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Part-Time Farming, Agricultural Socialized Services, and Organic Fertilizer Use: Implications for Climate Change Mitigation

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Abstract: The adoption of organic fertilizers is essential for advancing China's green agricultural transformation, ensuring food security, and supporting agricultural adaptations. However, several challenges hinder its widespread use in rural areas. This study examines how part-time farming and agricultural service provision influences organic fertilizer use, employing fixed and random effects models on data from 523 households in Shaanxi Province, one of China's main apple-producing regions. The results reveal: (1) Part-time farming reduces organic fertilizer use by 7.6%, primarily due to labor shortages; (2) Higher non-farm income exacerbates this decline, particularly for Type II part-time farmers; and (3) Mechanized fertilization services help mitigate this reduction. These findings offer valuable policy insights for promoting organic fertilizer adoption in the context of shifting rural labor dynamics and highlight the complex interactions between farming practices and labor migration in the broader trajectory of organic fertilizer use. Moreover, this study highlights the role of organic fertilizer use in enhancing food security while also helping to reduce the carbon footprint of the crop sector in China.

Keywords: part-time farming; organic fertilizer; agricultural socialized services; labor migration; food security; agricultural adaptations

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1. Introduction

Excessive chemical fertilizer use has long been a critical issue in China's agriculture [1], compromising production efficiency and causing widespread environmental pollution [2]. This poses substantial risks to food safety [3,4]. In the 1970s, China imported fertilizer production equipment from the Soviet Union, the Netherlands, and the United Kingdom, leading to a sharp increase in chemical fertilizer use. Fertilizer application rates rose from under 50 kg per hectare in 1970 to about 100 kg per hectare by 1979. By the 1980s, China had become the world's largest fertilizer consumer [5]. With rapid agricultural growth, China's fertilizer usage surpassed international environmental safety thresholds in the 1990s. Data from the National Bureau of Statistics of China indicate that, since 1994, the total application of nitrogen (N), phosphorus (P), and potassium (K) fertilizers in agriculture has consistently surpassed 225 kg per hectare. This usage reached a peak of 363 kg per hectare in 2014 and was recorded at 299 kg per hectare in 2022 (Figure 1).

Thus, we are challenged by increasing fertilizer use, making the development of strategies for sustainable agriculture essential [6,7]. Organic fertilizers, as an eco-friendly option, contribute significantly to environmental sustainability and enhanced agricultural productivity. They supply crops with abundant nutrients, particularly the organic matter essential for soil microorganisms, which helps improve soil fertility and crop yields. Unlike chemical fertilizers, organic fertilizers provide a steady, ongoing supply of nutrients that support continuous crop growth. Additionally, organic fertilizers improve soil structure, enhance water and nutrient retention, and help prevent soil erosion and compaction. By

using natural substances, organic fertilizers also reduce environmental pollution, mitigating water contamination and soil degradation associated with excessive chemical fertilizers, thereby promoting sustainable agricultural development [8–10].

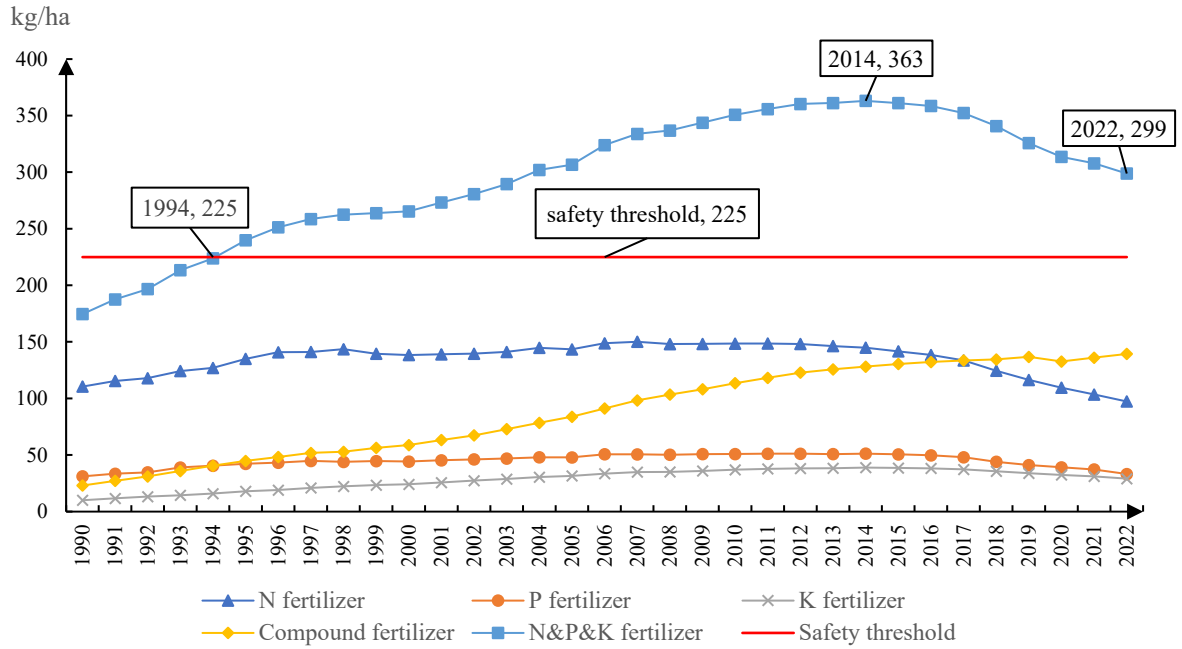


Figure 1. Fertilizer Application Intensity in Chinese Agriculture from 1990 to 2022. National Bureau of Statistics of China.

In 2015, the Chinese government introduced the 'Zero Growth in Fertilizer Use' policy, accompanied by a range of initiatives. Among these, organic fertilizer substitution has been identified as a sustainable long-term strategy for reducing chemical fertilizer application and has been featured in the No. 1 Central Document for several consecutive years. However, their adoption in China remains limited, and significant challenges hinder widespread use [11]. Research indicates that China's organic fertilizer utilization rate is only around 20%, compared to over 50% in most developed nations [12]. A survey of large-scale grain producers in Anhui Province revealed that organic fertilizers were applied to only 22% of the total cultivated area [13]. Similarly, a study in Hubei Province found that nearly 70% of farmers used organic fertilizers on less than 30% of their crops [14]. In Shaanxi Province, a major apple-producing region, this study finds organic fertilizer application rates below 1398 kg per acre, an absolute contrast to levels seen in modern agricultural countries like the Netherlands and the United States.

The limited use of organic fertilizers in China may be linked to the large-scale migration of rural labor to non-farm sectors. Since the reform and opening-up period, China has eased restrictions on labor mobility, and rapid urbanization has drawn substantial numbers of rural workers away from agriculture. This shift has created a labor redistribution within the agricultural sector, leading to a rise in 'part-time farmers,' who divide their time between farm and non-farm work. As a result, rural household income levels and structures have shifted, profoundly affecting agricultural production practices and the allocation of resources. On the one hand, labor migration reduces surplus agricultural labor, diversifies household income, and enhances the capacity for investment in farming activities [15–17]. On the other hand, studies suggest that migration has led to labor shortages in agriculture, particularly impacting labor-intensive inputs [18–20].

Research on the impact of rural labor migration to non-farm sectors on organic fertilizer use remains limited, with no consensus in the academic community. Some studies suggest that farmers' engagement in non-farm work can hinder eco-friendly agricultural practices [21,22] and reduce the application of organic fertilizers [23]. An empirical study

from Iowa and Missouri, USA, also found that higher non-farm income correlates with a lower likelihood of using organic fertilizers [24]. Conversely, other research shows the opposite: higher non-farm income is associated with greater organic fertilizer use [25,26]. A study in semi-arid regions of West Africa indicated that part-time farming increases the likelihood of organic fertilizer application [27]. These findings provide a foundational basis for analyzing the relationship between non-farm labor participation and organic fertilizer use in this study.

Agricultural socialized services in China have helped mitigate some of the effects of rural labor migration to non-farm sectors. These services emerged in response to the complex challenges of labor shortages, outdated farming practices, and resource constraints faced by smallholder farmers. Offering technical support, machinery access, a variety of improvements, and agency sales, agricultural socialized services shift production from individual farms to a specialized division of labor across the entire industry. This specialized approach enables stakeholders to leverage their expertise, easing farmers' resource limitations in accessing inputs [28]. As rural labor migrates to non-farm sectors, these services can play a crucial intervening role.

Using household data from four major apple-producing counties in Shaanxi, China, this study examines the impact of part-time farming on organic fertilizer use. The research has three objectives: (1) to clarify the mechanisms by which non-farm labor participation influences organic fertilizer application; (2) to differentiate between the 'push' and 'pull' effects, identifying the varying impacts of different levels of non-farm labor participation; and (3) to assess the moderating role of agricultural socialized services.

This study makes two key contributions. First, it develops a theoretical framework to analyze farmers' organic fertilizer use from the perspective of non-farm labor migration, incorporating the moderating influence of agricultural socialized services. This framework provides insights into farmers' decision-making processes regarding resource allocation, enriching the understanding of farmer behavior. Second, in the context of China's 'zero growth in fertilizer use' policy and rural labor migration, this study investigates organic fertilizer application behavior, offering policy recommendations for sustainable agricultural development in China and other developing countries transitioning towards greener practices.

2. Theoretical Analysis

Assuming rational economic behavior, farmers' decisions to use organic fertilizers are driven by profit maximization. Given household labor and capital constraints, farmers' participation in non-farm labor reallocates resources between agriculture and non-farm sectors [29]. This reallocation impacts net returns from both sectors, leading farmers to assess the combined benefits of labor and capital investments when determining whether to apply organic fertilizers.

This study proposes that part-time farming influences organic fertilizer use in two ways (Figure 2). On the one hand, non-farm labor participation boosts non-farm income, easing household liquidity constraints and creating an income-driven 'pull' effect that encourages organic fertilizer use. On the other hand, reduced agricultural labor input generates a labor loss effect, resulting in a 'push' effect that may discourage its application. This framework helps understand how income and labor loss affect the adoption of organic fertilizers among farmers.

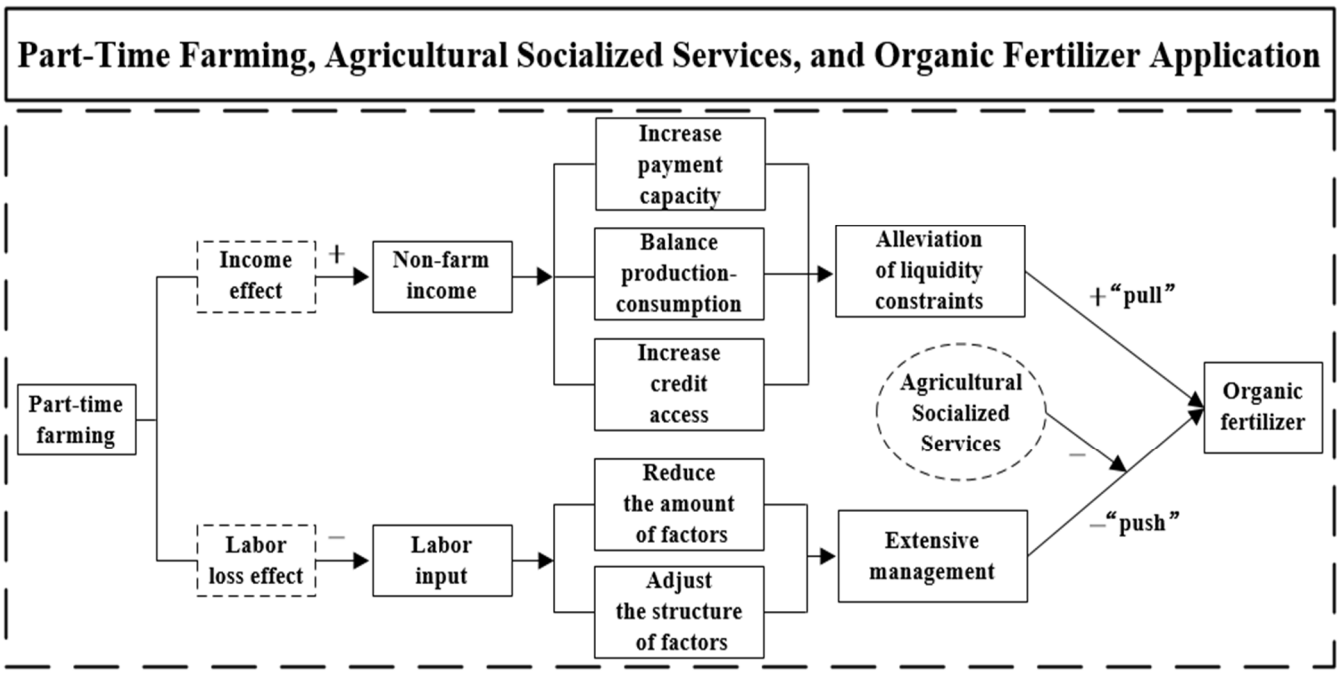


Figure 2. Conceptual Framework. Authors.

2.1. Income Effect

Research shows that part-time farmers engaged in both agriculture and non-farm work often face significant constraints related to operating scale and limited capital [30]. Rising costs of agricultural inputs, long investment return cycles, and restricted access to credit tighten liquidity constraints, limiting their ability to invest in agricultural production [31]. Organic fertilizers, which are rich in organic matter and beneficial microorganisms, are crucial for improving crop quality [32]. However, their higher unit price and slow-release nature [33–36], coupled with rising input costs, can deter farmers from using them, particularly when short-term returns are low.

Part-time non-farm work provides wage income that directly increases household cash flow, enhancing farmers' capacity to invest in organic fertilizers and balancing short-term consumption with agricultural investments. Moreover, non-farm income strengthens household wealth and repayment capacity, facilitating access to formal credit channels [37,38]. Based on this, this study posits the following hypothesis:

H1. *Part-time farming generates an income effect that positively impacts the application of organic fertilizers.*

2.2. Labor Loss Effect

Some studies have shown that part-time farming can lead to a decline in agricultural investment [20,39]. In this study, organic fertilizer is considered a labor-intensive production factor, with relatively high labor costs associated with its application process [40,41]. With limited household labor availability, part-time farming is likely to reduce the use of organic fertilizers. On one hand, as household labor shifts to non-farm sectors, the opportunity cost of agricultural labor increases, prompting farmers to focus more on non-farm activities. This shift leads to a gradual reduction in agricultural inputs, particularly in labor-intensive production factors like organic fertilizers. On the other hand, as the opportunity cost of labor rises, the relative returns on other factors decrease, prompting farmers to adjust the input structure of production factors to stabilize output. For example, farmers might replace organic fertilizers with chemical fertilizers that have similar functions but require less labor, thereby alleviating labor shortages. Both aspects reflect extensive management

practices caused by reduced agricultural labor supply, which negatively impacts farmers' use of organic fertilizers. Based on this, this study proposes Hypothesis 2.

H2. *Part-time farming causes a labor loss effect, which negatively affects organic fertilizer application.*

2.3. Total Effect

Based on the assumption of rational economic behavior, farmers' decisions to apply organic fertilizers follow the principle of profit maximization. In this study, farmers' income consists of wage income and net agricultural production income. If household labor and capital were not constrained, part-time farming would be considered to have no impact on the application of organic fertilizers. However, household labor and capital are limited, and with the large-scale migration of rural labor to non-farm sectors, the opportunity cost of agricultural labor continues to rise, becoming increasingly expensive. Conversely, the relative returns on other production factor inputs decrease, making the opportunity cost of applying organic fertilizers potentially much higher than the benefits they generate. Moreover, organic fertilizers are slow-acting and provide limited short-term returns. As a result, the income effect generated by part-time farming is relatively weak, while the labor loss effect outweighs the income effect. Furthermore, as the extent of farmers' part-time farming deepens, the gap between the income effect and the labor loss effect widens further. Based on this, this study proposes Hypothesis 3 and Hypothesis 4.

H3. *The labor loss effect outweighs the income effect and inhibits organic fertilizer application.*

H4. *Higher non-farm income reduces the likelihood of applying organic fertilizers.*

2.4. Intervention of Agricultural Socialized Services

Agricultural socialized services are an important means of promoting the organic integration of smallholder farmers with modern agriculture. They play a positive role in alleviating resource constraints faced by farmers [42] and promoting the green transformation of agriculture [43]. Studies have shown that agricultural socialized services introduce advanced production factors, such as modern technology and new agricultural machinery, into the agricultural production process and establish standardized technical guidelines. This helps address the shortcomings of smallholder farmers in terms of labor quantity and quality and improves the extensive management practices of traditional agricultural production [44,45]. Therefore, from the perspective of factor substitution, machinery and technical guidance services related to fertilization have a significant substitutive effect on agricultural labor. The loss of agricultural labor caused by farmers' participation in part-time farming can be compensated by agricultural socialized services, such as machinery and technical support. Based on this, this study proposes Hypothesis 5.

H5. *Agricultural socialized services can reduce the negative impact of part-time farming on organic fertilizer application.*

3. Data and Methods

3.1. Data

This study selected Shaanxi Province, one of China's main apple-producing regions, as the research area. A survey was conducted with 523 apple farming households across 12 towns and 54 villages in Pucheng County, Luochuan County, Yanchuan County, and Huangling County. The survey collected data on the farmers' production and management conditions from 2017 to 2019, including individual characteristics, household demographics and income, and the input of production factors such as organic fertilizers. During data cleaning, some outliers were removed, resulting in a three-year panel dataset comprising 523 households and 1569 valid samples.

3.2. Variable Description

This study examines the impact of part-time farming on the likelihood of organic fertilizer application. In our study, the focus is on whether farmers use organic fertilizers as a production behavior, so we follow the approach in prior research [12,13]; the dependent variable is defined as "organic fertilizer application". Farmers who apply organic fertilizers are assigned a value of 1, while those who do not are assigned a value of 0. Drawing on existing literature, this study uses "whether part-time farming is practiced" to indicate farmers' participation in non-farm labor. Farmers with a non-farm income proportion exceeding 5% are assigned a value of 1, while those with a non-farm income proportion of 5% or less are assigned a value of 0 [46–48].

This study controls for influencing factors across four levels. First, at the individual farmer level, variables include age, gender, years of education, village cadre status, Communist Party membership, and knowledge of organic fertilizers and related policies on chemical and organic fertilizers. Second, at the household level, variables include the number of household laborers, per capita income, and debt status. Third, at the agricultural production level, variables include farm size, NPK fertilizer input costs, the number of fertilization training sessions attended, agricultural insurance purchase status, and whether subsidies were received for purchasing fertilization machinery. Fourth, dummy variables are used to control for county-level regional effects. Table 1 presents the definitions and descriptive statistics of the variables.

Table 1. Variable description and summary statistics (n = 523).

Variable	Definition	Mean	SD	Min	Max
Orgfertilizer	Whether organic fertilizers are applied (1 = Yes; 0 = No)	0.734	0.251	0	1
Part-time	Whether part-time farming is practiced (1 = Yes; 0 = No)	0.364	0.481	0	1
Age	Years old	53.258	8.922	27	77
Gender	1 = Male; 0 = Female	0.946	0.225	0	1
Education	Years of education	7.822	3.247	0	15
Villcadre	Village cadre status (1 = Yes; 0 = No)	0.108	0.311	0	1
Commparty	Communist Party membership (1 = Yes; 0 = No)	0.182	0.386	0	1
Knoworg	Knowledge of organic fertilizers (1 = High; 0 = Low)	0.948	0.221	0	1
Knowpolicy	Knowledge of policies on fertilizers (1 = High; 0 = Low)	0.367	0.482	0	1
Labor	The number of household laborers	3.74	1.641	1	6
Perincome	Per capita income (10,000 CNY)	1.299	1.625	0.122	29.3
Debt	Whether the household is in debt (1 = Yes; 0 = No)	0.528	0.499	0	1
Farmscale	Farm size (Chinese acre)	12.301	16.916	2	290
NPK_cost	The cost of NPK (Ten thousand CNY/Chinese acre)	0.045	0.124	0	1.524
Train	Times of fertilization training attended	1.096	1.816	0	20
Insurance	Whether to purchase agricultural insurance (1 = Yes; 0 = No)	0.489	0.5	0	1
Machsubsity	subsidy for purchasing organic fertilizer application machinery (1 = Yes; 0 = No)	0.208	0.406	0	1
Region	1 = Pucheng County; 2 = Yanchuan County; 3 = Luochuan County; 4 = Huangling County	2.491	1.133	1	4

3.3. Econometric Model

Based on three-year panel data, this study employs random effects and fixed effects models to empirically test the impact of part-time farming on the application of organic fertilizers. The econometric model is expressed as follows:

$$Orgfertilizer_{it} = \alpha_0 + \alpha_1 Part\text{-}time_{it} + \beta X_{it} + \varepsilon_{it} \quad (1)$$

$$Orgfertilizer_{it} = \alpha_0 + \alpha_1 Part\text{-}time_{it} + \beta X_{it} + u_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Expression (1) represents the random effects model, and Expression (2) represents the fixed effects model. i denotes the individual, t denotes the observation time, and X_{it} represents the control variables. u_i represents individual fixed effects, λ_t represents time fixed effects, and ε_{it} represents the random error term. In the empirical analysis, this study primarily employs the Logit model for regression analysis.

In panel data analysis, endogeneity is a core issue. Endogeneity can arise from omitted variables, measurement errors, or reverse causality. To address these issues, fixed effects models and random effects models have different roles and approaches in mitigating endogeneity.

3.3.1. Fixed Effects Model

The fixed effects model mitigates the endogeneity problem by eliminating unobserved individual heterogeneity (those individual characteristics that do not change over time, such as personality, ability, talent, etc.). The fixed effects model assumes that these individual characteristics can be absorbed by the individual intercepts, thus controlling their influence on the dependent variable. The formula for the fixed effects model is as follows:

$$y_{it} = \alpha_0 + \beta X_{it} + u_i + \varepsilon_{it} \quad (3)$$

where y_{it} is the dependent variable for individual i at time t. u_i is the individual fixed effect, representing the unobservable time-invariant characteristics of individual i. The fixed effects model assumes that these time-invariant characteristics are correlated with the explanatory variables X_{it}, that is:

$$E(u_i|X_{it}) \neq 0 \quad (4)$$

The fixed effects model eliminates unobserved individual heterogeneity through a "demeaning" process. Specifically, this is conducted as follows:

$$y_{it} - \overline{y_i} = \beta(X_{it} - \overline{X_i}) + (\varepsilon_{it} - \overline{\varepsilon_i}) \quad (5)$$

By subtracting the time averages, the individual fixed effects u_i are eliminated, thereby reducing bias from unobserved individual characteristics.

Therefore, the fixed effects model mitigates endogeneity in two ways. First, it controls for unobserved individual heterogeneity by eliminating the influence of those individual characteristics that do not vary over time. Second, it excludes the impact of time-invariant explanatory variables, such as gender or race. However, it also has some limitations. First, if the explanatory variables show little variation within individuals (i.e., small variation over time), the estimation results of the fixed effects model may be less precise, as the model relies on this variation for estimation. Second, the fixed effects model can only eliminate time-invariant individual heterogeneity and cannot address endogeneity problems that vary over time. To address this second limitation, a two-way fixed effects approach can be adopted, which controls for unobserved factors that change over time. The formula for the two-way fixed effects model is as follows:

$$y_{it} = \alpha_0 + \beta X_{it} + u_i + \lambda_t + \varepsilon_{it} \quad (6)$$

where λ_t represents the unobserved factors that vary over time and are common to all individuals, such as the effects of macroeconomic factors, policy changes, or other external influences that affect all individuals in the dataset similarly over time.

3.3.2. Random Effects Model

The random effects model assumes that u_i is random and uncorrelated with the explanatory variables X_{it}. In other words, in the random effects model, individual heterogeneity is considered random and can be treated as part of the error term.

The assumptions and formula for the random effects model are as follows:

$$E(u_i|X_{it}) = 0 \quad (7)$$

$$y_{it} = \alpha_0 + \beta X_{it} + \varepsilon_{it} \quad (8)$$

The random effects model typically cannot effectively address endogeneity issues. This is because one of the core assumptions of the random effects model is that the individual effects (i.e., unobserved individual characteristics) are uncorrelated with the explanatory variables. If this assumption does not hold, meaning there is a correlation between individual effects and the explanatory variables, then endogeneity problems will lead to biased estimation results. However, the random effects model can estimate the impact of observable factors that do not change over time, such as gender, race, etc.

Therefore, this study uses both models. First, we assume that the time-invariant unobservable factors of the farmers are unrelated to part-time farming and evaluate the estimation results. Then, we apply the fixed effects model to control for factors such as the farmers' personality and ability and estimate the coefficients of the fixed effects model.

4. Empirical Results

4.1. Analysis of Total Effect

This study employs both random effects and fixed effects models to examine the overall impact of part-time farming on the application of organic fertilizers. In the random effects model, Column (5) of Table 2 shows that, after controlling for individual, household, production, regional, and year-specific factors, part-time farming significantly reduces the likelihood of applying organic fertilizers. The sigma_u value is 2.995, indicating considerable variability between individual farmers. The rho value is 0.732, suggesting that individual differences account for 73% of the total variance, highlighting strong heterogeneity among farmers. Some unobservable individual factors remain insufficiently controlled, which may affect the credibility of the random effects model results. For example, a farmer's personal ability can influence both the decision to engage in off-farm work and the decision to apply organic fertilizer. Farmers with greater ability are more likely to take advantage of opportunities for non-agricultural employment to increase their income, and at the same time, they may apply more organic fertilizer due to their more advanced management concepts. In the random effects model, however, these unobservable individual differences cannot be controlled, which can result in biased estimated coefficients. Among other control variables, farmers' awareness of organic fertilizer significantly promotes its use, indicating that the more knowledge a farmer has about organic fertilizer, the more incentivized they are to invest in it. Additionally, household labor and income positively impact the application of organic fertilizer, suggesting that its use is constrained by labor and capital availability.

Table 2. Total Effects: Random Effects Model.

Orgfertilizer	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Part-time	−0.053 ***	−0.057 ***	−0.048 ***	−0.047 ***	−0.051 ***
	(0.013)	(0.014)	(0.013)	(0.013)	(0.014)
Age		−0.001	−0.001	−0.001	−0.001
		(0.001)	(0.001)	(0.001)	(0.001)
Gender		0.029	0.035	0.035	0.028
		(0.033)	(0.032)	(0.033)	(0.033)
Education		0.004	0.002	0.002	0.002
		(0.003)	(0.002)	(0.003)	(0.003)
Villcadre		−0.019	−0.020	−0.024	−0.022
		(0.024)	(0.023)	(0.024)	(0.024)
Commparty		−0.006	−0.005	−0.007	−0.010
		(0.022)	(0.022)	(0.022)	(0.022)
Knoworg		0.128 ***	0.132 ***	0.130 ***	0.126 ***
		(0.026)	(0.026)	(0.026)	(0.026)
Knowpolicy		0.033 *	0.030	0.029	0.029
		(0.019)	(0.019)	(0.020)	(0.020)
Labor			0.010 *	0.011 **	0.010 *
			(0.005)	(0.005)	(0.005)
Perincome			0.011 *	0.011 *	0.011 *
			(0.006)	(0.006)	(0.006)
Debt			0.007	0.008	0.004
			(0.016)	(0.017)	(0.016)
Farmscale				−0.001	−0.001
				(0.001)	(0.001)
NPK_cost				−0.043	−0.051
				(0.051)	(0.051)
Train				0.003	0.001
				(0.006)	(0.005)
Insurance				0.007	0.015
				(0.017)	(0.018)
Machsubsity				0.017	0.022
				(0.023)	(0.023)
Region_Yanchuan					0.005
					(0.022)
Region_Luochuan					0.058
					(0.039)
Region_Huangling					0.019
					(0.025)
Constant	5.971 ***	2.748	0.209	0.244	−0.556
	(0.604)	(2.167)	(2.306)	(2.369)	(2.404)
Time fixed effects	Yes	Yes	Yes	Yes	Yes
sigma_u	3.296	3.125	3.013	3.067	2.995
rho	0.768	0.748	0.734	0.741	0.732
Observations	1569	1569	1569	1569	1569

Note: (i) Except for the intercept term, values reported are marginal effects (dy/dx). (ii) Standard errors are shown in parentheses. (iii) * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In Table 3, this study employs a fixed effects model to address potential endogeneity issues. The findings indicate that, after controlling for unobservable factors at the regional, individual, and time levels, part-time farming significantly reduces the likelihood of applying organic fertilizers at the 1% significance level. Compared to those solely engaged in agricultural production, farmers involved in part-time farming have a 7.6% lower probability of applying organic fertilizers. The results from both the fixed effects and random effects models are consistent with previous findings [23], supporting Hypothesis 3. It can be seen that, compared to the random effects model, the fixed effects model eliminates the influence of time-invariant individual differences, such as personal ability. However, it cannot estimate the effects of observable factors that vary little over time, such as gender.

This study also calculated the BIC values for both random effects and fixed effects models to assess their goodness of fit. Results indicate that the BIC for the random effects model is significantly higher than that of the fixed effects model, suggesting that the fixed effects model provides a more robust fit. Additionally, a Hausman test was conducted, yielding a p-value of 0.02, which leads to the rejection of the null hypothesis. Consequently, the fixed effects model is deemed more appropriate.

Table 3. Total Effects: Fixed Effects Model.

Orgfertilizer	**(1)**	**(2)**	**(3)**	**(4)**
Part-time	−0.129 ***	−0.081 ***	−0.078 ***	−0.076 ***
	(0.029)	(0.027)	(0.026)	(0.026)
Farmer-level control		Yes	Yes	Yes
Household-level control			Yes	Yes
Production-level control				Yes
Individual fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Observations	1569	1569	1569	1569

Note: (i) Values are marginal effects (dy/dx). (ii) Standard errors are shown in parentheses. (iii) *** $p < 0.01$.

This study classifies farmers into three groups—full-time farmers, Type I part-time farmers, and Type II part-time farmers—based on their level of participation in non-farm labor. The analysis in Table 4 reveals that Type I part-time farmers (with 5% to 50% of non-farm income) significantly reduce organic fertilizer use at the 10% significance level, while Type II part-time farmers (with over 50% non-farm income) show a stronger reduction at the 1% level, aligning with the findings of Nunez and McCann [24]. These results indicate that increased non-farm income corresponds to a greater decline in organic fertilizer application, supporting Hypothesis 4 and also lending support to prior studies [49,50]. Furthermore, the reclassification of these groups confirms the robustness of the findings. These findings imply that part-time farming poses a serious threat to implementing zero growth in chemical fertilizer policy. It reinforces that labor loss from the agriculture sector is strongly associated with the adoption of time- and labor-efficient technologies in agriculture. Hence, these findings suggest that paying more attention to full-time farming households holds sufficient potential to realize a transition.

Table 4. Estimates of Type I and Type II Part-Time Farmers.

Orgfertilizer	**(1)**	**(2)**	**(3)**	**(4)**
Full-time	−0.037 *	−0.074 *		
(5% < Non-farm income ≤ 50%)	(0.023)	(0.039)		
Type I part-time			−0.038 *	−0.071 *
(10% < Non-farm income ≤ 50%)			(0.022)	(0.037)
Type II part-time	−0.055 ***	−0.046 ***	−0.052 ***	−0.057 ***
(50% < Non-farm income)	(0.020)	(0.017)	(0.020)	(0.018)
Individual fixed effects	No	Yes	No	Yes
County fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Other factors control	Yes	Yes	Yes	Yes
Observations	1569	1569	1569	1569

Note: (i) Values are marginal effects (dy/dx). (ii) Standard errors are shown in parentheses. (iii) * $p < 0.1$, *** $p < 0.01$.

4.2. Test of Robustness

In Table 5, this study conducted robustness tests using two methods. First, the Ordinary Least Squares (OLS) model was applied, and the results aligned with those of the Logit model as expected. Second, the dependent variable was redefined to assess

"whether commercial organic fertilizers are applied" and "whether farmyard manure is applied". The findings show that part-time farming significantly reduces the use of commercial organic fertilizers but has no significant effect on farmyard manure application. This may be because farmyard manure is locally sourced, saving labor costs compared to commercial fertilizers.

Table 5. Test of Robustness.

	OLS		Commercial Organic		Farmyard Manure	
	(1)	(2)	(3)	(4)	(5)	(6)
Part-time	−0.094 ***		−0.146 ***		−0.076	
(Non-farm income ≤ 5%)	(0.025)		(0.018)		(0.051)	
Part-time		−0.085 ***		−0.171 ***		−0.069
(Non-farm income ≤ 10%)		(0.023)		(0.021)		(0.050)
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Other factors control	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1569	1569	1569	1569	1569	1569

Note: (i) Values are marginal effects (dy/dx). (ii) Standard errors are shown in parentheses. (iii) *** $p < 0.01$.

4.3. Test of Mechanism

In Table 6, this study employs "total household income (ten thousand CNY)" and "household non-farm labor supply time (months)" as proxies to test the income effect and labor loss effect, respectively. Results show that while part-time farming significantly increases total household income, this income does not promote the application of organic fertilizers, suggesting that liquidity constraints are not a primary concern. Conversely, increased non-farm labor supply significantly inhibits organic fertilizer use, supporting the labor loss hypothesis. The findings indicate that macroeconomic policies, such as poverty alleviation, may mitigate liquidity constraints, reducing the observed income effect.

Table 6. Test of Mechanism.

	Income Effect		Labor Loss Effect	
	Total Income	Orgfertilizer	Non-Farm Supply	Orgfertilizer
	(1)	(2)	(3)	(4)
Part-time	0.633 ***		1.653 ***	
	(0.018)		(0.050)	
Total income		0.029		
		(0.033)		
Non-farm supply				−0.018 ***
				(0.003)
Individual fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Other factors control	Yes	Yes	Yes	Yes
Observations	1569	1569	1569	1569

Note: (i) Columns (2) and (4) report marginal effects (dy/dx). (ii) Standard errors are shown in parentheses. (iii) *** $p < 0.01$.

Some studies have shown that government-implemented poverty alleviation policies and production subsidy policies directly increase farmers' cash flow, thereby alleviating household liquidity constraints [51,52]. From the perspective of other policy interventions, China's long-term "poverty alleviation" strategy, which includes establishing a rural minimum livelihood guarantee system, providing monthly financial aid to low-income families, and offering grassroots support for agricultural production, helps balance consumption and production for low-income farming households. Additionally, various agricultural input subsidy policies and the widespread establishment of rural credit cooperatives further

contribute to easing household liquidity constraints. As a result, the income effect in this study is not significant, and Hypothesis 1 cannot be empirically supported; the influence of some other macro policies may have been overlooked. Columns (3) and (4) show that part-time farming significantly increases non-farm labor supply time at the 1% significance level and has a significant negative inhibitory effect on the application of organic fertilizers, consistent with Hypothesis 2.

4.4. Test of Intervention Effect of Socialized Services

This study uses "whether the agricultural cooperative provides technical guidance services" and "whether the cooperative provides machinery services" as proxies for agricultural socialized services to evaluate potential intervention effects. Results in Column (3) of Table 7 show that the interaction term between technical guidance services and part-time farming is insignificant, indicating no effective mitigation of the labor loss effect. However, the interaction between machinery services and part-time farming is significantly positive, suggesting that machinery services alleviate the labor loss effect by substituting labor in tasks such as fertilizer application, thus supporting Hypothesis 5.

Table 7. Test of Intervention Effect of Socialized Services.

Orgfertilizer	**(1)**	**(2)**	**(3)**
Part-time	−0.075 ***	−0.073 ***	−0.073 ***
	(0.025)	(0.025)	(0.024)
Technical services	0.335	—	0.312
	(0.278)		(0.291)
Machinery services	—	0.245	0.228
		(0.239)	(0.232)
Part-time×Technical services	0.135	—	0.141
	(0.144)		(0.197)
Part-time×Machinery services	—	0.033 **	0.027 **
		(0.013)	(0.012)
Individual fixed effects	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Other factors control	Yes	Yes	Yes
Observations	1569	1569	1569

Note: (i) values are marginal effects (dy/dx). (ii) Standard errors are shown in parentheses. (iii) ** $p < 0.05$, *** $p < 0.01$.

4.5. Implications for Climate Change Mitigations

Based on the study's findings, several measures can be implemented to strengthen agricultural resilience and enhance adaptation to climate change. First, since the adoption of organic fertilizers is found to decline under labor loss scenarios, it is recommended to promote the integrated use of fertilizers. Farmers can concurrently apply both chemical and organic fertilizers to improve crop productivity, ensure food security, and boost farm income. This combined approach can reduce the reliance on chemical fertilizers, thereby contributing to climate change mitigation efforts. Second, there is a critical need to provide farmers with modern fertilization machinery. Given that rural labor migration threatens organic fertilizer adoption, the introduction of advanced machinery can optimize the use of organic fertilizers and support broader efforts toward climate-smart agricultural practices. Third, land consolidation can significantly enhance productivity and the adoption of sustainable, climate-resilient practices in agriculture. Facilitating land transfers through leasing mechanisms to larger-scale farmers could promote the use of organic fertilizers, as economies of scale enable these farmers to use resources more efficiently while maximizing profits. This strategy would contribute to improved food security and environmental sustainability in agriculture. Additionally, labor market policies should be revisited to curb the excessive transfer of labor from the agricultural sector, ensuring a balanced labor supply. The Chinese government's support for organic fertilizer use through socialized services

should also be expanded to include financial aid, technical assistance, and modern mechanization to facilitate a just transition to sustainable practices. Moreover, in regions severely affected by rural labor loss, organic fertilizer adoption can be encouraged through incentive mechanisms, such as subsidies or financial rewards for its use. These incentives would accelerate resilience-building and the transition to climate-smart, sustainable agriculture while reducing the carbon footprint of the agricultural sector.

5. Conclusions and Way Forward

The excessive use of chemical fertilizers in China has exacerbated climate change through increased greenhouse gas emissions, atmospheric nitrogen deposition, and global warming. To mitigate these effects, solutions include reducing fertilizer usage, improving its efficiency, replacing chemical fertilizers with organic alternatives, and adopting advanced technologies to lower emissions. To this end, this study examines how part-time farming, agricultural service provision, and rural labor migration influence organic fertilizer use. It employs fixed and random effects models on data from 523 households from Shaanxi Province, one of China's main apple-producing regions.

This study suggests that the impact of rural labor migration on organic fertilizer use is shaped by two opposing forces. On the one hand, labor migration away from agriculture reduces labor input, exerting a "push" effect that decreases organic fertilizer use. On the other hand, increased household income from non-farm work alleviates financial constraints, creating a "pull" effect that promotes organic fertilizer application. The overall impact depends on the balance between these forces, which varies according to the extent of labor migration and the resulting shifts in household resources.

This study investigates the effects of part-time farming on organic fertilizer use and the moderating role of agricultural socialized services. The findings reveal that: (1) Part-time farming significantly reduces the likelihood of using organic fertilizers, with part-time farmers being 7.6% less likely to apply them than full-time farmers. (2) A higher non-farm income correlates with a further decline in organic fertilizer use, especially among Type II part-time farmers. (3) The labor loss effect is the main driver of this reduction, while the income effect is negligible. (4) Agricultural machinery services mitigate this negative impact, though technical guidance services are less effective.

This study identifies the primary cause of reduced organic fertilizer use due to rural labor migration in China as a shortage of agricultural labor, a challenge likely affecting other regions pursuing green agricultural transformation. To address this, the following policies are recommended: (1) Subsidize fertilization machinery and promote the combined use of organic and water-soluble fertilizers to enhance labor efficiency. (2) Encourage land transfers to trained farmers for large-scale operations and strengthen rural labor market regulations. (3) Promote agricultural socialized services through cooperatives and government support to modernize production methods.

While this study rigorously analyzes the effects of part-time farming and agricultural socialized services on organic fertilizer use, future research could expand on the following aspects: First, refining the intensity and structure of organic fertilizer application by farmers, specifically by incorporating detailed data on the quantities of farmyard manure and commercial organic fertilizers used, would add depth to this study. Second, further examination of the organic fertilizer application behavior among full-time farmers, who are primary food producers, is warranted. Third, comparing the effects of organic fertilizer use across gender groups, landowners versus tenants, and various regions could provide complementary insights to the findings presented here. Additionally, exploring the impact of regional livestock industry development on farmers' use of organic fertilizers would yield valuable insights for promoting organic fertilizer adoption. Finally, future studies should assess the environmental impact of commercially produced organic fertilizers to evaluate their ecological sustainability.

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