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Digital Human Capital and Organic Fertilizer Adoption among Vegetable Farming Households in Vietnam: A Case Study in Phuc Loc Commune, Hanoi

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Abstract

This study examined the influence of digital human capital on organic fertilizer adoption among vegetable-farming households in Phuc Loc commune, Hanoi, Vietnam. Employing a fractional logit model, the study analyzed the determinants of adoption intensity, measured as the share of organic fertilizer expenditure in total fertilizer costs. Findings revealed that digital information utilization and learning capacity were primary drivers, significantly reducing information asymmetry and technical risks. The results suggest that promoting green agricultural practices requires systematic investment in the farmers' human capital, particularly digital skills.

Keywords

Digital human capital, organic fertilizer, vegetable farming

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Introduction

The global food system is currently facing a dual challenge: ensuring high-quality nutrition for a growing population while simultaneous mitigating environmental degradation caused by intensive agricultural practices (FAO, 2020). In many developing nations, including Vietnam, the chronic overuse and inefficient

application of chemical fertilizers have led to widespread soil pollution and compromised long-term sustainability (Le, 2024; Wen & Ma, 2024; Do & Pham, 2025). In response, transitioning toward green production behaviors has become a central objective for aligning local farming with the United Nations' Sustainable Development Goals (SDGs) (Schreurs *et al.*, 2017; Zhu *et al.*, 2024; Gong *et al*., 2025). The Fourth Industrial Revolution is accelerating digital transformation in agriculture, supporting the transition toward green production behaviors, particularly the adoption of organic fertilizers (Nguyen Huu Nhuan *et al*., 2022a; Lin *et al*., 2024). In Vietnam, this shift has been reinforced by Decision 749/QD-TTg, which aims to improve productivity and value chain efficiency (Cao Thi Ha, 2021; Nguyen Thi Mai, 2024). While technology provides the foundation, digital human capital—encompassing technical skills, digital literacy, and cognitive abilities—plays a decisive role in enabling farmers to access information and adopt organic fertilizer practices (Goldin, 2014; Nguyen Huu Nhuan *et al*., 2022b; Lin *et al*., 2023). From a theoretical perspective, a farmer's decisions regarding fertilizer use can be conceptualized as an input allocation process within the framework of production theory and the farm household model, where households allocate limited resources to maximize utility under various constraints. In this framework, the share of organic fertilizer costs in the total fertilizer expenditure reflects a continuous adjustment of input allocation based on perceived benefits and risks. However, a farmer's decisions are often made under conditions of imperfect information and bounded rationality, where limited access to reliable information leads to suboptimal input allocation (Akerlof, 1970 cited by Mattiacci *et al*., 2021; Jana & Helena, 2017). In this context, digtal human capital strengthens decision-making by improving information processing and reducing perceived risk. Enhancing digital human captial reduces information costs and information asymmetry, allowing farmers to better evaluate the long-term benefits of organic versus chemical fertilizers (Chen *et al*., 2022; Weng *et al*., 2023; Cheng *et al.*, 2024; Adeolu *et al*., 2025; Liao *et al*., 2025).

Despite these potential benefits, the adoption of organic fertilizers remains low among smallholders due to systemic barriers, including a lack of digital literacy and an aging demographic profile in the rural workforce (Wen & Ma, 2024; Hoang & Tran, 2023; Nguyen Thi Mai, 2024; Ngo Quynh Anh *et al.*, 2024). While digital platforms such as social media and messaging apps can amplify these networks for online learning, the specific impact of such digital interventions on the decision to use organic fertilizers in vegetable farming has not been sufficiently quantified in localized Vietnamese settings.

Phuc Loc commune in Hanoi provides a relevant empirical setting due to its transition toward safe vegetable production and the establishment of "Community Digital Technology Groups. The commune's adoption of the "Three-No Green Field" model—specifically prohibiting herbicides, chemical growth stimulants, and hazardous inputs – provides a critical foundation for studying green practices. Existing studies have primarily focused on the adoption of organic fertilizers as a binary decision, with limited attention to the intensity of input use. This study addresses these gaps by using the share of organic fertilizer cost as a nuanced measure of behavioral change. By quantifying the impact of digital human capital on decision-making, this research provides a scientific basis for enhancing sustainable livelihoods amidst rapid technological change.

Materials and Methods

Study area

Phuc Loc commune, located in an area enriched by alluvial deposits from the Red River, is a specialized vegetable production hub with over 900 ha of cultivation area and a population of 61,850 (**Figure 1**). Average yields ranged from 18 to 40 tons per ha, depending on crop type and cultivation intensity (**Table 1**).

Data collection

To address the research objectives, the study utilized secondary data from official reports and primary data gathered through structured questionnaires.

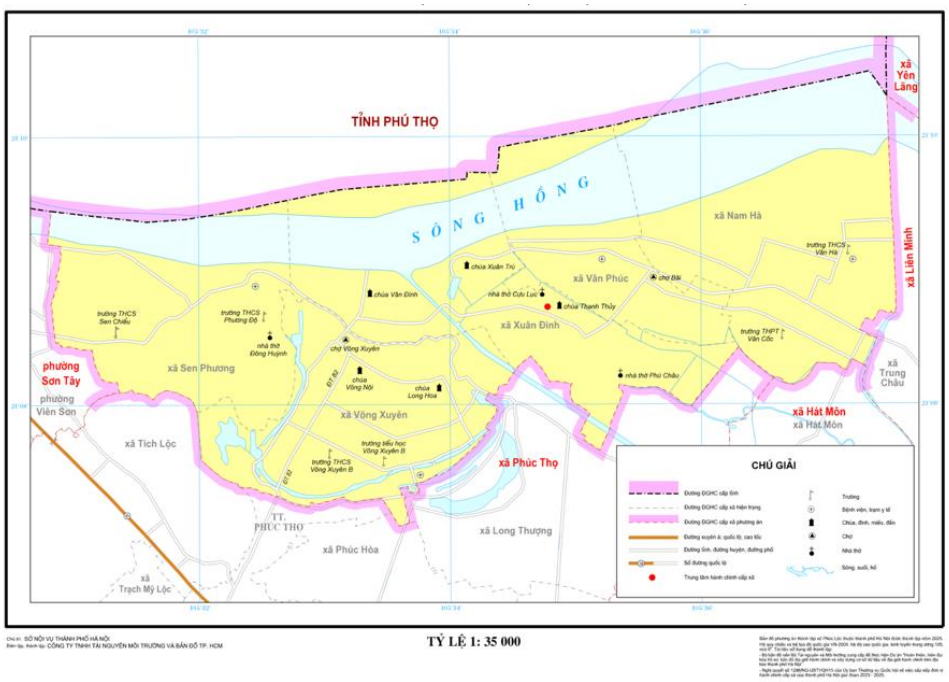


Figure 1. Location of Phuc Loc commune, Hanoi, Vietnam
Source: Phuc Loc Commune People's Committee (2025a)

Table 1. Overview of Vegetable Production in Phuc Loc Commune

Vegetable	Year 2025		
	Area (ha)	Yield (tons ha^{-1})	Output (tons)
Luffa	40	40	1,600
Scallions	286	35	10,010
Mustard greens	127	35	4,445
Kohlrabi	40	20	800
Eggplant	46	35	1,610
Other Vegetables	373	18	6,714
Total	912		25,179

Source: Phuc Loc Commune People's Committee (2025b)

The sample size was determined using the following formula (Cochran, 1977):

$$n = \frac{Z^2 p(1-p)}{e^2}$$

where n denotes the sample size, Z represents the standard normal value corresponding to the selected confidence level, P refers to the estimated population proportion, and e indicates the allowable margin of error.

Cochran (1977) recommended setting p = 0.5 in the absence of prior information in order to ensure a sufficiently large and statistically conservative sample size. With a 95% confidence level (Z = 1.96) and an allowable margin of error of e = 0.10, the calculated sample size was n = 96.04. Accordingly, the final survey sample size was rounded up to 100 vegetable-growing households. Households were selected through a combination of purposive and random sampling based on lists provided by local authorities. Additionally, a pilot study with 10 vegetable-farming households was conducted prior to the official survey to refine the questionaire for the local context.

Data analysis

To examine the effects of human capital on the use of organic fertilizer by vegetable-growing households in the context of digital

transformation in Phuc Loc, this study employed a fractional logit model, in which the dependent variable was defined as the share of the organic fertilizer expenditure in the total fertilizer costs at the household level. This modeling approach is particularly suitable for analyzing determinants of technology adoption intensity and resource allocation decisions when the dependent variable is bounded between zero and one (Allen, 2014; Misango *et al.*, 2022). The equations used in the fractional logit model were as follows with the variables described in **Table 2**:

$$Y_i = \frac{Cost\ of\ organic\ fertilizer}{Total\ cost\ of\ fertilizer} \in [0,1]$$

$$E(Yi|Xi) = f(\beta_0 + \beta_i HC_i + \delta_i X_{i.} + \varepsilon_i).$$

There were two groups of organic fertilizers utilized by farmers: (1) farmyard manure and green manure and (2) microbial organic fertilizer. The cost of organic fertilizers in this study was estimated based on both market prices and on-farm production conditions. The cost of farmyard manure was estimated at 10,000 VND kg^{-1} for purchased manure and 1,000 VND kg^{-1}

Table 2. Definitions of the Variables in the Fractional Logit Model

Variable	Description	Measurement
Yi	The share of the organic fertilizer costs in the total fertilizer expenditure of vegetable farm-households ($500m^2$)	Proportion
X1	Self-production of organic fertilizer	Dummy (1: Yes, 0: No)
X2	Price of organic fertilizer	Likert scale (1: Low; 2: Medium; 3: High)
X3	Perceived quality of organic fertilizer	Dummy (1: Quality good, 0: Quality poor)
X4	Age of the respondent	Years
X5	Sex	Dummy (1: Male, 0: Female)
X6	Formal education level	Number of years in school
X7	Household size	Number of members
X8	Number of laborers in vegetable production	Number of laborers
X9	Vegetable farming experience	Number of years
X10	Participation in fertilizer training courses	Number of training sessions attended
X11	Number of digital devices owned	Quantity
X12	Digital device usage skills	Likert scale (1-5)
X13	Digital information filtering/selection skills	Likert scale (1-5)
X14	Online market information searching skills	Likert scale (1-5)
X15	Diversity level of digital info on organic fertilizers	Likert scale (1-5)
X16	Skills in using digital devices to find fertilizer info	Likert scale (1-5)
X17	Frequency of searching for instructional videos	Likert scale (1-5)
X18	Ability to apply techniques from instructional videos	Likert scale (1-5)
X19	Awareness of risks associated with fertilizer use through digital information	Likert scale (1-5)
X20	Ability to purchase fertilizers via digital platforms	Likert scale (1-5)
X21	Digital payment application skills	Likert scale (1-5)
X22	Vegetable sales method	Dummy (1: Bulk-sale, 0: Retail)
X23	Product photography skills for digital platforms	Dummy (1: Yes, 0: No)
X24	Primary method of purchasing fertilizer	Dummy (1: Online by digital device, 0: Offline)
X25	Total cultivation area	m^2
X26	Annual income from vegetable production	VND $year^{-1}$

for self-produced green manure to account for labor and processing inputs.

The Likert scale levels were defined as follows: (1) No knowledge at all/ Never/ No understanding; (2) Limited knowledge/ Rarely/ Slight understanding; (3) Basic knowledge/ Occasionally/ Basic understanding; (4) Fairly proficient/ Frequently/ Good understanding; and (5) Highly proficient/ Very frequently/ Full understanding.

The internal consistency of the digital skills scale was verified using Cronbach's alpha, yielding a value of 0.9605, which indicates exceptional reliability and suggests that the constituent items within the digital human capital construct are highly interrelated and consistently measure the intended latent variable.

Results and Discussion

Current status of organic fertilizer use in vegetable production in Phuc Loc commune

Organic fertilizer use for vegetable production in Phuc Loc is on an increasing trend, with 2025 estimates reaching approximately 2,500 tons and 258 tons of microbial organic fertilizer. This shift is partly driven by internet-based information and social media, which have ecouraged households to compost agricultural by-products into green manure (**Table 3**).

Despite the continued dominance of inorganic fertilizers due to their rapid effects and lower labor requirements, 58% of surveyed households have integrated organic inputs into their farming practices. Specifically, on an average cultivated area of 500m², households using organic fertilizers applied 108.84kg farmyard manure and green manure and 17.18kg microbial organic fertilizer on average, while nitrogen, phosphorus, and potassium were applied at 18.58kg, 31.55kg, and 22.12kg, respectively. Survey results show that organic fertilizer users achieve a higher average yield (702.07 kg $500m^{-2}$) compared to non-users (575.26 kg $500m^{-2}$), despite using lower rates of inorganic fertilizer. This finding suggests that organic fertilizer use may contribute positively to productivity despite lower overall inorganic input intensity (**Table 4**).

However, the intensity of adoption remains moderate, while 58% of households use organic inputs, 42% still rely exclusively on inorganic fertilizers, and 40% of the sample allocates only 20% to less than 40% of their total fertilizer expenditure to organic options. Among the 100 surveyed households, only two households reported allocating more than 80% of fertilizer expenditures to organic fertilizers (**Table 6**).

Economically, households using organic fertilizers demonstrate superior efficiency. The gross output value for adopters (11,192,560 VND $500m^{-2}$) significantly exceeds that of non-users (9,099,909 VND $500m^{-2}$). Furthermore, the mixed income per family labor day for organic fertilizer users reached 353,883 VND compared to 306,786 VND for those relying solely on inorganic fertilizers (**Table 7**).

The impact of digital human capital on organic fertilizer adoption among vegetable-farming households in Phuc Loc commune

The current state of human capital in the context of digital transformation in Phuc Loc

Human capital constitutes a fundamental basis for household decision-making. A

Table 3. Fertilizer Use by Vegetable-Farming Households in Phuc Loc Commune

Fertilizer use	Quantity (tons)
I. Organic fertilizer	
Farmyard manure and green manure	2500
Microbial organic fertilizer	258
II. Inorganic fertilizer	
Nitrogen	177.92
Phosphorus	333.6
Potassium	133.44
Compound NPK	222.4

Source: Phuc Loc Commune People's Committee (2025b)

Table 4. Fertilizer application in vegetable production among farmers in Phuc Loc commune (per 500m^2)

Items	Unit	Organic fertilizer-using households	Non-users	Difference
Household	households	58	42	
Organic fertilizer				
Farmyard manure and green manure	kg	108.84	0	108.84***
Microbial organic fertilizer	kg	17.18	0	17.18***
Inorganic fertilizer				
Nitrogen	kg	18.58	23.07	4.49***
Phosphorus	kg	31.55	38.22	6.67**
Potassium	kg	22.12	26.35	4.23 **
Yield 500m^{-2}	kg 500m^{-2}	702.07	575.26	126.81***

Source: Survey results and difference test (2025)

*Note: ***, **, * denote significance at 1%, 5%, and 10% probability, respectively; ^{ns} : non-significant.*

Table 5. Organic fertilizer use by vegetable-farming households in Phuc Loc commune

Item	Number reporting	Percent (%)
Organic fertilizer-using households	58	100.0
Monocropping	8	13.8
Polyculture	50	86.2
Application practices		
Pre-planting fertilization	57	98.3
Top-dressing fertilization	23	39.7
Using multiple times/crop	32	55.2
Using once	26	44.8

Source: Survey results (2025)

Table 6. Organic Fertilizer Share in the Total Fertilizer Expenditure (Yi) of Vegetable Farms, Phuc Loc

Yi	Number of reporting households	Percent (%)
0%	42	42.0
20% to < 40%	40	40.0
40% to < 60%	12	12.0
60% to < 80%	4	4.0
80% to 100%	2	2.0
Total	100	100.0

Source: Survey results (2025)

comparison between households using organic fertilizers and those not using organic fertilizers revealed significant differences in overall human capital across several dimensions, including age, years of schooling, labor participation in vegetable production, farming experience, and the number of training sessions attended. In the context of digital transformation, human capital was further reflected through multiple aspects of digital human capital, such as the number of digital devices owned, digital device usage skills, digital information filtering/selection skills, assessment of information diversity, skills in using digital devices to find fertilizer information, frequency of searching for instructional videos, ability to apply techniques from instructional videos in practice, awareness of risks associated with fertilizer use through

Table 7. Economic efficiency of vegetable farming in Phuc Loc

Item	Unit	Organic fertilizer-using households	Non-users	Difference
Gross output value (GO)	VND	11,192,560	9,099,909	2,092,647***
Intermediation cost (IC)	VND	2,153,986.9	1,772,090.5	
Seeds	VND	135,494.5	132,564.4	2,930.1^{ns}
Land preparation	VND	164,555.9	163,105.4	1,450.5^{ns}
Inorganic fertilizer	VND	1,053,635	1,294,204	240,569***
Organic fertilizer	VND	603,045.5	0	603,045.5***
Plant protection cost	VND	197,256	182,216.7	15,039.3**
Hỉring/Labor cost	VND	400,643.4	316,617.4	84,026*
Depreciation	VND	473,835.5	372,345	101,490.5*
Family labor (L)	working days	23.07	21.64	1.43**
Value added (VA)	VND	9,038,573.1	7,327,818.5	
Mix income (MI)	VND	8,164,094.2	6,638,856.1	
GO/IC	times	5.19	5.13	
VA/IC	times	4.19	4.13	
MI/IC	times	3.79	3.74	
MI/L	VND working days-1	353,883	306,786	

Source: Survey results, 2025; 1US$ = 26,391VND

*Note: ***, **, * denote significance at 1%, 5%, and 10% probability, respectively; ^{ns}: non-significant.*

digital information, ability to purchase fertilizers via digital platforms, digital payment skills, product photography skills for digital platforms, and engagement in online fertilizer purchasing. Across all these indicators, households using organic fertilizers consistently outperformed non-users. The digital skill levels of organic fertilizer users were relatively high, with mean scores ranging from 3.96 (digital payment application skills) to 4.91 (frequency of searching for instructional videos) on a five-point Likert scale, indicating fairly proficient/frequently to highly proficient/very frequently. In contrast, non-users exhibited lower scores, ranging from 2.71 (online market information searching skills) to 3.45 (digital information filtering/selection skills), corresponding to basic to fairly proficiency levels (**Table 8**).

Determining the effect of human capital on organic fertilizer adoption among vegetable farming households in the context of digital transformation in Phuc Loc

To analyze how human capital influences organic fertilizer adoption, this study employed a fractional logit model. Due to high correlation among digital variables, Principal Component Analysis (PCA) was first used to group them. Carrying out PCA is particularly useful when dealing with datasets that include a large number of variables requiring simultaneous consideration (Nguyen *et al*., 2015). Components with eigenvalues greater than 1 were retained, and varimax rotation was applied to improve interpretability. The PCA results grouped the digital human capital variables into two main dimensions. The first component, labeled "Digital Information Utilization and Learning Capacity," reflected the farmers' digital device usage skills, online market information searching skills, diversity level of digital info on organic fertilizers, skills in using digital devices to find fertilizer info, frequency of searching for instructional videos, and ability to apply techniques from instructional videos. The second component, labeled "Digital Risk Awareness and Transaction Capacity," captured the farmers' digital information filtering/selection skills, awareness of risks associated with fertilizer use through digital information, ability to purchase

Table 8. Digital human capital of vegetable-farming households in Phuc Loc

Item	Unit	Organic fertilizer-using households	Non-users	Difference
I. General human capital				
Age of the respondent	Years	50.8	47	3.8***
Formal education level	School year	10.1	10.8	0.77**
Household size	Number of members	5.2	4.9	0.3ns
Number of laborers in vegetable production	Number of laborers	2.55	1.78	0.77***
Vegetable farming experience	Years	19.37	17.45	1.92*
Participation in fertilizer training courses	Number of training sessions attended	10.13	6.3	3.83***
II. Digital human capital				
Number of digital devices owned	Likert scale	2.27	1.92	0.35**
Digital device usage skills	Likert scale	4.77	2.85	1.91***
Digital information filtering/selection skills	Likert scale	4.32	3.45	0.87***
Online market information searching skills	Likert scale	4.86	2.71	2.15***
Diversity level of digital info on organic fertilizers	Likert scale	4.87	2.69	2.18***
Skills in using digital devices to find fertilizer info	Likert scale	4.87	2.52	2.35***
Frequency of searching for instructional videos	Likert scale	4.91	2.5	2.41***
Ability to apply techniques from instructional videos	Likert scale	4.86	2.66	2.20***
Awareness of risks associated with fertilizer use through digital information	Likert scale	4.22	3.21	1.01***
Ability to purchase fertilizers via digital platforms	Likert scale	4.25	3.40	0.85***
Digital payment application skills	Likert scale	3.96	2.92	1.04***
Product photography skills for digital platforms	Dummy (1: Yes, 0: No)	0.82	0.5	0.32***
Primary method of purchasing fertilizer	Dummy (1: Online by digital device, 0: Offline)	0.75	0.5	0.25***

Source: Survey results (2025)

*Note: ***, **, * denote significance at 1%, 5%, and 10% probability, respectively; ^{ns} : non-significant.*

fertilizers via digital platforms, and digital payment application skills (**Table 9**).

The second component (Digital Risk Awareness and Transaction Capacity) was excluded due to a high Variance Inflation Factor (VIF>10) to ensure model stablility. The final model showed robust explanatory power regarding the determinants—particularly human capital factors in the digital context—of the share of organic fertilizer expenditure in the total fertilizer costs among vegetable-growing households (Prob> Chi^2 = 0.0000).

The analysis identified statistically significant relationships at the 1% and 10% levels between the dependent variable and several human capital indicators with positive

Table 9. Combining digital human variables by the PCA technique

Variables	Comp1	Comp2
X12	0.4075	
X13		0.5141
X14	0.4043	
X15	0.3997	
X16	0.4141	
X17	0.4137	
X18	0.4083	
X19		0.4996
X20		0.5196
X21		0.4635
Eigenvalue	7.5077	2.1050

Source: PCA results (2026)

effects. These included the ability to self-produce organic fertilizers, perceived quality of organic fertilizer, number of laborers in vegetable production, digital information utilization and learning capacity, and skills in taking photos to promote products on social media (**Table 10**). Specifically, the capacity to produce organic fertilizers (e.g., farmyard manure and green manure) increased the share of the organic fertilizer expenditure in the total fertilizer costs in vegetable production. The variable "*self-production of organic fertilizer"* had a positive and statistically significant effect on the share of organic fertilizer expenditure (Coef. = 0.603; P <0.01), with a marginal effect of approximately 4.7%. This indicates that households capable of producing their own organic fertilizers tend to allocate a higher proportion of their fertilizer budget to organic inputs. This finding is consistent with studies by FAO (2021), Weng *et al*. (2023), and Liao *et al*. (2025), which indicated that farmers who have knowledge of compost preparation are more likely to adopt environmentally friendly practives. This effect can be explained by reduced dependence on external markets, lower cash costs, and greater familiarity with organic fertilizer practices. In the context of Phuc Loc commune, where agricultural by-products are readily available, self-production enhances both economic feasibility and the farmers' confidence in adopting organic fertilizers. In addition, the process of self-producing organic fertilizers is often associated with the accumulation of practical knowledge and experience among farming households. Farmers who are capable of composting typically have a better understanding of fertilizer characteristics, decomposition time, and appropriate application methods for different crops. This helps reduce technical risks—one of the major barriers to organic fertilizer adoption—thereby encouraging households to allocate a greater share of their fertilizer expenditure to organic inputs. Furthermore, self-production of organic fertilizers exerts an indirect effect by enhancing the farmers' awareness of the long-term benefits of sustainable farming practices. Through direct involvement in producing and applying organic fertilizers, farmers are more likely to observe improvements in soil quality, structure, and crop yields over time. These experiential insights help strengthen their confidence, leading to a higher prioritization of organic fertilizers within their overall input cost structure. Given the relatively high returns from vegetable cultivation, households tend to prioritize resource allocation to this activity, even though organic fertilizer production and application are labor-intensive and involve additional costs. This explains the positive effect of labor availability on the share of organic fertilizer expenditure in the total fertilizer costs of vegetable farming households in Phuc Loc commune.

Table 10. Estimated Regression Results on Human Capital Affecting Organic Fertilizer Adoption among Vegetable Farming Households in the Context of Digital Transformation in Phuc Loc Commune

Item	Fractional Logit Regression				
	Coef.	Std. Error	z	*P*>|z|	Dy/dx
Self-production of organic fertilizer	0.603***	0.205	2.93	0.003	0.047
Price of organic fertilizer	-0.127	0.112	-1.13	0.257	-0.008
Perceived quality of organic fertilizer	0.714***	0.211	3.38	0.001	0.048
Age of the respondent	-0.004	0.012	-0.38	0.707	-0.000
Gender of the respondent	-0.141	0.157	-0.89	0.372	-0.009
Formal education level	-0.045	0.044	-1.03	0.304	-0.003
Household size	-0.020	0.070	-0.29	0.771	-0.001
Number of laborers in vegetable production	0.483***	0.094	5.12	0.000	0.032
Vegetable farming experience	0.004	0.014	0.31	0.757	0.0003
Participation in fertilizer training courses	-0.007	0.021	-0.33	0.742	-0.0005
Number of digital devices owned	0.142	0.133	1.07	0.287	0.01
Digital Information Utilization and Learning Capacity	0.810***	0.130	6.22	0.000	0.055
Vegetable sales method	-0.609*	0.323	-1.88	0.060	-0.05
Product photography skills for digital platforms	0.607*	0.335	1.81	0.070	0.04
Primary method of purchasing fertilizer	0.034	0.035	0.11	0.909	0.0023
Total cultivation area	0.0001	0.000	0.23	0.822	0.00006
Annual income from vegetable production	0.0015	0.004	0.32	0.750	0.0001
Log Pseudo Likelihood	-38.538				
Prob>Chi square	0.0000				
Wald Chi square (17)	219.98				
Number of observations	100				

Source: Fractional logit regression results (2025)

*Note: ***, **, * denote significance at 1%, 5%, and 10% probability, respectively; ^{ns}: non-significant.*

In the context of digital transformation, farmers also need digital skills. The "Digital Information Utilization and Learning Capacity" had a positive affect on the share of organic fertilizer expenditure in the total fertilizer costs of vegetable farming. The composite variable "*Digital Information Utilization and Learning Capacity"* (DHC) represents the digital dimension of human capital among vegetable farming households. It was constructed from multiple components, namely digital device usage skills, online market information searching skills, the ability to access and evaluate information on organic fertilizers, the frequency of searching for instructional videos, and the capacity to apply acquired knowledge in practice. The fractional logit estimation results indicated that this variable had a relatively large positive coefficient (Coef. = 0.810) and was statistically significant at the 1% level (*P* = 0.000) (**Table 10**). Notably, the marginal effects suggested that a one-unit increase in DHC is associated with an average increase of 5.5% in the share of organic fertilizer expenditure in total fertilizer costs. This represented the largest marginal impact among all the explanatory variables, underscoring the central role of digital human capital in promoting the use of organic fertilizers. This finding aligns with recent research by Gong *et al*. (2025) in China, which posited that increasing digital human capital enhances a farmer's green production awareness

and helps them overcome technical literacy barriers. From a mechanistic perspective, digital device usage skills serve as a foundational condition enabling farmers to access diverse information sources via the internet. This capability lowers information costs and addresses the issue of information asymmetry within the fertilizer market. Weng *et al*. (2023) argued that the internet effectively breaks through information barriers, thereby optimizing farmers' investment decisions in eco-friendly inputs. In the context of Phuc Loc commune, where farmers traditionally rely heavily on experiential knowledge, enhanced digital literacy significantly expands learning opportunities and reshapes perceptions regarding the benefits of organic fertilizers. With improved access to information, farmers become less dependent on informal, experience-based knowledge systems that are often fragmented and less reliable. Moreover, online market information searching skills enable farmers to better understand consumer preferences and emerging demand trends for safe and environmentally friendly agricultural products. Although price differentiation between organically and conventionally produced vegetables remains limited in the local context, exposure to digital market information helps farmers form expectations about long-term benefits. This, in turn, encourages adjustments in input allocation, leading to an increased share of organic fertilizers as part of a forward-looking production strategy.

Another critical component is the ability to process and evaluate diverse sources of digital information related to organic fertilizers. In an environment characterized by abundant yet heterogeneous information, the capacity to filter and assess information quality becomes particularly important. As captured within the DHC variable, this ability reflects the farmers' competence in identifying credible sources, thereby reducing uncertainty and mitigating risks associated with misinformation. This enhances confidence in decision-making and supports greater adoption of organic fertilizers. In addition, skills in searching for technical information on organic fertilizers allow farmers to better understand product characteristics, application methods, and suitability for specific crops. This is especially relevant given the heterogeneity and lack of standardization in organic fertilizer products compared to chemical fertilizers. With improved knowledge and comparison capabilities, farmers can reduce trial-and-error costs and enhance application efficiency, thereby increasing their willingness to allocate a higher proportion of expenditures to organic fertilizers. The frequency of accessing instructional videos also plays a crucial role in the farmers' learning processes. Compared to traditional text-based materials, video content offers greater visual clarity and is more accessible, particularly for rural populations with moderate levels of formal education. Regular engagement with such content not only reinforces knowledge but also reduces technical uncertainties, thereby increasing the farmers' confidence in adopting organic fertilizer practices. More importantly, the ability to translate knowledge acquired from instructional videos into actual farming practices represents a key mechanism through which information is transformed into behavior. Farmers with such capabilities are better equipped to implement processes such as composting, proper fertilizer application, and dosage adjustments tailored to specific farming conditions. This enhances the effectiveness of organic fertilizer use, strengthens trust in its benefits, and ultimately encourages a higher allocation of expenditure toward organic inputs.

In the specific context of Phuc Loc commune, the positive effect of DHC can be explained through its role in reducing information asymmetry, which constitutes a major barrier to the adoption of sustainable agricultural practices. By enabling access to reliable and diverse information sources, digital human capital allows farmers to verify and compare information before making decisions. At the same time, it alleviates perceived risks and technical barriers by facilitating experiential learning through digital platforms. Beyond technical aspects, DHC also enhances the farmers' market connectivity. The use of digital platforms for product promotion and marketing

improves transparency and fosters consumer trust. When farmers perceive improved market opportunities, they are more likely to invest in higher-quality inputs, including organic fertilizers. This suggests that digital human capital exerts both direct and indirect effects, the latter operating through improved market access and incentives.

Besides the human capital factors, the farmers' assessment of organic fertilizer quality in the model exerted a positive effect on the share of organic fertilizer expenditure in the total fertilizer costs among vegetable-growing households. The variable *perceived quality of organic fertilizer* exhibited a positive and statistically significant effect on the share of organic fertilizer expenditure (Coef. = 0.714; P <0.01), with a marginal effect (dy/dx) of 0.048. This implies that a one-unit increase in perceived quality leads to an approximate 4.8% increase in the proportion of organic fertilizer costs in the total fertilizer expenditure. This result suggests that the farmers' subjective evaluation of fertilizer quality plays a crucial role in shaping input allocation decisions. In the context of Phuc Loc commune, where concerns about counterfeit or low-quality inputs remain prevalent, higher perceived quality reduces uncertainty and strengthens trust in organic fertilizers. Moreover, when farmers observe improvements in soil fertility, crop quality, and long-term productivity, their confidence is reinforced, thereby encouraging greater investment in organic fertilizers. This finding is corroborated by Weng *et al*. (2023), who highlighted that quality uncertainty and information asymmetry in the market create mistrust that deters organic investment, and Li *et al*. (2024), who demonstrated that enhanced technology cognition regarding functional effectiveness and risk reduction is a critical driver for the adoption of sustainable practices. By contrast, the vegetable sale method of farmers in Phuc Loc had a negative effect on the dependent variable. At harvest, households typically sell vegetables through two ways: a transaction in which the entire output is sold at once, or directly selling to different collectors/customers from their field. Households that tend to sell their entire output in a single transaction are generally less inclined to use organic fertilizers. In single, bulk transactions, buyers usually pay a uniform price based on quantity and appearance, not on how the crop is produced. Since organic fertilizer use does not bring a higher price in this channel, farmers have little incentive to bear its higher labor and management costs. In other word, farmers who sell vegetables in one transaction interact mainly with traders or collectors, not final consumers. This limits feedback on food safety, product quality, or environmental concerns—key factors that often encourage a higher share of organic fertilizer expenditure in the total fertilizer costs among vegetable-farming households.

The study's findings confirm the central role of human capital in promoting organic fertilizer use among vegetable-producing households in Phuc Loc commune within the context of digital transformation. These results reinforce theoretical perspectives suggesting that decisions to adopt sustainable agricultural practices depend not only on material resources or policy frameworks, but are also strongly shaped by the producers' cognitive capacities, digital skills, and their ability to access, process, and utilize information.

An important contribution of this study is its clarification of the distinction between traditional human capital and digital human capital. In the current context of digital transformation, while formal education and farming experience no longer exhibit a clear direct influence on household decision-making, they remain essential foundations for developing capabilities associated with digital human capital. Consequently, human capital in the digital era exerts a more pronounced and stable influence on decisions regarding organic fertilizer use, as evidenced across the estimation models. This corresponds with the argument by Cheng *et al*. (2024) that digital skills help farmers optimize the allocation of production factors through enhanced access to technology and social resources. In addition, this finding suggests that, in the digital age, accumulated knowledge over time or formal educational credentials alone are insufficient to enable farmers to make effective production decisions. Instead, the ability to use digital technologies to

search for, evaluate, and apply technical information plays a decisive role in recognizing the long-term benefits of green production relative to the short-term gains of conventional farming practices. These results are consistent with recent studies in developing countries that emphasize the role of information and communication techonology (ICT) skills in reducing information asymmetries and fostering innovation adoption in agriculture.

However, the effects of human capital are not uniform across household groups. The influence of digital human capital in promoting organic fertilizer use is stronger among older households with longer farming experience and smaller landholdings, but better internet connectivity. This finding is supported by Weng *et al*. (2023) and Gong *et al*. (2025), who suggested that digital human capital assists middle-aged and elderly farmers in overcoming cognitive barriers to access safety standards. In contrast, for younger- households, an emphasis on output expansion and highly commercialized vegetable production tends to dampen incentives to adopt organic fertilizers. This finding highlights a major challenge in Vietnam's agricultural digital transformation, particularly among younger farmers: despite higher awareness and better educational attainment, strong economic pressures may constrain their motivation to pursue green production opportunities.

In addition, the study showed that although organic fertilizers offer long-term environmental and health benefits, many vegetable-producing households remain hesitant to adopt them due to concerns about slower effectiveness, potential risks, and limited market recognition. This indicates that the decision to use organic fertilizers is not merely a technical issue but also an economic choice shaped by the farmers' risk perceptions and profit expectations. In this context, digital human capital plays a crucial role in enabling households to access market information, food safety standards, and policy support mechanisms, thereby improving expectations regarding the economic returns of organic production. This finding aligns with studies by Weng *et al*. (2023), Cheng *et al*. (2024), Liao *et al*. (2025), and Gong *et al*. (2025).

Compared with previous studies focusing mainly on formal education or traditional training, this research extends the analytical framework by integrating digital transformation and digital human capital within a local context. This contribution strengthens the theoretical understanding of green technology adoption in agriculture and provides empirical evidence from developing countries facing simultaneous challenges of digital transformation, sustainable development and food security. The findings indicate that promoting organic fertilizer use requires strengthening farmers' human capital, particularly digital human capital. In the context of Phuc Loc commune in particular and Vietnamese agriculture more broadly, digital transformation can only be effective when accompanied by systematic investment in human capacities, thereby laying the foundation for a transition toward green, sustainable, and resilient production systems capable of withstanding environmental and market shocks.

Conclusions

This study examined the impact of human capital on organic fertilizer use behavior among vegetable-producing households in Phuc Loc commune (Hanoi) in the context of agricultural digital transformation. The results revealed clear differences in both traditional human capital and digital human capital between households that use organic fertilizers and those that do not. The fractional logit model indicated that digital human capital exerts a stronger and more stable effect than other factors included in the model. This finding underscores that, in the digital era, the farmers' capacity to access, evaluate, and apply information through digital tools plays a pivotal role in promoting sustainable agricultural practices. From an academic perspective, the study contributes to the literature on green technology adoption in agriculture by highlighting the importance of digital human capital in developing-country contexts. From a policy perspective, the findings suggest that strategies to promote green production should be closely integrated with systematic investments in human capital development, particularly in enhancing farmers' digital skills. Despite

limitations related to scope and data, the study provides a foundation for further research on the linkages between digital transformation and sustainable agricultural development.

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