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Impact of environmental literacy on farmers' agricultural green production behavior: Evidence from rural China

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Agricultural green production has been regarded as an effective way to solve the increasing level of agricultural environmental pollution and the frequent safety crises of agricultural products. As the main decision makers of agricultural production, farmers' agricultural green production behavior directly determines the process of agricultural green development. However, few studies have explored farmers' agricultural green production behavior from the perspective of environmental literacy, and the formation mechanism of farmers' agricultural green production behavior is still unclear. This study aims to clarify the effect of environmental literacy on farmers' agricultural green production behavior and its impact mechanism. Based on survey data from 830 farmers in China, this study constructs comprehensive index systems to evaluate farmers' environmental literacy and agricultural green production behavior, and adopts multiple linear regression models and quantile regression model to explore the impact of environmental literacy on this behavior. Meanwhile, the mediation effect model is used to explore the mediation effect of agricultural green production cognition and agricultural green production willingness in the influence of environmental literacy on farmers' agricultural green production behavior. Three conclusions arise. First, farmers' environmental literacy and agricultural green production behavior are at the middle level, both of which should be strengthened. Second, environmental literacy has a significant positive impact on farmers' agricultural green production behavior. Finally, environmental literacy influences farmers' AGP behavior through the independent and chain mediation effects of AGP cognition and AGP willingness. Environmental literacy has heterogeneity impact on farmers' agricultural green production behavior under different level of agricultural green production and external environment. This research not only provides theoretical support for the study of farmers' agricultural green production behavior from the perspective of environmental literacy, it also provides a reference to the relevant government departments so that they can guide farmers to adopt more agricultural green production behavior.

KEYWORDS

environmental literacy, green production behavior, green production willingness, multiple linear regression models, mediation effect model

1 Introduction

Environmental risks are making the world sleepwalk into disaster in recent decades (Liu et al., 2020). In this regard, agricultural pollution has become increasingly serious throughout the world, especially in developing countries (Chen et al., 2017). In China, the contradiction between agricultural development and environmental protection is also serious (Cao et al., 2020; Jiang et al., 2020). Since China's reform and opening up, Chinese agriculture has made remarkable achievements. With only 9% of the arable land on the Earth, China's agricultural sector feeds nearly 20% of the world's population. Meanwhile, farmers' income and quality of life improved significantly (Mi et al., 2020). However, it has also created various non-negligible environmental consequences, such as serious environmental pollution, a shortage of natural resources, and an unbalanced ecosystem (Chen et al., 2017; Shen et al., 2018). According to the World Bank statistics, the per capita cultivated land and fresh water resources in China are only 1/2 and 1/3 of the world average level, the average grade of cultivated land is 9.95, the proportion of superior and higher cultivated land is less than 30%, and the effective utilization coefficient of agricultural irrigation water is only 0.53 (Liu et al., 2020). Furthermore, according to the First National Pollution Source Census Bulletin, agricultural pollution sources have become the major polluters of water environment in China. The proportion of agricultural chemical oxygen demand, total nitrogen, and total phosphorus emissions took 43.7%, 57.2% and 67.4% of the total emissions, respectively (Yang and Wu, 2018). If these problems are not effectively solved, they will threaten the sustainable development of the economy and society.

Fortunately, China has been aware of the imbalance between rapid economic growth and environmental protection (Wu et al., 2018; Chen et al., 2021). The government has issued a series of policies to solve agricultural environmental problems, such as "The Opinions on Promoting Agricultural Green Development by Innovating Institutions and Mechanisms". Central Document No. 1 in 2017, 2018, and 2019 also emphasized the implementation of green production modes to promote the sustainable development of agriculture. These policies aimed to promote agricultural green production (AGP) and realize the modernization of agriculture in China (Cao et al., 2020). According to the definition of the United Nations Environment Programme, AGP refers to the production model that aims to conserve energy, reduce consumption and reduce pollution, and uses technology and management as means to implement pollution control throughout the agricultural production process to minimize pollutant emissions (UNEP 2011). It was generally believed that AGP was a sustainable development pattern, including improved agricultural technologies and sustainable production practices such as the use of organic pesticides and manure, less or no tillage technology, crop rotation, soil protection measures, intercropping, and waste resource utilization (Li et al., 2020). As a vital part of green production, AGP aims at developing high-efficiency, high-quality, ecological and safe agriculture through standardized production models, and achieving the unification of economic, environmental and social benefits (Liu et al., 2020). Actively promoting AGP is an irresistible trend for the sustainable development of modern agriculture (Wan et al., 2018; Zhang et al., 2018). Through vertical comparisons of AGP in 1978 and 2017, China's AGP development has made some achievements. The supply of major agricultural products meets the national demand, but the quality of these products still needs to be improved. The restricting factors of agricultural green development mainly derives from resource shortage, ecological destruction and environmental pollution. The next task of promoting agricultural green development is to enhance the efficiency of resource utilization, keep the stability of the ecosystem and maintain the clean production environment (Liu et al., 2020).

At present, China's AGP is still in the initial stage of transformation, and farmers generally possess low cognition of green production policies and measures, which weakens the implementation of relevant policies (Li et al., 2020). Given the benefits of AGP, the relatively low adoption of AGP behavior created an important need for a large number of studies on factors that impact the adoption of AGP practice by farmers. In previous studies, many scholars pointed out that some demographic and socio-economic factors might be the major reasons that prevented farmers from adopting AGP behavior (Li et al., 2020). In addition to individual endowment (e.g., gender, age, education degree) (Yu et al., 2021), household characteristics (e.g., family income, off-farm income ratio, farm income ratio, e-commerce adoption) (Li et al., 2021; Xie and Huang, 2021), farming conditions (e.g., farm size, degree of farmland fragmentation; land transfer) (Qi et al., 2021; Xie and Huang, 2021), farmers' AGP behavior might be affected by social factors (e.g., training, cooperative, social capital, experience sharing, peer effects, supervision, government subsidies, government propaganda, community governance) (Kassie et al., 2013; Xie and Huang, 2021; Thu et al., 2020; Yu et al., 2022; Zhang et al., 2018; Li et al., 2019; Yi et al., 2021; Niu et al., 2022) and market environment (e.g., expected price) (Zhao et al., 2018). In terms of measuring AGP behavior, most of the existing research has extended in two directions. On the one hand, some scholars used binary choice variables to characterize farmers' AGP behavior, and then used Logistic and Probit models to explore its influencing factors (Zhang et al., 2018; Cao et al., 2020; Li and Shen, 2021; Niu et al., 2022). On the other hand, some studies have used multiple questions with binary selection variables to ask farmers about their AGP behavior, and used a count dependent variable measuring the number of AGP behavior adopted by farmers. These studies adopted Ordered Probit model and Poisson model to investigate the influencing factors (Bopp et al., 2019; Oyetunde-Usman et al., 2021).

We are now faced with serious environmental problems; environmental education has been seen as the most valuable defense against such threats. In recent years, environmental literacy became the most important component of environmental education (Saribas et al., 2014). Environmental literacy, defined as the knowledge, skills, values, attitudes and responsibility that people possess about the environment and the relationship between people and the environment (Roth, 1992), has become a key factor to promote the transformation of personal behavior into a more sustainable lifestyle in order to consciously respond to environmental challenges (Bissinger and Bogner, 2018). Some scholars measured the level of environmental literacy among upper primary students, undergraduate college students and business lecturers (Joseph et al., 2013; Bissinger and Bogner, 2018; Goldman et al., 2018; Lloyd-Strovas et al., 2018). Besides, some scholars explored the relationship between environmental literacy and individual environmental behavior. The results showed that environmental literacy had a positive effect on women's effort to manage household waste (Asteria, 2019); environmental literacy influenced environmental attitude towards environmental conservation and which eventually played a vital role in promoting people towards adoption of sustainable and healthy lifestyle practice (Biswas, 2020); people with environmental literacy could show more responsible environmental behavior (Hungerford and Volk, 1990; Hares et al., 2006; Ramdas and Mohamed, 2014).

The existing studies have carried out extensive research on farmers' AGP behavior, which has helped to enrich our understanding of this behavior. However, the existing research still has some limitations. First, most of the existing literature has focused on one or several AGP behavior of farmers (mainly the adoption of AGP technology), which is inadequate for fully reflecting the status quo of farmers' AGP behavior. Second, environmental literacy is highly concerned in the field of environmental education. Some research has evaluated the level of environmental literacy and explored its impact on individual environmental behavior, but little was known about the level of farmers' environmental literacy and its influence on farmers' AGP behavior. Third, the decision-making behind farmers' AGP behavior is a complicated process (Liu et al., 2020). At present, scholars have not sufficiently discussed the formation mechanism of this behavior. There is no clear explanation about the impact patterns, formation processes and interactions of each variable with environmental behavior (Li et al., 2019). To fill this gap, this study constructs comprehensive index systems to evaluate farmers' environmental literacy and AGP behavior, and uses multiple linear regression models and quantile regression model to explore the impact of environmental literacy on this behavior. In addition, we adopt the mediation effect model to reveal the mediation effect of AGP cognition and AGP willingness in the influence of environmental literacy on farmers' AGP behavior.

The main contributions of this research are as follows. First, this study designs an indicator system of farmers' AGP behavior from three aspects—pre-production, on-production and post-production—and the factor analysis method is used to measure it, which can fully reflect the status quo of this behavior. We also design an indicator system of farmers' environmental literacy from three aspects—environmental values, environmental responsibility and environmental knowledge and skills—and we use the factor analysis method to measure it, which can reflect the level of farmers' environmental literacy. Second, this study explores the impact of environmental literacy on farmers' AGP behavior, thereby enriching the research perspective of farmers' AGP behavior. Third, through the mediation effect test and heterogeneity analysis, we clarify the impact mechanism of environmental literacy on farmers' AGP behavior. These conclusions can inform strategies to improve farmers' AGP behavior through interventions such as the cultivation of farmers' environmental literacy, AGP cognition and AGP willingness.

The remainder of this study is organized as follows. Section 2 proposes the research hypothesis. Section 3 shows the materials and methods, including the data collection, scale development, measurement of the latent variables and econometric model construction. Section 4 presents the results of the empirical study. Section 5 discusses the study results. Section 6 summarizes the conclusions and points out the directions for future research.

2 Theoretical analysis and research hypothesis

The value-belief-norm (VBN) theory was first proposed by Schwartz, which considers three variables: consequence awareness, responsibility attribution, and personal norm (Schwartz, 1977). Stern extended this theory by integrating the new environmental paradigm theory and value theory, which connected value orientation, environmental concern, consequence awareness, responsibility attribution and personal norms (Zhang et al., 2021). Nowadays, the VBN theory has been widely used in the research of individual environmental behavior, and has been treated as the best theory for understanding environmental protection behaviors (Stern, 2000). According to the VBN theory, environmental friendly behavior stems from the personal norms such as the sense of moral obligation for environmental friendly behavior. These beliefs, that environmental conditions threaten individual values (consequences awareness) and people can reduce these threats (responsibility attribution), activate the personal norms. Based on VBN theory, consequences awareness and responsibility attribution depend on the general beliefs in the relationship between people and environment and to some extent the relatively fixed value orientations (Rezaei-Moghaddam et al., 2020).

As for the impact of environmental literacy on farmers' AGP behavior, environmental literacy reflects an individual's environmental values, responsibility, knowledge and skills (Tuncer et al., 2009). Farmers with good environmental literacy insist the value of harmonious coexistence between human beings and natural systems. They always care about the surrounding ecological environment and believe that human beings should not damage the environment for economic development. However, the traditional extensive agricultural development model induces serious agricultural environmental pollution, which threatens their environmental values. Farmers with good environmental literacy have a high sense of responsibility to solve agricultural environmental problems, which activates their personal norms, so they may take AGP actions to pursue harmony between human beings and nature. According to self-efficacy theory (Bandura and Adams, 1977), self-efficacy is an important factor affecting individual behavior. Individuals with high self-efficacy are more confident in their own abilities and more likely to carry out specific behaviors. Farmers with good environmental literacy master sufficient environmental knowledge and skills to engage in AGP. They have high self-efficacy towards AGP, which may promote them adopt more AGP behaviors. Based on this, environmental literacy may provide the foundation and power for farmers to adopt AGP behaviors (Asteria, 2019). In fact, previous studies have confirmed that environmental literacy is closely related to individual responsible environmental behavior. Hares et al. (2006) and Ramdas and Mohamed (2014) suggest that people with environmental literacy have the knowledge and skills needed to analyze environmental issues, respect nature, act in a responsible manner and show more environmentally friendly behavior. Hungerford and Volk (1990) found that under the influence of environmental attitudes, environmental values and ecological concepts, environmental literacy profoundly affects people's environmental behavior. Biswas (2020) pointed out that protecting the environment should begin with environmental literacy as it could cultivate human behavior and living practice in a more environmentally responsible way. Based on the above analysis, Hypothesis 1 is proposed in this study.

H1: Environmental literacy has a positive impact on farmers' AGP behavior.

At present, China is facing severe agricultural environment issues. If these problems cannot be effectively solved, they will threaten the sustainable development of China's agriculture. AGP has been regarded as an effective way to solve agricultural environmental problems. Farmers with good environmental literacy pursue harmony between human beings and nature and take solving environmental problems as their own responsibility. Against the background of increasing agricultural environmental pollution, farmers with a high level of environmental literacy can better understand the environmental value created by AGP and show more positive attitudes towards AGP. Economist Schultz proposed that people who master knowledge and skills are the most important resources in all production resources (Schultz, 1961). From the perspective of behavioral science, knowledge and skills are significant factors affecting individual cognitive ability, and lack of knowledge and skills may lead to cognitive bias. Farmers with a high level of environmental literacy master rich environmental knowledge and skills; they can form a positive cognition of AGP by comparing the traditional agricultural development model with the agricultural green development model. Based on this, environmental literacy may positively impact farmers' AGP cognition.

According to cognition and behavior theory (Beicfel and Turner, 1986), individual cognition has an important effect on their behavior. False cognition is the main source of bad behavior, while correct cognition is the main source of good behavior. Based on this theory, AGP cognition may have positive influence on farmers' AGP behavior. Indeed, previous studies have widely confirmed that cognition has an important effect on farmers' environmental protection behaviors. Hoffman et al. (2014) believe that farmers' consensus on the concept of green production can shape the mental model of the group, which significantly changes farmers' production behavior. Xue et al. (2021) pointed out that farmers' cognition of agricultural mulch film pollution affected their recycling behavior. Lu et al. (2020) found that if farmers believed that returning straw to the field would improve soil fertility, or subjectively believed that the income from this technology would increase, they were more likely to adopt this behavior. In summary, environmental literacy may positively affect farmers' AGP cognition, and AGP cognition may positively affect their AGP behaviors. Therefore, there may be an influence path between environmental literacy and farmers' AGP behavior as follows: environmental literacy→AGP cognition→AGP behavior. Based on this, we propose Hypothesis 2 in this study.

H2: AGP cognition plays a mediation role between environmental literacy and farmers' AGP behavior.

The rural environment has the attribute of public goods, and the interest subjects are diversified. The government, environmental protection organization and farmers may all become the governance subjects of environmental pollution. According to the attribution theory (Kelley and Michela, 1980), individuals with different characteristics may have different attribution to the same behavior, and different attribution leads to different behavioral tendency. Farmers with a high level of environmental literacy have ecological values and awareness of environmental responsibility. They believe that they are responsible for solving environmental problems and feel guilty for not taking measures to reduce environmental pollution, so they may have a strong willingness to adopt green production methods. In fact, numerous studies have confirmed that environmental literacy or its sub-dimensions have a vital influence on individual willingness to protect the environment. Research based on the environmental literacy model has shown that environmental literacy is an important factor influencing individual willingness to adopt responsible environmental behavior. Individuals with good environmental literacy are capable and willing to adopt responsible environmental behaviors (Goldman et al., 2018; Biswas, 2020). Wang et al. (2014) and Hamzah and Tanwir (2021) noted that environmental knowledge has a significant positive influence on eco-friendly purchasing willingness among customers. Vicente-Molina et al. (2013) believed that ecological knowledge can promote environmental behavioral willingness among college students. Thus, environmental literacy may have a positive impact on farmers' AGP willingness.

According to the theory of planned behavior, behavioral intention is an important predictor of individual behavior. The stronger the behavioral intention is, the more likely an individual is to implement a certain behavior (Ajzen, 1991; Daxini et al., 2019). A large number of empirical studies have also confirmed this view; Deng et al. (2016) found that farmers' ecological protection behavior was significantly affected by their willingness to protect the ecosystem. Li et al. (2020) discovered that there was a significant positive relationship between farmers' adoption willingness and the adoption of sustainable production technology. Based on the above analysis, farmers' AGP willingness may have a positive effect on their AGP behavior. In summary, environmental literacy may positively affect farmers' AGP willingness, and AGP willingness may positively influence their AGP behavior. Therefore, the relationship between environmental literacy and farmers' AGP behavior may have the influence path: environmental literacy→AGP willingness→AGP behavior. In view of the above, this paper proposes Hypothesis 3.

H3: AGP willingness has a mediation effect on the impact of environmental literacy on farmers' AGP behavior.

According to the theory of behavioral economics, individual cognition directly or indirectly affects people's preferences and willingness to choose (Crites et al., 1994; Xiong and Wang, 2020). Psychological cognition influences behavior willingness has become a common paradigm of psychological analysis, and numerous empirical studies have confirmed this theoretical viewpoint. Lu et al. (2020) found that farmers' environmental cognition promotes their willingness to implement straw incorporation. Li et al. (2021) discovered a significant positive relationship between cognition of the usefulness of photovoltaic agriculture and farmers' willingness to adopt it. Li et al. (2020) found that consumers' competence in environmental cognition had a direct effect on their willingness to pay for ecological consumption in West China. Based on the above analysis, AGP cognition may have a positive impact on farmers' AGP willingness. According to the previous analyses, environmental literacy may have a positive influence on farmers' AGP cognition and AGP willingness may positively affect farmers' AGP behavior. Therefore, the relationship between environmental literacy and farmers' AGP behavior shows the following logical relationship: environmental literacy→AGP cognition→AGP willingness→AGP behavior. Based on this, we propose Hypothesis 4 in this study.

H4: AGP cognition and AGP willingness play a chain mediation role in the relationship between environmental literacy and farmers' AGP behavior.

Based on the above theoretical deductions, this study constructed the following theoretical model, as shown in Figure 1:

3 Materials and methods

3.1 Data collection

Hebei Province, located in the North China Plain, is the only province in China with plateaus, mountains, hills, plains, lakes and coasts. The province is an important supply base of agricultural and sideline products for Beijing and Tianjin. The main agricultural products include grain crops such as wheat, corn, millet, rice, sorghum and beans, and cash crops such as cotton, oilseed and flax. According to the China Statistical Yearbook 2020, the planted area in the province in 2019 was 8,132,700 hectares, of which 6,469,200 hectares was planted to grain crops, and the grain output was 37.392 million tons. The sown area and grain output rank among the top in the country. However, the province has a large population and faces serious shortages of water resources. The extensive agricultural development model has further exacerbated the deterioration of the agricultural ecological environment. Hebei Province has issued the "Three-year Action Plan for Agricultural Supply-side Structural Reform (2018–2020)", which aimed to promote AGP and meet people's increasing demand for high-quality agricultural products. However, the extensive agricultural development model has not been fundamentally changed. Therefore, this study took Hebei Province as an example to explore the impact and mechanisms of environmental literacy on farmers' AGP behavior and to provide a reference for the government for formulating policies to promote AGP.

The data of this study were obtained from a field survey conducted by the research group from February to March 2021. This study examined planting farmers from six major agricultural counties in the Baoding and Handan regions of Hebei Province, namely Dingzhou, Anxin, Shunping, Guantao, Linzhang and Yongnian, as the research subjects. According to the principle of multi-stage sampling, 18 townships (towns) and 54 administrative villages were

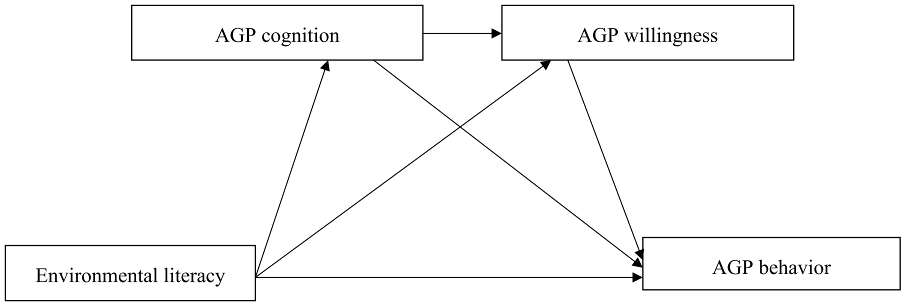

FIGURE 1
Conceptual framework.

TABLE 1 Descriptive statistics of the characteristics of farmers.

Characteristics	Percentage/average
Gender	
Male (%)	60.12
Female (%)	39.88
Age (years)	44.54
Years of schooling (years)	8.52
Agriculture laborers (persons)	1.80
Village cadres	
Yes (%)	6.14
No (%)	93.86
Cultivated area (mu)	5.82
Number of cultivated land pieces (pieces)	3.27
Cooperative membership	
Member (%)	18.55
Non-member (%)	81.45

sampled from 6 sample counties (districts and cities). In order to improve the accuracy of data collection, the survey adopted face-to-face interviews, in which the trained investigators interviewed the main decision-makers regarding farmers' agricultural production. In total, 850 questionnaires were distributed in this survey. After excluding the invalid questionnaires and those missing key variables, 830 valid questionnaires were finally obtained. Table 1 presents the descriptive statistics of the characteristics of the farmers. Among the sampled farmers, the proportion of males (60.12%) was higher than that of females (39.88%). The respondents were mainly middle-aged and elderly people, with an average age of 44.54 years. The interviewees had an average of 8.52 years of schooling, which indicates that their level of education is relatively low. On average, each family has 1.80 persons working in agriculture. 6.14% of the surveyed households have village cadres. The average cultivated area is 5.82 mu, and each household actually manages 3.27 pieces of cultivated land, which is characteristic of small farmers and land fragmentation. Only 18.55% of the sample farmers had joined a cooperative.

3.2 Scale development

The latent variables quantified in this study were mainly derived from the existing literature, and have been slightly modified according to the research topic. Before the formal investigation, the research group conducted a small-scale pilot investigation in Xushui District. Based on the feedback from the pilot investigation, some of the measurement items were revised so that they could be easily understood by the interviewees in the formal survey. This study used a Likert 5-point scale to measure the latent variables. For measuring environmental literacy, AGP cognition and AGP willingness, 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = fully agree. For measuring AGP behavior, 1 = never, 2 = rarely, 3 = sometimes, 4 = often and 5 = very often. The measurement items of all scales are shown in Table 2.

Independent variables: This study measured farmers' environmental literacy (EL) in terms of three dimensions: Environmental values (EV), environmental responsibility (ER) and environmental knowledge and skills (EKS) (Roth, 1992; Tuncer et al., 2009). Environmental values refer to the belief that individuals seek the harmony between humankind and nature in the development of economy. The environmental values scale was mainly developed from the work of Tuncer et al. (2009) and Maurer and Bogner (2020). Environmental responsibility is defined as an individual's sense of duty to take measures against environmental deterioration. The environmental responsibility scale was mainly developed from the work of Roth (1992), Tuncer et al. (2009), and Fransson and Gärling (1999). Environmental knowledge and skill help farmers discover, analysis, and provide the solutions for environmental problems. The environmental knowledge and skills scale was mainly developed from the work of Tuncer et al. (2009) and Pourg-hasem et al. (2020). As for levels of measurement items (Table 3), all three items used to measure the latent variable

TABLE 2 Measurement items of the latent variables.

Latent variables	Items	Interview questions
Environmental values (EV)	EV_1	I think environmental and ecological protection are more important than economic development
	EV_2	I think humankind is not the master of nature
	EV_3	I believe that human beings should live in harmony with nature
Environmental responsibility (ER)	ER_1	I think I should carry out AGP to reduce agricultural environmental pollution
	ER_2	I believe that I have the responsibility to carry out AGP to protect the agricultural ecological environment
	ER_3	I will feel guilty for not taking steps to protect the agricultural environment
Environmental knowledge and skills (EKS)	EKS_1	I have mastered a certain amount of environmental knowledge
	EKS_2	I can recognize agricultural ecological environment problems in time
	EKS_3	I can analyze the causes of agricultural ecological environment problems
	EKS_4	I have mastered some skills to solve agricultural environmental problems
Green production cognition (GPC)	GPC_1	AGP improves the agricultural ecological environment
	GPC_2	AGP reduces agricultural environmental pollution
	GPC_3	AGP improves the quality of agricultural products
Green production willingness (GPW)	GPW_1	I am willing to invest some labor in AGP
	GPW_2	I am willing to invest some time in AGP
	GPW_3	I am willing to invest some money in AGP
Pre-production (PREP)	$PREP_1$	The extent to which I purchase low-toxic and low-residue pesticides
	$PREP_2$	The extent to which I purchase new high-efficiency fertilizers
	$PREP_3$	The extent to which I purchase organic fertilizer
On-production (ONP)	ONP_1	The degree to which I dispense pesticides according to the instructions
	ONP_2	The degree to which I implement the safety interval of pesticides
	ONP_3	The degree to which I adopt the technology of formula fertilization by soil testing
	ONP_4	The degree to which I adopt the technology of green prevention and control
	ONP_5	The degree to which I adopt the technology of water-saving irrigation
Post-production (POSTP)	$POSTP_1$	The degree to which I recycle or reuse agricultural film
	$POSTP_2$	The degree to which I adopt the technology of straw return
	$POSTP_3$	The degree to which I adopt environmentally friendly packaging for agricultural products or reuse packaging

"environmental value" had an average of at least 3.489 and all three items used to measure the latent variable "environmental responsibility" had an average of at least 3.189, which means that farmers' environmental value and environmental responsibility are moderate. The item "I have mastered a certain amount of environmental knowledge" (mean = 3.175) scored relatively high in the latent variable of "environmental knowledge and skills", while the other three measurement items scored below 3, which indicates that farmers have a low level of environmental skills.

Dependent variables: In 2015, the Ministry of Agriculture indicated in the document Implementation Opinions on Fighting the Tough Battle against Agricultural Non-point Source Pollution that the total amount of agricultural water consumption should be controlled, the use of chemical fertilizers and pesticides should be reduced and agricultural film and crop straw should be recycled or harmlessly treated by 2020. Combined with these objectives, this study built the indicators of farmers' AGP behavior from three production stages—pre-production, on-production, and post-production (Zhou et al., 2019), which reflect farmers' procurement of green agricultural materials, standardized use of inputs, adoption of green production technology, and harmless disposal of agricultural waste, etc. As for levels of measurement items (Table 3), all three items used to measure the latent variable "pre-production" had an average below 3, which indicates that farmers are insufficient at procuring green agricultural materials. All five items used to measure the latent variable "on-production" had an average of at least 3.099 and all three items used to measure the latent variable "post-production" had an average of at least 3.355, which means that the degree of farmers' AGP in the on-production and post-production stages are moderate.

Mediating variables: The mediating variables in this study included AGP cognition and AGP willingness. The AGP cognition and AGP willingness scales were mainly developed from the work of Li et al. (2020). As for levels of measurement items (Table 3), all three items used to measure the latent variable "green production cognition" had an average of at least 3.335, which means that farmers' AGP cognition are moderate; all three items used to measure the latent variable "green production willingness" had an average of at least 3.673, which means that farmers' AGP willingness are moderate.

TABLE 3 Results of the reliability and validity test (n = 830).

Latent variables	Items	Mean	Standard deviation	Loading	Cronbach's α	KMO test	Bartlett test	p-Value
	EV_1	3.489	0.775	0.816				
	EV_2	3.584	0.849	0.794				
	EV_3	3.636	0.818	0.851				
	ER_1	3.522	0.808	0.879				
	ER_2	3.364	0.794	0.906				
EL	ER_3	3.189	0.773	0.877	0.894	0.861	5689.740	0.000
	EKS_1	3.175	0.860	0.769				
	EKS_2	2.778	0.800	0.824				
	EKS_3	2.582	0.797	0.889				
	EKS_4	2.443	0.818	0.845				
	GPC_1	3.469	0.869	0.928				
GPC	GPC_2	3.407	0.945	0.941	0.920	0.757	1862.453	0.000
	GPC_3	3.335	0.964	0.919				
	GPW_1	3.716	1.024	0.954				
GPW	GPW_2	3.730	1.014	0.963	0.947	0.761	2465.088	0.000
	GPW_3	3.673	1.026	0.938				
	$PREP_1$	2.905	1.242	0.960				
	$PREP_2$	2.875	1.235	0.947				
	$PREP_3$	2.840	1.250	0.942				
	ONP_1	3.188	0.883	0.906				
GPB	ONP_2	3.240	0.905	0.897	0.796	0.831	8310.900	0.000
	ONP_3	3.124	0.956	0.904				
	ONP_4	3.134	0.918	0.890				
	ONP_5	3.099	0.911	0.855				
	$POSTP_1$	3.381	1.111	0.931				
	$POSTP_2$	3.355	1.148	0.920				
	$POSTP_3$	3.442	1.146	0.952				

Control variables: Based on the existing literature (Cao et al., 2020; Thu et al., 2020; Yu et al., 2021) and field experience, this study selected control variables at the individual level (gender, age and years of schooling), the household level (number of agriculture laborers, whether there is a village cadre in the household, whether to participate in AGP technology training, whether to join a cooperative, farm income ratio, crop type) and the farmland characteristics level (the cultivated area, number of cultivated land, land type, land quality).

3.3 Measurement

3.3.1 Reliability and validity test

The Cronbach's α coefficient method was used to test the reliability of the measurement index. The closer α is to 1, the higher the reliability of the measurement index. In general, 0.5 is the acceptable critical value. The results show that Cronbach's α coefficient for the four variables–environmental literacy, AGP cognition, AGP willingness and AGP behavior–all pass the minimum standard for the reliability test (Table 3), which shows that the scales had good reliability. KMO and Bartlett test were used to test the validity of the measurement index. The results (Table 3) show that the KMO test values of all latent variables were greater than the recommended value 0.5. Meanwhile, the Bartlett test results reject the null hypothesis that the variable correlation matrix is the identity matrix (p < 0.001). The results indicate that all the scales are suitable for factor analysis. The factor analysis showed that the standardized factor loading values of each measurement item were in the range of 0.769–0.963, which exceeds the recommended threshold of 0.5, indicating that all measurement items have good convergent validity.

3.3.2 Construction of environmental literacy index

The principal component analysis method was used to extract the common factors with feature roots greater than 1.

After the rotation by the maximum variance method, three common factors (environmental knowledge and skills, environmental responsibility and environmental values) were extracted. The extracted variance was 30.289%, 26.388% and 22.981% respectively, and the cumulative variance contribution rate reached 79.658%. According to the scores of common factors of environmental literacy and their variance contribution rate, the total score of farmers' environmental literacy factor is calculated. The calculation formula is shown in Eq. 1:

$$EL = (30.289 \times Fac_1 + 26.388 \times Fac_2 + 22.981 \times Fac_3)/79.658 \quad (1)$$

In Eq. 1, EL represents the total score of farmers' environmental literacy factor, and Fac_1-Fac_3 represents three common factors respectively. Since the factor score reflects the relative quantity and it is difficult to achieve intuitive comparison, this study standardizes the factor score of environmental literacy to make the final data value between 0 and 1. The index of farmers' environmental literacy is constructed as follows.

$$ELI_i = \frac{EL_i - MinEL}{MaxEL - MinEL} \quad (2)$$

In Eq. 2, ELI_i represents the environmental literacy index of the ith surveyed farmer, EL_i represents the environmental literacy factor score of the ith surveyed farmer, MaxEL and MinEL represent the maximum and minimum values of factor scores of environmental literacy among the surveyed farmers respectively.

3.3.3 Construction of AGP cognition index

One common factor with characteristic root greater than 1 was extracted by principal component analysis, which was named AGP cognition of farmers, and the cumulative variance contribution rate reached 86.387%. Since the factor score reflects the relative quantity and it is difficult to achieve intuitive comparison, this paper standardizes the factor score of AGP cognition to make the final data value between 0 and 1. The index of farmers' AGP cognition is constructed as follows:

$$GPCI_i = \frac{GPC_i - MinGPC}{MaxGPC - MinGPC} \quad (3)$$

In Eq. 3, $GPCI_i$ represents the AGP cognition index of the ith surveyed farmer, GPC_i represents the AGP cognition factor score of the ith surveyed farmer, MaxGPC and MinGPC represent the maximum and minimum values of factor scores of AGP cognition among the surveyed farmers respectively.

3.3.4 Construction of AGP willingness index

One common factor with characteristic root greater than 1 was extracted by principal component analysis, which was named AGP willingness of farmers, and the cumulative variance contribution rate reached 90.512%. Since the factor score reflects the relative quantity and it is difficult to achieve intuitive comparison, this paper standardizes the factor score of AGP willingness to make the final data value between 0 and 1. The index of farmers' AGP willingness is constructed as follows:

$$GPWI_i = \frac{GPW_i - MinGPW}{MaxGPW - MinGPW} \quad (4)$$

In Eq. 4, $GPWI_i$ represents the AGP willingness index of the ith surveyed farmer, GPW_i represents the AGP willingness factor score of the ith surveyed farmer, MaxGPW and MinGPW represent the maximum and minimum values of factor scores of AGP willingness among the surveyed farmers respectively.

3.3.5 Construction of AGP behavior index

The common factors with characteristic root greater than 1 were extracted by principal component analysis. After the rotation by the maximum variance method, three common factors were extracted and named as AGP behavior in the stage of on-production, pre-production and post-production respectively. The extracted variance was 36.446%, 24.616% and 24.266% respectively, and the cumulative variance contribution rate reached 85.328%. According to the scores of common factors of AGP behavior and their variance contribution rate, the total score of farmers' AGP behavior factor is calculated. The calculation formula is shown in Eq. 5:

$$GPB = (36.446 \times Fac_1 + 24.616 \times Fac_2 + 24.266 \times Fac_3)/85.328 \quad (5)$$

In Eq. 5, GEB represents the total score of farmers' AGP behavior factor, and Fac_1-Fac_3 represents three common factors respectively. Since the factor score reflects the relative quantity and it is difficult to achieve intuitive comparison, this paper standardizes the factor score of farmers' AGP behavior to make the final data value between 0 and 1. The index of farmers' AGP behavior is constructed as follows.

$$GPBI_i = \frac{GPB_i - MinGPB}{MaxGPB - MinGPB} \quad (6)$$

In Eq. 6, $GPBI_i$ represents the AGP behavior index of the ith surveyed farmer, GPB_i represents the AGP behavior factor score of the ith surveyed farmer, MaxGPB and MinGPB represent the maximum and minimum values of factor scores of AGP behavior among the surveyed farmers respectively.

3.4 Measurement results

Table 4 reports the measurement results of farmers' environmental literacy index, AGP cognition index, AGP willingness index and AGP behavior index. The results show that the mean value of the environmental literacy index of sample farmers is 0.545 and the standard deviation is 0.160, indicating that the environmental literacy of farmers is at the medium level,

TABLE 4 Measurement results of latent variables.

Index	Mean value	Standard deviation	Minimum value	Maximum value
Environmental literacy index	0.545	0.160	0.000	1.000
AGP cognition index	0.602	0.215	0.000	1.000
AGP willingness index	0.677	0.243	0.000	1.000
AGP behavior index	0.493	0.175	0.000	1.000

and there is a certain gap among different farmers. The mean value of the AGP cognition index of sample farmers is 0.602 and the standard deviation is 0.215, indicating that farmers show relatively high AGP cognition, but there are some differences among farmers. The mean value of the AGP willingness index of sample farmers is 0.677 and the standard deviation is 0.243, indicating that farmers show high AGP willingness, but there are some differences among farmers. The mean value of the AGP behavior index of sample farmers is 0.493 and the standard deviation is 0.175, indicating that farmers' AGP behavior is at the middle level, and there is a certain gap among farmers.

3.5 Econometric model construction

3.5.1 Multiple linear regression models

In order to test the impact of environmental literacy on farmers' AGP behavior, the following model is constructed:

$$AGPB_i = \alpha_0 + \alpha_1 EL_i + \alpha_2 Controls_i + \varepsilon_{1i} \quad (7)$$

Where $AGPB_i$ represents farmers' AGP behavior, EL_i represents farmers' environmental literacy, $Controls_i$ represents the control variables, and ε_{1i} represents the random disturbance term. In this study, the ordinary least squares method was used to estimate the multiple linear regression models.

3.5.2 Quantile regression model

The OLS regression can only provide an average effect in estimation, which may be influenced by the outliers. While, the quantile regression model proposed by Koenker and Bassett (1978) adopts the weighted average of the absolute residual value as the objective function of minimization, which is not easily influenced by the outliers. Meanwhile, the quantile regression model can provide the estimation results in each quantile, and the results can be more accurate. The influence of environmental literacy on farmers' AGP behavior may be different in different quantiles. Therefore, we use the quantile regression model to test the heterogeneity impact of environmental literacy on farmers' AGP behavior in different quantiles. The empirical form of quantile regression model is given as:

$$Q_\tau(Y|X) = \alpha_\tau + \beta_\tau EL_i + \gamma_\tau Control_i + \varepsilon_\tau \quad (8)$$

Where $Q_\tau(Y|X)$ represents the AGP level of farmers in the τ quantile; EL_i represents farmers' environmental literacy; $Controls_i$ represents the control variables; ε_τ represents the random disturbance term; α_τ represents the constant term.

To explore the relationship between environmental literacy and farmers' AGP behavior, we chose several representative quantiles, such as 25th, 50th, 75th quantiles.

3.5.3 Mediation effect model

This study used the causal step regression method proposed by Baron and Kenny (1986) to test the mediation effect of AGP cognition. This study assigned the regression models of environmental literacy to farmers' AGP behavior (see Eq. 7), environmental literacy to farmers' AGP cognition, and environmental literacy and farmers' AGP cognition to farmers' AGP behavior. The last two equations were expressed as follows:

$$AGPC_i = b_0 + b_1 EL_i + b_2 Controls_i + \varepsilon_{2i} \quad (9)$$

$$AGPB_i = c_0 + c_1 EL_i + c_2 AGPC_i + c_3 Controls_i + \varepsilon_{3i} \quad (10)$$

Where EL_i is the environmental literacy of the respondent i; $AGPC_i$ indicates farmers' AGP cognition; $AGPB_i$ represents farmers' AGP behavior; $Controls_i$ represents the control variables. ε_{2i} and ε_{3i} are the random disturbance terms.

The mediation effect test procedures contain the steps as follows: 1) test the significance of a_1 in Eq. 7; if a_1 is significant, continue to test, otherwise stop the test.2) test the significance of b_1 in Eq. 9 and c_2 in Eq. 10; if at least one is not significant, we should conduct further assessment by using the Sobel test (step (4)). If b_1 and c_2 are both significant, conduct step (3): test whether c_1 in Eq. 10 is significant; if this variable is not significant, which means that $AGPC_i$ is a complete intermediary variable, but if it is still significant, and $c_1 < a_1$, $AGPC_i$ is a partial intermediary variable. 4) If the statistic z of Sobel test is significant, there exists a mediation effect (Baron and Kenny, 1986).

This study also used the causal step regression method proposed by Baron and Kenny (1986) to test the mediation effect of AGP willingness. This study assigned the regression models of environmental literacy to farmers' AGP behavior (see Eq. 7), environmental literacy to farmers' AGP willingness, and environmental literacy and farmers' AGP willingness to farmers' AGP behavior. The last two equations were expressed as follows:

$$AGPW_i = d_0 + d_1 EL_i + d_2 Controls_i + \varepsilon_{4i} \quad (11)$$

$$AGPB_i = e_0 + e_1 EL_i + e_2 AGPW_i + e_3 Controls_i + \varepsilon_{5i} \quad (12)$$

Where EL_i is the environmental literacy of the respondent i; $AGPW_i$ indicates farmers' AGP willingness; $AGPB_i$ represents farmers' AGP behavior; $Controls_i$ represents the control variables. ε_{4i} and ε_{5i} are the random disturbance terms.

The mediation effect test procedures contain the steps as follows: 1) test the significance of a_1 in Eq. 7; if a_1 is significant, continue to test, otherwise stop the test. 2) test the significance of d_1 in Eq. 11 and e_2 in Eq. 12; if at least one is not significant, we should conduct further assessment by using the Sobel test (step (4)). If d_1 and e_2 are both significant, conduct step (3): test whether e_1 in Eq. 12 is significant; if this variable is not significant, which means that $AGPW_i$ is a complete intermediary variable, but if it is still significant, and $e_1 < a_1$, $AGPW_i$ is a partial intermediary variable. 4) If the statistic z of Sobel test is significant, there exists a mediation effect (Baron and Kenny, 1986).

In addition, this study adopted the nonparametric percentile bootstrap CI method proposed by Preacher and Hayes (2004) to test the mediation effect, so as to further verify the independent mediation effect of AGP cognition and AGP willingness in the relationship between environmental literacy and farmers' AGP behavior. Meanwhile, we also adopted this method to test the chain mediation effect of AGP cognition and AGP willingness. The Bootstrap method operations on software are as follows. Data are input into SPSS 20.0 for statistical analysis. By adopting the PROCESS plug-in, the bootstrap setting is conducted first, when test the independent mediation effect, the model 4 is selected; when test the chain mediation effect, the model 6 is selected. The "bootstrap samples" are set to 5000 and the "confidence level for confidence intervals" is set to 95%.

4 Results

4.1 Test of the main effect

This study adopts the multiple linear regression models to test the impact of environmental literacy on farmers' AGP behavior. Table 5 shows that environmental literacy has a significant positive impact on farmers' AGP behavior (β = 0.079, $p < 0.05$). Thus, H1 is verified. The main reason is that farmers with high level of environmental literacy pursue the harmonious coexistence between human and nature, regard improving the agricultural environment as their obligation, and they have a strong sense of mission, responsibility and urgency to solve agricultural environmental problems. So, environmental literacy positively influences farmers' AGP behavior. In addition, farmers with high level of environmental literacy master more environmental knowledge and skills; they can keenly identify agricultural environmental problems, analyze the causes of these problems, and master the skills to deal with these problems, which reduce the limitation of AGP behavior caused by lack of environmental knowledge and skills. Therefore, environmental literacy can improve farmers' AGP behavior.

TABLE 5 Regression results of the impact of environmental literacy on farmers' AGP behavior.

Variable	Coefficient	Standard error
Environmental literacy	0.079**	0.034
Gender	−0.008	0.011
Age	−0.004***	0.001
Years of schooling	0.000	0.003
Number of agriculture laborers	0.038***	0.006
Village cadres	0.045**	0.023
Training	0.078***	0.015
Cooperative	0.065***	0.014
Farm income ratio	0.024	0.018
Crop type	−0.032***	0.011
Cultivated area	0.002	0.001
Number of cultivated land	−0.014**	0.007
Land type	0.015	0.012
Land quality	0.032***	0.006
Constant	0.426***	0.061
R^2	0.242	
Adj-R^2	0.229	
F	18.582***	

Note: $^{***}p < 0.01$, $^{**}p < 0.05$.

In terms of the control variables, age has a significant negative effect on farmers' AGP behavior and passes the test at a 1% significance level. The possible reason is that the older farmers have more conservative ideas and have been accustomed to the traditional extensive agricultural development model. However, they have insufficient recognition of the advantages of AGP, such as improving agricultural output, sales price of agricultural products, and reducing agricultural environmental pollution. Number of agricultural labors positively affects farmers' AGP behavior at a 1% significance level. The main reason is that AGP requires farmers to invest additional time and effort to learn AGP knowledge, participate in AGP technology training, disposal of agricultural waste, etc., Farmers with more agricultural labors can meet the demand for labor input in AGP, so they have higher level of AGP behavior. Whether there is a village cadre in the household has a significant positive impact on farmers' AGP behavior at a 5% significance level, which means that households with village cadres have higher level of AGP behavior, indicating that the households with village cadres could play the leading role in promoting AGP. Whether to participate in AGP technology training significantly positively affect farmers' AGP behavior at a 1% significance level, mainly because participating in training improves farmers' AGP skills and reduces the limitation of skill shortage on AGP. Whether to join a cooperative has a significant positive impact on farmers' AGP behavior at a 1% significance level, mainly due to the cooperatives provide farmers with resources such as pesticides, fertilizers and technologies needed for green production, which could help farmers reduce costs of AGP. In addition, cooperatives help farmers in terms of sales channels. If farmers do not carry out AGP in accordance with the requirements of cooperatives, their agricultural products may be rejected by cooperatives. So, cooperatives can promote farmers adopt more AGP behavior. Crop type has a significant negative impact on farmers' AGP behavior at a 1% significance level, indicating that the green production level of farmers who mainly grow cash crops is lower. The possible reason is that farmers who plant cash crops mainly pursue economic benefits, and they have been accustomed to the traditional extensive production mode. They may believe that adopting green production mode will reduce the output of agricultural products, which is not conducive to obtaining high economic benefits, so they have a lower level of green production. Number of cultivated land has a significant negative impact on farmers' AGP behavior at a 5% significance level. The possible reason is that farmers with larger number of cultivated land means higher degree of fragmentation of cultivated land, which restricts farmers' adoption of advanced green production technology. Land quality has a significant positive effect on farmers' AGP behavior at a 1% significance level. This is mainly because the high land quality can improve agricultural production efficiency, which improves farmers' income expectation of AGP.

4.2 Test for endogeneity

In view of the endogeneity issues caused by missing variables or reverse causality in the regression model, this study tests the endogeneity of environmental literacy, and makes judgments based on the results of Durbin-Wu-Hausman tests. We used the sample's average level of environmental literacy from the same village (excluding the respondent) as a possible valid instrumental variable (IV). For the IV to be valid, it must be related to the endogenous variable and not impact the dependent variable through other mechanisms (Staiger and Stock, 1997). Due to the frequent interaction between different farmers in the same village, the interviewed farmers can improve their environmental literacy by learning from other farmers around them, that is to say farmers' environmental literacy from the same village (excluding the respondent) are undeniably related to the respondents' environmental literacy. Regarding the exogeneity restriction, the respondents' AGP bahavior might not be affected by the environmental literacy of others from the same village. Thus, the two requirements, relevance and exogeneity, for a valid instrument may be satisfied. The results of endogeneity test and weak instruments test are shown in Table 6.

TABLE 6 Endogeneity and weak instruments tests.

Hausman test	χ^2	2.51
	p-Value	0.1129
Weak instruments test	F value	82.1597

The results show that Hausman test cannot reject the null hypothesis that environmental literacy is an exogenous explanatory variable at the significance level of 10%, so it is not necessary to adopt instrumental variable method for regression estimation, indicating that the estimation results of OLS model are reliable. The test results of weak instruments show that the Wald F-statistic of the model is greater than the critical value of 8.96 at the 15% bias level or 16.38 at the 10% bias level, so the null hypothesis of weak instruments is rejected. Based on the above analysis, environmental literacy is not an endogenous explanatory variable in the influence of environmental literacy on farmers' AGP behavior, and there is no endogeneity issue in the model.

4.3 Test of the mediation effect of AGP cognition

This study uses the analytical steps suggested by Baron and Kenny (1986) to verify the mediation effect of AGP cognition (Table 7). Specifically, environmental literacy has a significant positive impact on farmers' AGP behavior (Model 2, $\beta = 0.079$, $p < 0.05$), environmental literacy has a significant positive impact on farmers' AGP cognition (Model 3, $\beta = 0.480$, $p < 0.01$). After adding the variables of environmental literacy and AGP cognition, AGP cognition has a significant positive impact on farmers' AGP behavior (Model 4, $\beta = 0.132$, $p < 0.01$), while the regression coefficient of environmental literacy to farmers' AGP behavior becomes insignificant (Model 4, $\beta= 0.015$, $p > 0.1$). The result is consistent with the requirement of suggestion about complete mediation effect proposed by Baron and Kenny (1986). Therefore, AGP cognition plays a complete mediation role between environmental literacy and farmers' AGP behavior. Thus, H2 is verified.

This study further uses the bootstrap CI method to test the mediation effect (Table 8). As shown in Table 8, AGP cognition (indirect effect = 0.064, LLCI = 0.036, ULCI = 0.094) shows a significant mediation effect, because the confidence interval between LLCI and ULCI does not include 0. After controlling the mediating variable, environmental literacy (direct effect = 0.015, LLCI = -0.057, ULCI = 0.087) has no significant impact on farmers' AGP behavior, because the confidence interval between LLCI and ULCI contains 0, indicating that AGP cognition plays a

TABLE 7 The mediation effect of AGP cognition (Causal step regression).

Variables	AGP behavior		AGP cognition	AGP behavior
	Model 1	Model 2	Model 3	Model 4
Control variables				
Gender	−0.010	−0.008	−0.015	−0.006
Age	−0.004***	−0.004***	−0.002**	−0.003***
Years of schooling	0.000	0.000	-0.008**	0.001
Number of agriculture laborers	0.039***	0.038***	0.004	0.038***
Village cadre	0.044*	0.045**	0.030	0.041*
Training	0.084***	0.078***	0.164***	0.056***
Cooperative	0.066***	0.065***	−0.004	0.065***
Farm income ratio	0.023	0.024	0.035	0.019
Crop type	−0.031***	−0.032***	−0.029**	−0.028**
Arable area	0.002	0.002	0.002	0.002
Number of cultivated land	−0.014**	−0.014**	−0.008	−0.013*
Land type	0.015	0.015	0.030**	0.011
Land quality	0.032***	0.032***	0.002	0.031***
Independent variable				
Environmental literacy		0.079**	0.480***	0.015
Mediating variable				
AGP cognition				0.132***
R^2	0.237	0.242	0.272	0.261
Adj-R^2	0.225	0.229	0.260	0.247
F	19.507***	18.582***	21.787***	19.175***

Note: ***$p < 0.01$, **$p < 0.05$,*$p < 0.1$.

TABLE 8 The mediation effect of AGP cognition (Bootstrap CI).

	Effect	Boot SE	LLCI	ULCI
Total effect	0.079	0.034	0.011	0.146
Direct Effect (Environmental literacy)	0.015	0.037	−0.057	0.087
Indirect Effect (AGP cognition)	0.064	0.015	0.036	0.094

complete mediation role in the influence of environmental literacy on farmers' AGP behavior. Thus, H2 is further verified.

4.4 Test of the mediation effect of AGP willingness

This study uses the causal step regression to verify the mediation effect of AGP willingness (Table 9). Specifically, environmental literacy has a significant positive impact on farmers' AGP behavior (Model 2, β = 0.079, $p < 0.05$), environmental literacy has a significant positive impact on farmers' AGP willingness (Model 3, β = 0.523, $p < 0.01$). After adding the variables of environmental literacy and AGP willingness, AGP willingness has a significant positive impact on farmers' AGP behavior (Model 4, β = 0.104, $p < 0.01$), while the regression coefficient of environmental literacy to farmers' AGP behavior becomes insignificant (Model 4, β= 0.024, $p > 0.1$). The result is consistent with the requirement of suggestion about complete mediation effect proposed by Baron and Kenny (1986). Therefore, AGP willingness plays a complete mediation role between environmental literacy and farmers' AGP behavior. Thus, H3 is verified.

This study further uses the bootstrap CI method to test the mediation effect (Table 10). As shown in Table 10, AGP willingness (indirect effect = 0.054, LLCI = 0.027, ULCI = 0.088) shows a significant mediation effect, because the confidence interval between LLCI and ULCI does not include 0. After controlling the mediating variable, environmental literacy (direct effect = 0.024, LLCI = -0.047, ULCI = 0.096) has no significant impact on farmers' AGP behavior, because the

TABLE 9 The mediation effect of AGP willingness (Causal step regression).

Variables	AGP behavior		AGP willingness	AGP behavior
	Model 1	Model 2	Model 3	Model 4
Control variables				
Gender	−0.010	−0.008	−0.029*	−0.005
Age	−0.004***	−0.004***	−0.001*	−0.003***
Years of schooling	0.000	0.000	0.013***	−0.002
Number of agriculture laborers	0.039***	0.038***	0.004	0.038***
Village cadre	0.044*	0.045**	0.078**	0.037*
Training	0.084***	0.078***	0.119***	0.066***
Cooperative	0.066***	0.065***	0.015	0.063***
Farm income ratio	0.023	0.024	0.034	0.021
Crop type	−0.031***	−0.032***	0.030*	−0.035***
Arable area	0.002	0.002	0.002	0.002
Number of cultivated land	−0.014**	−0.014**	−0.008	−0.013*
Land type	0.015	0.015	0.007	0.015
Land quality	0.032***	0.032***	−0.011	0.033***
Independent variable				
Environmental literacy		0.079**	0.523***	0.024
Mediating variable				
AGP willingness				0.104***
R^2	0.237	0.242	0.243	0.258
Adj-R^2	0.225	0.229	0.230	0.244
F	19.507***	18.582***	18.649***	18.836***

Note: ***$p < 0.01$, **$p < 0.05$,*$p < 0.1$.

TABLE 10 The mediation effect of AGP willingness (Bootstrap CI).

	Effect	Boot SE	LLCI	ULCI
Total effect	0.079	0.034	0.011	0.146
Direct Effect (Environmental literacy)	0.024	0.037	−0.047	0.096
Indirect Effect (AGP willingness)	0.054	0.016	0.027	0.088

confidence interval between LLCI and ULCI contains 0, indicating that AGP willingness plays a complete mediation effect on the impact of environmental literacy on farmers' AGP behavior. Thus, H3 is further verified.

4.5 Test of the chain mediation effect

This study adopts the bootstrap CI method to test the chain mediation effect (Table 11). As shown in Table 11, AGP cognition→AGP willingness (indirect effect = 0.007, LLCI = 0.002, ULCI = 0.014) shows a significant chain mediation effect, because the confidence interval between LLCI and ULCI does not contain 0. Thus, H4 is verified. Meanwhile, AGP cognition (indirect effect = 0.057, LLCI = 0.028, ULCI = 0.087) shows a significant mediation effect, because the confidence interval between LLCI and ULCI does not include 0. AGP willingness (indirect effect = 0.040, LLCI = 0.016, ULCI = 0.069) shows a significant mediation effect, because the confidence interval between LLCI and ULCI does not contain 0. Thus, H2 and H3 are further verified.

4.6 Heterogeneity analysis

Although environmental literacy can improve farmers' AGP behavior, for farmers with different levels of AGP behavior, the impact of environmental literacy on their AGP behavior may be different. This paper uses quantile regression to test the heterogeneity impact. We selected three AGP behavior quantiles:

TABLE 11 The chain mediation effect of AGP cognition and AGP willingness (Bootstrap CI).

	Effect	Boot SE	LLCI	ULCI
Total indirect effect	0.104	0.020	0.066	0.144
Environmental literacy→AGP cognition→ AGP behavior	0.057	0.015	0.028	0.087
Environmental literacy→AGP willingness → AGP behavior	0.040	0.013	0.016	0.069
Environmental literacy→AGP cognition→AGP willingness → AGP behavior	0.007	0.003	0.002	0.014

TABLE 12 Quantile regression results.

	Farmers' AGP behavior		
	τ = 25th	τ = 50th	τ = 75th
Environmental literacy	0.032 (0.037)	0.073*(0.039)	0.104**(0.044)
Control variables	Controlled	Controlled	Controlled
Observations	830	830	830
R^2	0.12	0.12	0.16

Standard errors are in parentheses, and**, * represent significance level at 5% and 10%, respectively.

0.25, 0.5, and 0.75, representing low, medium and high levels of AGP behavior, respectively. Table 12 reports the quantile regression results. The results show that, in the 25% quantile, environmental literacy does not have significant impact on farmers' AGP behavior, while in the 50% and 75% quantiles, environmental literacy has significant positive effect on farmers' AGP behavior at the 10% and 5% significance levels respectively. This indicates that environmental literacy can improve the AGP behavior of farmers at medium and high levels of AGP behavior, while it cannot improve the AGP behavior of farmers at low level. This may be because farmers with low level of AGP behavior pursue the economic benefits of agricultural production, rather than the environmental benefits of AGP. In the case that the market of high-quality and safe agricultural product has not fully developed, the high income of AGP is uncertainty, so environmental literacy has not improved the AGP behavior of such farmers.

Farmers' AGP behavior is not only affected by internal factors, but also constrained by external environmental factors. In order to explore the heterogeneity impact of environmental literacy in detail, this study further analyzes the impact of environmental literacy on farmers' AGP behavior under different government intervention and market conditions (Table 13).

The estimation results of Model 1 and Model 2 in Table 13 show that environmental literacy has a significant positive impact on farmers' AGP behavior in the case of non-government supervision of agricultural production and agricultural product sales, while environmental literacy has no significant influence in the case of government supervision. This is mainly because government supervision increases farmers' cost of environmental illegal behaviors and all farmers take the initiative to adopt AGP behaviors out of the psychology of avoiding punishment. Therefore, environmental literacy has no significant impact on farmers' AGP behavior under the supervision of the government. While, in an unsupervised environment, farmers with high environmental literacy have a stronger sense of environmental responsibility, so they will take the initiative to adopt green production methods.

The estimation results of Model 3 and Model 4 in Table 13 show that environmental literacy has a significant positive impact on farmers' AGP behavior when the government does not subsidize green agriculture, while it has no significant impact when the government subsidizes green agriculture. This may be because government subsidies reduce the cost of AGP and mobilize farmers' enthusiasm for AGP, so farmers' AGP behavior has no difference among different levels of environmental literacy. While, in the case of non-government subsidies, farmers' AGP behavior is mostly spontaneous behavior, and environmental literacy plays a role in promoting it.

The estimation results of Model 5 and Model 6 in Table 13 show that environmental literacy has a significant positive influence on farmers' AGP behavior when the local sales channels of green agricultural products are not smooth, while the impact is not significant when the sales channels are smooth. The possible reason is that when the sales channels of green agricultural products are smooth, farmers can easily sell high quality agricultural products and obtain high income, so the AGP behavior of farmers does not show differences due to different levels of environmental literacy. However, when the sales channels of green agricultural products are not smooth, the high income of AGP faces uncertainty. In this case, AGP belongs to spontaneous behavior, so environmental literacy plays a promoting role.

Based on the above analysis, environmental literacy has a significant positive impact on farmers' AGP behavior when the external environment is not perfect, indicating that the improvement of farmers' environmental literacy can reduce the restriction of adverse external environment on farmers' AGP.

5 Discussion

The results of this study make three contributions to farmers' AGP behavior literature. First, this study constructed a comprehensive evaluation index system of farmers' AGP

TABLE 13 Heterogeneity influences under different external environments.

Variables	Whether the government regulates agricultural production and agricultural product sales		Whether the government provides subsidies for green agriculture		Whether the sales channels of local green agricultural products are smooth	
	No	Yes	No	Yes	No	Yes
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Environmental literacy	0.147***(0.047)	0.032 (0.049)	0.073*(0.038)	0.101 (0.079)	0.078**(0.036)	0.035 (0.119)
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Observations	378	452	636	194	731	99
R^2	0.314	0.239	0.203	0.365	0.224	0.416

Standard errors are in parentheses, and***, **, * represent significance level at 1%,5%, 10%, respectively.

behavior. In the extant literatures, some scholars discussed farmers' AGP behavior from one or several aspects, such as the application of organic fertilizer (Li and Shen 2021), the adoption of pro-green control technology (Niu et al., 2022; Lou et al., 2021), the adoption of straw return (Mi et al., 2020). The above research cannot fully reflect the characteristics of farmers' AGP behavior. In fact, due to the complexity of agricultural production process, farmers' AGP behavior is reflected in the three production stages: pre-production, on-production and post-production, which reflect the purchase of green agricultural materials, the standardized use of agricultural materials and the adoption of green agricultural technology, and the recycling or harmless treatment of agricultural waste respectively. This study evaluated farmers' AGP behavior from the above three production stages and the results showed that farmers' AGP behavior is at the middle level, which indicated that farmers' AGP behavior should be strengthened. The possible explanation is that farmers have been used to the traditional extensive agricultural development model (characterized by high input, high emission and high pollution), while AGP requires high opportunity costs (labor, time, capital, etc.), which reduces their enthusiasm to engage in AGP.

Second, this study evaluated the level of farmers' environmental literacy and explored its impact on farmers' AGP behavior. Individuals may change their environmental behavior when their beliefs, values, and pro-environmental norms change. While, improved environmental education and increased environmental literacy may result in such changes. Therefore, environmental literacy has become the most important component of environmental education in recent years (Saribas et al., 2014). Relevant studies also confirmed that environmental literacy could promote individuals to take responsible environmental behavior (Asteria, 2019; Biswas, 2020). Although much attention has been paid to environmental literacy in the field of environmental education, some studies also revealed that environmental literacy had significant positive impact on individuals' environmental behavior; little is known about farmers' environmental literacy and its influence on their AGP behavior. This study constructs a comprehensive index system to evaluate farmers' environmental literacy and explores its influence on farmers' AGP behavior. The result shows that farmers' environmental literacy is at the medium level, which indicated that farmers' environmental literacy should be strengthened. This is mainly due to the fact that the training for farmers mainly focuses on agricultural technology training and ignores the environmental literacy education for farmers, resulting in the environmental literacy level of farmers to be improved. Empirical test also shows that environmental literacy significantly positively affects farmers' AGP behavior, indicating that environmental literacy provided the power for farmers to adopt AGP behavior. The possible reason for this is that environmental literacy is an improvement of individuals' knowledge, skills, values, sensitivity and attitudes towards the environment. That, combined with personal development, may promote farmers' feelings of capacity and responsibility to advance AGP practices.

Third, this study explored the influence mechanism of environmental literacy on farmers' AGP behavior. Although the existing studies have confirmed that environmental literacy can promote individuals to take responsible environmental behavior, the influence mechanism remains unclear. This study revealed that environmental literacy affected farmers' AGP behavior through the independent and chain mediation effects of AGP cognition and AGP willingness. Farmers with higher levels of environmental literacy have mastered more environmental knowledge and skills, and they could more deeply perceive the problems of soil pollution, soil erosion, resource shortages and pesticide residues caused by the extensive agricultural development model. However, AGP could realize the sustainable development of agriculture. So, farmers with higher levels of environmental literacy may form positive perceptions of AGP by comparing the two different agricultural development models. Meanwhile, farmers with higher levels of environmental literacy have a stronger sense of responsibility to reduce agricultural environmental pollution. Therefore, farmers with higher levels of environmental literacy show higher levels of AGP willingness. It is generally believed that individual decision making depends on two disposal systems: a cognitive analysis system and an emotion system (Liu et al., 2020). AGP cognition belongs to the cognitive analysis system and AGP willingness belongs to the emotion system, so they could promote farmers to adopt AGP behavior. Meanwhile, this research explores the heterogeneity influence of environmental literacy on farmers' AGP behavior. We find that environmental literacy improves the AGP behavior of farmers at medium and high levels of AGP behavior, while it cannot improve the AGP behavior of farmers at low level. Besides, environmental literacy promotes farmers' AGP behavior when the government does not regulate agricultural production and agricultural product sales, does not provides subsidies for green agriculture, and the sales channels of local green agricultural products are not smooth.

6 Conclusion and directions for future research

This study designed an evaluation index system of farmers' AGP behavior from three production stages—pre-production, on-production and post-production. Based on the measurement of farmers' environmental literacy and AGP behavior, multiple linear regression model, quantile regression model and mediation effect model were used to explore the impact of environmental literacy on farmers' AGP behavior and its influencing mechanism. The results revealed that farmers' environmental literacy and AGP behavior are at the middle level, both of which should be strengthened. This study showed that environmental literacy significantly positively affects farmers' AGP behavior; AGP cognition and AGP willingness mediate the relationship between environmental literacy and farmers' AGP behavior respectively. Meanwhile, AGP cognition and AGP willingness play a chain mediation role in the association between environmental literacy and farmers' AGP behavior. Heterogeneity analysis found that environmental literacy improves farmers' AGP behavior at medium and high levels of AGP behavior, and environmental literacy enhances this behavior when the external environment is not perfect.

The conclusions of this study provided some practical implications: The government can promote farmers to engage in AGP by enhancing their environmental literacy, such as conducting environmental education activities to enhance their environmental knowledge and skills, and cultivate their ecological values and environmental responsibility. In order to optimize farmers' AGP behavior, the policy makers should fully respect farmers' AGP willingness. So, it is necessary to identify and eliminate the factors that hinder farmers' willingness to adopt AGP behavior. Meanwhile, government and agricultural colleges should publicize the advantages of AGP to farmers, such as reducing agricultural environmental pollution, improving agricultural output and reducing pesticide residues.

This study is of great significance for clarifying the impact and influencing mechanism of environmental literacy on farmers' AGP behavior. However, some limitations still exist in this study, which are worthy of further study in the future. First, this study explored the influence paths between environmental literacy and farmers' AGP behavior based on cross-sectional data and failed to provide a temporal sequence. Therefore, future studies should explore the development of the relationships linking environmental literacy, AGP cognition, AGP willingness and AGP behavior over time by obtaining panel data. Second, this study only investigated the green production behavior of planting farmers, which may affect the universality of the research conclusions. Future research can study the green production behavior of livestock farmers, or carry out a comparative study between the planting and livestock industries.

Data availability statement

The data will be provided upon reasonable request by the correspondent author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

Conceptualization, LY and WL. Methodology, LY, SY, and XH. Formal analysis, LY. Investigation, LY. Data curation, LY and SY. Writing—original draft preparation, LY. Writing—review and editing, LY, WL, and XH. Supervision, RK. Project administration, RK. Funding acquisition, RK and XH. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Ajzen, I. (1991). The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* 50, 179–211. doi:10.1016/0749-5978(91)90020-T

Asteria, D. (2019). Women's environmental literacy in managing waste for environmental sustainability of the city. *Development* 62, 178–185. doi:10.1057/s41301-019-00227-y

Bandura, A., and Adams, N. E. (1977). Analysis of self-efficacy theory of behavioral change. *Cogn. Ther. Res.* 1, 287–310. doi:10.1007/BF01663995

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Personality Soc. Psychol.* 51, 1173–1182. doi:10.1037/0022-3514.51.6.1173

Beicfel, D. C., and Turner, S. M. (1986). A critique of the theoretical bases of cognitive-behavioral theories and therapy. *Clin. Psychol. Rev.* 6, 177–197. doi:10.1016/0272-7358(86)90011-5

Bissinger, K., and Bogner, F. X. (2018). Environmental literacy in practice: Education on tropical rainforests and climate change. *Environ. Dev. Sustain.* 20, 2079–2094. doi:10.1007/s10668-017-9978-9

Biswas, A. (2020). A nexus between environmental literacy, environmental attitude and healthy living. *Environ. Sci. Pollut. Res.* 27, 5922–5931. doi:10.1007/s11356-019-07290-5

Bopp, C., Engler, A., Poortvliet, P. M., and Jara-Rojas, R. (2019). The role of Farmers'Intrinsic motivation in the effectiveness of policy incentives to promote sustainable agricultural practices. *J. Environ. Manag.* 244, 320–327. doi:10.1016/j.jenvman.2019.04.107

Cao, H., Zhu, X. Q., Heijman, W., and Zhao, K. (2020). The impact of land transfer and Farmers'Knowledge of farmland protection policy on pro-environmental agricultural practices: The case of straw return to fields in ningxia, China. *J. Clean. Prod.* 277, 123701. doi:10.1016/j.jclepro.2020.123701

Chen, L., Zhou, R., Chang, Y., and Zhou, Y. (2021). Does green industrial policy promote the sustainable growth of polluting firms? Evidences from China. *Sci. Total Environ.* 764, 142927. doi:10.1016/j.scitotenv.2020.142927

Chen, W. H., Chen, J. C., Xu, D. Y., Liu, J. C., and Niu, N. N. (2017a). Assessment of the practices and contributions of China's green industry to the socio-economic development. *J. Clean. Prod.* 153, 648–656. doi:10.1016/j.jclepro.2016.11.065

Chen, Y. H., Wen, X. W., Wang, B., and Nie, P. Y. (2017b). Agricultural pollution and regulation: How to subsidize agriculture? *J. Clean. Prod.* 164, 258–264. doi:10.1016/j.jclepro.2017.06.216

Crites, S., Fabrigar, L., and Petty, R. (1994). Measuring the affective and cognitive properties of attitudes: Conceptual and methodological issues: Conceptual and methodological issues. *Pers. Soc. Psychol. Bull.* 20, 619–634. doi:10.1177/0146167294206001

Daxini, A., Ryan, M., O'Donoghue, C., Barnes, P., and Barnes, A. P. (2019). Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour. *Land Use Policy* 85, 428–437. doi:10.1016/j.landusepol.2019.04.002

Deng, J., Sun, P. S., Zhao, F. Z., Han, X. H., Yang, G. H., and Feng, Y. Z. (2016). Analysis of the ecological conservation behavior of farmers in payment for ecosystem service programs in eco-environmentally fragile areas using social psychology models. *Sci. Total Environ.* 550, 382–390. doi:10.1016/j.scitotenv.2016.01.152

Fransson, N., and Gärling, T. (1999). Environmental concern: Conceptual definitions, measurement methods, and research findings. *J. Environ. Psychol.* 19, 369–382. doi:10.1006/jevp.1999.0141

Goldman, D., Ayalon, O., Baum, D., and Weiss, B. (2018). Influence of 'green school certification' on Students'Environmental literacy and adoption of sustainable practice by schools. *J. Clean. Prod.* 183, 1300–1313. doi:10.1016/j.jclepro.2018.02.176

Hamzah, M. I., and Tanwir, N. S. (2021). Do pro-environmental factors lead to purchase intention of HybridVehicles? The moderating effects of environmental knowledge. *J. Clean. Prod.* 279, 123643. doi:10.1016/j.jclepro.2020.123643

Hares, M., Eskonheimo, A., Myllyntaus, T., and Luukkanen, O. (2006). Environmental literacy in interpreting endangered sustainability: Case studies from Thailand and the Sudan. *Geoforum* 37, 128–144. doi:10.1016/j.geoforum.2005.01.006

Hoffman, M., Lubell, M., and Hillis, V. (2014). Linking knowledge and action through mental models of sustainable agriculture. *Proc. Natl. Acad. Sci. U. S. A.* 111, 13016–13021. doi:10.1073/pnas.1400435111

Hungerford, H. R., and Volk, T. L. (1990). Changing learner behavior throughEnvironmental education. *J. Environ. Educ.* 21, 8–21. doi:10.1080/00958964.1990.10753743

Jiang, W. J., Yan, T. W., and Chen, B. (2020). Impact of media channels and social interactions on the adoption of straw return by Chinese farmers. *Sci. Total Environ.* 756, 144078. doi:10.1016/j.scitotenv.2020.144078

Joseph, C., Nichol, E. O., Janggu, T., and Madi, N. (2013). Environmental literacy and attitudes among Malaysian business educators. *Int. J. Sust. High. Ed.* 14, 196–208. doi:10.1108/14676371311312897

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., and Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technol. Forecast. Soc. Change* 80, 525–540. doi:10.1016/j.techfore.2012.08.007

Kelley, H. H., and Michela, J. L. (1980). Attribution theory and research. *Annu. Rev. Psychol.* 31, 457–501. doi:10.1146/annurev.ps.31.020180.002325

Koenker, R., and Bassett, G. (1978). Regression quantiles. *Econometrica* 46, 33–50. doi:10.2307/1913643

Li, B., Ding, J., Wang, J., Zhang, Biao., and Zhang, L. (2021). Key factors affecting the adoption willingness, behavior, and willingness-behavior consistency of farmers regarding photovoltaic agriculture in China. *Energy Policy* 149, 112101. doi:10.1016/j.enpol.2020.112101

Li, B. W., and Shen, Y. Q. (2021). Effects of land transfer quality on the application of organic fertilizer by large-scale farmers in China. *Land Use Policy* 100, 105124. doi:10.1016/j.landusepol.2020.105124

Li, D., Zhao, L. M., Ma, S., Shao, S., and Zhang, L. X. (2019). What influences an individual's pro-environmental behavior? A literature review. *Resour. Conservation Recycl.* 146, 28–34. doi:10.1016/j.resconrec.2019.03.024

Li, J., Feng, S. Y., Luo, T. Y., and Guan, Z. F. (2020a). What drives the adoption of sustainable production technology? Evidence from the large scale farming sector in east China. *J. Clean. Prod.* 257, 120611. doi:10.1016/j.jclepro.2020.120611

Li, J. F., Ren, L., and Sun, M. X. (2020c). Is there a spatial heterogeneous effect of willingness to pay for ecological consumption? An environ-mental cognitive perspective. *J. Clean. Prod.* 245, 118259. doi:10.1016/j.jclepro.2019.118259

Li, M. Y., Wang, J. J., Zhao, P. J., Chen, K., and Wu, L. B. (2020b). Factors affecting the willingness of agricultural green production from the perspective of farmers' perceptions. *Sci. Total Environ.* 738, 140289. doi:10.1016/j.scitotenv.2020.140289

Liu, P. H., Teng, M. M., and Han, C. F. (2020a). How does environmental knowledge translate into pro-environmental behaviors? The mediating role of environmental attitudes and behavioral intentions. *Sci. Total Environ.* 728, 138126. doi:10.1016/j.scitotenv.2020.138126

Liu, Y. F., Sun, D. S., Wang, H. J., Wang, X. J., Yu, G. Q., and Zhao, X. J. (2020b). An evaluation of China's agricultural green production: 1978-2017. *J. Clean. Prod.* 243, 118483. doi:10.1016/j.jclepro.2019.118483

Lloyd-Strovas, J., Moseley, C., and Arsuffi, T. (2018). Environmental literacy of undergraduate college students: Development of the environmental literacy instrument (ELI). *Sch. Sci. Math.* 118, 84–92. doi:10.1111/ssm.12266

Lou, S., Zhang, B. R., and Zhang, D. H. (2021). Foresight from the hometown of green tea in China: Tea Farmers'Adoption of pro-green control technology for tea plant pests. *J. Clean. Prod.* 320, 128817. doi:10.1016/j.jclepro.2021.128817

Lu, H., Hu, L., Zheng, W., Yao, S., and Qian, L. (2020). Impact of household land endowment and environmental cognition on the willingness to implement straw incorporation in China. *J. Clean. Prod.* 262, 121479. doi:10.1016/j.jclepro.2020.121479

Maurer, M., and Bogner, F. X. (2020). Modelling environmental literacy with environmental knowledge, values and (reported) behaviour. *Stud. Educ. Eval.* 65, 100863. doi:10.1016/j.stueduc.2020.100863

Mi, Q., Li, X. D., and Gao, J. Z. (2020). How to improve the welfare of smallholders through agricultural production outsourcing: Evidence from cotton farmers in xinjiang, northwest China. *J. Clean. Prod.* 256, 120636. doi:10.1016/j.jclepro.2020.120636

Niu, Z. H., Chen, C., Gao, Y., Wang, Y. Q., Chen, Y. S., and Zhao, K. J. (2022). Peer effects, attention allocation and farmers' adoption of cleaner production technology: Taking green control techniques as an example. *J. Clean. Prod.* 339, 130700. doi:10.1016/j.jclepro.2022.130700

Oyetunde-Usman, Z., Olagunju, K. O., and Ogunpaimo, O. R. (2021). Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria. *Int. Soil Water Conservation Res.* 9, 241–248. doi:10.1016/j.iswcr.2020.10.007

Pourg-hasem, F., Alibaygi, A. H., and Papzan, A. (2020). Rural women's environmental literacy in kermanshah province: An extension perspective. *J. Agr. Sci. Tech.* 22, 919–934.

Preacher, K. J., and Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behav. Res. Methods Instrum. Comput.* 36, 717–731. doi:10.3758/BF03206553

Qi, X. X., Liang, F. C., Yuan, W. H., Zhang, T., and Li, J. C. (2021). Factors influencing Farmers'Adoption of eco-friendly fertilization technology in grain production: An integrated spatial–econometric analysis in China. *J. Clean. Prod.* 310, 127536. doi:10.1016/j.jclepro.2021.127536

Ramdas, M., and Mohamed, B. (2014). Impacts of tourism on environmental attributes, environmental literacy and willingness to pay: A conceptual and theoretical review. *Procedia - Soc. Behav. Sci.* 144, 378–391. doi:10.1016/j.sbspro.2014.07.307

Rezaei-Moghaddam, K., Vatankhah, N., and Ajili, A. (2020). Adoption of pro-environmental behaviors among farmers: Application of value–belief–norm theory. *Chem. Biol. Technol. Agric.* 7, 7. doi:10.1186/s40538-019-0174-z

Roth, C. E. (1992). *Environmental literacy: Its roots, evolution, and direction in the1990s*. Columbus: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Saribas, D., Teksoz, G., and Ertepinar, H. (2014). The relationship between environmental literacy and self-efficacy beliefs toward environmental education. *Procedia - Soc. Behav. Sci.* 116, 3664–3668. doi:10.1016/j.sbspro.2014.01.820

Schultz, T. W. (1961). Investment in human capital. *Am. Econ. Rev.* 51 (1), 1–17. doi:10.2307/1818907

Schwartz, S. H. (1977). *Normative influences on altruism*. New York, NY, USA: Academic Press.

Shen, Z. Y., Baležentis, T., Chen, X. L., and Valdmanis, V. (2018). Green growth and structural change in Chinese agricultural sector during 1997-2014. *China Econ. Rev.* 51, 83–96. doi:10.1016/j.chieco.2018.04.014

Staiger, D., and Stock, J. H. (1997). Instrumental variables regression with weak instruments. *Econometrica* 65, 557–586. doi:10.2307/2171753

Stern, P. C. (2000). New environmental theories: Toward a coherent theory of environmentally significant behavior. *J. Soc. Isssues.* 56, 407–424. doi:10.1111/0022-4537.00175

Thu, V. H., Tran, D., Goto, D., and Kawata, K. (2020). Does experience sharing affect Farmers'Pro-environmental behavior? A randomized controlled trial in vietnam. *World Dev.* 136, 105062. doi:10.1016/j.worlddev.2020.105062

Tuncer, G., Tekkaya, C., Sungur, S., Cakiroglu, J., Ertepinar, M., and Kaplowitz, M. (2009). Assessing pre-service Teachers'Environmental literacy in Turkey as a mean to develop teacher education programs. *Int. J. Educ. Dev.* 29, 426–436. doi:10.1016/j.ijedudev.2008.10.003

United Nations Environment Programme (UNEP) (2011). *Towards a green economy: Pathways to sustainable development and poverty eradication*. Nairobi: Report, United Nations Environment Programme.

Vicente-Molina, M. A., Fernández-Sáinz, A., and Izagirre-Olaizola, J. (2013). Environmental knowledge and other variables affecting pro-environmental behavior: Comparison of university students from emerging and advanced countries. *J. Clean. Prod.* 61, 130–138. doi:10.1016/j.jclepro.2013.05.015

Wan, B. Y., Tian, L. X., Zhu, N. P., Gu, L. Q., and Zhang, G. Y. (2018). A new endogenous growth model for green low-carbon behavior and its comprehensive effects. *Appl. Energy* 230, 1332–1346. doi:10.1016/j.apenergy.2018.09.076

Wang, P., Liu, Q., and Qi, Y. (2014). Factors influencing sustainable consumption behaviors: A survey of the rural residents in China. *J. Clean. Prod.* 63, 152–165. doi:10.1016/j.jclepro.2013.05.007

Wu, J. W., Wei, Y. D., Li, Q. Z., and Yuan, F. (2018). Economic transition and changing location of manufacturing industry in China: AStudy of the yangtze river delta. *Sustainability* 10, 2624. doi:10.3390/su10082624

Xie, H. L., and Huang, Y. Q. (2021). Influencing factors of farmers' adoption of pro-environmental agricultural technologies in China: Meta-analysis. *Land Use Policy* 109, 105622. doi:10.1016/j.landusepol.2021.105622

Xiong, Y., and Wang, L. (2020). Policy cognition of potential consumers of new energy vehicles and its sensitivity to purchase willingness. *J. Clean. Prod.* 261, 121032. doi:10.1016/j.jclepro.2020.121032

Xue, Y., Guo, J., Li, C., Xu, X., Sun, Z., Xu, Z., et al. (2021). Influencing factors of farmers' cognition on agricultural mulch film pollution in rural China. *Sci. Total Environ.* 787, 147702. doi:10.1016/j.scitotenv.2021.147702

Yang, L. Z., and Wu, Y. H. (2018). Prevention and control of agricultural non-point source pollution and aquatic environmental protection. *Bull. Chin. Acad. Sci.* 33 (02), 168–176. (In Chinese). doi:10.16418/j.issn.1000-3045.2018.02.006

Yi, X. Y., Yu, L. R., Chang, S., Yin, C. B., Wang, H., and Zhang, Z. F. (2021). The effects of China's organic-substitute-chemical-fertilizer (OSCF) policy on greenhouse vegetable farmers. *J. Clean. Prod.* 297, 126677. doi:10.1016/j.jclepro.2021.126677

Yu, L. L., Chen, C., Niu, Z. H., Gao, Y., Yang, H. R., and Xue, Z. H. (2021). Risk aversion, cooperative membership and the adoption of green control techniques: Evidence from China. *J. Clean. Prod.* 279, 123288. doi:10.1016/j.jclepro.2020.123288

Yu, Y. L., Lu, T., Hu, Y. G., Meng, K. W., and Li, H. (2022). How to improve Farmers'Green production level in a TargetedManner? *Front. Environ. Sci.* 10, 901844. doi:10.3389/fenvs.2022.901844

Zhang, L. G., Li, X. R., Yu, J. L., and Yao, X. L. (2018). Toward cleaner production: What drives farmers to adopt eco-friendly agricultural production? *J. Clean. Prod.* 184, 550–558. doi:10.1016/j.jclepro.2018.02.272

Zhang, S. Y., Zhao, M. J., Ni, Q., and Cai, Y. (2021). Modelling farmers' watershed ecological protection behaviour with the value-belief-norm theory: A case study of the wei river basin. *Int. J. Env. Res. Pub. He.* 18, 5023. doi:10.3390/ijerph18095023

Zhao, L., Wang, C. W., Gu, H. Y., and Yue, C. Y. (2018). Market incentive, government regulation and the behavior of pesticide application of vegetable farmers in China. *Food control.* 85, 308–317. doi:10.1016/j.foodcont.2017.09.016

Zhou, J. H., Yang, Z. Y., Li, K., and Yu, X. H. (2019). Direct intervention or indirect support? The effects of cooperative control measures on farmers' implementation of quality and safety standards. *Food Policy* 86, 101728. doi:10.1016/j.foodpol.2019.05.011