

Agricultural Practices, Climate Resilience, and Socioeconomic Factors Influencing Coffee Value and Productivity in Vietnam

Ha Quang Trung¹ , Le Minh Tu^{1*} , Luong Hong Quang² 

¹Thai Nguyen University of Agriculture and Forestry, Thai Nguyen, Vietnam

²Nong Lam University Ho Chi Minh City, Ho Chi Minh, Vietnam

*Corresponding author: leminhtu@tuaf.edu.vn

Editor: Samuel Pereira de Carvalho

Received in November 12, 2024 and approved in April 10, 2025

ABSTRACT

This study examines the factors affecting coffee value and yield among farming households in Vietnam's Central Highlands. Utilizing data from the Vietnam Household Agriculture Research Survey and applying ordinary least squares regression, we examine how key variables such as Arabica cultivation, organic certification, input costs, labor, household characteristics, infrastructure access, and climate resilience impact coffee productivity and profitability. The results indicate that increasing the proportion of Arabica coffee significantly enhances both coffee value and yield. Efficient management of economic inputs, particularly irrigation and pesticide use, is found to be crucial in boosting productivity. Household characteristics, including education level and social organization membership, also positively impact coffee yield and profitability, reflecting the role of knowledge dissemination and community engagement. Conversely, high labor costs and remote farm locations negatively affect coffee productivity, while drought events significantly reduce coffee value, highlighting the vulnerability of coffee production to climate change. The findings provide empirical support for policy interventions aimed at strengthening Vietnam's coffee sector through infrastructure investment, climate adaptation strategies, and the promotion of diversified coffee varieties. Additionally, the study underscores the importance of balancing economic inputs with sustainable farming practices to enhance both environmental and financial resilience.

Key words: Coffee production; Arabica; organic certification; agricultural inputs; climate resilience.

1 INTRODUCTION

Coffee remains a cornerstone of the global agricultural market, playing a critical economic role in many developing countries located in equatorial and subequatorial regions (Kouadio et al., 2021). As a climate-sensitive perennial crop, coffee is particularly vulnerable to climate fluctuations, with rising variability posing risks to yield, crop health, and overall production in coffee-growing regions worldwide (Thao et al., 2022). Extreme weather events, such as intense droughts and heavy rains associated with the El Niño Southern Oscillation (ENSO), have a marked impact on coffee supply in the global market (Kouadio et al., 2021). Therefore, this study seeks to examine key solutions that influence coffee yield and value, focusing on solutions to mitigate the effects of extreme weather on coffee production in developing countries, specifically Vietnam.

Vietnam, a major global coffee producer, exported approximately 1.7 million tons in 2020, with conditions ideally suited for coffee cultivation, particularly Robusta coffee, which flourishes in the Tay Nguyen region (Trinh et al., 2020). Robusta coffee (*Coffea canephora*) constitutes over 90% of Vietnam's coffee production, attributed to its adaptability to local climate and soil conditions (Trinh et al., 2020). To boost the coffee sector's economic value, the Vietnamese government has implemented various policies to promote coffee as a key strategic crop. Recently, Arabica coffee (*Coffea arabica*)

production has also expanded in Vietnam, aiming to create a better balance between the two coffee species and ultimately increase farmers' profits (Trinh et al., 2009). As a result, the cultivation of Arabica coffee has extended into northern mountainous provinces, such as Dien Bien and Son La, and to a smaller extent, the Central Highlands, particularly between 2010 and 2016 (Nguyen et al., 2020). Despite the economic benefits, Robusta coffee remains vulnerable to droughts, which can adversely affect profitability in dry years (Byrareddy et al., 2021). Meanwhile, Arabica coffee faces threats from root rot disease, as well as climate-related challenges like storms, floods, and frost in northern regions (Nguyen et al., 2020). This underscores the need for a thorough assessment of the economic and environmental outcomes associated with diversifying coffee species in Vietnam.

Additionally, the prevailing coffee monocultures under full sun are unsustainable over the long term and have led to negative environmental impacts (Nguyen et al., 2020). Existing coffee studies in the Central Highlands have mainly focused on identifying and managing soil-borne pests and diseases (Duong et al., 2022; Hoang et al., 2021; Nguyen et al., 2021), as well as on reducing input use to lower both management costs and environmental impacts. For instance, modeling studies have shown that irrigation practices could be reduced without compromising yields. For instance, modeling work has demonstrated the possibility of reducing irrigation practices without compromising yields (Byrareddy et al., 2020). Similarly,

data envelopment analysis on farming practices suggests that farmers could cut input levels by 55% to 80% without yield loss (Gaitán-Cremaschi et al., 2018; Ho et al., 2021). Clément et al. (2023) highlighted that coffee farmers in the Central Highlands are beginning to transition from monocultures to mixed cropping systems, incorporating crops like pepper.

Furthermore, Over the last decades, consumers have steadily increased their consumption of organic food, forming a global market for organic food and drinks amounting to 135.5 billion euros in 2021 (Willer et al., 2023). Coffee production has aligned with this sustainability movement, with organic practices increasingly being adopted in the industry (Flores-Anaya et al., 2022). Mexico has emerged as a global leader in organic coffee production, with small-scale indigenous farmers in Chiapas organizing to improve their socioeconomic conditions and gain international recognition for their certified organic coffee (Flores-Anaya et al., 2022). Their success demonstrates the potential for organic coffee to provide economic and environmental benefits, even in challenging contexts (Flores-Anaya et al., 2022). Thus, the Vietnam government promotes organic cultivation to increase coffee value organic farming, characterized by low carbon emissions, is considered environmentally friendly. Currently, three primary coffee cultivation methods are practiced in Vietnam: conventional intensive (CI), conventional moderate (CM), and organic intensive (OI) (Noponen et al., 2012). While CI produces high yields, it contributes significantly to environmental degradation due to the excessive use of chemical inputs. CM, which uses fewer pesticides but still employs synthetic fertilizers, has moderate environmental impacts. In contrast, OI eliminates synthetic chemicals entirely, utilizing organic manures like compost and coffee pulp. This results in higher-quality beans and improved environmental outcomes, such as reduced carbon emissions and enhanced ecosystem health. Organic coffee beans, rich in antioxidants, offer health benefits, with organic-intensive farming currently being piloted on small-scale farms in Vietnam, excluding large-scale plantations (Trinh et al., 2020). This study assesses whether these new approaches can indeed boost the value of coffee production.

In addition to strategies aimed at enhancing coffee value, productivity-boosting measures are essential to support sustainable coffee cultivation development. Specifically, traditional factors such as socioeconomic conditions and technology adoption significantly influence coffee yield (Wambua et al., 2021). Wambua et al. (2021) found that off-farm income, credit access, land tenure, and farm size positively affect productivity, suggesting that coffee farmers could benefit from diversified income sources and credit financing as land use policies are refined. The study further emphasized the positive impact of recommended rates for manure, fungicides, and pesticides on productivity. Another critical factor in perennial

crop cultivation is plant age, with mature coffee plants yielding optimally, while younger and older plants typically produce lower yields (Wanzala et al., 2024).

Beyond these structural factors, coffee production can be increased through acreage expansion, adoption of scientifically developed technologies, and improved resource allocation efficiency (Wambua et al., 2021). To quantify these relationships, various econometric approaches can be applied. Non-parametric techniques such as the DEA-Malmquist index allow for measuring productivity changes over time, while propensity score matching (PSM), which employs logistic regression, helps control for selection bias in technology adoption studies (Wanzala et al., 2024). Additionally, parametric models like the Cobb-Douglas production function, estimated using ordinary least squares (OLS), provide insights into input elasticity and returns to scale in coffee production (Wambua et al., 2021). These methodological approaches offer robust analytical frameworks for evaluating productivity determinants and guiding policy decisions in the coffee sector.

This study explores factors influencing coffee production in Vietnam, focusing on both value-enhancing strategies and traditional productivity drivers. By examining recommended agricultural practices such as crop diversification, organic farming, and improved irrigation alongside socioeconomic factors like income diversification, credit access, and land management, this research aims to address the vulnerabilities of coffee production to climate variability and extreme weather events. Moreover, the study considers how factors such as plant age and the adoption of specific inputs (e.g., manure, pesticides, and fungicides) can optimize yields. The findings are expected to provide valuable insights into the combined impact of these solutions and socioeconomic characteristics on farm-level productivity, thereby guiding policymakers in crafting sustainable interventions to maximize coffee production. Through both an evaluation of these factors and empirical analysis, this study contributes to understanding how targeted strategies can support resilience and productivity in coffee cultivation under changing environmental conditions.

2 MATERIAL AND METHODS

This study utilizes data from the Vietnam Household Agriculture Research Survey (VARHS), a longitudinal survey initiated in 2002 and conducted biennially from 2006 to the present. The VARHS dataset, publicly available through collaborative agreements with Vietnamese institutions (Central Institute for Economic Management, Institute of Policy and Strategy for Agriculture and Rural Development, and Institute of Labour Science and Social Affairs) and international partners (Development Economics Research Group, Danish International Development Agency, and

United Nations University World Institute for Development Economics Research), focuses on rural households in Vietnam. VARHS complements the nationally representative Vietnam Household Living Standards Survey (VHLSS) by providing granular data on agricultural practices and climate resilience. The survey captures household-level demographic, economic, institutional, and environmental characteristics, with an emphasis on land, labor, and credit market interactions—key drivers of coffee production in the three provinces of Dak Lak, Dak Nong, and Lam Dong, located in Vietnam's Central Highlands (see Figure 1).

To analyze the determinants of coffee productivity and value, we employ two OLS regression models, Specification (1) for coffee value per hectare (Val) and Specification (2) for coffee yield per hectare (Qty). Both specifications account for household-level fixed effects and provincial-level heterogeneity. The regression equations are defined as follows: influences on coffee productivity and value:

$$Val_i = \alpha_i + \beta_1 Mix_i + \beta_2 Arb_i + \beta_3 Org_i + \beta_4 Age_i + \beta_5 Irr_i + \beta_6 Lab_i + \beta_7 Int_i + \beta_8 Pes_i + \beta_9 OrF_i + \beta_{10} Chm_i + \beta_{11} Grp_i + \beta_{12} Agr_i + \beta_{13} NFE_i + \beta_{14} Slf_i + \beta_{15} Mig_i + \beta_{16} Ext_i + \beta_{17} HHA_i + \beta_{18} HHG_i + \beta_{19} Tot_i + \beta_{20} Edu_i + \beta_{21} Rdl_i + \beta_{22} Ele_i + \beta_{23} Fld_i + \beta_{24} Drt_i + \beta_{25} Typ_i + e_i + u_i \quad (\text{Specification 1})$$

$$Qty_i = \alpha_i + \beta_1 Mix_i + \beta_2 Arb_i + \beta_3 Org_i + \beta_4 Age_i + \beta_5 Irr_i + \beta_6 Lab_i + \beta_7 Int_i + \beta_8 Pes_i + \beta_9 OrF_i + \beta_{10} Chm_i + \beta_{11} Grp_i + \beta_{12} Agr_i + \beta_{13} NFE_i + \beta_{14} Slf_i + \beta_{15} Mig_i + \beta_{16} Ext_i + \beta_{17} HHA_i + \beta_{18} HHG_i + \beta_{19} Tot_i + \beta_{20} Edu_i + \beta_{21} Rdl_i + \beta_{22} Ele_i + \beta_{23} Fld_i + \beta_{24} Drt_i + \beta_{25} Typ_i + e_i + u_i \quad (\text{Specification 2})$$

Where α_i denotes the intercept term, β_i represents the coefficients for independent variables, and e_i captures provincial fixed effects, accounting for localized policy support for coffee development. Additionally, u_i denotes the household-level error term. The independent variables in these models encompass a range of socioeconomic and agricultural factors

Research Area: Dak Lak, Dak Nong, and Lam Dong in Vietnam

Study on Coffee Production and Climate Resilience

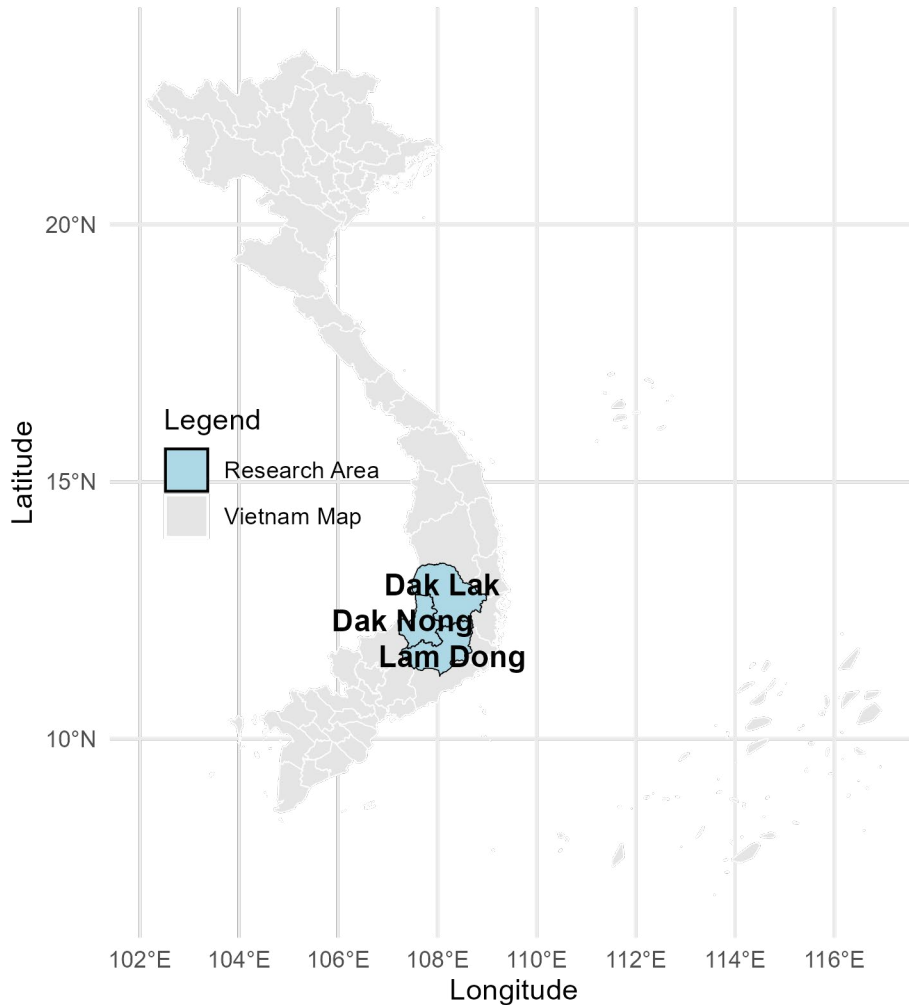


Figure 1: Map of Research Location in Vietnam.

relevant to coffee cultivation and household characteristics. These independent variables include agricultural practice variables, socioeconomic variables, demographic variables, and infrastructure and environmental variables.

Table 1 presents descriptive statistics for the variables, emphasizing the diverse conditions among coffee-farming households in Vietnam's Central Highlands. Key environmental variables, including flood occurrence, drought occurrence, and other extreme weather events, reveal the exposure of these areas to climate risks. The flood variable, with a mean value of 0.036, indicates that flooding affects specific regions, while the drought variable has a mean of

0.075, reflecting a higher presence of droughts. The variable for other disasters, including events like typhoons, has a mean of 0.0073, suggesting these occurrences are infrequent.

In terms of productivity, the variable representing the average coffee value per hectare has a mean of 104 million Vietnamese Dong (VND) per hectare, with a wide range from 3.1 to 960 million VND per hectare. This variation signifies considerable differences in coffee value across farms. The average yield per hectare is 3.3 tons, with yields ranging from 0.11 to 25 tons per hectare, highlighting variability in productivity among farms. Agricultural practices also vary, with 21 percent of households participating in mixed cropping

Table 1: Description and statistics of independent variables.

Variables	Description	Count	Mean	SD	Min	Max
<i>Dependen Variables</i>						
<i>Val</i>	Coffee value per hectare (Million VND)	413	104	103	3.1	960
<i>Qty</i>	Coffee yield per hectare (ton)	413	3.3	3.2	0.11	25
<i>Agricultural practices variables</i>						
<i>Mix</i>	Binary indicator for mixed cropping with pepper (1 = yes, 0 = otherwise)	413	0.21	0.4	0	1
<i>Arb</i>	Percentage of Arabica coffee cultivated	413	2.3	14	0	100
<i>Org</i>	Organic certification status (1 = certified, 0 = otherwise)	413	0.0048	0.07	0	1
<i>Age</i>	Age of coffee plants (years)	413	14	7	1	40
<i>Irr</i>	State irrigation fee per hectare (thousands VND)	413	0.097	1.5	0	27
<i>Lab</i>	Labor cost per hectare (million VND)	413	11	29	0	400
<i>Int</i>	Interest on borrowed capital per hectare (million VND)	413	2.5	9.7	0	150
<i>Pes</i>	Pesticide cost per hectare (million VND)	413	7.3	24	0	450
<i>OrgF</i>	Organic fertilizer cost per hectare (million VND)	413	2.8	4.5	0	16
<i>Chm</i>	Chemical fertilizer cost per hectare (million VND)	413	33	27	0	124
<i>Socioeconomic variables</i>						
<i>Grp</i>	Membership in social-political organizations (1 = membership, 0 = otherwise)	413	0.89	0.31	0	1
<i>Agr</i>	Household members engaged in coffee farming	413	3.3	1.6	1	11
<i>NFE</i>	Household members in non-farm employment	413	1	1.1	0	5
<i>Slf</i>	Self-employed household members	413	0.18	0.6	0	4
<i>Mig</i>	Migrated household members	413	0.33	0.65	0	4
<i>Ext</i>	The number of times households engage with agricultural extension services	413	0.32	1.5	0	12
<i>Demographic variables</i>						
<i>HHA</i>	Age of household head (years)	413	47	11	21	86
<i>HHG</i>	Gender of household head (1 = male, 0 = otherwise)	413	0.89	0.31	0	1
<i>Tot</i>	Total household members	413	4.8	1.9	1	14
<i>Edu</i>	Education level of household head (years)	413	7	3.6	0	12
<i>Infrastructure and environmental variables</i>						
<i>RdI</i>	Distance to paved roads (kilometers)	413	1.3	3.4	0	40
<i>Ele</i>	Access to national electricity grid (1 = yes, 0 = otherwise)	413	1	0.07	0	1
<i>Fld</i>	Flood occurrence in past three years (1 = yes, 0 = otherwise)	413	0.036	0.19	0	1
<i>Drt</i>	Drought occurrence in past three years (1 = yes, 0 = otherwise)	413	0.075	0.26	0	1
<i>Typ</i>	Other disasters (e.g., typhoons) in past three years (1 = yes, 0 = otherwise)	413	.0073	.085	0	1

with pepper. The Arabica coffee percentage has a low mean of 2.3 percent, though some farms dedicate their entire production to Arabica. Organic certification remains limited, with a mean of 0.0048, illustrating that certified organic practices are rare among coffee producers.

The use of OLS regression in this study is justified by its ability to estimate the relationships between independent variables and coffee productivity efficiently. OLS is widely applied in agricultural economics due to its straightforward interpretation and ease of implementation in analyzing farm-level production data. However, linear regression assumes a linear relationship between explanatory variables and the dependent variable, which may not always hold in reality. To address potential nonlinear dependencies, this study also employs Pearson correlation analysis to examine the strength and direction of associations between key variables, providing a complementary perspective to the OLS estimates. This dual approach ensures a more comprehensive and robust evaluation of the factors affecting coffee yield and value.

3 RESULTS

Table 2 presents the regression results on factors influencing coffee value and yield per hectare among coffee-farming households in Vietnam's Central Highlands. The models capture the effects of various agricultural practices, economic inputs, household characteristics, and environmental conditions on coffee outcomes. Table 2 includes four models, with the first two estimating the impact on coffee product value according to Specification 1 and the latter two estimating the impact on coffee yield according to Specification 2.

The percentage of Arabica coffee cultivated (*Arb*) has a consistently strong, positive, and significant effect on both coffee value and yield across all models. In Models 1 and 2, the coefficient for *Arb* ranges from 0.72 to 0.78, indicating that a 1% increase in Arabica coffee cultivation significantly enhances coffee value by 0.72 to 0.78 million VND per hectare. Similarly, in Models 3 and 4, the coefficient for *Arb* is 0.03, reflecting a positive impact on yield, meaning a 1% increase in Arabica coffee cultivation boosts coffee productivity by 0.03 tons per hectare. These consistent and significant results across all models suggest that Arabica cultivation could be a key driver of increased profitability and productivity for coffee farmers. In contrast, mixed cropping systems (*Mix*) and organic certification (*Org*) have positive but statistically insignificant coefficients across the models, indicating that organic practices and mixed cropping with pepper may currently have a limited impact on coffee productivity or profitability in this region.

The age of coffee plants (*Age*) shows a positive and significant effect on both the value and yield of coffee plantations, with coefficients ranging from 1.14 to 1.27 in Models 1 and 2 and from 0.06 to 0.07 in Models 3 and 4. This

suggests that a one-year increase in plant age increases the value of coffee by 1.14 to 1.27 million VND per hectare and yield by 0.06 to 0.07 tons per hectare.

Several inputs are critical for coffee production. The state irrigation fee per hectare (*Irr*) has a positive and highly significant effect on both coffee value and yield, with coefficients of 12.15 to 12.18 in Models 1 and 2 and 0.28 in Models 3 and 4. This indicates that an additional irrigation fee of 10,000 VND per hectare could increase coffee value by 121,000 VND per hectare and yield by 2.8 tons per hectare, underscoring irrigation's importance in maintaining productive coffee farms, especially under variable climatic conditions. Interest expenses (*Int*) also positively impact coffee value and yield, with coefficients of 2.44 to 2.45 in Models 1 and 2 and 0.06 in Models 3 and 4, indicating that an additional 1 million VND in loan expenses per hectare increases farm value by 2.44 to 2.45 million VND and yield by 0.06 tons per hectare.

Similarly, pesticide costs (*Pes*) have positive and significant coefficients of 2.27 to 2.30 in Models 1 and 2 and 0.06 in Models 3 and 4, suggesting that effective pest management contributes positively to both coffee value and yield. An additional expenditure of 1 million VND on pesticides increases the farm's value by 2.27 to 2.30 million VND per hectare and yield by 0.06 tons per hectare. Chemical fertilizer costs (*Chm*) also show significant positive effects, with coefficients ranging from 1.02 to 1.04 in Models 1 and 2 and 0.04 in Models 3 and 4, reinforcing the role of nutrient inputs in enhancing productivity. However, the impact of chemical fertilizers on value is relatively modest compared to costs, although yield benefits are notable. In contrast, labor costs (*Lab*) have negative and significant effects on both coffee value and yield, with coefficients from -0.49 to -0.51 in Models 1 and 2 and -0.02 in Models 3 and 4. This suggests that high labor expenses may reduce net profitability, underscoring the need for labor efficiency or cost-reduction strategies to improve productivity outcomes.

Household characteristics and social engagement also influence coffee outcomes. Membership in social-political organizations (*Grp*) positively and significantly affects coffee yield, especially in Models 3 and 4, with coefficients of 0.73 and 0.74, respectively, suggesting that social network membership may enhance productivity by providing access to shared resources or collective knowledge, leading to an increase of approximately 0.73–0.74 tons per hectare. Conversely, the number of household members working in coffee farming (*Agr*) has a negative impact on coffee income and yield. Specifically, each additional family member working on the coffee farm reduces coffee income by 6.33 million VND per hectare and yield by 0.20 tons per hectare, suggesting a missed opportunity to leverage social-political systems to enhance coffee value and productivity.

Table 2: Regression Results for Determinants of Coffee Value and Yield Among Coffee-Farming Households.

	Model 1	Model 2	Model 3	Model 4
<i>Mix</i>	12.36	12.82	0.19	0.18
	-9	-9.23	-0.31	-0.32
<i>Arb</i>	0.78***	0.72***	0.03***	0.03***
	-0.25	-0.26	-0.01	-0.01
<i>Org</i>	26.73	27.74	0.71	0.66
	-53.38	-53.44	-1.86	-1.86
<i>Age</i>	1.14**	1.27**	0.07***	0.06***
	-0.56	-0.58	-0.02	-0.02
<i>Irr</i>	12.15***	12.18***	0.28***	0.28***
	-2.41	-2.42	-0.08	-0.08
<i>Lab</i>	-0.51***	-0.49***	-0.02***	-0.02***
	-0.18	-0.18	-0.01	-0.01
<i>Int</i>	2.44***	2.45***	0.06***	0.06***
	-0.35	-0.35	-0.01	-0.01
<i>Pes</i>	2.30***	2.27***	0.06***	0.06***
	-0.21	-0.21	-0.01	-0.01
<i>OrgF</i>	-0.09	-0.22	0.01	0.02
	-0.81	-0.82	-0.03	-0.03
<i>Chm</i>	1.02***	1.04***	0.04***	0.04***
	-0.15	-0.15	-0.01	-0.01
<i>Grp</i>	10.81	11.01	0.75**	0.74*
	-10.91	-10.92	-0.38	-0.38
<i>Agr</i>	-6.33*	-5.11	-0.14	-0.20*
	-3.25	-3.43	-0.11	-0.12
<i>NFE</i>	-4.99	-4.55	-0.12	-0.14
	-3.34	-3.37	-0.12	-0.12
<i>Slf</i>	-0.81	-0.41	-0.01	-0.03
	-5.8	-5.84	-0.2	-0.2
<i>Mig</i>	-7.87	-8.14	-0.3	-0.29
	-5.49	-5.5	-0.19	-0.19
<i>Ext</i>	0.68	0.74	0.01	0.01
	-2.37	-2.39	-0.08	-0.08
<i>HHA</i>	0.34	0.34	-0.01	0
	-0.32	-0.32	-0.01	-0.01
<i>HHG</i>	0.55	0.78	0.28	0.26
	-11.59	-11.64	-0.4	-0.4
<i>Tot</i>	6.73**	6.12**	0.11	0.14
	-2.78	-2.84	-0.1	-0.1
<i>Edu</i>	2.62***	2.56**	0.07**	0.08**
	-1.01	-1.02	-0.04	-0.04
<i>RdI</i>	-2.00**	-1.94*	-0.06*	-0.07*
	-1	-1	-0.03	-0.03

Continue.

Table 2: Continuation.

<i>Ele</i>	78.13	80.62	1.64	1.49
	-49.25	-49.52	-1.72	-1.72
<i>Fld</i>	2.52	5.86	-0.57	-0.75
	-18.57	-18.82	-0.65	-0.65
<i>Drt</i>	-25.47*	-24.82*	0.2	0.16
	-13.37	-13.44	-0.47	-0.47
<i>Typ</i>	-18.96	-14.54	-1.49	-1.71
	-43.96	-44.17	-1.53	-1.54
<i>Mix</i>	12.36	12.82	0.19	0.18
	-9	-9.23	-0.31	-0.32
Obs.	413	413	413	413
R-squared	0.59	0.60	0.48	0.49
adj	0.57	0.57	0.45	0.45
R-squared				
Province FE	No	Yes	No	Yes

Significance levels are denoted as follows: * p<0.1, ** p<0.05, *** p<0.01.

Household size (*Tot*) positively and significantly affects coffee value, with coefficients from 6.12 to 6.73, indicating that larger household labor pools may contribute beneficially to farm productivity. Each additional household member raises coffee income by 6.12 to 6.73 million VND per hectare. Moreover, the education level of the household head (*Edu*) consistently shows a positive association with both coffee value and yield, with coefficients from 2.56 to 2.62 in Models 1 and 2 for value and from 0.07 to 0.08 in Models 3 and 4 for yield, suggesting that an additional year of formal education for the household head could enhance coffee income by 2.56 to 2.62 million VND per hectare and yield by 0.07 to 0.08 tons per hectare. This indicates that better-educated household heads may apply more effective management practices, positively impacting both coffee value and productivity.

The results also highlight the importance of infrastructure and climate resilience for coffee production. Distance to paved roads (*RdI*) has a negative and significant effect on both coffee value and yield, with coefficients from -1.94 to -2.00 in Models 1 and 2 and from -0.06 to -0.07 in Models 3 and 4. Each 1 km reduction in distance to paved roads can potentially increase household income by 1.94 to 2 million VND per hectare and yield by 0.06 to 0.07 tons per hectare. These findings suggest that accessibility to infrastructure may facilitate better market integration and input use, enhancing productivity. Among environmental factors, drought occurrence (*Drt*) has a significant negative effect on coffee value, with coefficients of -25.47 in Model 1 and -24.82 in Model 2, indicating that drought conditions substantially reduce profitability. Droughts could cause losses of 24.82 to 25.47 million VND per hectare, underscoring the importance of resilience strategies to mitigate climatic risks.

4 DISCUSSION

The models exhibit moderate explanatory power, with R-squared values ranging from 0.48 to 0.49 for yield and from 0.59 to 0.60 for value, suggesting that 48 to 49% of the variance in coffee yield and 59 to 60% of the variance in coffee value are explained by the included factors. The addition of provincial fixed effects in Models 2 and 4 further refines these results, indicating that regional policies and infrastructure may also play a role in influencing coffee outcomes; however, the impact remains minimal as indicated by negligible differences in adjusted R-squared values.

In summary, the results highlight the importance of Arabica cultivation, efficient economic inputs, and household education in enhancing coffee value and yield. Infrastructure access and climate resilience are also essential, as remote locations and drought significantly hinder productivity. These insights provide a comprehensive understanding of the factors shaping coffee production, informing strategies to strengthen productivity and profitability in Vietnam's Central Highlands.

The Pearson correlation analysis in Table 3 reveals significant relationships between key variables, corroborating findings from the regression models. Coffee value (*Val*) and yield (*Qty*) exhibit a strong positive correlation (0.826***), underscoring their interdependence. Both outcomes are positively associated with irrigation fees (*Irr*: 0.334*** for *Val*, 0.285*** for *Qty*), pesticide costs (*Pes*: 0.626*** for *Val*, 0.522*** for *Qty*), and chemical fertilizer expenses (*Chm*: 0.499*** for *Val*, 0.484*** for *Qty*), reinforcing their critical roles in enhancing productivity. Several variables demonstrate moderate correlations with coffee yield, including irrigation fees, labor costs, and interest on borrowed capital, underscoring the importance of financial resources in determining coffee productivity. Conversely, weak correlations are observed between coffee yield and factors such as Arabica cultivation, organic fertilizer costs, household head's education level, membership in social organizations, and drought occurrence.

Moreover, Arabica cultivation (*Arb*) shows a notable positive correlation with drought occurrence (*Drt*: 0.165***), suggesting Arabica farms may be strategically located in drought-prone areas. Organic certification (*Org*) exhibits weak correlations with other variables, aligning with its statistically insignificant impact in regression results. Negative correlations, such as between education (*Edu*) and household members engaged in farming (*Agr*: -0.205***), imply that educated households may diversify labor away from coffee farming. Infrastructure variables like distance to roads (*Rdl*) and electricity access (*Ele*) show minimal correlations, highlighting their indirect influence. Notably, labor costs (*Lab*) and pesticide expenses (*Pes*) are highly correlated (0.688***), warranting caution against multicollinearity in interpretation. These correlations validate the regression insights while emphasizing the need for targeted interventions to address interrelated factors shaping coffee production.

This study provides a comprehensive analysis of factors influencing coffee value and yield per hectare among coffee-farming households in Vietnam's Central Highlands. The findings underscore the significant roles of agricultural practices, economic inputs, household characteristics, and environmental conditions in shaping coffee productivity and profitability, offering valuable insights for developing targeted interventions to support sustainable coffee production.

The analysis highlights the positive impact of Arabica cultivation on both coffee value and yield. The robust and significant effect of the percentage of Arabica coffee cultivated suggests that diversifying production to include more Arabica coffee could enhance economic returns for coffee farmers. Despite Vietnam's traditional emphasis on Robusta coffee, these results advocate for a gradual shift toward Arabica, particularly in areas suited to its cultivation. Studies in other coffee-producing countries have reported similar results. For example, Kilambo et al. (2013) found that shifting towards Arabica coffee in Tanzania improved both farm income and quality scores, making it a more viable long-term investment. Additionally, findings from Brazil indicate that Arabica coffee, when cultivated with optimized shade levels, can achieve higher cupping scores and better resistance to temperature fluctuations (DaMatta; Ramalho, 2006).

However, the limited impact of organic certification and crop diversification with pepper on coffee value and yield suggests that the adoption of these practices may currently lack sufficient market incentives or support. To enhance the effectiveness of organic certification as a value-adding strategy, policies could focus on reducing certification costs, improving access to organic farming resources, and developing markets that reward organic practices with price premiums.

Production inputs, such as irrigation, pesticides, and chemical fertilizers, emerge as essential drivers of coffee value and productivity. The positive and significant coefficients for these inputs underscore the importance of effective resource management in boosting productivity. Similar conclusions were drawn by (Wambua et al., 2021) in Kenya, where optimal fertilizer application and pest control practices significantly improved coffee yields. The results indicate that irrigation fees and pesticide costs, in particular, are crucial for achieving higher coffee yields. Conversely, the negative impact of labor costs on coffee outcomes suggests that high labor expenses can reduce net profitability, indicating a need for labor optimization. Investments in labor-saving technologies or training programs to enhance labor efficiency could mitigate this issue, allowing coffee farms to improve productivity without incurring unsustainable labor costs.

Household size and the education level of the household head, also play an important role in enhancing productivity

Table 3: Pearson Correlation.

	<i>Val</i>	<i>Qty</i>	<i>Mix</i>	<i>Arb</i>	<i>Org</i>	<i>Age</i>	<i>Irr</i>	<i>Lab</i>	<i>Int</i>	<i>Pes</i>	<i>OrgF</i>	<i>Chm</i>	<i>Grp</i>	<i>Agr</i>
<i>Val</i>	1													
<i>Qty</i>	0.826***	1												
<i>Mix</i>	0.147***	0.128***	1											
<i>Arb</i>	0.103**	0.122**	0.0106	1										
<i>Org</i>	0.0162	-0.00183	0.0508	0.0387	1									
<i>Age</i>	0.0347	0.0276	0.00991	-0.0156	0.108**	1								
<i>Irr</i>	0.334***	0.285***	-0.0338	-0.0102	-0.00463	0.0334	1							
<i>Lab</i>	0.420***	0.325***	0.220***	0.117**	-0.0142	0.113**	0.0878*	1						
<i>Int</i>	0.300***	0.244***	-0.0932*	-0.00543	-0.0184	-0.0248	-0.0168	0.0517	1					
<i>Pes</i>	0.626***	0.522***	0.143***	-0.00575	-0.00416	0.0313	0.247***	0.688***	0.0949*	1				
<i>OrgF</i>	0.194***	0.201***	0.224***	0.0013	-0.0316	0.0257	0.122**	0.153***	-0.0136	0.253***	1			
<i>Chm</i>	0.499***	0.484***	0.260***	0.109**	-0.027	0.0109	0.153***	0.467***	0.135***	0.394***	0.226***	1		
<i>Grp</i>	0.0505	0.0818*	0.00503	-0.0484	0.0244	-0.0866*	0.0232	0.0324	-0.0156	0.0377	-0.00111	0.0267	1	
<i>Agr</i>	-0.0492	-0.0634	-0.0705	-0.0379	-0.0122	0.0811*	-0.0236	0.0954*	0.0716	-0.0474	-0.0481	0.058	0.0565	1
<i>NFE</i>	-0.0718	-0.071	-0.0895*	-0.0331	-0.0664	-0.0884*	0.0804	-0.0341	0.0557	-0.0439	-0.0208	-0.014	-0.0161	0.247***
<i>Slf</i>	0.000984	-0.00326	-0.0143	0.037	-0.0211	-0.0113	-0.019	-0.0143	-0.0464	-0.0328	-0.041	-0.0471	0.0539	-0.0911*
<i>Mig</i>	0.0586	0.0356	0.0332	0.0357	0.0716	0.0974**	-0.0329	0.102**	-0.0104	0.109**	0.0693	0.121**	0.0962*	-0.0245
<i>Ext</i>	-0.00892	-0.0301	0.0158	-0.0196	-0.0153	0.00447	-0.0146	-0.0216	0.0204	-0.0206	-0.00576	-0.0506	0.0447	0.0055
<i>HHA</i>	-0.00902	-0.0674	-0.0850*	0.0292	-0.016	0.151***	-0.0335	0.0163	0.0112	-0.0181	-0.038	-0.0543	0.0507	0.183***
<i>HHG</i>	-0.0202	0.0198	-0.0101	0.00322	0.0247	0.0133	0.0221	-0.0526	0.0368	-0.120**	-0.0194	0.0494	0.0491	0.149***
<i>Tot</i>	-0.018	-0.0527	-0.0984**	-0.0116	0.0274	0.0543	0.00805	0.0597	0.065	-0.0545	-0.0751	-0.013	0.0635	0.707***
<i>Edu</i>	0.132***	0.119**	0.139***	-0.0419	0.0679	0.128***	0.00301	0.0829*	-0.0236	0.0806	0.0508	0.0336	0.0816*	-0.205***
<i>RdI</i>	-0.0687	-0.0609	0.0386	-0.032	-0.00268	-0.0638	-0.0173	-0.0254	-0.015	0.0086	-0.0386	-0.00691	0.042	0.014
<i>Ele</i>	0.0544	0.0484	0.0355	0.0116	0.00487	0.0701	0.00463	0.0192	0.00398	0.0017	0.0431	0.0371	-0.0244	0.0342
<i>Fld</i>	-0.0101	-0.0448	-0.00279	-0.0322	-0.0135	-0.0396	-0.0129	-0.0285	-0.00869	-0.0238	-0.021	0.0244	0.0264	0.0149
<i>Drt</i>	-0.0833*	0.0144	-0.00864	0.165***	-0.0199	-0.000835	-0.0185	-0.0578	-0.0168	-0.0212	0.120**	-0.0745	0.0406	-0.00366
<i>Typ</i>	-0.0176	-0.031	-0.0435	-0.0142	0.405***	0.0863*	-0.00568	0.0102	0.00831	-0.0144	-0.0374	-0.0222	-0.0616	-0.051
	<i>NFE</i>	<i>Slf</i>	<i>Mig</i>	<i>Ext</i>	<i>HHA</i>	<i>HHG</i>	<i>Tot</i>	<i>Edu</i>	<i>RdI</i>	<i>Ele</i>	<i>Fld</i>	<i>Drt</i>	<i>Typ</i>	
<i>NFE</i>	1													
<i>Slf</i>	-0.0919*	1												
<i>Mig</i>	-0.00461	0.00583	1											
<i>Ext</i>	0.0699	-0.0607	-0.0361	1										
<i>HHA</i>	-0.036	0.00835	0.134***	0.0865*	1									
<i>HHG</i>	0.069	0.0301	0.04	0.0249	-0.192***	1								
<i>Tot</i>	0.330***	0.0725	0.0930*	0.01	0.0289	0.214***	1							
<i>Edu</i>	-0.162***	0.0941*	0.151***	0.0496	-0.0970**	0.191***	-0.161***	1						
<i>RdI</i>	0.0335	-0.0568	-0.0432	-0.0334	-0.0082	0.0418	-0.00215	-0.0162	1					
<i>Ele</i>	-0.0295	0.0211	-0.0178	-0.0805	0.062	-0.0247	-0.0646	-0.039	-0.0046	1				
<i>Fld</i>	0.0762	-0.0371	-0.0202	0.206***	0.042	-0.0547	0.00386	0.0512	-0.00263	-0.173***	1			
<i>Drt</i>	0.0741	-0.0860*	0.0516	-0.0184	-0.0353	0.0132	0.00174	-0.0313	0.027	0.0199	-0.00618	1		
<i>Typ</i>	0.0231	-0.0258	-0.000106	-0.0188	-0.0697	0.0303	0.0108	0.0714	-0.0122	0.00597	-0.0166	0.0838*	1	

mirrors findings from Kenya (Wambua et al., 2021). Household size and the education level of the household head also show positive impacts on coffee value and yield. These results suggest that family-based labor and higher educational attainment equip farmers with the human capital necessary for efficient farm management, supporting both economic value and productivity. Moreover, social engagement, as reflected by membership in social-political organizations, positively influences yield, particularly when cooperative or social network effects provide farmers with shared knowledge and resources. This aligns with findings from Honduras, where Jha et al. (2011) reported that farmers who actively participated in cooperatives had greater access to agronomic training and fair trade markets, ultimately increasing their earnings. Policies aimed at enhancing educational opportunities in farming communities, along with programs supporting family labor, could meaningfully impact coffee production outcomes.

The study further emphasizes the importance of infrastructure and climate resilience. The negative effect of distance to paved roads on coffee value and yield underscores the importance of physical connectivity in ensuring market access and resource availability. Investments in rural infrastructure, such as road construction and maintenance, could significantly enhance the productivity and profitability of coffee farms in remote areas. Similar conclusions were drawn by Ricketts et al. (2004), who found that poor infrastructure limited market access for smallholder coffee farmers in Costa Rica, reducing overall farm income. Additionally, the negative impact of drought on coffee value reveals the susceptibility of coffee production to climatic stress, highlighting the need for climate adaptation strategies. Implementing irrigation systems, adopting drought-resistant coffee varieties, and promoting water management practices are crucial for sustaining coffee yields under increasingly variable climate conditions.

Although this study provides valuable insights into the factors influencing coffee value and yield in Vietnam's Central Highlands, certain limitations warrant consideration. First, the research focuses primarily on internal factors within coffee-farming households, without addressing broader market forces, such as international coffee price fluctuations or trade policies, which could significantly impact profitability and farmers' decision-making. Second, as the data were collected over a single period, this study does not capture long-term changes, especially in the context of climate change, which could have substantial effects on coffee yield and quality in the future. Finally, while environmental variables like drought and flooding were analyzed, the specific impacts of adaptation strategies and household-level resilience measures were not thoroughly examined.

Future research can address these limitations by incorporating longitudinal data to analyze trends and the long-term effects of economic, political, and climatic shifts on the

coffee sector. Additionally, employing multilevel modeling approaches could help assess factors at various levels—from household and community to national levels—to provide a more comprehensive understanding of influences on coffee production. Further studies might also delve deeper into climate adaptation measures, such as the adoption of drought-resistant coffee varieties, and explore the role of government support or international organizations in promoting sustainable practices. These directions could ultimately enrich our understanding of sustainable coffee production and provide actionable insights for policy and practice.

5 CONCLUSIONS

This study analyzes the factors influencing coffee value and yield among farming households in Vietnam's Central Highlands using multiple regression models. The findings reveal distinct patterns across the models, highlighting the importance of Arabica cultivation, economic inputs, household economic and social characteristics, and climate resilience in shaping coffee productivity and profitability. The findings can significantly enhance the sustainability and profitability of Vietnam's coffee sector.

6 ACKNOWLEDGMENTS

The authors declare no conflict of interest. No funding was received for conducting this study.

The datasets generated during this study are available online from the corresponding author upon reasonable request and within the framework of cooperation agreements and scientific research projects.

The authors did not receive support from any organization for the submitted work.

7 AUTHORS' CONTRIBUTION

Conceptual idea: Quang Trung, H.; Hong Quang, L. Methodology design: Minh-Tu, L.; Data collections: Minh-Tu, L.; Data analysis and Interpretation: Minh-Tu, L.; and Writing and editing: Quang Trung, H.; Minh-Tu, L.; Hong Quang, L.

8 REFERENCES

- BYRAREDDY, V., et al. Win-win: Improved irrigation management saves water and increases yield for robusta coffee farms in Vietnam. **Agricultural Water Management**, 241:106350, 2020.
- BYRAREDDY, V. et al. Coping with drought: Lessons learned from robusta coffee growers in Vietnam. **Climate Services**, 22:100229, 2021.

- CLÉMENT, R. et al. Transitioning from monoculture to mixed cropping systems: the case of coffee, pepper, and fruit trees in Vietnam. **Ecological Economics**, 214:107980, 2023.
- DAMATTA, F. M.; RAMALHO, J. D. C. Impacts of drought and temperature stress on coffee physiology and production: A review. **Brazilian Journal of Plant Physiology**, 18:55-81, 2006.
- DUONG, B. et al. Potential of the coffee endophytic *Bacillus cereus* sensu lato strain CCBLR15 to control the plant-parasitic nematode *Radopholus duriophilus*. **Biocontrol Science and Technology**, 32(8):971-988, 2022.
- FLORES-ANAYA, Y. Z. et al. Organic coffee growing as a competitive strategy for Mexico in international trade. **Coffee Science**, 17:172005, 2022.
- GAITÁN-CREMASCHI, D. et al. Assessing the sustainability performance of coffee farms in Vietnam: A social profit inefficiency approach. **Sustainability**, 10(11):4227, 2018.
- JHA, S. et al. A review of ecosystem services, farmer livelihoods, and value chains in shade coffee agroecosystems. In: CAMPBELL, W.; LOPEZ ORTIZ, S. **Integrating agriculture, conservation and ecotourism: examples from the field. Issues in Agroecology - Present Status and Future Prospectus**. 1.ed. Springer, Dordrecht, 2011. 141p.
- HOANG, H. et al. Investigation of the soil nematode community composition in a monoculture Robusta coffee plantation in Dak Lak, Vietnam. **Global Ecology and Conservation**, 32:01932, 2021.
- KILAMBO, D. L. et al. A decade of contributing to a profitable and sustainable coffee industry in Tanzania: The arabica and robusta improvement programmes. **American Journal of Research Communication**, 3(1):31-35, 2015.
- KOUADIO, L. et al. Performance of a process-based model for predicting robusta coffee yield at the regional scale in Vietnam. **Ecological Modelling**, 443:109469, 2021.
- NGUYEN, D. N. et al. Potential application of rhizobacteria isolated from the central highland of Vietnam as an effective biocontrol agent of robusta coffee nematodes and as a bio-fertilizer. **Agronomy**, 11(9):1887, 2021.
- NGUYEN, M. P. et al. Local knowledge about ecosystem services provided by trees in coffee agroforestry practices in northwest Vietnam. **Land**, 9(12):486, 2020.
- NOPONEN, M. R. A. et al. Greenhouse gas emissions in coffee grown with differing input levels under conventional and organic management. **Agriculture, Ecosystems & Environment**, 151:6-15, 2012.
- RICKETTS, T. H. et al. Economic value of tropical forest to coffee production. **Proceedings of the National Academy of Sciences**, 101(34):12579-12582, 2004.
- THAO, N. T. T. et al. Early prediction of coffee yield in the Central Highlands of Vietnam using a statistical approach and satellite remote sensing vegetation biophysical variables. **Remote Sensing**, 14(13):2975, 2022.
- TRINH, L. et al. Comparative life cycle assessment for conventional and organic coffee cultivation in Vietnam. **International Journal of Environmental Science and Technology**, 17:1307-1324, 2020.
- TRINH, P. Q. et al. Plant-parasitic nematodes associated with coffee in Vietnam. **Russian journal of Nematology**, 17(1):73, 2009.
- WAMBUA, D. M. et al. Smallholder coffee productivity as affected by socioeconomic factors and technology adoption. **International Journal of Agronomy**, 8852371, 2021.
- WANZALA, R. W. et al. Impact of agricultural credit on coffee productivity in Kenya. **World Development Sustainability**, 5:100166, 2024.
- WILLER, H. et al. **The world of organic agriculture. Statistics and emerging trends 2023**. FiBL, IFOAM - Organics International, 2023. 134p.