

The impact of internet access on green production practices among farmers

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Abstract: Amidst mounting global imperatives for sustainable agriculture and China's 'dual carbon' goals, this study investigates how internet access promotes farmers' adoption of green production practices, specifically defined as reducing chemical inputs through decreased fertiliser and pesticide application, using panel data from the Rural Observation Point in Henan Province (2009–2022). The findings reveal that internet access exerts a significant positive impact on farmers' green production behaviours, specifically reducing fertiliser and pesticide expenditures by 13.3% and 16.3%, respectively. Internet access enhances information accessibility, improves technical learning efficiency, and strengthens market linkages, thereby elevating farmers' economic returns and production expertise. Crucially, mechanism analysis demonstrates that both economic benefits and production technologies positively influence the promoting effect of internet access on farmers' green production practices. Heterogeneity analysis further identifies more pronounced effects among farmers with higher education levels, greater mechanisation, larger operational landholdings, robust health, younger age, centralised decision-making structures and those who are in urban suburbs, poor villages and traditional villages. This research offers critical insights for designing targeted digital interventions to advance ecological agriculture and achieve sustainable rural development goals.

Keywords: China; digital farming; fertiliser; pesticide; sustainable farming practice

Green production practices constitute an increasingly imperative component of sustainable agricultural development, particularly through technological innovations that reduce chemical inputs via diminished fertiliser and pesticide application (Xu et al. 2024). China faces critical challenges in farmland ecological protection due to excessive agrochemical usage (Hu and Liu 2024), which compromises ecosystem stability and food security through water contamination, disruption of soil biological activity and heavy metal

accumulation, collectively inducing severe soil health degradation. Consequently, reducing agrochemical inputs has emerged as a pivotal strategy for enhancing soil quality and advancing sustainable agriculture. Confronting this pressing challenge, our study investigates technology-driven pathways to reconcile productivity and ecological sustainability.

Concurrently, the internet has evolved into foundational infrastructure for agricultural operations and rural livelihoods in China, demonstrating significant potential

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to advance green production practices through reduced agrochemical application (Nie et al. 2024). It serves as a critical conduit for disseminating agricultural techniques, market intelligence, and environmental regulations, thereby enabling the adoption of ecologically sustainable methods (Zhu et al. 2021). Notwithstanding these hypothesised benefits, empirical evidence quantifying internet access effects on green production behaviours remains underdeveloped. The aim of this study is therefore to examine how internet access influences green production practices, quantify its effects on reducing fertiliser and pesticide inputs, examine the potential theoretical mechanisms, and identify heterogeneous impacts across diverse farmer characteristics.

This study advances existing scholarship through dual contributions. First, it extends research on internet access impacts within agricultural systems. Extant literature establishes that digital connectivity significantly enhances agricultural technology adoption (Zheng et al. 2022; Ma et al. 2024) and the transfer of farmland (Guo et al. 2025), consequently elevating grain production efficiency (Zheng et al. 2022). Furthermore, scholars demonstrate that internet access augments farmers' informational access, strengthening environmental awareness (Deng et al. 2022) while substantively increasing rural incomes (Khan et al. 2022; Liu et al. 2022), which collectively accelerates the process of agricultural modernisation. Second, this study provides new evidence for the determinants of agricultural green production. At the individual level, empirical studies identify significant influences from

household head characteristics including age (Olu-doye et al. 2023), gender (Nchanji et al. 2023), educational attainment (Alebachew et al. 2023), personal ethics (Meunier et al. 2024), physical health (Kumar et al. 2023), and ecological consciousness (Tabe-Obong et al. 2023). Household-level determinants include operational landholdings (Tan et al. 2022), equipment accessibility (Su et al. 2022; Saranya et al. 2023), and farm organisational structure (Athukorala et al. 2023), where scale economies and mechanisation facilitate green practice adoption.

Theoretical mechanism. Internet access facilitates farmers' green production practices by mitigating institutional transaction costs, correcting behavioural decision biases, and reconstructing market incentive structures (Figure 1). Within the institutional economics framework, transaction costs arising from information asymmetry and institutional segmentation of factor markets impose dual constraints: non-excludability of agricultural knowledge induces path-dependent technological lock-in, while market search costs suppress green premium realisation. Three mechanisms drive the transformation. First, the transaction cost compression effect reduces information acquisition costs for sustainable technologies, alleviating adverse selection (Lv et al. 2025). Second, digital learning platforms address bounded rationality by enhancing information transmission efficiency to correct cognitive biases (Simon 1955). Third, e-commerce establishes demand-induced incentives where price signals generate quality premium expectations, inducing farmers

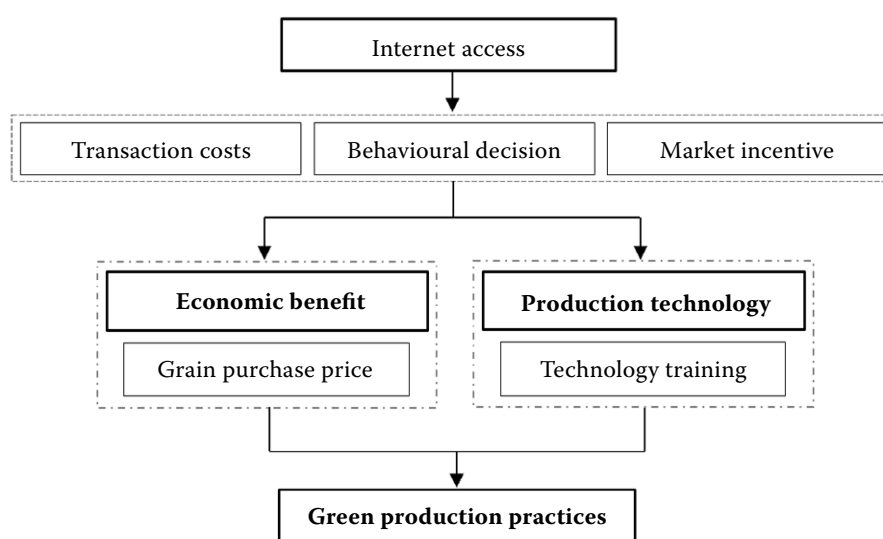


Figure 1. The conceptual model

Source: Authors' own elaboration

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to internalise eco-production as inter-temporal utility-maximising strategies. This triggers factor substitution elasticity adjustments, achieving Pareto improvements in chemical input reduction. This paper proposes the following hypothesis:

H_1 : Internet access facilitates farmers' green production practices.

Internet access significantly enhances farmers' economic benefits by reducing information acquisition transaction costs, enabling more responsive market engagement. Broader information channels facilitate production adjustments to meet demand signals, where higher agricultural purchase prices reflect both market scarcity (Chandio et al. 2023) and evolving consumer preferences for greener products (Yin and Zhao 2024). This generates dual economic returns: scale economies reduce per-unit input costs while quality premiums reward chemical input reduction. Consequently, improved profitability simultaneously funds operational scaling and incentivises environmentally conscious production methods, fostering autonomous adoption of sustainable practices through reinforced economic rationality. Therefore, this paper proposes the following hypothesis:

H_2 : Economic benefits are positively regulating the promoting effect of internet access on farmers' green production practices.

Internet access fundamentally enhances agricultural production techniques by dramatically reducing knowledge acquisition transaction costs, thereby mitigating bounded rationality constraints. Its ubiquitous connectivity simultaneously improves training accessibility (Karunathilake et al. 2023) and expands technical dissemination coverage by lowering implementation costs in underserved rural areas. Farmers consequently acquire advanced cultivation methods and environmental policy awareness through on-demand video tutorials, virtual expert consultations, and online policy resources (Saranya et al. 2023). This democratisation of agricultural knowledge catalyses dual improvements: practical skills to optimise input efficiency and heightened ecological consciousness regarding chemical application. The resultant technical proficiency and environmental realisation collectively empower farmers to adopt precision application methods that intrinsically reduce fertiliser and pesticide usage through capability enhancement rather than external incentives. Therefore, this paper proposes the following hypothesis:

H_3 : Production techniques are positively regulating the promoting effect of internet access on farmers' green production practices.

MATERIAL AND METHODS

The data are sourced from the fixed observation points in rural areas of China. Due to limitations in data acquisition, this study only focuses on farmers in Henan Province. There were 16 rural fixed observation points in Henan Province, distributed in 16 prefecture-level cities and the specific geographical distribution is shown in Figure 2 (red dots). Due to the latest available data being up to 2022, and the questionnaires used in the rural fixed observation points having undergone significant changes in 2009, this study selected the primary data from 16 fixed observation points in Henan Province from 2009 to 2022 as the research sample. After cleaning and organising, a total of 13 923 sample observation data were obtained.

Green production practices. Aligned with the environmental externality internalisation framework, this study operationalises green production practices through per hectare fertiliser expenditures (*Fertiliser*) and per hectare pesticide expenditures (*Pesticide*). This measurement method follows established agroecological measurement conventions (Ma et al. 2018; Peng et al. 2025), since lower input expenditure per hectare reflects reduced chemical application intensity.

Internet access. The core explanatory variable (*Internet*) is operationalised as a binary variable grounded in information asymmetry reduction theory (Stiglitz 2002), where assignment follows digital infrastructure access verification based on the results of the internet use survey in the statistical annual report of farmers. Specifically, *Internet* assumes value 1 when households report functional broadband connectivity at their residence and 0 otherwise.

Control variables. Consistent with the agricultural household model (Singh et al. 1986) and behavioural decision theory, this study accounts for heterogeneity in green production adoption through comprehensive controls spanning: (i) individual human capital endowments, including gender (*Igender*), age (*Iage*), education (*Ieduc*), health status (*Ihealth*), and occupation (*Ijob*); (ii) household production characteristics, such as income sources (*Fsource*), primary economic activities (*Fbusin*), number of family members (*Fpopu*), and labour endowment (*Flabour*); and (iii) institutional embeddedness, including political capital proxied by village cadre status (*Fcadre*) and Communist Party membership (*Fparty*). Following established econometric conventions, financial controls for family income (*Fincome*) and expenditure (*Fexpend*) further isolate production decisions from liquidity constraints,

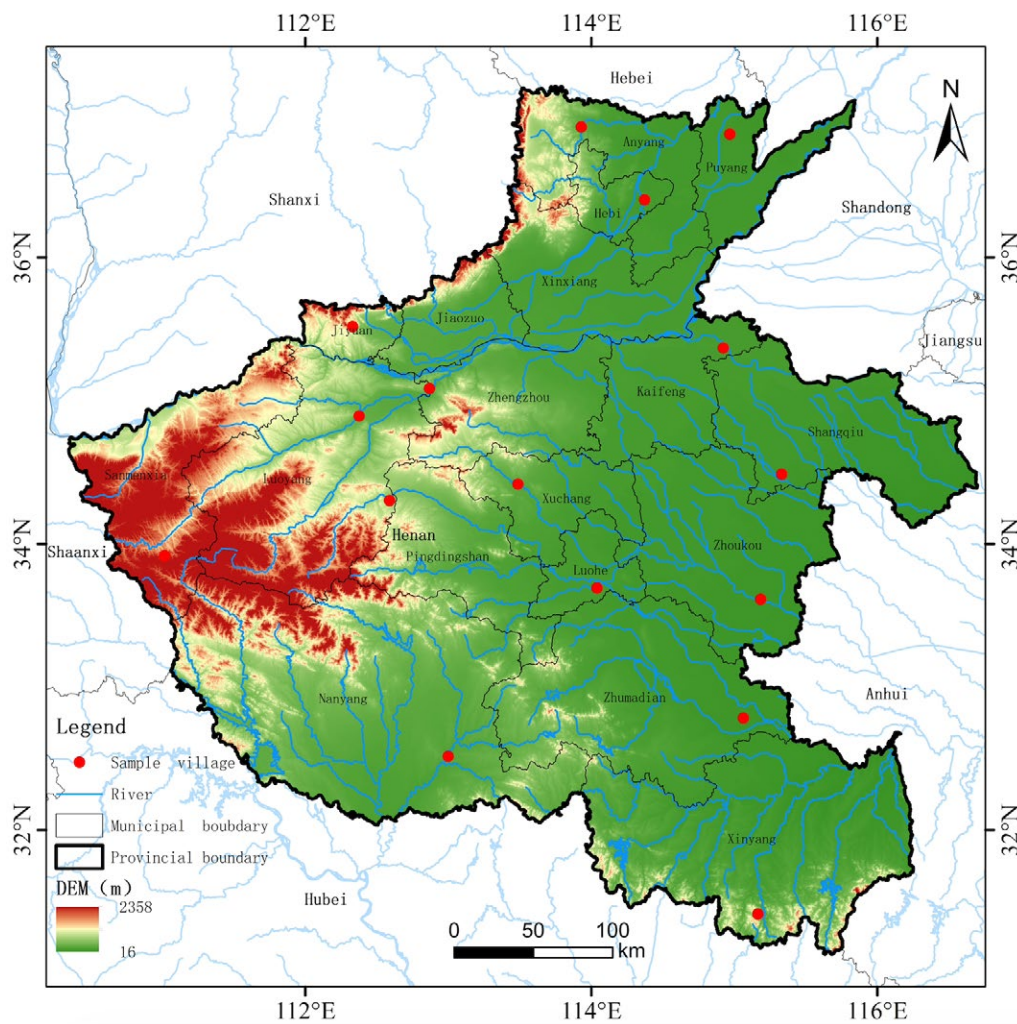


Figure 2. Location distribution of rural fixed observation points in Henan Province

Source: Created in ArcMap software by the authors

collectively addressing omitted variable bias in technology adoption pathways. Variable definitions and descriptive statistics are shown in Table 1.

This paper examines the impact of internet access on farmers' green production practices, and the equation is specified as follows:

$$\begin{aligned} Green_{it} = & \alpha + \beta \times Internet_{it} + \\ & + Controls'_{it} \gamma + \delta_i + \delta_t + \varepsilon_{it} \end{aligned} \quad (1)$$

where: i – the farmer; t – year; $Green_{it}$ – the farmers' green production practices, which are measured by *Fertiliser* and *Pesticide*; $Internet_{it}$ – whether the farmer's household has access to the internet, with access to the internet taken as 1 and 0 otherwise; $Controls$ – a series of control variables; δ_i and δ_t – farmer fixed effects and year fixed

effects, respectively; ε_{it} – the error term. The regression standard errors are clustered at the farmer level.

RESULTS

The baseline regression results presented in Table 2 demonstrate that internet access significantly reduces expenditure on chemical inputs. Columns 1 and 3, excluding control variables, show statistically significant negative coefficients for Internet, indicating reduced fertiliser and pesticide expenditure respectively. This association persists in columns 2 and 4 after incorporating control variables, with coefficients remaining significantly negative at conventional levels. Quantitatively, internet connectivity corresponds to 13.3% and 16.3% reductions in fertiliser and pesticide expenditures. These robust findings establish

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Table 1. Descriptive statistics ($n = 13\,923$)

Variable	Definition	Mean	S.D.
<i>Fertiliser</i>	annual fertiliser purchase expenditure divided by farmland area	0.614	0.727
<i>Pesticide</i>	annual pesticide purchase expenditure divided by farmland area	0.215	0.329
<i>Internet</i>	whether the farm household has access to the internet (1 = yes, 0 = no)	0.352	0.478
<i>Igender</i>	gender of the farmer (1 = male, 2 = female)	1.072	0.259
<i>Iage</i>	age of the farmer	59.252	11.499
<i>Ieduc</i>	years of education of the farmer	7.281	2.481
<i>Ihealth</i>	health status of the farmer (1 = excellent, 2 = good, 3 = moderate, 4 = poor, 5 = incapacitated)	1.917	1.147
<i>Ijob</i>	industry engaged by the farmer (1 = agriculture, 2 = mining, 3 = manufacturing, 4 = electricity, gas production and supply, 5 = construction, 6 = transportation, 7 = retail, 8 = catering, 9 = business services, 10 = residential services, 11 = others)	3.516	4.739
<i>Fsource</i>	household income sources (1 = household business operation, 2 = private enterprise operation, 3 = employed laborer, 4 = employed management, 5 = cadre salary, 6 = others)	2.098	1.574
<i>Fbusin</i>	household's main business (1 = household business operation, 2 = private enterprise operation, 3 = animal husbandry, 4 = fishery, 5 = industry, 6 = construction, 7 = transportation, 8 = commerce, 9 = others)	1.929	2.211
<i>Fpopu</i>	total number of household members	3.679	1.797
<i>Flabor</i>	number of household laborers	2.442	1.290
<i>Fcadre</i>	whether the household has village cadres (1 = yes, 2 = no)	0.038	0.192
<i>Fparty</i>	whether the household has party members (1 = yes, 2 = no)	0.150	0.357
<i>Fincome</i>	total annual household income	15.292	1.532
<i>Fexpend</i>	total annual household expenditure	8.733	0.915

Fertiliser and pesticide expenditures are measured in thousand US dollars per hectare, while household annual income and expenditures are in thousand US dollars

Source: Authors' own elaboration

that internet access meaningfully contributes to the adoption of green production methods through diminished chemical inputs.

Endogenous treatment

Endogeneity concerns arising from reverse causality or omitted variables necessitate addressing potential estimation bias. This study employs village-level power grid construction expenditure as an instrumental variable (IV), implementing a two-stage least squares (2SLS) approach. The selection satisfies the relevance criterion as enhanced grid infrastructure reduces proximity-based internet installation costs, thereby increasing adoption likelihood. Furthermore, the exclusion restriction holds since grid expenditure constitutes macroeconomic infrastructure investment that bears no direct relationship to individual agricultural decisions. Farmers' per-unit chemical input

allocation represents micro-level behavioural choices unaffected by village-level capital projects, thus ensuring the exogeneity.

The instrumental variable regression outcomes, presented in Table 3, demonstrate robust empirical support. Column 1 reports first-stage estimates showing a statistically significant positive coefficient for the instrument, confirming its strong positive correlation for internet access. The respective second-stage specifications in columns 2 and 3 corroborate baseline findings, with coefficients retaining statistically significant negative signs for both fertiliser and pesticide expenditures. This consistency persists after mitigating endogeneity concerns, thereby validating the study's core proposition. Consequently, the evidence substantiates that internet access significantly promotes green production practices among farmers.

Table 2. Benchmark regression results ($n = 13\,894$)

Variable	(1)	(2)	(3)	(4)
	<i>Fertiliser</i>	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Pesticide</i>
<i>Internet</i>	–0.114*** (0.025)	–0.133*** (0.025)	–0.149*** (0.012)	–0.163*** (0.012)
<i>Igender</i>		–0.098*** (0.036)		–0.015 (0.014)
<i>Iage</i>		–0.002 (0.002)		0.000 (0.001)
<i>Ieduc</i>		0.005 (0.006)		–0.000 (0.002)
<i>Ihealth</i>		0.003 (0.010)		–0.001 (0.005)
<i>Ijob</i>		–0.006** (0.002)		–0.001 (0.001)
<i>Fsource</i>		–0.053*** (0.006)		–0.016*** (0.003)
<i>Fbusin</i>		–0.014*** (0.004)		–0.005*** (0.002)
<i>Fpopu</i>		0.011 (0.007)		0.008*** (0.003)
<i>Flabor</i>		0.019** (0.008)		0.009*** (0.003)
<i>Fcadre</i>		0.049 (0.054)		–0.016 (0.024)
<i>Fparty</i>		0.005 (0.032)		0.009 (0.011)
<i>Fincome</i>		0.004 (0.010)		0.011* (0.006)
<i>Fexpend</i>		0.018 (0.014)		0.011** (0.005)
Constant	0.654*** (0.009)	0.687*** (0.195)	0.267*** (0.004)	0.003 (0.095)
Famer FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.359	0.370	0.364	0.372

***, ** and *significance at 0.01, 0.05 and 0.1 levels, respectively; values in parentheses are standard errors; FE – fixed effect

Source: Authors' own elaboration

Robustness tests

To address potential confounding factors, multiple robustness checks were conducted. First, fertiliser and pesticide expenditures were replaced with physical quantities to mitigate inflationary effects; columns 1–2 in Table 4 maintain significantly negative coefficients, confirming reduced chemical usage. Second, samples prior to 2012 were excluded to account for China's

2011 agricultural chemical policies – the Opinions of the Ministry of Agriculture on Further Promoting Scientific Fertilisation as well as the Administrative Measures on Further Prohibiting and Restricting the Use of Highly Toxic Pesticides; consistent results in columns 3–4 indicate policy interventions do not drive our findings. Finally, restricting the sample to 2009–2018 in columns 5–6 eliminates COVID-19

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Table 3. Instrumental variable results ($n = 13\,894$)

Variable	(1)	(2)	(3)
	<i>First Stage</i>	<i>Second Stage</i>	
	<i>Internet</i>	<i>Fertiliser</i>	<i>Pesticide</i>
IV	0.015*** (0.002)		
<i>Internet</i>		–1.301*** (0.253)	–0.670*** (0.139)
Controls	Yes	Yes	Yes
Famer FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Kleibergen-Paap rk LM <i>P</i> -value		0.000	
Kleibergen-Paap Wald rk <i>F</i> statistic		59.740	

***significance at 0.01 level; values in parentheses are standard errors; FE – fixed effect; IV – instrumental variable; LM – Lagrange multiplier

Source: Authors' own elaboration

pandemic disruptions, with coefficients remaining significantly negative. These comprehensive sensitivity analyses – addressing price fluctuations, regulatory changes, and exogenous shocks – consistently demonstrate that internet access significantly reduces chemical inputs and promotes green production practices among farmers.

Mechanism and heterogeneity analysis

This paper adopts the moderating effect model to investigate the mechanism of internet access affecting farmers' green production practices, and the model is constructed as follows:

$$\begin{aligned}
 Green_{it} = & \alpha + \beta_1 \times Internet_{it} \times M_{it} + \\
 & + \beta_2 \times Internet_{it} + \beta_3 \times M_{it} + \\
 & + Controls'_{it} \gamma + \delta_i + \delta_t + \varepsilon_{it}
 \end{aligned} \quad (2)$$

where: M – economic benefits (*Price*) and production technologies (*Tech*).

This paper uses the purchase price of agricultural products to measure economic benefits and agricultural technology training to measure production technologies. The purchase price of agricultural products is related to the income of farmers engaged in agricultural production, if the purchase price of agricultural products increases, the economic benefits of farmers will also increase; farmers receive agricultural technology training helps to improve production methods and production techniques. Other variables are defined as before.

The results of the economic benefits mechanism are shown in columns 1–2 of Table 5. The coefficients of the interaction terms are both significantly negative, indicating that the greater the economic benefits, the stronger the inhibitory effect of internet access on fertiliser and

Table 4. Robustness test results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>
<i>Internet</i>	–0.254*** (0.061)	–0.289*** (0.027)	–0.159*** (0.030)	–0.189*** (0.015)	–0.144*** (0.024)	–0.168*** (0.013)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Famer FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
n	13 894	13 894	10 900	10 900	10 958	10 958
R^2	0.660	0.434	0.426	0.434	0.410	0.399

***significance at 0.01 level; values in parentheses are standard errors; FE – fixed effect

Source: Authors' own elaboration

Table 5. Mechanism test ($n = 13\,894$)

Variable	(1)	(2)	(3)	(4)
	<i>Economic Benefits</i>		<i>Production Technologies</i>	
	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>
<i>Internet</i> × <i>M</i>	−0.019*** (0.004)	−0.008*** (0.002)	−0.535*** (0.134)	−0.167*** (0.060)
<i>Internet</i>	−0.033 (0.030)	−0.126*** (0.013)	0.281*** (0.034)	−0.067*** (0.014)
<i>M</i>	−0.000 (0.006)	0.007** (0.003)	−0.031 (0.133)	0.037 (0.059)
Controls	Yes	Yes	Yes	Yes
Famer FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.371	0.374	0.398	0.380

*** and **significance at 0.01 and 0.05 levels, respectively; values in parentheses are standard errors; FE – fixed effect

Source: Authors' own elaboration

pesticide use by farmers. That is, the promotion effect of internet access on farmers' green production practices increases with the increase of economic benefits. Internet access unblocks farmers' access to information, strengthens the closeness of the connection with the market, and thus improves the economic benefits of farmers. To better meet the needs of consumers and further improve economic benefits, farmers' willingness to adopt green production methods has been significantly enhanced (Yu et al. 2024).

The results of the production technologies mechanism are shown in columns 3–4 of Table 5. The coefficients of the interaction terms are both significantly negative, indicating that the inhibitory effect of internet access on fertiliser and pesticide use by farmers increases with the improvement of production technologies. That is, as production technique improves, the greater the contribution of internet access to farmers' green production practices. Internet access provides more channels for the development of agricultural technology training and improves the coverage of agricultural technology training, thus improving the production techniques of farmers (Karunathilake et al. 2023). Agricultural technology training helps farmers to learn agricultural knowledge, improve production techniques, and understand agricultural policies, thus contributing to reduce fertiliser and pesticide use.

To explore the impact of internet access on the green production practices by farmers with different characteristics, this paper conducts a heterogeneity analysis spanning the education level of farmers, the degree

of production mechanisation, the area of farmland operated by the family, the decision-making of household business, the health status of farmers, the age of farmers, urban suburbs, poor villages and traditional villages. The model is set as follows:

$$Green_{it} = \alpha + \beta_1 \times Internet_{it} \times H_{it} + \beta_2 \times Internet_{it} + \beta_3 \times H_{it} + Controls_{it}'\gamma + \delta_i + \delta_t + \varepsilon_{it} \quad (3)$$

where: H – heterogeneous dummy variables, including whether the farmer has a high level of education, whether the degree of production mechanisation is high, whether the household operates a large farmland area, whether the farmer is a decision maker, whether the farmer is healthy, whether the farmer is old, whether the village is a suburb of the city, whether the village is a poor village and whether the village is a traditional village.

It should be noted that the urban suburb refers to the areas outside the city where there are a large number of people, mainly residential areas retain agricultural activities under city jurisdiction, poor village refers to a village that has been identified by the provincial, prefectural, and county-level governments as being below the poverty line according to certain standards; and traditional village refers to a village that was built before 1912 that retains a relatively complete historical architectural style and traditional layout, preserving a rich agricultural civilisational heritage.

Level of education. Given higher-educated farmers typically demonstrate greater capacity for adopting sustainable techniques (Haruna et al. 2023), this paper assigns the value of 1 to farmers with more

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Table 6. Heterogeneity of productive capital ($n = 13\,894$)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	<i>Level of Education</i>		<i>Degree of Mechanization</i>		<i>Farmland Area</i>	
	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>
<i>Internet</i> × <i>H</i>	−0.458*** (0.097)	−0.101*** (0.031)	−0.394*** (0.049)	−0.093*** (0.020)	−0.365*** (0.047)	−0.117*** (0.020)
<i>Internet</i>	0.308*** (0.097)	−0.068** (0.031)	0.180*** (0.044)	−0.094*** (0.018)	0.179*** (0.039)	−0.078*** (0.016)
<i>H</i>	−0.062 (0.045)	0.020 (0.021)	−0.154*** (0.031)	−0.018 (0.015)	−0.191*** (0.034)	−0.012 (0.016)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Famer FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.373	0.373	0.390	0.377	0.392	0.378

*** and **significance at 0.01 and 0.05 levels, respectively; values in parentheses are standard errors; FE – fixed effect

Source: Authors' own elaboration

than six years of education, and 0 otherwise. Table 6 columns 1–2 reveal significantly negative interaction terms, indicating internet access more substantially reduces chemical inputs among educated farmers. This enhanced effect reflects their superior analytical capacities, heightened environmental awareness during cultivation, and greater proficiency in implementing green production practices.

Degree of mechanisation. Higher mechanisation reduces chemical input costs through efficient application (Batoool et al. 2024). Dichotomising the sample by median farm machinery assets (high = 1, low = 0), Table 6 columns 3–4 show significantly negative interaction terms. This indicates internet access more strongly promotes green production practices among highly mechanised farmers. Their superior operational efficiency enables greater reduction in fertiliser and pesticide usage when leveraging online agricultural guidance, demonstrating how technical capability enhances digital sustainability adoption.

Farmland area. Larger-scale operators (often through land transfers) achieve greater input efficiency via mechanisation, reducing chemical usage (Qing et al. 2023). Dichotomising by median farmland area (large = 1, small = 0), columns 5–6 of Table 6 reveal significantly negative interaction terms. Internet access thus more strongly promotes green practices among largeholders. Their scale economies, advanced techniques, and responsiveness to consumer demand for natural produce accelerate chemical input reduction when leveraging digital resources.

Household decision maker. Post-1984 household responsibility reforms amplify decision-makers' production influence (Yue et al. 2023a). Coded 1 for household decision-makers (else 0), Table 7 columns 1–2 show significantly negative interaction terms, indicating internet access more substantially enhances green practices among this group. Their superior agricultural knowledge, management capabilities, and responsiveness to policy directives drive stronger adoption of sustainable methods when utilising digital resources.

Health status. Farmers in poorer health (chronic conditions) frequently engage in agriculture through constrained participation. Assigning excellent health status as 1 (else 0), Table 7 columns 3–4 reveal significant negative interaction coefficients. This indicates internet access more substantially promotes green practices among healthier farmers, whose greater food safety consciousness and capacity to implement sustainable methods amplify digital resource utilisation for chemical input reduction (Wang et al. 2024).

Age. Given the sample's advanced average age (59 years), farmers were dichotomised by median age (older = 1; younger = 0). Table 7 columns 5–6 show significantly positive interaction coefficients, indicating internet access more substantially promotes green practices among younger farmers. Their greater digital literacy and receptiveness to innovation contrast with older farmers' entrenched traditional methods, where constrained behavioural adaptation limits internet's efficacy in reducing chemical inputs (Yue et al. 2023b).

Table 7. Heterogeneity of livelihood capital ($n = 13\,894$)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	<i>Decision Maker</i>		<i>Health Status</i>		<i>Age</i>	
	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>
<i>Internet</i> × <i>H</i>	−0.111** (0.052)	−0.045** (0.018)	−0.336*** (0.043)	−0.142*** (0.018)	0.381*** (0.044)	0.117*** (0.018)
<i>Internet</i>	−0.040 (0.051)	−0.126*** (0.017)	0.142*** (0.039)	−0.061*** (0.016)	−0.214*** (0.030)	−0.191*** (0.015)
<i>H</i>	0.076*** (0.024)	0.041*** (0.013)	−0.173*** (0.029)	−0.000 (0.013)	0.111*** (0.027)	0.018 (0.014)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Famer FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.370	0.373	0.385	0.379	0.386	0.378

*** and **significance at 0.01 and 0.05 levels, respectively; values in parentheses are standard errors; FE – fixed effect

Source: Authors' own elaboration

Urban suburbs. Farmers in urban suburbs (coded 1; others 0) exhibit significantly negative interaction coefficients in Table 8 columns 1–2, indicating heightened internet efficacy in promoting green practices. Proximity to urban markets facilitates shortened green supply chains, enabling precise matching of premium consumer demand with reduced-chemical production. This demand-access synergy – combined with digital optimisation of factor allocation – strengthens marginal returns on sustainable transition for peri-urban farmers, accelerating their adoption of input-reduction strategies relative to remote counterparts through integrated market incentives and technological adaptation mechanisms.

Poor villages. Farmers in state-designated poor villages (coded 1; others 0) show significantly negative interaction coefficients in Table 8 columns 3–4, revealing stronger internet effects on green adoption. High policy capital enables synergistic institutional-digital dividends: precision poverty alleviation infrastructure delivers targeted green technologies, lowering adoption costs. Internet connectivity accelerates policy resource dissemination within these networks, creating a reinforced governance framework where digital tools and institutional support jointly facilitate sustainable transitions through efficient knowledge transfer and reduced input dependency in prioritised communities.

Table 8. Heterogeneity of spatial capital ($n = 13\,894$)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	<i>Urban Suburbs</i>		<i>Poor Villages</i>		<i>Traditional Villages</i>	
	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>	<i>Fertiliser</i>	<i>Pesticide</i>
<i>Internet</i> × <i>H</i>	−0.262*** (0.077)	−0.183*** (0.031)	−0.094*** (0.036)	−0.039*** (0.015)	−0.200*** (0.043)	−0.135*** (0.018)
<i>Internet</i>	−0.089*** (0.021)	−0.134*** (0.010)	−0.096*** (0.025)	−0.146*** (0.012)	−0.075*** (0.023)	−0.125*** (0.011)
<i>H</i>	0.125*** (0.043)	0.122*** (0.023)	−0.020 (0.022)	−0.034*** (0.012)	0.029 (0.029)	0.023* (0.013)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Famer FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.373	0.380	0.371	0.375	0.373	0.379

*** and *significance at 0.01 and 0.1 levels, respectively; values in parentheses are standard errors; FE – fixed effect

Source: Authors' own elaboration

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Traditional villages. Farmers in designated traditional villages (coded 1; others 0) demonstrate significantly negative interaction coefficients in Table 8 columns 5–6, indicating amplified internet efficacy for green production. Village collective action traditions enhance digital collaboration for localised technological adaptation, while cultural identity bonds increase adoption adherence and mitigate reversal risks. This synergistic integration of indigenous knowledge systems with digital access transforms cultural capital into sustained endogenous drivers, facilitating green transitions through strengthened community cooperation and reduced behavioural uncertainty in culturally embedded contexts.

DISCUSSION

Our empirical results strongly indicate that the prevalence of the internet has a statistically significant positive impact on the adoption of environmentally friendly agricultural practices by farmers in Henan Province. Specifically, the fertiliser input per unit of cultivated area has decreased by 13.3%, and the pesticide input has decreased by 16.3%. This is consistent with existing research findings that digital technology can promote ecological intensification (Zheng et al. 2022; Xu et al. 2024). Additionally, this study makes a unique methodological contribution through continuous panel data analysis, addressing the fundamental limitations of previous cross-sectional data or discontinuous time data (Khan et al. 2022; Liu et al. 2022), thereby providing unprecedented precision in measuring behavioural responses.

Second, our findings support that information access and property rights is essential for protecting the environment (Nygaard and Silkoset 2023). Internet connectivity functions as critical institutional infrastructure broadening farmers' timely information acquisition. This expansion elevates environmental awareness and facilitates green practice adoption, aligning with Deng et al.'s (2022) evidence on digital technology's consciousness-raising effects. Crucially, our analysis extends beyond informational mechanisms by demonstrating that internet's impact is jointly driven by economic incentives and technological assimilation. The statistically significant amplification of agrochemical reduction effects correlates strongly with enhanced farm profitability and production technology mastery. This confirms internet access operates as a dual-channel institutional catalyst: it concurrently reduces transaction costs for

market integration while accelerating learning curves for sustainable techniques.

Third, our heterogeneity analysis reveals significant differential effects of internet access across farmer demographics, with notably stronger adoption of green production practices observed among younger operators, more educated producers, highly mechanised farms, larger-scale operations, and healthier agricultural workers. These findings align fundamentally with established theoretical frameworks positing that individual characteristics critically mediate sustainable technology adoption. Specifically, younger farmers exhibit heightened technological receptiveness while advanced education enhances both information assimilation and implementation capacities, as evidenced by Alebachew et al. (2023). The collective patterns substantiate Oludoye et al.'s (2023) demographic paradigm while reinforcing Kumar et al.'s (2023) human capital postulations and Ma et al.'s (2018) health-productivity nexus in agricultural innovation systems. Mechanisation advantages and operational scale emerge as complementary physical capital factors stratifying internet-driven sustainability transitions.

This study empirically establishes internet access as pivotal infrastructure for advancing green agricultural practices, extending digital agriculture's environmental impact literature. Crucially, findings significantly extend prior theoretical frameworks by elucidating causal mechanisms through which technology reshapes production decisions. These micro-level insights provide indispensable behavioural microfoundations for digital economy policies, advancing beyond Ding et al. (2024)'s macroeconomic analyses through empirical grounding. Outcomes delineate transferable pathways across developing regions, though scaling requires context-specific adaptations and targeted investments, offering an integrated micro theoretical framework for digital agriculture's transformational capacity.

CONCLUSION

This study conclusively establishes rural broadband connectivity as a pivotal driver in attenuating agricultural chemical input intensity, thereby substantiating digital infrastructure's transformative role in sustainable agrarian transitions. Empirical evidence confirms that internet access fundamentally reconfigures production paradigms through the complementary mechanisms of transaction cost reduction and information asymmetry mitigation, which collectively elevate economic

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returns while enhancing technological capacity. This dual pathway intrinsically motivates autonomous adoption of ecologically sound practices. Crucially, the technology's impact exhibits significant heterogeneity across socioeconomic strata, with substantially amplified effects observable among operators possessing superior human capital endowments, scaled operations with advanced mechanisation, and those within spatially distinct rural typologies. These differential returns underscore the imperative for precision targeting in digital inclusion policies to simultaneously optimise environmental gains and equitable development outcomes across diverse agricultural landscapes.

This study proposes three targeted policy interventions calibrated to distinct farmer typologies. For older operators experiencing human capital depreciation, implement intergenerational knowledge transfer schemes coupled with voice-interface digital advisory systems to circumvent technological adoption barriers. For educationally constrained smallholders, develop icon-based mobile applications integrated with input-subsidy conditionalities based on verified input-intensity reductions. For geographically isolated producers in traditional villages, prioritise satellite-based connectivity solutions while algorithmically integrating localised production databases into extension platforms. All interventions should incorporate mechanism design principles to simultaneously correct information asymmetries, internalise environmental externalities, and optimise resource allocation efficiency across heterogeneous agricultural production systems.

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