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Impact of Labor Migration on Chemical Fertilizer Application of Citrus Growers: Empirical Evidence from China

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Abstract: Due to the growing trend of rural labor migration, farmers' labor allocation under the condition of constant time endowment has gradually become a key factor in the transformation of green agricultural production methods. Using the propensity score matching method, this paper verified the influence of labor migration on citrus growers' fertilizer application using 814 survey data from Sichuan Province, China. The study found that the boosting effect of capacity accumulation brought on by farmers' labor migration was greater than the weakening effect of labor constraints and that the average chemical fertilizer application per acre decreased from 6.95 to 6.74 after farmers' labor migration, a 3.06 percent decrease. Second, labor migration reduces chemical fertilizer application by allowing farmers to acquire knowledge and technology for green agricultural production and to increase off-farm income. Third, the choice of labor migration by farmers with higher agricultural incomes and younger ages promotes a reduction in their chemical fertilizer application. Therefore, this paper makes the following suggestions: the government should appropriately guide farmers in their labor migration decisions, increase public awareness of green agricultural knowledge and technology, and encourage farmers to to invest their off-farm income in green production. Farmers with higher agricultural income and younger ages, in particular, should be encouraged to choose labor migration and train to become new agricultural business entities.

Keywords: labor migration; amount of chemical fertilizer; citrus growers; propensity score matching; mediating effect

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1. Introduction

Most developing countries have witnessed population urbanization and a fall in rural population in recent years as the threshold for labor migration has been lowered [1–3]. According to the World Bank, the rural populations of China, Russia, India, South Africa, and Brazil have fallen dramatically between 1960 and 2015 [4], with the rural shares of their populations declining by 47 percent, 44 percent, 15 percent, 34 percent, and 73 percent, respectively. In addition, total labor migration in China climbed from 158.63 million in 2011 to 174.25 million in 2019 [5]. As more and more Chinese rural residents engage in labor migration, more rural households are showing signs of "half-working and half-farming", with about 85% of rural households having at least one member employed in the non-agricultural sector [6]. Labor migration is an important strategy for farmers to cope with shocks and risks [7], as is the reallocation of labor resources within households, which has implications for agricultural productivity and management decisions [8]. Rural labor migration has been shown to have a significant impact on overall household income [9–11], agricultural production inputs and efficiency [12–14], land use management [15,16], and household energy consumption [17]. Most researchers have found that labor migration is beneficial in increasing overall household income, but there is no consensus of findings regarding its impact on farmers' agricultural production and management decisions.

More than 98 percent of all agricultural operations in China are run by small-scale farmers. Their agricultural production input decisions, particularly chemical fertilizer inputs, have a substantial impact on agricultural output efficiency and product quality. Davis, J, and Lopez-Carr [18] in the New Economics of Labor Migration (NELM) framework, using data from the Latin American Migration Project, found that remittances from labor migration are used to increase the number of crops and pastures rather than to qualitatively change land-use patterns. Based on data from 818 households in three counties in northern Jiangsu Province, Zhang et al. [19] found that working outside the home limits households' conservation inputs for soil conservation and that the proportion of farmers adopting measures such as mulching, straw application, and organic fertilizer is still low. In addition, Ma et al. [20] concluded from a non-farm employment study based on data from apple growers in the Gansu, Shanxi and Shandong provinces of China that non-farm employment increased the use of fertilizers and chemical pesticides used to improve yields. Chang et al. [21] used data from 630 rice farmers in the Qinba Biodiversity Ecological Function Area and found that off-farm work generally inhibited the ecological production behavior of farmers. On the other hand, using survey data from 1122 rice-producing farm households in China, Zhang et al. [22] used a treatment effects model to investigate the effects of rural–urban migration experiences on fertilizer use in rice production. The results indicated that the rural–urban migration experience was beneficial in reducing fertilizer use in rice production. Du et al. [23] found that labor migration promoted adoption of green control technologies by farmers by influencing their economic, social, and ecological perceptions. There is no uniformity in the findings of the existing literature concerning the impact of labor migration on farmers' green production behavior.

This paper contributes to existing research in three ways. First, existing studies have explored the impact of labor migration on agricultural production inputs, but most of them have focused on rice and other food crops. Overfertilization of cash crops has become an important cause of increased chemical fertilizer application in China as the area planted for cash crops such as vegetables and fruits has increased [24]. Citrus is the most cultivated and profitable cash crop in China. Therefore, understanding the factors affecting chemical fertilizer application during citrus cultivation is important to improve soil quality and promote agricultural safety and sustainable development. Second, considering the heterogeneity of farmers' resource endowments, this study proposes some options for different types of farmers. It is useful for farmers in China and other developing countries to change their agricultural production habits. Third, using a mediating effects test [25], labor migration was found to inhibit chemical fertilizer application by increasing off-farm income and decreasing access to green production information and technology, thus enriching the literature in this category. Therefore, this paper investigates the relationship between labor migration and chemical fertilizer use using 814 survey data from citrus growers in Sichuan Province, China, and constructs a relevant theoretical model to provide theoretical references and practical suggestions for further reducing chemical fertilizer inputs and achieving sustainable agricultural development.

2. Theoretical Analysis

2.1. Off-Farm Income from Labor Migration Affects Chemical Fertilizer Application by Citrus Farmers

According to the traditional view of "factor substitution", as more and more farmers opt for labor migration, the reduction of labor inputs leads to an increase in the use of agrochemicals to secure agricultural output [26]. The New Economic Theory of Labor Migration (NELM) proposed by Stark and Bloom [27] emphasizes that rural households should be the basic object of analysis. Labor migration uses remittance income to provide economic support to households for productive investments or for daily consumption [28]. Currently, there are inconsistent findings regarding the effect of labor migration on fertilizer application inputs.

According to a study conducted in the Ecuadorian Andean highlands, the use of fertilizers and pesticides increased with an increase in non-farm income [29]. In contrast, in the U.S., Chang and Mishra [30] found that an increase in non-farm income reduced the risk of a single income structure, which discouraged fertilizer use. Chang and Mishra's findings are supported by Zhang et al.'s study of rice growers in China [22]. With cash crops, Liu et al. found that labor migration can increase crop yields by increasing wages and removing capital and credit constraints [31]. However, no further studies have been conducted on the effect of labor migration on chemical fertilizer application in cash crop cultivation.

Hypothesis 1 (H1). *labor migration will increase off-farm income, which will affect the amounts of chemical fertilizers applied in the citrus growing process.*

2.2. Labor Migration Allows Growers to Reduce the Use of Chemical Fertilizers by Gaining Knowledge and Techniques for Green Production

Lack of information leads to factor allocation failure and increases the risk of adoption of new technologies [32,33]. The more that farmers master agricultural production techniques and technology, the more likely it is to promote agricultural production method transformation [34], ultimately affecting the amount of chemical fertilizer needed by farmers [35]. On the one hand, labor migration overcomes the constraints of traditional communication channels, such as acquaintance networks, by expanding access to information and technology and improving information acquisition [36]. On the other hand, farmers' choice of labor migration alleviates the information asymmetry in the process of green agricultural production. Farmers have easier access to knowledge and technology on green agriculture. With an awareness of cost-and-benefit information related to green production, farmers come to understand that excessive use of chemical fertilizers is detrimental to soil fertility and land quality, which encourages them to adopt green technologies instead of using more chemical fertilizers [37,38].

Hypothesis 2 (H2). *labor migration enables growers to obtain knowledge and technology of green products to reduce the amounts of chemical fertilizers used.*

Based on the above analysis, the theoretical analysis framework of this paper is proposed, as shown in Figure 1.

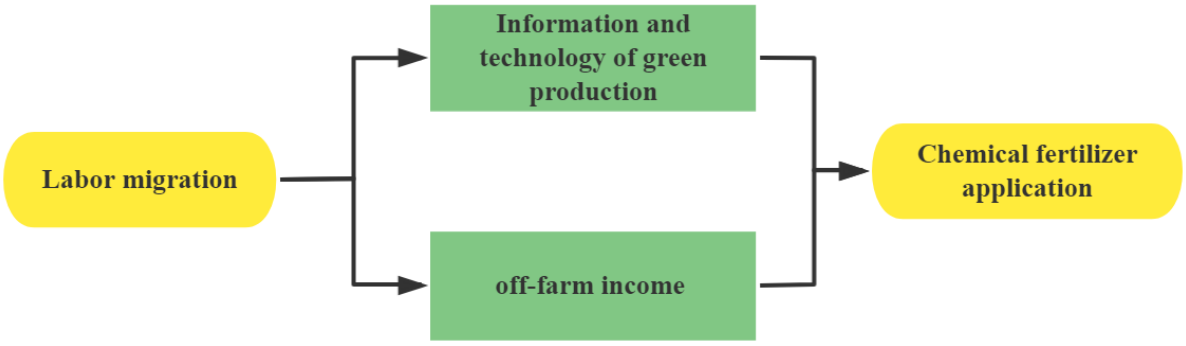


Figure 1. Analytical framework.

3. Data and Methodology

3.1. Data

Citrus is one of the most important economic crops in the world and leads international trade volumes among fruits. In recent years, the scale of China's citrus industry has continued growing steadily. In 2018, China's citrus planting area reached 39 million mu and total output was 41,381,400 tons, both ranking first in the world [5]. In contrast to the plain areas where grain, cotton, rape and sugar are important industries related to national food security, the citrus industry occupies a very important position in the

economic development of the hilly mountainous areas in southern China [39] and affects the poverty alleviation of farmers in southern China. The data in this paper are taken from the field survey on citrus growers in Sichuan Province by the research team. Data from Thank you for your suggestions, I did not change this layout, and I have checked and revised all. I have made sure that all symbols in the paper are in the same format. Sichuan have been selected to explore the relationship between labor migration and citrus growers' chemical fertilizer application for the following three reasons: First, Sichuan's citrus industry has developed rapidly since 2015 with an annual increase of about 14% in planting area until 2018, making Sichuan the country's largest late-maturing citrus base. Second, Sichuan is a typical representative region of hilly and mountainous areas. As of 2018, total labor migration from Sichuan reached about 9.6 million, ranking second in the country, causing a serious farm labor drain in Sichuan rural regions. Third, the amount of chemical fertilizer applied per unit of arable land area in Sichuan Province in 2020 is 313.69 kg/hm^2, which is 1.39 times the internationally accepted safe chemical fertilizer application limit of 225 kg/hm^2. These facts are of great significance for determining the relationship between labor migration and chemical fertilizer application.

The survey was conducted during July and August 2020, with the following sampling survey steps: First, the research team chose nine sample localities in Sichuan Province based on citrus production and planting areas. These were Pujiang County, Dongpo District, Renshou County, Danling County, Nanbu County, Anyue County, Zizhong County, Jiang'an District, and Yanjiang District. Second, in each sample district and county, the team members chose 4–5 townships at random, as well as 2–3 villages in each township. Finally, 8–10 citrus growers were randomly selected from each village. After sorting and eliminating invalid samples from the total of 837 issued questionnaires in this survey, 814 valid samples were collected. The questionnaire's effective rate was 97.25 percent, with 101, 104, 94, 72, 68, 111, 113, 68, and 83 copies from each of the nine counties. The survey focused on the output and input costs of citrus, as well as on individual and household characteristics and household labor migration.

3.2. Variable Definition and Measurement

3.2.1. Dependent Variable

Based on the availability of data and the concrete situation of the research, this paper uses the same method as Ma et al. [20] which measures the chemical fertilizer application amounts of citrus growers through the input cost of chemical fertilizer per mu. Input costs are more precise than quantities because the measurement units used by farmers for chemical fertilizers vary significantly.

3.2.2. Independent Variables

In this paper, household decision makers working outside their own township boundaries in the past year are considered as labor migration. This is mainly due to two considerations: first, the decisions of agricultural household operators have a greater impact on agricultural production inputs; second, limiting the scope of labor migration makes both the labor loss and income effects of their labor migration behavior more significant than those of farm households in their own townships. Overall, about 32.1% of family business decision-makers in the sample experienced labor migration.

3.2.3. Intermediary Variables

To examine the influence of labor migration on the amounts of chemical fertilizer applied, this article considers two factors: income from off-farm income, and access to information and technology related to green agriculture. This method is based on the existing literature on labor migration and agricultural inputs [28,33,35]. Access to information and technology for green production is measured using a Likert five-level scale, while non-agricultural income is expressed as a logarithmic value.

3.2.4. Controlled Variables

Studies have shown that differing amounts of economic capital, human capital, social capital, physical capital and natural capital of farm households have a significant impact on their green production behavior [40,41]. In this paper, economic capital variables were defined as annual household income and income from citrus sales. Zhang et al. [42] noted that households with higher income have higher risk-taking capacity and are more likely to engage in green production. Tian et al. [43] also showed that households with higher agricultural income have their production focused on agriculture and are therefore more likely to adopt sustainable agricultural production practices. Human capital variables were defined as age, acreage of labor, and physical health. An older labor force is less capable of learning new technologies and acquiring information, which is not conducive to increased green production. The healthier the farmer is, the easier it is for him to learn and adopt new technologies and implement green production. The social capital variables assessed whether farmers had served as village cadres and expressed their degree of trust in their neighbors. Rural China is a society of acquaintances, and farmers obtain information through social interaction, which plays an important role in the diffusion of green technologies in agriculture [44]. Li and Mu et al. [45] found that village cadres generally have a broader perspective and product awareness, and are more inclined to apply organic fertilizers. Natural capital variables referred to the local cold chain logistics status and to the local citrus-processing plant situation. A higher degree of local cold chain logistics is conducive to the development of e-commerce, thus reducing transaction costs, increasing product price expectations, and promoting the transformation of agricultural production methods [46]. Processing plants are conducive to increasing the added value of products and to transforming production methods. Finally, regional dummy variables were included in the regressions to reduce the estimation bias caused by regional differences.

The specific definitions and assignments of the variables are shown in Table 1.

Table 1. Variable definitions and statistical characteristics.

Variable	Variable Name	Symbol	Assignment Description	Mean Value	Standard Deviation
Dependent variable	Chemical fertilizer application	Y	The logarithm of chemical fertilizer input per mu 1 mu = 1/15 ha	6.824	0.854
Independent variable	Labor migration	X	With labor migration in the family: yes = 1, no = 0	0.321	0.467
Intermediate variable	Accessibility to information and technology of green production	M_1	Ease of access to green production information and technologies (1 = very easy; 2 = easy; 3 = general; 4 = difficult; 5 = very difficult)	3.415	0.870
	Non-agricultural income	M_2	The logarithm of household non-agricultural income	1.759	1.211
Controlled variable					
Economic capital	Total household income	K_1	The logarithm of total household income in 2018	2.552	1.031
	Citrus sales revenue	K_2	Citrus sales revenue in 2018 (unit: ten thousand yuan)	10.951	55.831
Human capital	Age	K_3	Age of planter	55.247	10.277
	Health	K_4	Health of planter (1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good)	3.890	0.793
	Labor force	K_5	Number of citrus-growing laborers in family	2.051	1.028
Social capital	Village officials	K_6	Whether served as village officials: yes = 1, no = 0	0.097	0.296
	Trust in neighbors	K_7	Level of trust in neighbors (1 = very distrustful; 2 = relatively distrustful; 3 = fair; 4 = relatively trustful; 5 = very trustful)	3.785	0.827

Table 1. *Cont.*

Variable	Variable Name	Symbol	Assignment Description	Mean Value	Standard Deviation
Natural capital	Market distance	K_8	Distance to the nearest market (km)	3.509	2.971
	Planting experience	K_9	Citrus planting period (years)	13.981	10.709
Material capital	Cold chain logistics	K_{10}	Availability of local cold chain logistics: yes = 1, no = 0	3.219	1.14
	Processing plant	K_{11}	Is there a citrus processing plant in this township: yes = 1, no = 0	0.445	0.497
Regional characteristics	Sample source	K_{12}	1 = Chengdu City; 2 = Meishan City; 3 = Nanchong City; 4 = Ziyang City; 5 = Neijiang City; 6 = Yibin City	3.187	1.530

3.3. Methodology

3.3.1. Propensity Score Matching Method

The paper uses the propensity score matching method to investigate the impact of labor migration on citrus growers' chemical fertilizer usage. Because it is a "self-selection" process for residents to choose whether or not to engage in labor migration, the parameter estimation results are skewed. This paper effectively addresses the endogeneity problem by establishing a counterfactual hypothesis [47].

As a first step, the fitted value of the conditional probability of labor migration in citrus farming was estimated by a Logit model. The calculated propensity score (PS) is:

$$PS_i = P_r[D_i = 1|X_i] = E[D_i = 0|X_i] \quad (1)$$

$D_i = 1$ represents families of citrus growers with labor migration, $D_i = 0$ indicates families without labor migration, and X_i serves as the observable characteristics of the citrus growers (covariates).

In this paper, the kernel matching method, the radius caliper matching method and the nearest neighbor matching method were used to calculate the average treatment effect (ATT) of the treatment groups.

Finally, the differences in chemical fertilizer application per acre between the treatment group and the control group of citrus growers were calculated and estimated by using the ATT of the chemical fertilizer application input of the treatment group (i.e., families with labor migration):

$$ATT = E(Y_1|D = 1) - E(Y_0|D = 1) = E[Y_1 - Y_0|| D = 1] \quad (2)$$

Y_1 is the chemical fertilizer application amount per mu of citrus-grower families with labor migration, and Y_0 is the chemical fertilizer application amount per mu of citrus-grower families without labor migration.

3.3.2. Mediating Effect

In this paper, the stepwise test of Wen et al. [25] was used to further verify the transmission mechanism of labor migration on chemical fertilizer application by citrus growers. The mediating effect model was set as follows:

$$Y_i = \alpha_0 + \alpha_1 X_i + \alpha_2 K_i + \varepsilon_i \quad (3)$$

$$M_i = \beta_0 + \beta_1 X_i + \alpha_2 K_i + \mu_i \quad (4)$$

$$Y_i = \gamma_0 + \gamma_1 X_i + \gamma_2 M_i + \alpha_2 K_i + \varphi_i \quad (5)$$

The explanatory variable X_I represents the labor migration of citrus growers. X is equal to 1 when citrus growers have a labor migration situation; otherwise, X is equal to 0.

I represents the intermediary variable, including the off-farm income of citrus growers and the difficulty of obtaining green production information and technology. I_I indicates the control variables, including annual household income, citrus sales income, age, family labor force per mu, laborers' physical condition, experience of village officials, trust in neighbors, local cold-chain logistics, local citrus-processing factory status, etc. I, I_i, and I denote residuals, and α_1 reflects the total effect of migrant-working on the chemical fertilizer application amount of the citrus grower. β_1 shows the influence of migrant-working on the intermediary variables. γ_1 and γ_2 respectively indicate the direct effects of labor migration and intermediate variables on the chemical fertilizer application amount of the i-th citrus grower. Bringing (4) into (5), $\beta_1\gamma_2$ represents the indirect impact of labor migration on the chemical fertilizer application amount used by citrus growers through intermediary variables.

3.4. The Mean Value Comparison of Characteristics among the Two Groups of Citrus Growers

Table 2 shows the *t*-tests for the differences in the means of the characteristic variables between households with and without labor migration. Households with labor migration had better access to green production information and technology than those without labor migration. Households with labor migration also had higher off-farm income and consumed significantly less fertilizer. In terms of control variables, citrus grower households with labor migration have higher incomes, are younger, have been growing for longer, and are more likely to reduce fertilizer inputs. Of course, more empirical tests are needed to verify these findings.

Table 2. Test results of the difference in the mean values of basic variables between growers.

Families with and without Labor Migration			
Variable Name	**with Labor Migration**	**without Labor Migration**	**Difference**
Chemical fertilizer application	6.746 (0.062)	6.861 (0.033)	−0.115 *
Non-agricultural income	2.431 (0.064)	1.442 (0.050)	−0.989 ***
Accessibility of information and technology of green production	3.241 (0.049)	3.496 (0.038)	−0.255 ***
Total household income	2.919 (0.052)	2.379 (0.045)	0.540 ***
Citrus sales revenue	8.824 (1.207)	11.954 (2.834)	−3.130
Age	54.085 (0.447)	57.709 (0.578)	−3.624 ***
Health	3.926 (0.033)	3.816 (0.052)	0.110 *
Labor force	0.516 (0.333)	2.134 (0.022)	−1.618
Village officials	0.096 (0.018)	0.097 (0.012)	−0.001
Trust in neighbors	3.812 (0.052)	3.772 (0.035)	0.040
Market distance	3.690 (0.186)	3.423 (0.126)	0.267
Planting experience	14.613 (0.714)	13.685 (0.436)	0.928 **
Cold chain logistics	3.268 (0.069)	3.197 (0.049)	0.089
Processing plant	0.475 (0.031)	0.432 (0.021)	0.043
Sample source	3.065 (0.096)	3.244 (0.065)	0.179

Notes: ***, **, and * represent the significance level at 1%, 5%, and 10%, respectively; standard error in parentheses.

4. Results

4.1. Impact of Labor Migration on the Amount of Chemical Fertilizer Applied

4.1.1. Results of the Logit Model Estimation

The conditional probability fitted values of citrus producers with labor migration were used in a regression analysis to match the samples of citrus growers with and without labor migration. The maximum likelihood estimation results based on the Logit model are shown in Table 3.

The table shows that total household income has a strong positive effect on whether decision-makers choose to migrate in the labor force. This may be due to the fact that wealthier households have a greater incentive to engage in off-farm work due to their

ability to diversify their business risks. Citrus sales income has a strong negative effect on whether decision-makers choose labor migration because households with higher farm incomes tend to grow on a larger scale, which requires more labor [48]. Physical fitness has a strong favorable effect on whether decision-makers choose labor migration, most likely because farmers with superior physical fitness are more likely to find work and earn higher incomes, and therefore prefer non-farm work. Regional fixed effects also have a significant effect on labor migration, which suggests the need to control for region.

Table 3. Estimated model results for citrus-planting families with labor migration based on the Logit model.

	Variable Name	Coefficient	Standard Error	Z Statistics
Economic capital	Total household income	1.038 ***	0.125	8.31
	Citrus sales revenue	−0.023 ***	0.007	−3.27
Human capital	Age	−0.174	0.110	−1.58
	Health	0.052 ***	0.009	5.32
	Labor force	0.196	0.179	1.09
Social capital	Village officials	−0.281	0.294	−0.96
	Trust in neighbors	0.080	0.106	0.76
Natural capital	Market distance	0.022	0.029	0.77
	Planting experience	−0.153	0.127	−1.20
Material capital	Cold chain logistics	−0.002	0.082	−0.02
	Processing plant	0.137	0.201	0.68
Regional features	Sample source	−0.120 *	0.067	−1.80
Constant term		−5.269 ***	1.044	−5.05
LR statistics		127.26 ***		
Pseudo R^2 Sample size		0.126		
		807		

Notes: ***, and * represent the significance level at 1%, and 10%.

4.1.2. Common Support Domain

To ensure matching quality, the conditions of the matching common support domain must be taken into consideration. The wider the common support domain, the smaller the occurrence of sample loss in the matching process. Figure 2 represent probability density plots of propensity scores for the labor migration and non-migration groups before and after matching. It can be seen that there is a large range of overlap between the propensity score intervals of the two matched samples, and the matching results are better.

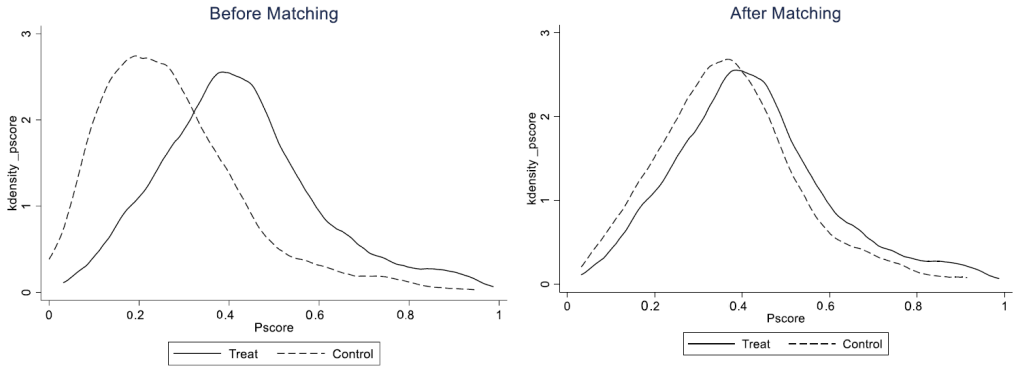


Figure 2. The common support domains of labor migration treatment group and the control group. (**a**) Before matching; (**b**) After matching.

4.1.3. Balance Test

After the samples are matched, the statistical significance of the differences in explanatory variables between the two groups of samples is further tested. The balance test results

are shown in Table 4. Pseudo R^2 decreased from 0.125 to 0.003–0.006, LR statistics decreased from 126.79 to 1.98–3.96, mean deviation dropped from 13.5 to 3.7–4.3, and median deviation dropped from 7.3 to 2.5–3.1. The difference in explanatory factors between the treatment and control groups was dramatically reduced after sample matching, and the degree of matching was improved.

Table 4. Matching quality indicators.

Matching Method	Pseudo R^2	*lr* Value	*p*-Value	Mean Deviation	Median Deviation
Before matching	0.125	126.79	0.000	13.5	7.3
K-nearest neighbor matching	0.006	3.96	0.984	4.3	2.5
Caliper matching	0.004	2.96	0.996	4.3	3.6
Kernel matching	0.003	1.98	0.999	3.7	3.1

4.1.4. Analysis of Average Treatment Effects

As shown in Table 5, the ATT for kernel matching passed the test at the 1% significance level, and the ATT for caliper matching and K-nearest neighbor matching passed the test at the 5% significance level. The average of fertilizer inputs per acre decreased from 6.95 to 6.74., a decrease of 3.06%, if the family members choose labor migration. Thus, labor migration can reduce the chemical fertilizer application input per mu significantly. This is consistent with the study of Zhang et Al. that the experience of urban–rural migration can help reduce the use of chemical fertilizers in rice production in China [22].

Table 5. Average treatment effects of labor migration on chemical fertilizer application amounts.

Matching Method	Mean of Treatment Group	Mean of the Control Group	ATT	*t* Value
K-nearest neighbor matching	6.741	6.953	−0.213 **	−2.53
Caliper matching	6.741	6.947	−0.206 **	−2.55
Kernel matching	6.746	6.935	−0.212 ***	−2.43
Average value	6.743	6.945	−0.210 **	−2.50

Notes: ***, and ** represent the significance level at 1%, and 5%, respectively.

4.1.5. Robustness Test

The IPWRA model has been adopted in this thesis to verify the impact of labor migration on the chemical fertilizer application of citrus growers and to test the robustness of the regression results. IPWRA is a bi-robust estimation model that combines the inverse probability weighting method (IPW) and the regression adjustment method (RA) to generate a consistent estimate of the parameters to be estimated using one of two approaches [49]. The estimated results of the IPWRA model are shown in Table 6 and the estimated results of the RA model and the IPW model are also given in the table for comparative analysis. It is evident that under the three different estimation methods of the RA model, the IPW model, and the IPWRA model, the estimated results of treatment effects are roughly the same as those in Table 5, showing labor migration has a significant impact on the chemical fertilizer application of citrus growers. Thus, it can be stated that the regression results of the PSM model are more robust and its conclusions are more reliable.

Table 6. Robustness test of the overall effect of labor migration on the chemical fertilizer application amounts of citrus growers.

Method	RA	IPW	IPWRA
ATT	6.893 ***	6.844 ***	6.871 ***
	(0.043)	(0.086)	(0.032)

Notes: *** represent the significance level at 1%.

4.2. Heterogeneity Test

4.2.1. Distinguishing between Farmers of Different Ages

Schultz [50] concluded that human capital plays an important role in the process of technological progress and transformation of traditional practices in agriculture. In a broad sense, the knowledge, skills, health and physical strength of the agricultural labor force are the main components of human capital, all of which change with age. Therefore, in this paper, the overall sample is divided into two subsamples, the younger farmers group and the older farmers group, with the international standard of 60 years old as the boundary. Those above 60 years old are the older farmers group, and those below 60 years old are the younger farmers group. According to the results of the data in Table 7, labor migration had a more significant effect on the chemical fertilizer application behavior of the younger farmer group compared to the older farmer group, with an average reduction of 0.224. This may be because the older labor force, although experienced, tends to have an older knowledge system and is less able to recognize and learn new technologies [51]. The younger labor force is more capable of learning and is more conducive to changing mindsets.

Table 7. Effects of labor migration on chemical fertilizer application by farmers of different ages.

Matching Method	Younger Farmers			Older Farmers		
	Treatment Group	Control Group	ATT	Treatment Group	Control Group	ATT
K-nearest neighbor matching	6.858	7.091	−0.232 **	6.512	6.468	0.043
Caliper matching	6.858	7.075	−0.216 ***	6.512	6.479	0.032
Kernel matching	6.849	7.076	−0.226 ***	6.509	6.585	0.036
Average value	6.855	7.081	−0.224 ***	6.511	6.511	0.037

Notes: *** and ** represent the significance level at 1%, and 5%.

4.2.2. Distinguishing between Farmers with Different Agricultural Incomes

Considering the differences in the effects of labor migration on farmers' chemical fertilizer application behavior under different degrees of part-time employment, the proportion of household agricultural income can be used to assess the degree of part-time employment. Therefore, the proportion of agricultural income of the household is used to assess whether the household's agricultural income is more than 50%. Table 8 shows that labor migration significantly reduces the probability of chemical fertilizer application behavior by 0.151 in farming households with a predominantly agricultural income. A possible reason is that farming households with predominantly agricultural income attach more importance to agriculture. Labor migration promotes farmers' focus on sustainable agricultural farming, thus reducing the amount of fertilizer applied.

Table 8. Effects of labor migration on chemical fertilizer application by farmers with different farm incomes.

Matching Method	High Agricultural Income			Low Agricultural Income		
	Treatment Group	Control Group	ATT	Treatment Group	Control Group	ATT
K-nearest neighbor matching	6.941	7.157	−0.215 *	6.604	6.745	−0.140
Caliper matching	6.668	6.741	−0.073 *	6.950	7.114	−0.163
Kernel matching	6.950	7.115	−0.164 *	6.617	6.715	−0.097
Average value	6.853	7.004	−0.151 *	6.724	6.858	−0.133

Notes: * represent the significance level at 10%.

4.3. Mechanism Analysis of the Influence of Labor Migration on the Amount of Chemical Fertilizer Applied by Citrus Growers

It can be concluded from model (5) that labor migration can significantly inhibit chemical fertilizer application. Citrus farmers' off-farm income has a partly mediating influence, according to models (5), (6), and (8). The difficulty of citrus growers' access to green production information and technology plays a partly mediating role in models (5), (7), and (9) as well. It should be noted that the total effect of labor migration on the chemical fertilizer application quantity is −0.147, which is greater than the total effect after adding intermediary variables, −0.072 and −0.094. Table 9 demonstrates the mediating effect of labor migration on farmers' fertilizer application and the total effect as a percentage of the total effect. To enhance the robustness of the mediating effect test, Bootstrap method was applied. The results of the robustness test in Table 8 are consistent with Table 9. Hypotheses H1 and H2 are proved (Table 10).

Table 9. Regression results of effects of labor migration and intermediary variables on chemical fertilizer application amounts of citrus growers.

Variable	Model 5 Chemical Fertilizer Application Rate	Model 6 Off-Farm Income	Model 7 Information and Technology of Green Production	Model 8 Chemical Fertilizer Application Rate	Model 9 Chemical Fertilizer Application Rate
Labor migration	−0.147 ** (0.060)	0.465 *** (0.065)	−0.293 *** (0.056)	−0.094 * (0.062)	−0.095 * (0.057)
Non-agricultural income	—	—	—	−0.123 *** (0.028)	—
Information and technology of green production	—	—	—	—	0.178 *** (0.048)
Controlled variable	Yes	Yes	Yes	Yes	Yes
F		82.98	32.98	25.18	22.73
Prob > chi (2)	0.000	0.000	0.000	0.000	0.000
R^2		0.563	0.329	0.251	0.262

Notes: ***, **, and * represent the significance level at 1%, 5%, and 10%, respectively; standard error in parentheses.

Table 10. The mediating effects of off-farm and mediating variables on the amount of chemical fertilizer applied by citrus growers, and bootstrap test.

	Total Effect	Mediating Effect	Proportion	BootSE	LLCI	ULCI
Information and technology of green production	−0.147	−0.052	0.353	0.017	−0.086	−0.017
Labor migration income	−0.147	−0.057	0.387	0.015	−0.088	−0.026

5. Conclusions

With accelerated urbanization in China, the number of migrant workers is increasing year by year. Labor migration not only raises household income but also affects households' investment choices in agricultural production. In this study, the micro survey data method was used to study 814 citrus growers in Sichuan Province, and the propensity score matching method was used to construct a counterfactual framework to empirically investigate the impact of labor migration on fertilizer application among citrus growers. The internal influence mechanism was then addressed.

The study showed that, first, the boosting effect of capacity accumulation brought on by farmers' labor migration was greater than the weakening effect of labor constraints, and the average chemical fertilizer application per acre decreased from 6.95 to 6.74 after farmers' labor migration, a 3.06 percent decrease; second, the transmission mechanism showed that

labor migration reduced chemical fertilizer use by allowing farmers to acquire knowledge and technology of green production and increase off-farm income.; third, there was strong heterogeneity in the effect of labor migration on farmers' fertilizer application behavior, with higher-income and younger farmers choosing labor migration to promote a reduction in their chemical fertilizer application.

Based on the above findings, the following insights can be stated: First, the government should appropriately guide farmers to choose labor migration and create a favorable labor environment. Second, the government should increase publicity of green agriculture knowledge and technology to enable farmers who choose labor migration to understand the current situation of excessive use of soil chemical fertilizers and other hazards in their region, and to encourage them to invest their non-farm income in green production. Farmers with higher agricultural income and those of younger ages, in particular, should be encouraged to choose labor migration and be trained to become new agricultural business entities.

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