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Can Digital Literacy Promote Pesticide Reduction Among Farmers? An Analysis of Heterogeneity

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Abstract

Against the backdrop of the deepening green transformation of agriculture and the development of digital rural communities, exploring the impact of digital literacy on the reduction of agricultural inputs holds significant practical importance. Based on data from county statistical yearbooks and government statistical bulletins, this study employs the Digital Inclusive Finance Index to measure digital literacy levels and empirically examines its impact on pesticide use. The findings reveal that improved digital literacy significantly curbs pesticide use, indicating that the accumulation of digital capabilities helps drive farmers' transition from experience-based inputs to precision-based inputs. Heterogeneity analysis indicates that this inhibitory effect is more pronounced in eastern and central regions, as well as in key environmental protection cities and old industrial bases. This study argues that efforts to enhance farmers' digital literacy should be integrated with the development of a green agricultural governance system to better leverage the role of digital empowerment in reducing pesticide and fertilizer use while improving efficiency.

Keywords

digital literacy, pesticide usage, agricultural economics

1. Introduction

The "14th Five-Year Plan for Green Agricultural Development" explicitly calls for the in-depth implementation of initiatives to reduce the use of chemical fertilizers and pesticides while enhancing their efficiency, ensuring a transition toward green and sustainable agricultural production methods. The report of the 20th National Congress of the Communist Party of China also emphasized "accelerating the green transformation of development patterns," positioning the control of agricultural pollution as a crucial component of ecological civilization construction. However, in actual production, there is a discrepancy between statistical data and on-the-ground observations regarding the use of pesticides and chemical fertilizers. Due to pressure from local performance evaluations, statistical data often shows a year-on-year decline. Yet, field surveys indicate that, at the micro level, pesticide usage is actually increasing—driven by factors such as the evolution of pests and diseases and the development of resistance—as farmers strive to maintain yields and income. Pesticide residues not only threaten food safety but also exert profound, latent impacts on ecological health through soil and water cycles. Therefore, against the backdrop of the nation's vigorous promotion of digital rural development, exploring how to leverage digital tools to address the challenges of pesticide reduction not only implements the national “Action Plan for the Reduction of Chemical Pesticides by 2025” but also holds urgent contemporary significance for ensuring the quality and safety of agricultural products for the public.

2. Literature Review

Existing research on digital literacy has gradually shifted its focus from the “access gap” to the “usage gap” [1]. While early literature primarily focused on rural digital infrastructure coverage, internet access conditions, and the prevalence of hardware devices, recent studies have placed greater emphasis on rural households’ ability to identify, integrate, process, and transform digital information into value. As research continues to deepen, the concept of digital literacy has expanded from basic digital literacy skills to encompass an individual’s comprehensive adaptability within the digital environment, covering multiple dimensions such as information identification, tool application [2], social interaction, data processing, ethical awareness, and production decision-making. Correspondingly, measurement methods have exhibited distinct contextual and group-specific characteristics. Particularly in studies of farming communities, digital literacy has been refined into specific dimensions such as general literacy, social literacy, specialized literacy [3], and security literacy, to more accurately depict the varying capabilities of rural households in the digital transformation.

In agricultural production, digital literacy—as a new form of human capital—no longer serves merely to improve the efficiency of information acquisition; rather, its impact is increasingly evident in reshaping farmers’ decision-making processes and input management practices [4]. A higher level of digital literacy helps farmers break free from the constraints of traditional empiricism, enabling them to more effectively access plant protection knowledge, market trends, and technical information, and to achieve more precise production management through digital monitoring, pest and disease early warning systems, and online service platforms. Consequently, agricultural production is shifting from an extensive model reliant on chemical inputs to a precision model driven by data [5]. At the same time, digital literacy can expand farmers’ digital social capital, enhancing their interactions with agricultural experts, service organizations, and other producers, thereby mitigating to some extent the information asymmetry that arises when smallholder farmers integrate into modern agriculture [6]. Overall, digital literacy serves not only as a crucial intermediary for the effective functioning of digital infrastructure but also as a vital foundation for promoting green agricultural development and fostering endogenous rural growth.

Correspondingly, research on farmers’ pesticide reduction behaviors has expanded from a simple analysis of technical efficiency to a comprehensive examination of behavioral logic, institutional environments, and practical constraints. Existing studies generally agree that pesticides are typical hazard-control inputs [7]; farmers’ decisions regarding pesticide application are essentially the result of balancing the risks of pests and diseases, the risks of yield loss, and input costs, exhibiting distinct characteristics of bounded rationality [8]. Therefore, pesticide reduction is not merely a matter of cutting back on inputs, but rather a complex behavioral process involving risk perception, expected returns, technological accessibility, and the institutional environment. In terms of influencing factors, participation in cooperatives, agricultural socialized services, and unified pest control systems help reduce the costs of pesticide reduction by standardizing technical standards, promoting specialized operations, and ensuring the supply of green inputs, thereby increasing the likelihood that farmers will adopt green plant protection technologies; simultaneously, neighborhood demonstrations, social norms, and diversified technology extension pathways can also drive pesticide reduction behaviors by strengthening external constraints and cognitive guidance [9]. However, farmers’ pesticide application behaviors are equally influenced by multiple factors, including an aging labor force, rising opportunity costs, adjustments in environmental policies, and market preferences for sensory quality. These practical constraints can easily lead farmers to adopt preventive over-application strategies driven by risk-aversion motives.

In summary, existing research has yielded substantial findings in both digital literacy and pesticide reduction behaviors, laying an important foundation for this study. However, a closer examination reveals the following shortcomings: First, while the existing literature acknowledges the impact of digital literacy on farmers’ production behaviors, it primarily focuses on income growth, technology adoption, or improvements in production efficiency, and has not sufficiently explored the mechanisms through which digital literacy influences reduced-pesticide agricultural production [10]; Second, research on pesticide reduction has emphasized the influence of external institutions, organizational services, and market environments, while paying relatively less attention to farmers' endogenous capabilities, particularly digital literacy; third, existing studies have not fully elucidated how digital literacy influences farmers' pesticide reduction behaviors through pathways such as information access, risk perception optimization, and the expansion of digital social capital. Based on this, this paper attempts to incorporate digital literacy into the analytical framework of farmers' green production behaviors, examining its impact on pesticide reduction behaviors and regional heterogeneity, with the aim of providing new empirical evidence and policy implications for agricultural green transformation in the context of digital rural development [11].

3. Theoretical and Hypothesis Analysis

As a key variable input in agricultural production, the decision to apply pesticides is the result of farmers balancing yield risks, labor costs, and market demand under conditions of bounded rationality. Digital literacy, as a new form of endogenous capability for farmers in the context of digital rural development, can break the path dependence of traditional empiricism and drive pesticide reduction through various dimensions, including cognitive adjustment, factor substitution, and information empowerment. First, digital literacy optimizes the structure of factor inputs through the "technological substitution effect" [12]. Faced with the realities of an aging rural workforce and soaring labor costs, chemical agents such as herbicides have become a low-cost substitute for labor. Farmers with high digital literacy possess the skills to operate intelligent plant protection equipment; this substitution of labor by digital technology not only reduces labor intensity but also significantly improves efficiency through high penetration and precise targeting of pesticide solutions. Second, digital literacy corrects market-driven practices of excessive pesticide use. Driven by the premium placed on sensory quality in vegetable markets, farmers often overuse pesticides in pursuit of perfect product appearance. Digital literacy enhances farmers' scientific understanding of pesticide residue toxicity and ecological risks. By perceiving the brand premium and market feedback for green agricultural products through digital social platforms, farmers shift from a sole focus on appearance to a pursuit of quality and safety, thereby generating an endogenous motivation to reduce pesticide use. Based on this, this paper proposes the following hypothesis:

H: Improving digital literacy can significantly encourage farmers to reduce their use of pesticides.

4. Data Sources and Model Design

4.1 Explanatory Variables

Drawing on the research by Guo Feng et al. [13] this article uses the Digital Inclusive Finance Index to measure a region's digital literacy.

4.2 Dependent Variable

"Pesticide usage" refers to the quantity of chemical agents used in agricultural production to control pests and diseases, including purchased and self-produced insecticides, fungicides, herbicides, and acaricides, but excluding veterinary drugs, fisheries chemicals, and traditional agricultural pesticides.

4.3 Model Design

Based on the theoretical derivations outlined above, to empirically test the driving effect of digital literacy on pesticide reduction and its mechanisms, this study constructs the following econometric model:

$$Y_{i,c}=\beta_0+\beta_1 DL_{i,c}+\gamma_c+\alpha_i+\varepsilon_{i,c} \tag{1}$$

In the equation (1), $Y_{i,c}$ represents the amount of pesticides used by farmer "i" in region "c"; DL represents the digital literacy index; γ_c and α_i are fixed effects for region and time, respectively, $\varepsilon_{i,c}$ is the random error term.

4.4 Data Source

The data in this article are primarily drawn from county statistical yearbooks; missing values were supplemented using government statistical bulletins. Descriptive statistics for this article are presented in Table 1.

Table 1: Decriptive statistics

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	N	mean	sd	min	p50	max
digitization_level	26,583	100.6160	26.4848	-165.3900	110.4366	307.5700
AF	10,605	2.3772	3.1272	0.0000	1.3469	32.6625

5. Regression Result

Table 2 presents the results of baseline regressions for the cases where no controls are included, where only time is controlled, and where both individuals and time are controlled. All results are significantly negative at the 1% significance level, indicating that digital literacy can curb the use of pesticides and chemical fertilizers, thereby confirming Hypothesis H.

Table 2: Benchmark Regression Results

	(1) AF	(2) AF	(3) AF
digitization_level	-0.0109***	-0.0037***	-0.0020***
	(-9.2847)	(-12.7116)	(-3.3767)
_cons	3.4866***	2.8199***	2.6698***
	(29.2549)	(112.1562)	(46.2791)
City	NO	YES	YES
Year	NO	NO	YES
N	9383	9331	9331
r2	0.0099	0.9499	0.9524

t statistics in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The same applies below.

6. Heterogeneity Analysis

According to Table 3, digital literacy has a significant moderating effect on pesticide usage among farmers in the eastern and central regions, but no significant effect in the western and northeastern regions. This may be closely related to differences in agricultural production conditions, factor endowments, and digital infrastructure across regions. Agricultural operations in the eastern and central regions are relatively more intensive, and digital infrastructure is relatively well-developed. Farmers in these areas have more accessible channels for obtaining pest and disease alerts, scientific pesticide application guidance, and information on agricultural input markets; consequently, digital literacy is more easily translated into tangible incentives for reducing pesticide use. At the same time, agricultural products in these regions are highly market-oriented, and green production standards and quality and safety regulations are stricter, which further reinforces the regulatory effect of digital literacy on farmers' pesticide application decisions. In contrast, in the western regions, constraints such as topographical conditions, the cost of accessing information, and limited capacity for technology dissemination, as well as factors in the northeastern regions such as farm size, crop structure, and extensive production methods, have led to a certain lag in farmers’ absorption and application of digital information. This, in turn, weakens the marginal impact of digital literacy on pesticide application behavior.

Table 3: Heterogeneity Analysis (1)

	(1) AF	(2) AF	(3) AF	(4) AF
digitization_level	-0.0018***	-0.0039***	-0.0007	0.0028
	(-2.7500)	(-3.0233)	(-0.8648)	(0.5298)

_cons	2.1024***	3.4820***	2.0365***	4.7696***
	(34.7235)	(28.6330)	(25.4908)	(9.8822)
City	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	1923	2170	2994	881
r2	0.9876	0.9760	0.9633	0.9387

According to columns (1) and (2) in Table 4, digital literacy exerts a stronger inhibitory effect on fertilizer use in cities designated as environmental protection priorities. This may be related to the fact that these cities face stricter ecological governance constraints and more rigorous regulation of non-point source pollution. On the one hand, these cities have implemented policies regarding fertilizer reduction, green agricultural transformation, and ecological performance evaluations earlier and enforced them more strictly, prompting farmers to place greater emphasis on the guiding role of digital information in scientific fertilization. On the other hand, agricultural technology extension systems, digital service platforms, and training programs for green production are relatively well-developed in these regions. Farmers can more easily access information on soil testing and formula-based fertilization, crop nutrient management, and optimization of agricultural input use, thereby improving the precision of their fertilizer application decisions. In contrast, non-priority cities have relatively weaker institutional constraints and supporting services, which limits the practical impact of digital literacy in driving fertilizer reduction behaviors.

According to columns (3) and (4) in Table 4, digital literacy exerts a stronger inhibitory effect on fertilizer use in traditional industrial bases. This may be closely related to the heavier ecological restoration tasks, stricter resource and environmental constraints, and more pronounced pressure for agricultural transformation in these regions. On the one hand, these regions have long faced the dual demands of industrial restructuring and environmental governance. Local governments often allocate more institutional resources to promoting green agricultural development and strengthening the prevention and control of non-point source pollution, thereby providing clearer policy guidance for digital literacy to facilitate fertilizer reduction. On the other hand, during the process of industrial upgrading, these regions place greater emphasis on integrating information technology and smart solutions into agricultural production. Farmers in these areas are more likely to use digital platforms to access soil testing and fertilization formulas, crop nutrient diagnostics, and scientific fertilization recommendations, thereby enhancing the precision of fertilizer application decisions. Furthermore, the more urgent practical need for ecological and environmental improvement in these regions makes it easier for farmers to translate digital information into green production practices, thereby reinforcing the inhibitory effect of digital literacy on fertilizer use.

Table 4: Heterogeneity Analysis (2)

	(1) AF	(2) AF	(3) AF	(4) AF
digitization_level	-0.0033***	-0.0003	-0.0026**	-0.0009
	(-4.0784)	(-0.3361)	(-2.0189)	(-1.0048)
_cons	2.6369***	2.8694***	2.9947***	2.6137***
	(33.6504)	(28.9842)	(24.8344)	(29.5730)
City	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	3453	4515	2947	5021
r2	0.9726	0.9484	0.9567	0.9582

7. Conclusions and Policy Recommendations

Based on county-level data, this paper conducts an empirical analysis of the relationship between digital literacy and farmers' use of agricultural inputs. The results indicate that higher digital literacy generally leads to a significant reduction in pesticide use. This suggests that improved abilities to access, identify, absorb, and apply digital information help farmers optimize their pesticide application decisions and reduce their reliance on traditional experience and extensive input methods, thereby promoting a transition toward greener and more precision-oriented agricultural production practices. Heterogeneity analysis reveals that the reduction effect of digital literacy is not uniformly distributed across all regions but exhibits significant regional variations. Regarding pesticide use, the inhibitory effect is more pronounced in the eastern and central regions, whereas no significant impact is observed in the western and northeastern regions. In key environmental protection cities and old industrial bases, digital literacy exerts a stronger inhibitory effect on fertilizer use.

Efforts should focus on enhancing farmers' digital literacy as a key driver to promote the green transformation of agriculture. First, in response to the need for reduced pesticide use and scientific fertilization, we should improve the digital skills training system for farmers, strengthening content such as pest and disease early warning, soil testing and formula-based fertilization, identification of agricultural inputs, and platform applications, thereby enhancing farmers' ability to translate digital information into green production decisions. Second, efforts should be accelerated to address shortcomings in rural digital infrastructure and public information services in western and northeastern regions, promoting the extension of agricultural technologies, the development of digital platforms, and the expansion of socialized services to these areas, with a focus on resolving the issue of insufficient translation of digital literacy into practical action. Third, leveraging cooperatives, family farms, and agricultural socialized service organizations, we should promote the deep integration of digital technologies with services such as unified pest control and precision fertilization, thereby reducing the cost for small-scale farmers to adopt green production technologies. Finally, for key environmental protection cities and old industrial bases, we should further strengthen the synergy among ecological regulations, policy incentives, and digital governance to amplify the promotional effect of digital literacy on reducing agricultural inputs, and gradually establish a long-term mechanism that integrates digital empowerment, technology diffusion, and green governance.

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Conflicts of Interest

The authors declare no conflict of interest.

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