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Empowering green agricultural development: how digital literacy shapes farmers' willingness to participate in high-standard farmland construction

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Promoting green agricultural development and achieving sustainable land management are core tasks in the transformation toward agrarian modernization. High-standard farmland construction is a key policy instrument in this process, yet its effectiveness depends on the active participation of farmers. Farmer participation depends on both individual capabilities and the external institutional environment. This study uses survey data from farmers in Qinghai Province, China and Integrates human capital theory and institutional theory to construct a three-dimensional digital literacy assessment framework. The study conducts an empirical analysis of the effect of farmers' digital literacy on their intention to participate in high-standard farmland construction, and explores how varying levels of information trust moderate this relationship. The results indicate that digital literacy significantly enhances farmers' participation intentions. However, Information trust exerts a significant negative moderating effect on the relationship between digital literacy and farmers' participation intentions. This study reveals that enhancing digital literacy is a critical pathway to incentivize farmer participation in high-standard farmland construction, thereby advancing rural revitalization and sustainable agricultural development during the green transition. Policy measures should synergistically focus on cultivating digital capabilities, improving information transparency, and strengthening social support systems to achieve a virtuous cycle of technological empowerment and farmer-driven development.

KEYWORDS

digital literacy, farmer participation willingness, green agricultural development, high-standard farmland construction, information trust

1 Introduction

Green agricultural development is a key pathway for advancing agricultural modernization and achieving sustainable development goals. The development of high-standard farmland not only contributes to ensuring food security but also presents significant opportunities for advancing green agricultural transformation and sustainable development (Zhang et al., 2023). Historically, agricultural expansion in China has depended on intensive resources use and chemical inputs, which has contributed to decline soil productivity and escalating ecological degradation (Zhang et al., 2019; Zhang et al., 2023). This resource-intensive development model is unsustainable (Wang et al., 2023). Against this backdrop, advancing agricultural green transformation not only addresses China's internal needs but also aligns with the global goal of "halting land degradation" outlined in the United Nations 2030 Agenda for Sustainable Development (Yang et al., 2022). At the policy level, China has continuously strengthened

institutional frameworks for high-standard farmland since its initial introduction in Central Document No. 1 (2005). The 2022 *General Rules for High-Standard Farmland Construction* (HSFC) further systematized construction requirements, covering three major domains: soil fertility improvement, farmland infrastructure development, and management standards (Zhou et al., 2024).

This initiative is not an isolated case; it resonates closely with the green transitions pursued by the European Union, Japan, the Netherlands, and other countries through approaches such as ecological agriculture, circular technologies, and precision management, all converging on the global goal of sustainable agriculture. However, unlike many countries that primarily rely on market mechanisms or regulatory incentives to implement isolated technological solutions, China approach is characterized by strong state leadership, centralized planning, and engineering-driven implementation. In ecologically fragile regions such as Qinghai, these projects go beyond agricultural modernization, serving as integrated interventions that enhance ecological resilience while securing farmers' livelihoods. This distinctive model offers a valuable reference point for global regions facing similar environmental constraints and developmental challenges (Ma et al., 2018).

Academic research on high-standard farmland has yielded substantial findings, focusing on construction outcomes, practical challenges, implementation models, and influencing factors. Existing research indicate that development of HSFC promotes agricultural scaling expansion and enhances production specialization (Zhang et al., 2021), fosters the growth of new professional farmers (Zhao and Sun, 2022), and drives household income growth alongside county-level economic expansion (Zhang et al., 2019). In terms of models, classifications include intensive, industrial, and resource-based types (Zeng, 2014). However, practical challenges persist, such as regulatory gaps and a tendency to prioritize construction over management (Liu and Zhu, 2015; Liu et al., 2022). Furthermore, unclear responsibilities for maintenance and management severely undermine farmers' willingness to participate (Cao and Zhao, 2017; Shi et al., 2022; Cao, 2023). Concurrently, digital literacy, a critical human capital influencing farmer behavior remains underexplored in terms of measurement and effects (Lu et al., 2023). Since Gilster (1997) defined it as "the ability to understand and use digital information resources," related concepts (e.g., digital skills, digital competence) are often used interchangeably (Yang and Zhang, 2024). The European Union further conceptualizes it as a comprehensive capability encompassing critical and innovative usage (Qu et al., 2025). Although existing studies have attempted to construct indicator systems and measure them using metrics such as usage frequency, a unified standard remains elusive (Li et al., 2025). Additionally, recent studies indicate that systematically assessing groundwater potential and water quality is crucial for ensuring irrigation safety, optimizing land use, and enhancing agricultural productivity in high-standard farmland construction, which is particularly important in ecologically fragile or water-scarce regions (Gupta et al., 2021; Gupta et al., 2022; Gupta et al., 2024).

Overall, while existing research generally acknowledges the positive role of digital literacy in promoting agricultural technology adoption, its context-dependent nature and boundary conditions remain underexplored. There is particularly a lack of in-depth, systematic analysis of the interaction mechanisms between digital literacy and external institutional factors, such as information trust. In this context, Qinghai Province provides a particularly relevant setting: the region is ecologically fragile, has a relatively closed information environment, and is economically underdeveloped, with farmers exhibiting a high reliance on public governance systems and authoritative information. These conditions offer a unique opportunity to examine the interactive effects of digital literacy and information trust. Building on this, the present study integrates human capital theory and institutional theory to construct a measurement framework for farmers' digital literacy and systematically analyze how digital literacy and information trust jointly influence farmers' willingness to participate in HSFC. The findings not only deepen the understanding of the complex determinants of farmers' behavior in ecologically vulnerable regions but also offer China-specific theoretical and practical insights for promoting agricultural green transformation in other ecologically fragile and developing regions worldwide.

2 Basic assumptions and analysis framework

Digital literacy, as a comprehensive manifestation of an individual's ability to recognize, comprehend, and apply digital technologies, serves as a core human capital factor that impacts farmers' engagement in the agricultural modernization process (Li et al., 2025). Drawing on Becker's (1964) human capital theory, proficiency in knowledge and skills enhances individuals' capacities for information processing and decision-making, thereby boosting their cognitive gains and willingness to adopt new technologies and initiatives. As a form of human capital that integrates mental and technical attributes, digital literacy helps alleviate farmers' perceived barriers to accessing high-standard farmland-related information and technologies, while improving their understanding of technological usability (Makhafola et al., 2025). Furthermore, digital literacy enhances farmers' knowledge of digital agricultural information platforms, policy communications, and operational procedures, thereby reducing the cognitive costs and uncertainties associated with participation (Shatila et al., 2025). Notably, improved digital literacy elevates farmers' cognitive understanding of and trust in high-standard farmland construction, ultimately increasing their willingness to participate.

From an economic standpoint, digital literacy improves farmers capacity to process complex information, enhancing human capital and enables efficient decision-making under uncertainty. This allows farmers to better assess the long-term ecological and economic benefits derived from high-standard farmland relative to short-term costs (Wang et al., 2024). Consequently, farmers with higher digital literacy are more inclined to perceive HSFC as feasible and advantageous, thereby strengthening their willingness to participate. Based on this rationale, the following hypothesis is proposed.

> *H1*: Digital literacy has a positive impact on farmers' willingness to participate.

According to institutional theory, organizations such as village committees act as key institutional agents. The authoritative information they disseminate can shape individuals' cognitive and behavioral norms, fostering institutional trust (Weiqi et al., 2025). When trust in such external information is particularly high, farmers' decision-making processes may shift from a rational calculation

model, relying on personal capabilities, to a compliance model, dependent on institutional signals. Meanwhile, the attention-based view in management theory posits that decision-makers' attention constitutes a scarce resource (Estadieu et al., 2025). When official information is perceived as highly reliable and sufficient to guide actions, farmers may rely on it rather than actively developing or applying their own digital literacy, instead prioritizing reliance on this convenient and authoritative external information source (Hu et al., 2021). This substitution effect can diminish the marginal contribution of digital literacy to decision-making and participation. Based on this, the following moderating hypothesis is proposed:

> *H2*: Information trust negatively moderates the relationship between digital literacy and farmers' willingness to participate.

2.1 Analysis framework

This study investigates the mechanisms influencing farmers' intention to participate in high-standard farmland construction (HSFC). First, based on human capital theory, digital literacy, as a form of cognitive human capital, can enhance farmers' ability to acquire, understand, and apply digital technologies, reduce technical cognitive barriers, and improve their perceptions of the ease of use and potential benefits of HSFC, thereby increasing their willingness to participate (Hypothesis H1). Second, drawing on institutional theory, authoritative information shapes institutional trust. When farmers have a high level of trust in external information, they may rely more on institutional guidance rather than their own digital skills, which could weaken the marginal effect of digital literacy on participation intention (Hypothesis H2). Finally, grounded in the Theory of Planned Behavior (TPB), this study incorporates farmers' psychological cognitive traits, including behavioral attitude, subjective norm, and perceived behavioral control, as control variables to construct a more comprehensive framework for analyzing participation intention.

By integrating digital literacy, information trust, and psychological cognitive traits, the study develops a systematic analytical mechanism to uncover the pathways and potential determinants of farmers' decision-making regarding HSFC participation. This framework not only aids in understanding farmers' behavioral patterns within the agricultural development context of China's highland regions but also has broad applicability and transferability. It can provide valuable insights for policymakers in other developing countries or regions characterized by high-altitude, arid conditions, or undergoing digital transformation, offering guidance for designing targeted interventions, enhancing farmers' engagement, and optimizing agricultural development strategies, thereby contributing to sustainable agricultural development in diverse national and regional contexts.

3 Materials and methods

3.1 Study area

Qinghai Province is located in the northeastern part of the Qinghai–Xizang Plateau and is characterized by high-altitude terrain and a typical plateau continental climate, which together shape its distinctive natural environment. As the source region of several major rivers in China, including the Yangtze River and the Yellow River, Qinghai holds a critical ecological position. At the same time, it is recognized as an ecologically sensitive and fragile area with limited environmental carrying capacity. Constrained by harsh natural conditions, agricultural activities in Qinghai are mainly distributed across high-altitude agro-pastoral transition zones. The dominant soil type is alpine meadow soil, and cropping systems are generally limited to a single growing season per year. Major crops include wheat, rapeseed, potatoes, and legumes, with crop rotation being widely practiced. Agricultural production in the region has long relied on a combination of traditional crop cultivation and livestock husbandry, exhibiting a strong dependence on local natural endowments and institutional arrangements (Zhou et al., 2024).

Rural economic development in Qinghai Province exhibits pronounced urban–rural disparities. According to the Qinghai Statistical Yearbook (2024), the per capita disposable income of rural residents was 15,614 Chinese yuan (CNY), accounting for only 38.6% of that of urban residents. Meanwhile, the share of net operating income in rural household income has continued to decline, indicating increasing constraints on income growth potential and livelihood stability under traditional agricultural production systems. Against this backdrop, the construction of high-standard farmland demonstrates particular necessity. It not only serves as a critical intervention for improving cultivated land quality and safeguarding food and livelihood security, but also functions as an important policy instrument for reconciling agricultural production with ecological protection objectives. By mitigating soil erosion and reducing non-point source pollution, high-standard farmland construction directly contributes to water conservation and ecosystem maintenance, thereby facilitating the development of sustainable livelihood strategies that are better aligned with local environmental carrying capacity. Accordingly, this study selects Qinghai Province as a representative region characterized by ecological fragility and ongoing development transition. The "ecological protection–livelihood improvement" synergy explored in this context provides valuable practical insights for other plateau and arid regions worldwide facing similar environmental constraints and development challenges (Figure 1).

3.2 Data sources

This study selected SB Town (County D), HP Town (County H), and LY Town and TG Town (County G) in Qinghai Province as the sampling sites. To protect the privacy of respondents, all place names have been anonymized throughout the paper. The sampling strategy strictly followed scientific sampling principles, with particular emphasis on data representativeness and independence. A stratified random sampling method was employed, using household registration data from the China County (City) Statistical Yearbook 2020 (Township Volume), compiled by the Rural Socioeconomic Survey Division of the National Bureau of Statistics of China, as the sampling frame. This approach ensured that the sample structure adequately reflects the characteristics of the target population.

To ensure data quality, the survey was conducted in July 2023 using a combination of face-to-face interviews and online questionnaires. This dual-mode data collection strategy allowed for cross-validation of responses, thereby enhancing the reliability and

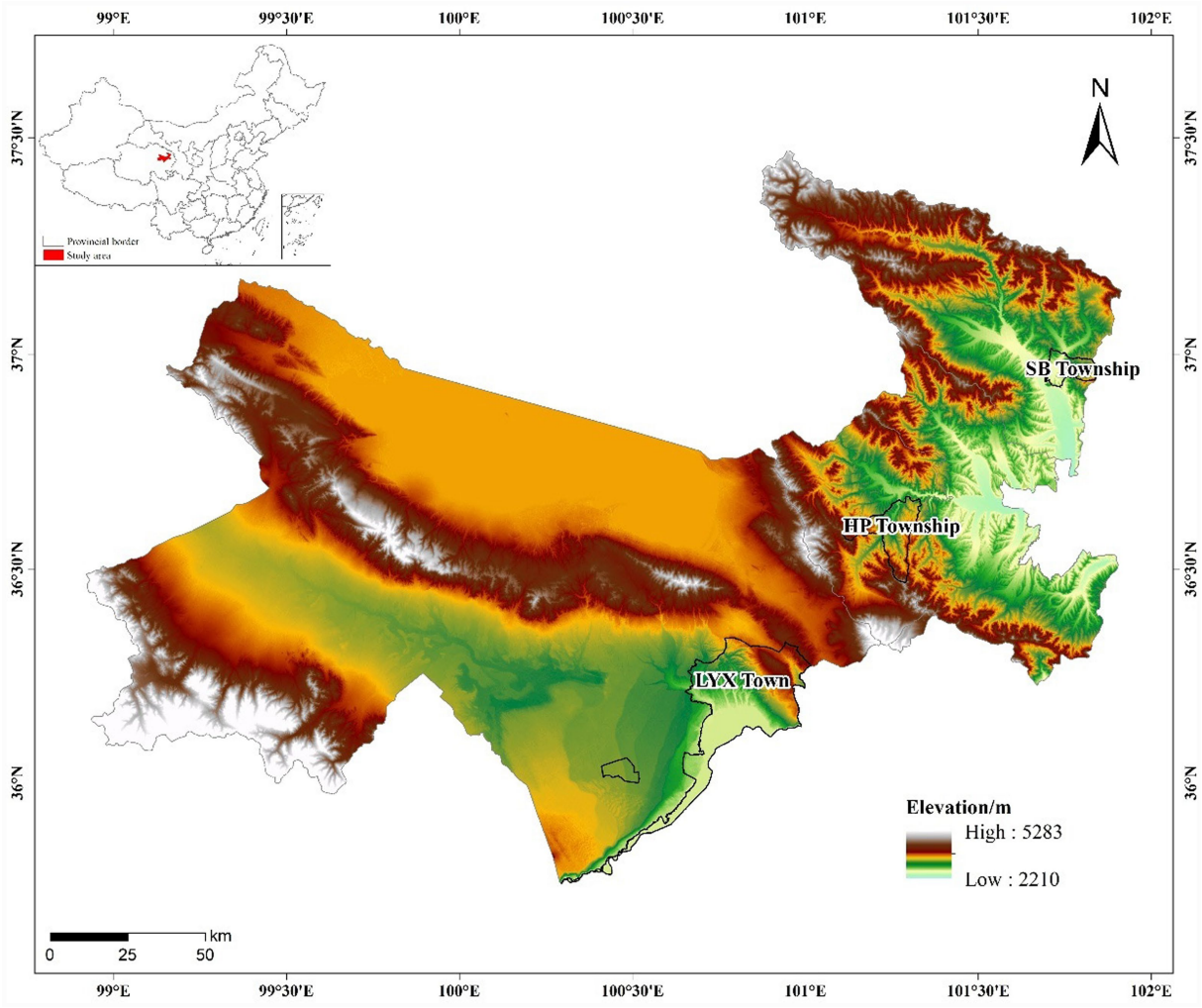

FIGURE 1
Digital elevation model of the study area.

accuracy of the data. Following data collection, a systematic data-cleaning procedure was applied, including the removal of outliers and the treatment of missing values. After these procedures, a total of 325 valid questionnaires were retained, corresponding to an effective response rate of 93.14%, which provides a robust and high-quality data foundation for subsequent empirical analysis.

3.3 Indicator setting

3.3.1 Dependent variable

Willingness to participate in HSFC is operationalized as a binary variable indicating farmers' stated intention to participate in HSFC activities (1 = willing to participate; 0 = not willing to participate). This variable directly reflects farmers' inclination to support and participate in the HSFC project, serving as a key leading metric for assessing the effectiveness of policy implementation.

3.3.2 Core explanatory variable

Digital literacy serves as the core explanatory variable in this study. Drawing on existing research and adapting to local conditions, a comprehensive evaluation system was constructed across three dimensions: digital access, basic operations, and communication and learning, with six measurement items ultimately selected. First, reliability analysis was conducted for the six items, yielding an average inter-item covariance of 0.0405 and an overall scale reliability coefficient of 0.692 (Cronbach's α = 0.6915), indicating good internal consistency. Second, the indicators were normalized using the range standardization method to eliminate dimensional differences. Finally, the entropy method was applied to assign weights and calculate a composite score, resulting in a continuous measure of farmers' digital literacy ranging from 0 to 1. This composite score accurately captures farmers' capacity to acquire, process, and apply information in the digital era, providing a quantitative basis for analyzing their digital adaptability and decision-making behavior.

3.3.3 Control variable

To control for other potential factors, this study introduces the following series of control variables. Head of household characteristics: Includes "head of household age" and "head of household years of education" to capture the influence of the decision-maker's personal traits. Household characteristics:

Includes "household dependency ratio" (i.e., the ratio of non-labor force to labor force) and "annual household income" (log-transformed) to control for constraints related to household population structure and economic capital. Farmland Status: Includes "Existing Cultivated Land Area" (continuous variable) and "Land Transfer Status" (dummy variable, 1 = yes, 0 = no), controlling for existing resource endowments and land allocation conditions.

The Theory of Planned Behavior (TPB) posits that Attitude Toward Behavior (ATB) represents an individual's overall positive or negative evaluation of performing a specific action, which is primarily shaped by prior experiences and subjective perceptions. For example, when farmers believe that high-standard farmland construction can generate higher income, this favorable perception significantly strengthens their intention to participate in the project. Subjective Norm (SN) refers to the perceived social pressure an individual experiences during decision-making, reflecting the expectations of others and the influence of the surrounding social environment. Such social pressure can heighten farmers' awareness and consideration of high-standard farmland construction, thereby affecting their willingness to engage. Perceived Behavioral Control (PBC) reflects individuals' assessment of their own capability to perform a given behavior. In agricultural contexts, farmers' perceptions of their skills, available resources, and existing conditions largely determine whether they choose to participate in high-standard farmland construction (HSFC). Overall, TPB represents an important extension of the earlier Theory of Reasoned Action (TRA), incorporating the dimension of perceived behavioral control to provide a more comprehensive explanation of how behavioral intentions are formed (Hu et al., 2021).

Based on the aforementioned theoretical framework, this study conceptualizes farmer cognition as comprising three dimensions: behavioral attitude, subjective norm, and perceived behavioral control, in order to systematically examine their influence on farmers' intention to participate in high-standard farmland construction (HSFC). Behavioral attitude is measured using two statements: "High-standard farmland has more pronounced ecological functions compared with ordinary farmland" and "High-standard farmland generates greater social benefits than ordinary farmland." Subjective norm is assessed with the following items: "Participating in HSFC helps gain others' approval" and "The behavior of my neighbors affects my willingness to participate in HSFC." Perceived behavioral control is measured through the statement: "My current farmland conditions fall significantly short of the standards required for HSFC." Collectively, these indicators capture the psychological cognition and decision-making logic of farmers in the context of participation (Zhou et al., 2024; Shi et al., 2019).

3.3.4 Instrumental variable

To mitigate potential endogeneity issues in the model (such as bidirectional causality), this study selects "number of household agricultural machinery" (a continuous variable) as an instrumental variable. The quantity of agricultural machinery correlates with farmers' production methods and may influence specific application scenarios of their digital skills; however, it is unrelated to the unobservable random error term, thereby satisfying the requirements of correlation and exogeneity. Additionally, "type of work" (categorical variable: full-time farming, part-time farming, non-farming) is incorporated as part of the identification strategy.

3.3.5 Moderating variable

Information Trust is measured using the item "*I believe construction information from the village committee is highly authoritative*." This variable is introduced as a moderating variable, based on the hypothesize that trust in official information sources may either amplify or diminish the impact of influence of digital literacy on HSFC participation intentions (Table 1).

3.4 Model design

This study first constructed a multidimensional indicator system and employed the entropy method to quantitatively measure farmers' digital literacy, ensuring the objectivity and scientific rigor of the indicator weighting. Subsequently, empirical analyses were conducted using SPSS: binary logistic regression was initially applied to examine the effect of digital literacy on farmers' willingness to participate in high-standard farmland construction. To assess the robustness of the model, key variables were replaced, and a GMM model with instrumental variables was further employed to address potential endogeneity, thereby enhancing the reliability of the results. Finally, information trust was introduced as a moderating variable to explore the interactive effect between digital literacy and the institutional environment on farmers' participation willingness.

The following binary logistic regression model (Equations 1 and 2) is established in this study:

$$P_i = \frac{1}{1+e^{-Y_i}} = \frac{1}{1+e^{-(\alpha+\beta_i)}} \tag{1}$$

$$\ln\frac{P_i}{1-P_i} = Y = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} +, \ldots, +\varepsilon_i \tag{2}$$

Where P_i represents the probability of farmers intension to participate in HSFC, X_i is the explanatory variable, β is the coefficient size of the influencing factor, α is the intercept, and ε_i is the error term (Cao et al., 2024).

4 Results

As presented in Table 2, the mean of the dependent variable is 0.867. This suggests that most farmers in Qinghai Province exhibit a high willingness to participate, with the vast majority of respondents holding a positive attitude toward the project. The core explanatory variable "farmers' digital literacy," comprehensively measured using the entropy method, yielded a mean value of 0.323. This indicates that the overall digital literacy of rural residents in Qinghai Province currently remains at a relatively low level and requires further enhancement.

4.1 Regression analysis

As shown in Table 3, digital literacy (DL) is found to exerts a positive and statistically significant impact on farmers' willingness to engage in HSFC. The estimated coefficient for DL is 6.011 and is

TABLE 1 Detailed indicator specifications.

Variable	Primary indicator	Second-level indicators	Name	Test item	Scoring method/unit
Dependent variable	Participation willingness (Y)	Participation willingness	Y	Would you be willing to participate in the construction of high-standard farmland?	1 = Yes, 0 = No
Primary explanatory variable	Digital literacy (DL)	Internet access	DL1	Does your household have a computer with internet access?	1 = Yes, 0 = No
			DL2	Do you have a smartphone?	1 = Yes, 0 = No
		Basic operations	DL3	Do you use the internet?	1 = Yes, 0 = No
			DL4	How frequently do you actively browse or access agricultural information using a mobile phone, computer, or other digital devices?	0 = Never, 1 = Rarely, 2 = Sometimes, 3 = Often, 4 = Always
		Communication link	DL5	Approximately how long do you spend using your phone/computer per session?	1 = Less than 15 min, 2 = 15–30 min, 3 = 30–45 min, 4 = 45–60 min, 5 = Over 60 min
			DL6	Have you ever learned agricultural skills on a digital platform?	1 = Yes, 0 = No
Control variables	Household head characteristics	Age	AGE	How old are you this year?	Years
		Education level	EDU	What is your level of education?	0 = Illiterate, 6 = Elementary school, 9 = Junior high school, 12 = High school or vocational school, 15 = College degree or higher
	Family characteristics	Household dependency ratio	HDR	Number of working-age household members (18–65 years old)/total household population	%
		Annual household income	HI	What was your household's total income last year?	10,000 CNY
	Current farmland status (FPS)	Acreage of farmland	FPS1	How many mu of arable land does your household currently have?	Mu
		Land transfer	FPS2	Is your family's farmland being transferred?	1 = Yes, 0 = No
	Behavioral attitude (ATB)	Ecological attitude	ATB1	Compared to conventional farmland, HSFC possesses strong ecological functions	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree
		Social attitude	ATB2	Compared to conventional farmland, HSFC can provide numerous social functions	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree
	Subjective norm (SN)	Expected approval	SN1	Participating in HSFC facilitates gaining others' approval	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree
		Neighbor influence	SN2	My neighbors influence my willingness to participate in HSFC	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree
	Perceived behavioral control (PBC)	Perceived behavioral control	PBC1	I believe there is currently a gap between farmland and HSFC	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree
		Self-efficacy	PBC2	I have sufficient energy and time to participate in HSFC	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree

(Continued)

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TABLE 1 (Continued)

Variable	Primary indicator	Second-level indicators	Name	Test item	Scoring method/unit
Instrumental variables	Capital endowment (CE)	Number of household agricultural machinery	CE	How many agricultural machines does your household own?	Units
	Livelihood strategy (LS)	Type of work	LS	What is your type of work?	1 = Full-time farming, 2 = Part-time farming, 3 = Non-farming
Regulating variables	Information trust (IT)	Information trust	IT	I believe construction information from the village committee is highly authoritative	1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neutral, 4 = Somewhat agree, 5 = Strongly agree

Terms in parentheses represent abbreviations of the variable indicators.

significant at the 1% level ($p = 0.001$), thereby validating the core hypothesis proposed in this paper and confirming the acceptance of Hypothesis H1. This result indicates that, controlling for other factors, a one-unit increase in farmers' digital literacy level leads to an approximate 6.011-unit increase in the log odds ratio for their participation in HSFC. This reflects digital literacy as a key positive driver of farmers' willingness to participate.

In the set of control variables, several factors also exhibit statistical significance. The age of the household head (AGE) has a positive effect at the 10% significance level, whereas the household dependency ratio (HDR) shows a significant negative effect at the same level. With respect to farmland conditions, the size of cultivated land (FPS1) is significantly negative at the 1% level. Notably, variables derived from the Theory of Planned Behavior framework demonstrate strong explanatory power: ecological attitude (ATB1) exerts a significantly negative effect at the 1% level; expected approval (SN1) and neighbor influence (SN2), as components of subjective norms, are both significantly positive at the 1% level; and within perceived behavioral control, perceived gap (PBC1) and self-efficacy (PBC2) display significant positive effects at the 5 and 10% levels, respectively.

4.2 Stability test

Replacing the core explanatory variable. The digital literacy score was substituted for the digital literacy level variable calculated using the entropy method, with the sample mean of digital literacy being. Table 4 presents the regression results after replacing the core explanatory variable, indicating that the total digital literacy score (DL-sum) of farmers has a significant positive effect on their willingness to participate at the 5% significance level, consistent with the findings of previous studies.

4.3 Endogeneity test

Endogeneity was tested using the instrumental variables method (GMM model). The questions "How many agricultural machines does your household own?" and "What is your type of work?" were selected as instrumental variables. As shown in Table 5, both instrumental variables passed the weak instrumental variable test and the over-identification test, confirming the theoretical validity of the chosen instrumental variables. The impact of digital literacy on farmers' willingness to participate in HSFC was estimated to overcome endogeneity issues caused by omitted variables and reverse causality. Results show that, regardless of whether simple logistic regression or instrumental variable regression is used, all findings are significant and consistent. Digital literacy has a positive influence on farmers' willingness to participate, further validating the study's hypothesis.

4.4 Moderation effect analysis

As shown in Table 6, the positive effect of digital literacy (DL) on farmers' willingness to participate remains statistically significant at the 1% level, further validating the robustness of the main effect. The main impact of the moderator variable, information trust (IT), was not statistically significant. However, the interaction term between

TABLE 2 Results of descriptive statistical analysis.

Variable	Name	Maximum	Minimum	Mean	Variance
Dependent variable	Y	1	0	0.867	0.116
Core explanatory variable	DL1	1	0	0.215	0.169
	DL2	1	0	0.883	0.104
	DL3	1	0	0.641	0.231
	DL4	4	0	1.156	1.332
	DL5	5	1	2.074	1.324
	DL6	1	0	0.332	0.223
	DL	0.967	0	0.323	0.065
Control variables	EDU	15	0	6.668	17.093
	AGE	79	21	53.655	11.751
	HDR	1	0	0.281	0.047
	HI	30	0	3.891	13.455
	FPS1	600	0	19.171	2199.59
	FPS2	1	0	0.23	0.178
	ATB1	5	2	4.266	0.298
	ATB2	5	3	4.164	0.232
	SN1	5	2	4.055	0.279
	SN2	5	1	3.824	0.914
	PBC1	5	2	3.945	0.264
	PBC2	5	1	3.797	0.492
Instrument variables	CE	35	0	1.137	4.981
	LS	3	1	1.402	0.586
Adjustment variable	IT	5	2	4.102	0.458

DL values are obtained using min–max normalization.

TABLE 3 Results of logistic regression.

Indicator	Coefficient	Standard error	Wald	*P*	Confidence interval (CI; 95%)	
					Lower	Upper
DL	6.011	1.888	10.137	0.001***	10.083	16512.099
AGE	2.233	1.156	3.729	0.053*	0.967	89.906
EDU	−0.126	0.314	0.16	0.689	0.477	1.631
HDR	−1.695	1.161	2.131	0.144	0.019	1.788
HI	0.049	0.101	0.236	0.627	0.861	1.281
FS1	−7.905	2.907	7.394	0.007***	1.24e-06	0.110
FS2	1.086	0.713	2.32	0.128	0.732	11.991
ATB1	−2.314	0.767	9.115	0.003***	0.022	0.444
ATB2	1.283	0.857	2.241	0.134	0.673	19.343
SN1	1.855	0.682	7.408	0.006***	1.681	24.314
SN2	0.937	0.295	10.107	0.001***	1.432	4.545
PBC1	1.463	0.69	4.503	0.034**	1.118	16.696
PBC2	0.781	0.462	2.859	0.091*	0.883	5.396
C	−14.408	3.257	19.572	0.000***	9.35e-10	0
Pseudo R2		0.435				
LR chi2(13)		87.21***				

Where LR is likelihood ratio; statistical significance at the 1, 5, and 10% levels is denoted by ***, **, and *, respectively.

TABLE 4 Robustness test results.

Variable	Coefficient	Standard error	Wald	*P*
Core explanatory variable (DL)	1.186	0.331	12.805	0.000***
Control variables	Controlled			
Constant term	−18.607	4.052	21.085	0.000***
Natural chi-square ratio	112.271***			

Statistical significance at the 1, 5, and 10% levels is denoted by ***, **, and *, respectively. Abbreviations in parentheses represent variable indicators and have the same meanings as those in Table 1.

TABLE 5 Results of endogeneity test.

Variable	Coefficient	Standard error	*Z*	*P*
Core explanatory variable (DL)	0.458	0.299	2.039	0.041**
Control variables	Controlled			
Constant term	−0.333	0.269	−1.238	0.016***
R^2	0.243			
C-statistic	2.312*			
Hansen J-test	0.291			
Wald statistic	74.497***			

Where statistical significance at the 1, 5, and 10% levels is denoted by ***, **, and *, respectively. Abbreviations in parentheses represent variable indicators and have the same meanings as those in Table 1.

TABLE 6 Results of moderation effect tests.

Variable	Coefficient	Standard error	*P*
Core explanatory variable (DL)	1.271	0.370	0.001***
Moderator variable (IT)	0.212	0.204	0.301
Interaction term (DL*IT)	−1.375	0.504	0.007***
Control variables	Controlled		
Constant term	−0.57	0.244	0.020**
Pseudo R2	0.435		
LR χ^2	87.28***		

Statistical significance at the 1, 5, and 10% levels is denoted by ***, **, and *, respectively. Abbreviations in parentheses represent variable indicators and have the same meanings as those in Table 1.

digital literacy and information trust (DL*IT) yielded a coefficient of −1.375, which was significant at the 1% level, supporting Hypothesis 2.

This finding indicates that information trust significantly moderates the effect of digital literacy on participation farmers' willingness in a negative direction. As farmers' confidence in the authority of village committee information increases, the marginal effect of digital literacy on their willingness to participate in HSFC declines. This may suggest that in high-trust environments, farmers tend to rely more on external authoritative information rather than their own digital capabilities for decision-making, thereby partially weakening the marginal contribution of digital literacy.

5 Discussion

The logistic regression analysis indicate that higher level of digital literacy is significant associated with increased willingness among Qinghai farmers to participate in HSFC, thereby validating Hypothesis H1. This finding aligns with existing research (Bai and Yang, 2025; Zhang and Zhang, 2024), further confirming that digital competence has become a critical human capital factor driving farmer participation in agricultural modernization and sustainable land management. From a human capital theory perspective, digital literacy enhances farmers' informational competencies and promotes clearer interpretation of policy content, project benefits, and technical approaches. This fosters cognitive advantages and strengthens behavioral confidence in HSFC. Farmers with higher digital literacy can more effectively utilize channels such as online platforms and mobile devices to promptly access information about policy subsidies, land improvement progress, and technical support. This reduces information asymmetry and uncertainties in the participation process, strengthening their rational decision-making capabilities and willingness to engage.

Qinghai's vast territory and dispersed village distribution underscore the limitations of traditional face-to-face information dissemination, making digital channels increasingly vital for the transfer of agricultural information. Farmers with higher digital literacy typically gain earlier access to government-released information and policy updates on HSFC. They accurately grasp policy directions and subsidy mechanisms while recognizing the project's potential value in improving farmland water management, enhancing production efficiency, and boosting ecological benefits. Consequently, they are more inclined to view project participation as a rational decision to improve production capacity and mitigate operational risks (Zhu et al., 2020).

Further analysis grounded in the Theory of Planned Behavior indicates that farmers' willingness to participate in Qinghai is not driven solely by attitude-based cost–benefit assessments, but is more strongly shaped by subjective norms and perceived behavioral control. This pattern reflects the strong community embeddedness and collective orientation of rural society in agro-pastoral transition zones and multi-ethnic areas, where farmers' decisions are closely tied to village organizations, neighbors' behaviors, and collective expectations. The positive effect of subjective norms suggests that participation is more likely when HSFC is viewed as a socially endorsed collective action, while the significance of perceived behavioral control highlights the importance of farmers' confidence in their ability to understand technical requirements and operational procedures. In contrast, behavioral attitude exhibits an inhibiting effect, reflecting farmers' concerns about project-related risks and uncertainties under high-altitude conditions, including long construction cycles, delayed returns, and post-construction maintenance responsibilities. These findings imply that, in the Qinghai context, policy efforts should prioritize reducing perceived risks and implementation uncertainties rather than relying solely on attitudinal persuasion centered on long-term benefits.

Moderation analysis indicates that information trust negatively moderates the relationship between digital literacy and farmers' willingness to participate in HSFC, confirming Hypothesis H2. Specifically, when information trust is high, the positive effect of digital literacy on participation weakens. From a social cognitive theory perspective, higher information trust may strengthen farmers' tendency toward external attribution. In ecologically fragile and economically less developed regions such as Qinghai, farmers generally rely heavily on public governance systems. When authoritative information sources provide clear guidance, farmers are more likely to attribute decision-making responsibility and expected outcomes to external authorities rather than their own digital capabilities and information-processing skills. This externalization of responsibility diminishes intrinsic motivation to leverage personal digital literacy to influence decision outcomes, thereby partially "crowding out" the effect of digital literacy on behavioral willingness (Wang and Wang, 2024).

At the information-processing level, high trust in official channels, such as village committees, can generate a pronounced "cognitive substitution" effect. In rural Qinghai, where information flows are relatively limited, formal institutions and informal social networks jointly constitute the primary information environment for farmers. For those who could otherwise rely on digital literacy for independent judgment, highly authoritative external information directly provides clear decision-making cues, leading them to adopt an "experience-compliance" simplified decision-making model rather than investing cognitive resources to autonomously gather and analyze information. Such reliance on authoritative information reduces both the necessity and motivation to enhance digital literacy for optimizing individual decision-making, thereby weakening its marginal effect on participation (Ma and Zheng, 2023).

This study has important global implications. Notably, enhancing farmers' digital literacy emerges as a key human capital strategy for promoting sustainable agricultural infrastructure, consistent with evidence that digital village initiatives improve green agricultural productivity (Li, 2025). The observed substitution effect of institutional trust indicates that highly authoritative information may reduce the marginal benefits of digital skills, a dynamic relevant in other high-trust contexts. By highlighting the interaction between digital capabilities and local trust in shaping participation, the findings can guide international development policies in ecologically fragile and resource-limited regions. Overall, integrating digital skill development with transparent, trustworthy institutions can support more effective rural revitalization and sustainable land-use outcomes (Wang et al., 2025; Zhang, 2021).

Drawing on the three key findings, this study proposes the following policy implications. First, digital literacy enhancement should be positioned as a core policy instrument for promoting HSFC and agricultural modernization. Given its significant positive effect on farmers' participation willingness, digital literacy development should be systematically integrated into high-standard farmland programs and agricultural digitalization strategies. Targeted and differentiated digital skills training, combined with hands-on guidance in the use of agricultural digital platforms, can strengthen farmers' ability to acquire, interpret, and apply policy-related information, thereby fostering endogenous motivation for participation in agricultural infrastructure development (Chen et al., 2025; Huang et al., 2023). Second, policy design and implementation should place greater emphasis on farmers psychological mechanisms by strengthening social norm guidance and perceived behavioral control. Since subjective norms and perceived behavioral control play a decisive role in shaping participation willingness, policymakers should leverage village-level organizations, farmer cooperatives, and demonstration households to reinforce the social legitimacy and collective recognition of participation in HSFC. At the same time, improving technical support, simplifying participation procedures, and reducing institutional barriers can enhance farmers' perceptions of feasibility and controllability, thereby facilitating the translation of willingness into actual behavior (Jia and Cheng, 2024; Cai and Han, 2024). Third, capacity building and trust construction should be advanced in a coordinated manner to create an institutional environment conducive to the effective functioning of digital literacy. Given the dampening effect of information trust on the marginal role of digital literacy, policy implementation should avoid overreliance on top-down authoritative information dissemination. Instead, while maintaining transparency, consistency, and credibility in policy communication, greater attention should be paid to cultivating farmers' independent information evaluation and digital decision-making capacities. By balancing institutional trust with individual capability development, digital literacy and trust can become mutually reinforcing, thereby enhancing the sustainability and effectiveness of farmers' participation in HSFC (Yang et al., 2025; Zhang, 2025).

6 Conclusions and future implications

The results of the logistic regression indicate that digital literacy has a statistically significant positive effect on farmers' willingness to participate, thereby supporting the core theoretical hypothesis of this study. This suggests that, in the context of agricultural digital transformation, digital literacy should be understood not merely as an individual skill, but as a critical form of human capital that enhances farmers' capacity to access, comprehend, and respond to modern agricultural policies, providing a cognitive and behavioral foundation for engagement in agricultural infrastructure upgrading and sustainable development. Further analysis reveals that farmers' participation decisions are shaped by a multidimensional behavioral structure. Subjective norms and perceived behavioral control significantly enhance farmers' willingness to participate, whereas behavioral attitudes exhibit a suppressing effect. This result implies that farmers' policy responses are not driven solely by rational cost–benefit calculations, but are deeply embedded in a psychological decision-making framework formed by social interactions and self-efficacy perceptions. Psychological mechanisms therefore play a crucial role in transmitting policy incentives into actual participation behavior.

The moderating effect analysis highlights the context-dependent nature of digital literacy. The results show that information trust negatively moderates the relationship between digital literacy and participation willingness. In high-trust information environments, farmers tend to rely more heavily on external authoritative information rather than on their own digital capabilities when making decisions, which in turn weakens the marginal effect of digital literacy. This finding indicates that the behavioral impact of digital literacy does not operate in isolation, but is conditioned by the credibility of the information environment and the broader structure of institutional trust.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was conducted in accordance with ethical research standards. Informed consent was obtained from all participating farmers before data collection, and participation was entirely voluntary. Data were anonymized to ensure confidentiality, and no personal or sensitive information was disclosed. The research protocol was reviewed and approved by the relevant institutional ethics committee.

Author contributions

YJ: Writing – original draft, Writing – review & editing, Conceptualization, Methodology, Resources.

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