation effect value of $a \times b = -7.397$ (as shown in Table 3, $a = 0.282$, $b = -26.231$). The signs of the mediation effect of these two types of farmers are opposite to one another. Combining the regression analysis results in Table 3, we found that although the mediating effect of land resource endowment is established, the effect on different groups is different. Compared to the full-time agricultural households, the regular part-time farmers have poorer land resource endowment conditions, which encourages farmers to increase pesticide application to a certain extent, weakening the pesticide reduction performance. Additionally, the ir-regular part-time farmers hold richer land resource endowment conditions, leading to reduced pesticide application.

Table 2. Relative mediating effect of farmers' livelihood differentiation on pesticide application.

Farmer Livelihood Differentiation→Land Resources Endowment Conditions→Pesticide Application				
(Reference Level: Full-Time Agricultural Households F_1)	**Effect**	**SE (Boot)**	**LLCI**	**ULCI**
Regular part-time farmers	7.2810	4.0570	0.5926	16.5889
Ir-regular part-time farmers	−7.3994	4.1824	−16.9150	−0.6940
OMNIBUS	−0.9114	0.5401	−2.2554	−0.1886

Table 3. Regression results of the intermediary model of land resource endowment conditions.

	Model (1)			**Model (2)**			**Model (3)**		
	Dependent Variable: Land Resource Endowment Conditions			**Dependent Variable: Pesticide Application**			**Dependent Variable: Pesticide Application**		
	Coef.	T	P	Coef.	T	P	Coef.	T	P
Constant	7.177	18.533	0.000	211.189	2.858	0.004	399.443	4.244	0.000
Control variable									
Age X1	−0.004	−0.457	0.648	2.460	1.364	0.173	2.347	1.312	0.190
Farming experience X2	0.001	0.164	0.870	−2.130	−1.528	0.127	−2.099	−1.518	0.130
Co-operative X3	0.097	0.881	0.379	−42.451	−2.026	0.043	−39.912	−1.920	0.055
Social network X4	−0.002	−0.816	0.415	−0.885	−1.601	0.110	−0.947	−1.727	0.085
Family labor force X5	−0.053	−1.482	0.139	12.747	1.868	0.062	11.357	1.675	0.095
Region X6	−0.340	−5.317	0.000	23.523	1.927	0.055	14.603	1.176	0.240
Key variable									
Farmers' livelihood differentiation F: (Reference level: full-time agricultural households)									
The regular part-time farmers F2	−0.278	−2.116	0.035	−58.290	−2.328	0.020	−65.571	−2.630	0.009
The ir-regular part-time farmer F3	0.282	2.166	0.031	−66.115	−2.661	0.008	−58.716	−2.373	0.018
Intermediary variable									
Land resources endowment M							−26.231	−3.186	0.002
R^2	0.084			0.041			0.060		
F value	6.070			2.849			3.704		

Note: Rounded to three decimal places.

After the mediation effect is established, the second step is to check the significance of c′. In model (3), C2′ is negatively significant at the 1% statistical level (C2′ = −65.571), and C3′ is negatively significant at the 5% statistical level (C3′ = −58.716), indicating that the land resource endowment condition is not the only intermediary variable.

The third step is to calculate whether the product of a*b*c′ is greater than zero. Compared to the full-time agricultural households, the product of a × b × c′ of the regular part-time farmers is less than 0, indicating that there are other competitive intermediary variables affecting the pesticide application path of regular part-time farmers. Similarly, compared to the full-time agricultural households, the product of the ir-regular part-time farmers $a \times b \times c'$ is greater than 0, indicating that there are other complementary intermediary variables affecting the pesticide application path of the ir-regular part-time farmers. The above empirical results are consistent with the theoretical hypotheses.

5. Conclusions and Policy Implications

With the rapid development of urbanization, farmers in rural China have more opportunities to participate in off-farm employment. Under the objective of maximizing household income, the application behaviors of agricultural factors will be different for different groups of farmers. Based on the microdata of 537 rice farmers in Fujian Province, this paper discusses pesticide application behavior from the perspectives of agronomics and economics by using land resource endowment as a mediating variable to demonstrate the causal relationship between farmers' livelihood differentiation and pesticide use. The main conclusions are as follows:

First, the livelihood differentiation of farmers had a direct effect on their amount of pesticide use, which passed the 1% and 5% significance levels test, and the coefficient was negative, which was expected. The results of the model show that compared to full-time farmers, ir-regular part-time and regular part-time farmers were more inclined to apply lower levels of pesticides on the whole, which is due to the low income resulting from rice production. Considering the total household income, round-trip time costs, and labor costs, they have to reduce the frequency and amount of pesticide application.

Secondly, using the bootstrap process test to determine the intermediary effect, taking the full-time farmers as the reference level, the confidence interval of the relative intermediary for regular part-time households is (0.5926, 16.5889), and the confidence interval of the relative intermediary for ir-regular part-time households is (−16.9150, −0.6940), all of which exclude 0, indicating that there is an intermediary effect in the land endowment conditions, and the intermediary effect is different among different types of farmers (as shown in Tables 2 and 3). Compared to the full-time agricultural households, pesticide application for the regular part-time farmers is reduced on a whole, but the performance of pesticide reduction is weakened by the mediating effect of land resource endowment. The explanation is that the income diversity of the regular part-time farmers reduces the value of land survival security; land is the most important means of production for farmers, especially before the production role of farmers is undifferentiated, as the quality of land directly affects the economic situation of farmers' families. Therefore, for farmers, agricultural land has the attribute of survival security, and reducing the field management time will virtually affect the process of "raising farmland and cultivating soil", resulting in the weakening of land resource endowment conditions and the increased probability of overusing pesticides in secondary farmland habitats.

Third, compared to the full-time agricultural households, the ir-regular part-time farmers reduced their pesticide use through the mediating effect of land resource endowment, which is explained by the fact that ir-regular part-time farmers face more survival risks and choose to maintain better land resource endowment to secure their future livelihood. Good farmland habitats reduce pesticide use.

Moreover, we found that land endowment is not the only mediating variable. According to the empirical results, there are other competitive mediating variables affecting the application paths of the regular part-time farmers (according to the mediation effect test, $a \times b \times c' > 0$, $a \times b \times c' = -478.14$) and that there are other complementary mediating variables that affect the application paths of the ir-regular part-time farmers (according to the mediation effect test, $a \times b \times c' > 0$, $a \times b \times c' = 434.32$).

Some suggestions of measures that can be implemented to reduce pesticide application in policy design are as follows:

First, it is necessary to pay full attention to the phenomenon of farmers' livelihood differentiation and to develop agricultural socialized hosting services to reduce the cost of farm field management to promote the socialized service of crop prevention and control.

In neighboring countries such as Pakistan, similar public advisory services are used to improve the local farm ecological environment through hiring and training extension staff [34,35]. This suggests the need to move away from the idea of "relying solely on land aggregation to achieve large-scale management" and a move towards making use of the technological advantages of the third party and mastering the best prevention and control period to complete the professional division of prevention and control links to achieve reduction.

Second, it is critical that we strengthen the technical training of full-time agricultural households and standardize manual operation in the field. In terms of policy formulation, the government can refer to the EU regulations management on food safety, including the maximum pesticide residues in crops and the use specifications of biological substances [36]. We should continue to encourage the development and growth of co-operative agricultural production companies, support the "leading co-operative and farmer" model, and strengthen pest situation prediction to reduce the worries of the full-time agricultural farmers about the loss of diseases and pests.

Third, in terms of public policy design of land management, we should pay attention to the positive impact of improving land resource endowment conditions on pesticide reduction. We will continue to implement farmland protection policies and determine the fertilizer formulation using soil testing technology. At the same time, the quality rating of agricultural land can be added to the land transfer management terms. Additionally, it is time to promote the testing of the fertilizer formulations that are currently used on the agricultural land in the main commodity grain planting areas to make up for the possible land resource endowment differences between "optimal agricultural land production and utilization" and "actual scale agricultural land".

There are still some problems worthy of further study. The empirical results show that there may be other intermediary variables or hidden regulatory variables that weaken the performance of pesticide reduction of part time farmers. Are there differences in pesticide application behaviors among different crop types? We hope to find the answer in the follow-up study.

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