frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 12 June 2025
DOI 10.3389/fenvs.2025.1502291

OPEN ACCESS

EDITED BY
Jiachao Peng,
Wuhan Institute of Technology, China

REVIEWED BY
Barbara Magdalena Wieliczko,
Polish Academy of Sciences, Poland
Seher Dirican,
Cumhuriyet University, Türkiye
Wang Zhang,
Northwest University, China

*CORRESPONDENCE
Qinqing He,
heqq@lingnan.edu.cn

RECEIVED 26 September 2024
ACCEPTED 13 May 2025
PUBLISHED 12 June 2025

CITATION
Zhang W, Liang S, Wu W, Zhuang H and He Q (2025) Willingness to perform environmentally friendly practices in rural areas: evidence from environmental regulation in agriculture. *Front. Environ. Sci.* 13:1502291. doi: 10.3389/fenvs.2025.1502291

Willingness to perform environmentally friendly practices in rural areas: evidence from environmental regulation in agriculture

Weikun Zhang, Sicheng Liang, Wanying Wu, Haijie Zhuang and Qinqing He*

School of Public and Social and Administration, Lingnan Normal University, Zhanjiang, China

Background: Environmental problems arising from agriculture and rural living have drawn increasing scholarly attention worldwide. The transition from traditional, resource-intensive farming and rural practices to more ecologically responsible modes of production and household behaviors has become a critical challenge.

Methods: Promoting the transformation of farmers' green production methods and lifestyles is of great significance to the greening of China's rural areas, which determines the importance of analyzing the underlying logic behind farmers' willingness to perform environmentally friendly practices (FWPEPs). Against this backdrop, an empirical study was carried out using the probit model, based on the analysis framework of digitization and farmers' data from the China Land Economic Survey from 2021 to 2022.

Results: The findings revealed that farmers' willingness to perform environmentally friendly practices can be attributed to both constrained environmental regulation–through mandatory laws and regulations–and incentive-based environmental regulation involving economic subsidies and other incentive measures. The positive effect of environmental regulation on FWPEPs varies according to gender and education level.

Conclusions: Digitization plays an important regulatory role by enhancing farmers' environmental awareness and rule perception and encouraging them to adopt more environmentally friendly production methods and lifestyles. These insights enable policymakers to design targeted, environmentally friendly, and sustainable mitigation strategies by synergizing regulatory precision with digital empowerment.

KEYWORDS

environmentally friendly practices, environmental regulation, agricultural digitization, information acquisition ability, rule perception

1 Introduction

Agricultural non-point source pollution (ANSP) has become increasingly widespread due to the extensive production methods. This type of pollution refers to the ecological environmental pollution caused by excessive chemical inputs in the planting industry and the excessive accumulation of organic matter in soil or water bodies resulting from the improper disposal of crop residues and livestock manure in the farming industry. The pollution is driven by the combined effects of rainfall and topography. It is characterized by temporal randomness, spatial uncertainty, and delayed consequences of pollution (Wei et al., 2016; Cho et al., 2016). ANSP is an essential driver of systemic pollution of the ecological environment, which directly threatens the sustainable development of agriculture and human health and safety (Zhang et al., 2019). China, with only 9% of arable land in the world, feeds nearly 20% of the global population (Mi et al., 2020). This causes various non-negligible environmental consequences, such as the fertilizer application per unit of arable land exceeding the international safety threshold by 2.3 times, a shortage of agricultural resources, and an imbalanced ecosystem (Yu et al., 2022). According to the World Bank statistics, the *per capita* cultivated land and freshwater resources in China are, respectively, 1/2 and 1/3 of the global average levels, but the agricultural chemical oxygen demand, total nitrogen, and total phosphorus emissions account for 43.7%, 57.2%, and 67.4% of total emissions (Xiong and Wang, 2020; Liu et al., 2020; Yu et al., 2022). Due to the severity of ANSP and the urgency of its governance, the overall situation of performing environmentally friendly practices in rural China is pessimistic, as the majority of farmers have not adopted green agricultural production (AP) methods or sustainable living habits. Common problems in rural China, such as agricultural pollution, environmental pollution, and domestic waste, have become increasingly prominent. If these problems are not addressed, the ecosystem will become imbalanced, resulting in impaired cultivated land fertility and a disharmonious rural society.

Sustainable actions in some rural areas of developed regions have received widespread attention (Osborne et al., 2002). These actions include the "Regional Nature Parks Project" in Switzerland (Hirschi, 2010), the "Rural Development Program" in Britain (Dwyer and Powell, 2016), the "One Village One Product Movement" in Japan (Noble, 2019), and the "New Village Movement" in Korea (Hong et al., 2022), showing that a gradual strategy can improve the ecological quality in rural areas. Fortunately, China has also implemented environmental policies to regulate agricultural green production, such as the Rural Revitalization Strategy in 2017 and the Five-Year Action Program for Upgrading the Rural Living Environment in 2021 (Shen and Chou, 2022). Ma et al. (2022) considered environmental regulation (ER), consisting of various agri-ecological policies, to be the critical tool for achieving green goals in agricultural production. But the excessive use of chemical inputs by farmers has not changed, reflecting the phenomenon described as "the government does it, the villager sees it" (Chi et al., 2021; Du et al., 2021). Hence, it is of practical importance to encourage farmers to participate in environmentally friendly behaviors with ERs implemented in rural areas.

Scholars categorize ER into three types, namely, government-constrained ER, market-incentive ER, and voluntary agreement-based ER (Pargal and Wheeler, 1996). Relevant studies have shown that increased ER intensity will decrease resource use efficiency (Boyd and McClelland, 1999). It cannot be ignored that the increase in the intensity of government environmental management is conducive to improving the effectiveness of environmental pollution control (Potoski and Prakash, 2004). Similar studies have also confirmed that ER positively impacts agricultural green total factor productivity, with a double threshold effect, which is affected by the proportion of crop cultivation, trade dependence, and the cultural level of the labor force (Ding et al., 2019). Economic incentives under ERs significantly and positively correlate with managing agricultural pollution (Winesten et al., 2011). Notably, information nudges can enhance farmers' perceived susceptibility and severity of environmental pollution, thereby significantly increasing their willingness to adopt environmentally friendly practices (Sereenonchai and Arunrat, 2023). At the same time, ER policies can force technological progress in AP (Mbanyele and Wang, 2022).

Furthermore, the formulation of ER in China has been strengthened to promote the agricultural departments' supervisory and enforcement capabilities for making the prosecutions of environmental violations by farm operations timelier and more effective (Fang et al., 2021; Hu et al., 2023). However, no consensus exists regarding ER's effect on agricultural operations. Existing research predominantly focuses on the adverse impact of ER on agricultural producers, particularly concerning the excessive use of fertilizers, from the perspective of dynamic changes in ER (Ouyang et al., 2020; Wang et al., 2022). The "acquaintance society" (Fei, 1948) in rural China—characterized by closed social networks and informal norms—may reshape the interaction between ER enforcement and farmer behavior, particularly under state-led digital initiatives such as the "Digital Village" pilot policy (Zhang et al., 2023). In this regard, the transformation of green AP involves the rational control of agricultural water use, chemical fertilizers, and pesticides and the resourceful use of livestock and poultry manure, agricultural film, and straw, thus strengthening the willingness to perform environmentally friendly practices (Pawłowska and Grochowska, 2021; Järnberg et al., 2018). In addition, "acquaintance society" naturally forms social connections. The interaction between farmers creates a relatively stable social system and provides the action function of "herd (imitation) effect" and "mutual protection" (Gross, 1971), which avoids the external supervision and accountability for environmental pollution to a large extent and then adopts the extensive production mode, curbing the performance of environmentally friendly practices in rural areas (Wu and Ge, 2019).

Environmentally friendly practices in rural areas are actions primarily at the individual or family level that are beneficial to the environment or at least minimize negative impacts on the environment (Engel et al., 2021). These can be divided into environmentally friendly practices in the public domain (Zhang et al., 2024) and those in the private domain (Zhao et al., 2022). This study defines environmentally friendly actions as farmers' ecological behavior in resourcefully treating farm waste. In terms of factors influencing farmers' environmentally friendly practices, in addition to individual characteristics (e.g., gender, economic condition, and protection behavior strategies) (Tang et al., 2021; Zhang et al., 2022), social factors (e.g., social norms, ER, and business characteristics) have been critically examined (Yu and Yu, 2019; Zhao et al., 2022). Apart from the positive role of ER, an essential controversial debate exists about how farmers maintain their environmentally friendly practices with ER (Si et al., 2019). Hence, few studies have examined the effect of ER through administrative policy on farmers' environmentally friendly behavior, and the administrative governance of agricultural green producers is still fragmented.

An answer to identify the willingness to perform environmentally friendly practices in rural areas is relevant to China's considerations for digitization construction. Studies have shown that cloud computing, the Internet of Things, and other digital technologies in agriculture can optimize the allocation of AP factors and improve AP's economic and ecological efficiency to achieve the green transformation in traditional agriculture (Stupina et al., 2021; Pérez et al., 2020). Digitization has facilitated the urban–rural flow of agricultural green production technologies and ER information, and the continuous improvement of rural digital infrastructure has provided farmers with more learning opportunities, improved their quality of life, and enhanced their perception of rules (Michailidis et al., 2012). In addition, digitization breaks the relatively closed rural social environment. It significantly promotes the awakening of farmers' awareness and improves legal literacy (Zerrer and Sept, 2020), breaking the phenomenon of "mutual protection" caused by the "acquaintance society" that relies on a closed environment, a lack of public power, and weak personal awareness. The digitization of ER in the process of agricultural environmentally friendly practices exhibits spatial and temporal variability. Significant differences exist in the intensity of the ER, the level of digitization, and agricultural environmentally friendly practices in different periods and regions (Zhang et al., 2023). It can be considered that the ER's role in performing environmentally friendly practices in rural areas is not apparent, which can be better explained through digitization. However, studies on digitization in rural areas are still scarce, especially research on the relationship between ER and environmentally friendly farmer behavior. There is room to improve ER's effectiveness using digital technology to guide farmers in adopting environmentally friendly agricultural practices.

Our study fills this gap by integrating ER, digitization, and farmers' environmentally friendly behavior into a unified framework, where constrained ER and market-incentive ER by administrative policy are considered. This study has two main contributions. On one hand, by embedding digitization and ER in an analytical framework, it addresses a critical question, breaks the "behavioral lock-in" caused by the acquaintance society, and activates farmers' willingness to perform environmentally friendly practices (FWPEPs). On the other hand, an in-depth investigation into the interaction mechanism between ER and digitization—using data from China's Land Economic Survey from 2021 to 2022, a comprehensive survey conducted in Jiangsu- is discussed, providing a reference for policies supporting the green transformation of agriculture.

2 Theory and hypothesis

2.1 Performance of environmentally friendly practices with ER in rural areas

Farmers, to obtain more crop output, and the government, to promote agricultural GDP growth, tend to engage in "opportunistic" behavior, i.e., taking advantage of the situation to enrich themselves while disregarding the rules, and damaging the environment (Van der et al., 2017; Romero Granja and Wollni, 2019). Therefore, a rationally designed ER is a significant environmental protection and governance tool. ER can be divided into restrictive ER means and incentive-based means (Bowen et al., 2020). From the perspective of the constrained ER, local governments have formulated strict pollution control regulations and proposed measures for different types of pollution sources, such as fertilizers and pesticides (e.g., a registration system for fertilizers and pesticides and the designation of prohibited and restricted areas) to control pollution at the source. If farmers deviate from the set targets, they face administrative penalties such as fines. Therefore, farmers with a strong awareness of ER tend to weigh the costs of violations before implementing their pollution behavior, and through their economic rationality, they are driven by loss avoidance to perform environmentally friendly practices in agriculture.

Regarding horizontal governance tools, neoclassical economics suggests that farmers, as producers, are "rational economic men" who seek to maximize profits (Schwarze et al., 2014). FWPEPs depend on the cost of AP and the expected benefits (Zhang et al., 2018; Pan et al., 2022). Local governments have shifted the direction of financial subsidies, shifting from price subsidies for fertilizers, pesticides, and other purchases and sales to subsidies for the research and development of green AP technologies and incentives for farmers to engage in green and ecological farming activities, thus promoting the greening of agricultural inputs and the resourceful use of AP and household waste. At the same time, the use of economic incentives such as "awards to promote governance" and "rewards instead of compensation" (Russi et al., 2016) has guided farmers toward a shift to environmentally friendly methods. Therefore, Hypothesis 1 is proposed.

Hypothesis 1: ER has a significant positive effect on FWPEPs.

2.2 Digitization and FWPEPs

Behavioral decision-making theory suggests that humans have limited rationality, i.e., they are susceptible to perceptual bias when identifying and discovering problems. Hence, decision-makers need to fully understand and master information intelligence about the decision-making environment, along with business and market dynamics trends when making decisions (Slovic et al., 1977). However, in rural Chinese society, where living spaces are relatively closed and channels for farmers to obtain information are relatively narrow, there exists a severe asymmetric information problem (Liao and Chen, 2017), leading to biased behavioral decisions. Asymmetric information is one of the essential conditions for the emergence of "opportunism"; that is, the asymmetry between the government's information on the ER and farmers' access to information leads to ex ante "adverse selection" or ex post "risk of pollution," thus contributing to the deterioration of AP and the rural living environment. With the development of rural digitization, the Internet has become the primary source of information for farmers, and environmental regulatory information can be rapidly disseminated by relying on various new media platforms. The combination of point-to-point and face-to-face dissemination, interpersonal dissemination, mass dissemination, etc., characterizes the dissemination mode. The dissemination content takes various forms, such as text, voice, and video, and the dissemination path meets the complexity and diversity of the characteristics of the social network (Sept, 2020). Therefore, the level of digital infrastructure in a region or the availability of broadband and intelligent communication devices in farmers' homes can reflect the number of opportunities for information sharing (Aben et al., 2021); i.e., digitization enhances the interconnection of the ER's information among farmers, breaks down the "opportunistic" behavior of farmers, and has a positive effect on the achievement of green agriculture and green living. It should be noted that "digital inclusive finance + green finance," with the support of the Internet, big data technology, and blockchain, among others, can process vast amounts of data at a low cost, thus reducing transaction and information costs (Sovetova, 2021; Macchiavello and Siri, 2022) and then empowering the incentive-based ER to become more comprehensive, precise, green, and efficient (Shi et al., 2022). Therefore, Hypothesis 2 is put forward.

Hypothesis 2: Digital construction plays a moderating role in ER promoting FWPEPs.

3 Data, variables, and model

3.1 Data

The data used in this study were derived from the household surveys conducted from 2021 to 2022, and are available through the China Land Economic Survey (CLES). that the surveys cover the land market, agricultural production, and other aspects and were carried out by Nanjing Agricultural University in Jiangsu Province from 2021 to 2022. The PPS sampling method was used to select 26 counties from 13 prefecture-level cities under the jurisdiction of Jiangsu Province. Two sample towns were selected in each county, one administrative village was chosen in each city, and 50 households were randomly selected in each town. In the baseline survey, 2,628 households were included, and the second phase successfully followed up with 1,695 households in the baseline survey. At the same time, after eliminating the samples with missing data and logical errors, 1,118 households were retained, with a total of 2,236 sample datasets.

3.2 Variable selection

The explained variable consists of FWPEPs. Environmentally friendly behavior mainly included agricultural practices and actions in rural lives (Su et al., 2021). Based on the actual structure of the questionnaire, this study evaluates whether farmers use low-toxic, low-residue pesticides and whether they sort domestic waste in daily life. These indicators are used to measure farmers' environmentally friendly practices from the perspectives of AP and rural life (RL). If the answer is yes, the value assigned is 1; if no, ==a value of 0 is assigned.

The explanatory variable is ER. ER is considered a critical formal institution for regulating agricultural pollution and standardizing farmers' pro-environmental behavior through laws and administrative systems (Guo et al., 2022). Constrained ER is measured by the number of environmental regulations promulgated in prefecture-level cities. The data are derived from the Peking University magic database and consist of continuous variables. Incentive-based ER is measured by whether the government has implemented reward and punishment measures. If so, the value assigned is 1; if not, it is 0, a binary variable.

Rural digitization has broadened the channels for farmers to obtain information and thus enhanced the farmers' perception of rules (Zhang et al., 2023). The main channels through which various details are obtained are used as a measurement indicator. The assignment is as follows: 1, basic access to information through non-network channels; 2, access to information mainly through non-network channels and less commonly through network channels; 3, there is little difference in the proportion of information acquired through network and non-network channels; 4, information obtained mainly through network channels and less commonly through non-network channels; and 5, basic access to information through network channels.

Referring to existing related studies (Yang, 2018; Li and Ma, 2023), three levels of the control variables were selected, namely, personal characteristics, family characteristics, and external environment. Personal characteristics include gender, age, health status, individual awareness of environmental information, and recognition of other villagers' garbage classification behavior. Family characteristics include family population size indicators and length of residence in the area; the external environment comprises indicators such as the village environment. The specific variable descriptions and descriptive statistics are shown in Table 1.

3.3 Model

The measurement indicator of FWPEPs is whether farmers use high-efficiency, low-toxicity, and low-residue pesticides in agricultural production. Additionally, the adoption of garbage classification and disposal practices in farmers' lives has been considered another measurement index. These measurements include a "yes" or "no" response in two cases. Because the error term of FWPEPs with unobserved latent variables (e.g., environmental literacy) may follow a normal distribution, the probit model is more suitable for the model estimation affecting FWPEPs than the logit or linear models, which may be sensitive to data points in the case of extreme values. Therefore, the probit model was selected for the empirical test. The formula is as follows:

$$FWPEP_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \sum_{j=1} \beta_{3j} Control_{ij} + \varepsilon_i, \qquad (1)$$

where FWPEP is the explained variable and X_1 and X_2 refer to the constrained ER and incentive-based ER, respectively. Personal characteristics, family characteristics, and external environment were assessed as control variables. In Equation 1, β_1, β_2, and β_3 are the regression coefficients, and ε is a random disturbance term.

Digitization is considered an emerging driving force for information access and regulatory enforcement, enabling agricultural departments to implement effective proactive regulations (Yang et al., 2024). In addition, the regulatory effect of digitization on FWPEPs via

10.3389/fenvs.2025.1502291

TABLE 1 Variable description and descriptive statistics.

Variable	Definition	Mean (Std.)	22
FWPEPs	Do farmers use high-efficiency, low-toxicity, and low-residue pesticides in agricultural production? (1 = yes; 0 = no)	0.789 (0.408)	11
	Do farmers sort domestic waste in RL? (1 = yes; 0 = no)	0.517 (0.5)	
Constrained ER	The number of environmental laws and regulations promulgated in prefecture-level cities (piece)	78.895 (85.532)	
Incentive-based ER	Has the government implemented reward and punishment measures? (1 = yes; 0 = no)	0.318 (0.218)	
Digital construction	What is your usual way to acquire all kinds of information? 1, access to information through non-network channels; 2, access to information less commonly through network channels; 3, information acquisition through both network and non-network channels; 4, access to information mainly through network channels; 5, basic access to information through network channels	2.069 (1.329)	
Gender	Gender (1 = men subjects; 0 = female subjects)	0.743 (0.437)	
Age	Age (in full years)	62.12 (10.965)	
Health condition	Self-identified health status (1, incapacity to work; 2, poor; 3, medium; 4, good; and 5, excellent)	3.989 (1.064)	
Personal perception of environmental awareness	Do you agree that the sorting of domestic waste has a positive effect on improving the rural environment? (1, completely disagree; 2, disagree; 3, general; 4, comparative consent; and 5, totally agree)	4.027 (3.925)	
Personal perception of other villagers' environmental protection behavior	Your attitude toward other villagers' environmental protection behavior (1, disagree; 2, general; and 3, strongly agree)	2.088 (1.051)	
Number of permanent residents in the household	How many people are permanent residents (living in your household for 6 months or more per year)? (persons)	3.092 (1.633)	
Duration of residence in the area	Months of living out of town (months)	0.373 (1.808)	
Village environment	What do you think of the village's living environment? (1, no pollution; 2, slight pollution; 3, moderate pollution; and 4, serious pollution)	1.382 (0.612)	

ER is verified. The interaction term between ER and digitization was constructed and incorporated into the model (1) as follows:

$$FWPEP_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 dig_i + \beta_4 \left(X_{1i} \times dig_i\right) + \beta_5 \left(X_{2i} \times dig_i\right) + \sum_{j=1} \beta_{6j} Control_{ij} + \varepsilon_i, \quad (2)$$

where dig_i represents village digitization and $X_{1i} \times dig_i$ and $X_{2i} \times dig_i$ are, respectively, the interaction between digitization and constrained ER and that between digitization and incentive-based ER in Equation 2. These regression coefficients are obtained from β_3, β_4, and β_5.

4 Results

4.1 Baseline regression

To avoid multicollinearity, a maximum variance inflation factor (VIF) test needed to be carried out. The results showed that the VIF value was 1.58, which is less than 2, indicating no multicollinearity between the variables. Table 2 reports the estimation results of ER on FWPEPs using the probit model. The findings reveal that both constrained ER and incentive-based ER significantly and positively influence FWPEPs across all model specifications. The results of models 1 and 4 indicate that in the case of uncontrolled individual characteristic variables, family characteristic variables, external environmental variables, individual fixed effects, and time-fixed effects, both forms of ER significantly positively impact FWPEPs. Similarly, models 2 and 5 confirmed the persistent positive effect of both constrained and incentive-based ER on FWPEPs after controlling for individual characteristics, family characteristics, and external environmental factors. The regression coefficients exhibited a downward trend, suggesting that omitting controls for farmers' individual, familial, and external environmental factors leads to overestimating ER's effect on FWPEPs. Models 3 and 6, which account for individual and time-fixed effects, revealed further attenuation of the influence of both constrained ER and incentive-based ER on FWPEPs. These findings confirm that ER positively and significantly drives FWPEPs (supporting hypothesis 1), primarily by incentivizing greener agricultural inputs, optimizing AP and domestic waste utilization, and implementing economic measures such as "award-driven governance" and "subsidy-to-award transitions" to steer farmers toward environmentally friendly agricultural production and rural livelihood practices.

4.2 Robustness test

4.2.1 Propensity score matching

A potential concern was that the statistical significance of constrained ER and incentive-based ER might have stemmed

TABLE 2 Estimation of ER and FWPEPs using the probit model.

Variable	AP			RL		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constrained ER	0.187**	0.123**	0.093***	0.110***	0.108***	0.103***
	(0.026)	(0.085)	(0.035)	(0.029)	(0.054)	(0.036)
Incentive-based ER	0.155***	0.152***	0.135**	1.033***	0.939***	0.941***
	(0.001)	(0.106)	(0.107)	(0.056)	(0.058)	(0.058)
Gender		0.240**	0.214**		0.088**	0.081*
		(0.101)	(0.103)		(0.061)	(0.061)
Age		0.010***	−0.011**		−0.008***	−0.008***
		(0.004)	(0.005)		(0.003)	(0.005)
Education		0.016*	0.014*		0.039***	0.037***
		(0.012)	(0.012)		(0.008)	(0.008)
Health		−0.038	−0.053**		0.032*	0.036*
		(0.041)	(0.042)		(0.025)	(0.025)
Residents in the household		−0.029*	−0.023*		0.009	0.010
		(0.024)	(0.024)		(0.017)	(0.017)
Residence		−0.008	−0.001		0.043**	0.043***
		(0.026)	(0.026)		(0.020)	(0.020)
Village environment		0.236***	0.243***		−0.201***	−0.193
		(0.056)	(0.071)		(0.065)	(0.05)
Individual fixed effects	YES	YES	YES	YES	YES	YES
Time-fixed effects	YES	YES	YES	YES	YES	YES
Constant	0.773***	1.691***	−59.401	0.529**	0.696***	−48.51***
	(0.046)	(0.409)	(44.366)	(0.047)	(0.242)	(46.85)
Obs.	2,236	2,236	2,236	2,236	2,236	2,236

Note: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively, and the numbers in brackets are robust standard errors.

from sample selection bias. To mitigate endogeneity issues arising from data bias and confounding factors, this study has employed the propensity score matching (PSM) method to re-estimate the effects of ER on FWPEPs, distinguishing the results for AP and RL. First, treatment and control groups were identified. Based on the average number of ERs issued at the prefecture level (79.895 regulations), regions were classified into high- and low-constraint ER groups. Similarly, governments implementing reward and penalty mechanisms were categorized into the incentive-based ER group, while those without such mechanisms were categorized into the non-incentive ER group. Next, three matching methods, namely, nearest-neighbor, caliper, and kernel matching, were applied to estimate the average treatment effect (ATE) between the treatment and control groups. Table 3 shows a positive correlation between ER and FWPEPs, further confirming the robustness of this study's estimates.

4.2.2 Measurement with estimation bias

For some unmeasurable variables that may exist, the estimation results are biased. Observed variables are used to calculate the possibility of estimation bias caused by unobserved variables. The primary approach is divided into three steps. First, two groups of regressions are established. One group does not add control variables or adds only a few (gender, age, and health status) constrained control variables; the other group adds the regression of all control variables. Then, the coefficients βr and βf of the key explanatory variables in the two groups of regressions are calculated, respectively (r represents the group that does not contain or contains some control variables, and f represents the group that contains all control variables). Second, the F-value statistic is calculated using the formula is $F = |\beta f/(\beta r-\beta f)|$. If $F \geq 1$, the result is robust, and the larger the F value, the smaller the error caused by unobserved factors in the current estimation results. According to the F-value calculation formula, the closer βr and βf are, the smaller the influence of the known control variables on the estimation results is. If the current fundamental conclusion changes with the addition of more control variables, a larger βf indicates that unknown variables that might affect the robustness of the existing estimates play a more significant role. The effect of FWPEPs by ER is examined through two

TABLE 3 PSM estimation.

Variable	Match type	AP			RL		
		ATT	ATU	ATE	ATT	ATU	ATE
Constrained ER	Nearest-neighbor	0.013**	0.012**	0.012**	0.026**	0.021**	0.024**
	Caliper	0.012**	0.01*	0.011***	0.024**	0.026*	0.025***
	Kernel	0.01***	0.01***	0.01***	0.021***	0.025***	0.023***
Incentive-based ER	Nearest-neighbor	0.008***	0.01**	0.009***	0.254*	0.22**	0.233*
	Caliper	0.012**	0.008*	0.01***	0.241**	0.263**	0.249***
	Kernel	0.012**	0.008*	0.01***	0.215*	0.201**	0.209*

Note: ATT is the average treatment effect of the experimental group, ATU is the average treatment effect of the control group, and ATE is the average processing effect. The ***, **, and * represent the significance levels of 1%, 5%, and 10%.

TABLE 4 Robustness test for ER and FWPEPs.

Circumstance	Constrained control group	Full control variable group	F-value (AP)	F-value (RL)
Circumstance 1	Without control variables	After adding all control variables, excluding health status	Constrained ER (2.189)/ incentive-based ER (2.147)	Constrained ER (3.126)/ incentive-based ER (2.854)
Circumstance 2	Without control variables	After adding all control variables	Constrained ER (1.564)/ incentive-based ER (2.156)	Constrained ER (1.986)/ incentive-based ER (2.153)
Circumstance 3	After adding control variables such as gender and age	After adding all control variables, excluding health status	Constrained ER (3.989)/ incentive-based ER (2.854)	Constrained ER (3.214)/ incentive-based ER (1.694)
Circumstance 4	After adding control variables such as gender and age	After adding all control variables	Constrained ER (2.641)/ incentive-based ER (3.254)	Constrained ER (2.589)/ incentive-based ER (2.147)

regression models: one that includes only a subset of control variables and another that incorporates all control variables. As shown in Table 4, the F-values across the four cases range from 1.564 to 3.989, with an average of 2.560. This suggests that, to improve the robustness of the model estimates in Table 2, the number of unknown or unobservable variables would need to be at least 1.564 times greater than the current control variables. As this scenario is unlikely, the estimation results remain robust.

4.3 Heterogeneity analysis

The previous research presented the impact of ER on FWPEPs, that is, the impact of homogeneity. However, the effect of ER on FWPEPs was found to differ based on different personal characteristics. Next, the heterogeneous impact of ER on FWPEPs was examined from the perspectives of gender and education levels in the light of agricultural production. Tables 5, 6 report the heterogeneous impact of ER on FWPEPs in AP. The results show that, based on the discussion of different genders in the context of AP, the impact of constrained ER and incentive-based ER on FWPEPs was more significant for men than for women.

Conversely, in RL for environmentally friendly practices, the role of constrained ER was found to be more significant for women, and there was no apparent heterogeneity in incentive-based ER. The reason is that the social role theory posits that gender differences in social behavior stem from the gender division of labor established by society. Men and women are often viewed as being physiologically driven to assume the roles of breadwinner and caregiver, respectively, reinforcing the belief that men and women are inherently related to these roles.

Based on the discussion of different education levels, whether in AP or RL, the impact of constrained and incentive-based ER on FWPEPs was found to be more significant for those with a junior high school education or higher than for those with an education level of primary school or lower. The reason is that farmers with junior high school and above education levels will have greater cognitive ability due to the influence of good education, will be more sensitive to changes in the external environment, and will have a deeper understanding of the rules. Therefore, environmentally friendly methods are often adopted under the joint drive of constrained ER and incentive-based ER.

4.4 ER and FWPEPs moderated by digitization

To test the regulatory role of digitization in the impact of ER on FWPEPs, data were only available for 2022, as the relevant questionnaire was conducted exclusively for that period. Therefore, to verify the moderating effect of digitization, only the 2022 data were used for regression analysis. The interaction terms of

TABLE 5 Heterogeneity analysis of ER in AP.

Variable	Gender		Education	
	Male	Female	Primary or lower	Middle or above
Constrained ER	0.239*** (0.104)	0.072 (0.150)	0.126 (0.148)	0.374*** (0.135)
Incentive-based ER	0.211** (0.147)	0.104 (0.045)	0.045 (0.031)	0.241*** (0.111)
C.V.	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time-fixed effects	YES	YES	YES	YES
Obs	1,002	1,234	678	1,558

Note: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively, and the numbers in brackets are robust standard errors.

TABLE 6 Heterogeneity analysis of ER in RL.

Variable	Gender		Education	
	Male	Female	Primary or lower	Middle or above
Constrained ER	0.008 (0.001)	0.098*** (0.024)	0.091 (0.051)	0.125*** (0.158)
Incentive-based ER	0.523*** (0.154)	0.651*** (0.104)	0.058 (0.041)	0.415*** (0.074)
C.V.	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time-fixed effects	YES	YES	YES	YES
Obs	1,002	1,234	678	1,558

Note: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively, and the numbers in brackets are robust standard errors.

constrained ER and incentive-based ER were added for regression. The regression results, presented in Table 7, demonstrate that constrained ER, incentive-based ER, digitization, and their interaction terms significantly and positively influence FWPEPs when no control variables are included. When controlling for individual, family, and external environmental variables, the coefficients for constrained ER, incentive-based ER, and their interaction terms with digitization remain positively significant but decrease in magnitude. This suggests that, without controlling for farmers' individual, family, and external environmental factors, the impact of digitization and its interaction with ER mechanisms are overestimated, thereby validating hypothesis 2. These findings demonstrate that digitization enhances the dissemination of ER-related information among farmers, mitigates opportunistic behavior, and plays a constructive role in promoting green agricultural production and sustainable rural living.

5 Discussion and conclusion

Based on the analytical framework of ER and digitization, an empirical study was conducted using data from China's Land Economic Survey and employing a binary probit model. The results of this study provide significant insights into how different types of ERs—constrained ER and incentive-based ER—affect FWPEPs. In particular, the findings indicate that both types of ER positively influence the adoption of environmentally friendly practices in farming. The critical contribution of this study lies in demonstrating how digitization enhances ER's efficacy in promoting environmentally friendly behavior among farmers. Digitization expands farmers' awareness of ER and provides them with the skills and tools to effectively implement these regulations. The findings from this study underscore the role of digital empowerment in overcoming the barriers to adopting environmentally friendly practices in agriculture.

From the perspective of internal mechanisms, ER affects FWPEPs through external constraints and internal incentives. On one hand, constrained ER strengthens behavioral norms by imposing significant economic and social costs for violations, thus forcing farmers to comply with environmental standards. On the other hand, incentive-based ER reduces the risks and costs of behavior transformation through positive incentives, encourages farmers to respond to policy calls actively, and reflects the advantages of combining government and market measures in environmental governance. Furthermore, domestic

TABLE 7 Regression ER and FWPEPs moderated by digitization.

Variable	AP	RL	AP	RL
Constrained ER	0.085** (0.054)	0.108*** (0.054)	0.124* (0.047)	0.087*** (0.025)
Incentive-based ER	0.099** (0.073)	0.015*** (0.058)	0.198* (0.309)	0.016*** (0.012)
Constrained ER*digitization	0.487***	0.147***	0.115***	0.054*
	(0.087)	(0.254)	(0.148)	(0.014)
Incentive-based ER*digitization	0.091***	0.097***	0.015*	0.004*
	(0.018)	(0.145)	(0.124)	(0.003)
C.V.	NO	NO	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time-fixed effects	YES	YES	YES	YES
Obs	2,236	2,236	2,236	2,236

Note: * * *, * *, and * represent the significance levels of 1%, 5%, and 10%, respectively, and the numbers in brackets are robust standard errors.

and foreign research has also confirmed that there are significant individual heterogeneity characteristics in the effectiveness of ER. The gender and education level differences discovered in this study are highly consistent with similar findings in the international literature. In Thailand, male farmers are more sensitive to policy perception in agricultural production decisions, while women are more inclined to participate in environmental activities in their daily lives (Sereenonchai and Arunrat, 2024). The positive effects of both types of ER in guiding farmers toward adopting environmentally friendly practices in rural areas support the general theory that ER, whether constrained or incentivized, serve as a crucial lever for achieving environmental sustainability in agriculture. It is also essential to recognize that the effectiveness of ER may depend on the local context, which can vary due to cultural, economic, and infrastructural factors.

In this study, digitization has been proven to be an important moderating factor in the relationship between ER and FWPEPs. This means that digitization has significantly improved farmers' cognitive accuracy in information acquisition and their timely response to environmental regulatory policy information. Another study focused on product knowledge and perceived benefits in the digital era (Foster et al., 2022). The authors noted that digitization plays a significant role in enhancing farmers' understanding and perception of ER. Similarly, village digitization can highlight role models or demonstrate how local departments implement ER, such as norms and laws, fostering a sense of collective endeavor. Additionally, the study confirms that, when combined with ER, digitization is crucial in reducing the "opportunistic behavior" often observed in rural communities, wherein farmers take advantage of their lack of information to evade compliance.

In conclusion, this study provides strong evidence that ER and digitization play critical roles in shaping farmers' environmentally friendly behaviors. Combining ER and digitization empowers environmentally friendly sustainability in agriculture and rural life. These findings suggest that policymakers should focus on integrating digital strategies into ER frameworks to maximize the impact of both on farmers' performance of environmentally friendly practices. Future research should continue to explore the interactions between digital tools and ER and embed the risk perception and knowledge sharing into farmers' behavior, in order to refine and improve agricultural sustainability strategies.

6 Policy implications and limitations

Preventing and controlling agricultural non-point source pollution is not a long-term goal but a substantial process. Based on the aforementioned findings, this study draws the following policy implications.

First, the laws and regulations of agricultural ecological civilization are established to standardize AP and RL in several selected typical areas with positive prevention and control work and remarkable results. Financial support for agricultural enterprises' green AP technology innovation will be increased to provide full play to the 'leader' role of agricultural enterprises' technological innovation through industry benchmarking publicity and the establishment of models. Governments should provide leverage institutional advantages by focusing on significant events and strengthening rural infrastructure construction. Notably, they should establish an ecological data observation platform to systematically and quantitatively evaluate the environmental *status quo* and improve and make timely adjustments. Promoting rural ecological construction has become the driving force of green rural development. By combining legal publicity, vocational training, and road shows, and making full use of information dissemination channels such as the Internet, knowledge of agricultural green production will be popularized, raising farmers' awareness of environmental protection, and leveraging their regulatory role.

Second, digitization in rural areas has increased with consolidated digital architecture. The digital construction plan has been improved to form an implementation mechanism for government fund guidance, broad social capital participation, strict social group supervision, and reasonable resource investment. Next, the establishment of a universal service compensation mechanism for rural telecommunications will support the construction of optical fiber networks and 5G base stations in villages and towns for realizing the "same network and same speed" in rural cities, reducing the "digital divide" between urban and rural areas, and opening up the application channels of digital AP technology and the dissemination channels of AP information. Additionally, the development and application of high-end technologies, such as big data and blockchain, in AP can be actively promoted to improve the scope of digital financial inclusion services, with a focus on "pilot fault tolerance" while maintaining fundamental principles. The aforementioned measures are expected to further promote the green effects of digital finance and help with the green transformation and upgrading of rural economic development.

This study has several limitations. First, the data were drawn from farmer surveys in Jiangsu Province, which may restrict the generalizability of the findings to broader geographical and economic contexts. Second, environmental regulations and digitization measurements were simplified, potentially overlooking the complexity of policy instruments and technological applications. Additionally, the influence of informal institutional factors, such as farmers' social networks, on behavioral decisions was not fully explored. Future research could validate these mechanisms through cross-regional longitudinal data and a more nuanced variable design.

Data availability statement

Publicly available datasets were analyzed in this study. These data can be found at the China Land Economic Survey from Nanjing Agriculture University.

Author contributions

WZ: conceptualization, data curation, formal analysis, and writing – original draft. SL: data curation and writing – original draft. WW: writing – original draft. HZ: validation and writing – review and editing. QH: supervision, validation, and writing – review and editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was supported by the Ministry of Education Humanities and Social Sciences Youth Project (23YJC630235) and the Guangdong University Student Climbing Plan's Social Survey Report on Philosophy and Social Science and the General Project of Academic Papers (pdjh2023b0329).

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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

References

Aben, T. A. E., Van der Valk, W., Roehrich, J. K., and Selviaridis, K. (2021). Managing information asymmetry in public–private relationships undergoing a digital transformation: the role of contractual and relational governance. *Int. J. Oper. Prod. Man.* 41 (7), 1145–1191. doi:10.1108/ijopm-09-2020-0675

Bowen, F., Tang, S., and Panagiotopoulos, P. (2020). A classification of information-based environmental regulation: voluntariness, compliance and beyond. *Sci. Total Environ.* 712, 135571. doi:10.1016/j.scitotenv.2019.135571

Boyd, G. A., and Mcclelland, J. D. (1999). The impact of environmental constraints on productivity improvement in integrated paper plants. *J. Environ. Manage.* 38 (2), 121–142. doi:10.1006/jeem.1999.1082

Chi, Y., Xu, Y., Wang, X., Jin, F., and Li, J. (2021). A win-win scenario for agricultural green development and farmers' agricultural income: an empirical analysis based on the EKC hypothesis. *Sustainability* 13, 8278. doi:10.3390/su13158278

Cho, M., Jang, T., Jang, J. R., and Yoon, C. G. (2016). Development of agricultural non-point source pollution reduction measures in Korea. *Irrig. Drain.* 65, 94–101. doi:10.1002/ird.1993

Ding, X., Tang, N., and He, J. (2019). The threshold effect of environmental regulation, FDI agglomeration, and water utilization efficiency under "double control actions"—an empirical test based on Yangtze river economic belt. *Water* 11 (3), 452. doi:10.3390/w11030452

Du, Y., Liu, N., and Chen, L. (2021). An analysis of farmers' collective inaction in rural environmental governance and its turning. *China Rural. Surv.* 158 (02), 81–96. (in Chinese). doi:10.20074/j.cnki.11-3586/f.2021.02.006

Dwyer, J., and Powell, J. (2016). Rural development programmes and transaction effects: reflections on Maltese and English experience. *J. Agr. Econ.* 67 (3), 545–565. doi:10.1111/1477-9552.12166

Engel, M. T., Vaske, J. J., and Bath, A. J. (2021). Ocean imagery relates to an individual's cognitions and pro-environmental behaviours. *J. Environ. Psychol.* 9, 101588. doi:10.1016/j.jenvp.2021.101588

Fang, Z., Kong, X., Sensoy, A., Cui, X., and Cheng, F. (2021). Government's awareness of environmental protection and corporate green innovation: a natural experiment from the new environmental protection law in China. *Econ. Anal. Policy* 70, 294–312. doi:10.1016/j.eap.2021.03.003

Fei, H.-T. (1948). *Peasant life in China*. London: Routledge and Kegan.

Foster, B., Hurriyati, R., and Johansyah, M. D. (2022). The effect of product knowledge, perceived benefits, and perceptions of risk on Indonesian student decisions to use E-wallets for warunk upnormal. *Sustainability* 14, 6475. doi:10.3390/su14116475

Gross, D. R. (1971). Ritual and conformity: a religious pilgrimage to northeastern Brazil. *Ethnology* 10 (2), 129–148. doi:10.2307/3773005

Guo, Z. D., Chen, X. Q., and Zhang, Y. W. (2022). Impact of environmental regulation perception on farmers' agricultural green production technology adoption: a new perspective of social capital. *Technol. Soc.* 71, 102085. doi:10.1016/j.techsoc.2022.102085

Hirschi, C. (2010). Strengthening regional cohesion: collaborative networks and sustainable development in Swiss rural areas. *Ecol. Soc.* 115 (4), 16. doi:10.5751/es-03714-150416

Hong, J. Y., Park, S., and Yang, H. (2022). In strongman we trust: the political legacy of the New Village Movement in South Korea. *Am. J. Polit. Sci.* 67 (3), 850–866. doi:10.1111/ajps.12716

Hu, K., Li, D., Shi, D., and Xu, W. (2023). Environmental regulation and energy efficiency: evidence from daily penalty policy in China. *J. Regul. Econ.* 63, 1–29. doi:10.1007/s11149-022-09455-6

Järnberg, L., Kautsky, E. E., Dagerskog, L., and Olsson, P. (2018). Green niche actors navigating an opaque opportunity context: prospects for a sustainable transformation of Ethiopian agriculture. *Land Use Policy* 71, 409–421. doi:10.1016/j.landusepol.2017.11.053

Li, S., and Ma, J. (2023). Village clans and rural households' willingness to participate in domestic waste governance: evidence from China. *J. Clean. Prod.* 425, 138951. doi:10.1016/j.jclepro.2023.138951

Liao, C. N., and Chen, Y. J. (2017). Farmers' information management in developing countries—a highly asymmetric information structure. *Prod. Oper. Manag.* 26 (6), 1207–1220. doi:10.1111/poms.12678

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

Ma, G., Lv, D., Luo, Y., and Jiang, T. (2022). Environmental regulation, urban-rural income gap and agricultural green total factor productivity. *Sustainability* 14, 8995. doi:10.3390/su14158995

Macchiavello, E., and Siri, M. (2022). Sustainable finance and fintech: can technology contribute to achieving environmental goals? A preliminary assessment of 'green fintech' and 'sustainable digital finance. *Eur. Co. Financ. Law R.* 19 (1), 128–174. doi:10.1515/ecfr-2022-0005

Mbanyele, W., and Wang, F. (2022). Environmental regulation and technological innovation: evidence from China. *Environ. Sci. Pollut. R.* 29 (9), 12890–12910. doi:10.1007/s11356-021-14975-3

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

Michailidis, A., Nastis, S. A., and Loizou, E. (2012). Mobile communications technology in rural societies of developing countries. *J. Rural. Dev.*, 319–334.

Noble, V. (2019). Mobilities of the one-Product policy from Japan to Thailand: a critical policy study of OVOP and OTOP. *Territ. Polit. Gov.* 7 (4), 455–473. doi:10.1080/21622671.2018.1511463

Osborne, S. P., Williamson, A., and Beattie, R. (2002). Community involvement in rural regeneration partnerships in the UK: key issues from a three nation study. *Reg. Stud.* 36 (9), 1083–1092. doi:10.1080/0034340022000024303

Ouyang, X., Li, Q., and Du, K. (2020). How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data. *Energ. Policy.* 139, 111310. doi:10.1016/j.enpol.2020.111310

Pan, S., Di, C., Chandio, A. A., Sargani, G. R., and Zhang, H. (2022). Investigating the impact of grain subsidy policy on farmers' green production behavior: recent evidence from China. *Agriculture* 12 (8), 1191. doi:10.3390/agriculture12081191

Pargal, S., and Wheeler, D. (1996). Informal regulation of industrial pollution in developing countries: evidence from Indonesia. *J. Polit. Econ.* 104, 1314–1327. doi:10.1086/262061

Pawłowska, A., and Grochowska, R. (2021). Green transformation of the common agricultural policy and its impact on farm income disparities. *Energies* 14 (24), 8242. doi:10.3390/en14248242

Pérez, E., Domínguez, J. P., Chamoso, P., Plaza, M., and Alonso, R. (2020). Efficiency, profitability and productivity: technological applications in the agricultural sector. *ADCAIJ-Adv. Distrib. C.* 9 (4), 47–54. doi:10.14201/ADCAIJ2020944754

Potoski, M., and Prakash, A. (2004). The regulation dilemma: cooperation and conflict in environmental governance. *Public admin. Rev.* 64 (2), 152–163. doi:10.1111/j.1540-6210.2004.00357.x

Romero Granja, C., and Wollni, M. (2019). Opportunistic behaviour and trust: experimental results from broccoli farmers in Ecuador. *J. Agr. Econ.* 70 (1), 62–80. doi:10.1111/1477-9552.12271

Russi, D., Margue, H., Oppermann, R., and Keenleyside, C. (2016). Result-based agri-environment measures: market-based instruments, incentives or rewards? The case of Baden-Württemberg. *Land Use Policy* 54, 69–77. doi:10.1016/j.landusepol.2016.01.012

Schwarze, J., Holst, G. S., and Mußhoff, O. (2014). Do farmers act like perfectly rational profit maximisers? Results of an extra-laboratory experiment. *Int. J. Agr. Manag.* 4 (1029-2017-1486), 11–20. doi:10.22004/ag.econ.262336

Sept, A. (2020). Thinking together digitalization and social innovation in rural areas: an exploration of rural digitalization projects in Germany. *Eur. Countrys.* 12 (2), 193–208. doi:10.2478/euco-2020-0011

Sereenonchai, S., and Arunrat, N. (2023). Urban agriculture in Thailand: adoption factors and communication guidelines to promote long-term practice. *Int. J. Environ. Res. Public Health* 20, 1. doi:10.3390/ijerph20010001

Sereenonchai, S., and Arunrat, N. (2024). Pro-environmental agriculture to promote a sustainable lifestyle. *Sustainability* 16, 7449. doi:10.3390/su16177449

Shen, J., and Chou, R.-J. (2022). Rural revitalization of Xiamei: the development experiences of integrating tea tourism with ancient village preservation. *J. Rural. Stud.* 90, 42–52. doi:10.1016/j.jrurstud.2022.01.006

Shi, F., Ding, R., Li, H., and Hao, S. (2022). Environmental regulation, digital financial inclusion, and environmental pollution: an empirical study based on the spatial spillover effect and panel threshold effect. *Sustainability* 14 (11), 6869. doi:10.3390/su14116869

Si, R. S., Pan, S. T., Yuan, Y. X., and etal (2019). Effect of environmental regulation on the behavior of farmers to recycling the dispose wastes. *J. Arid. Land Resour. Environ.* 33 (9), 17–22. (in Chinese). doi:10.13448/j.cnki.jalre.2019.260

Slovic, P., Fischhoff, B., and Lichtenstein, S. (1977). Behavioral decision theory. *Annu. Rev. Psychol.* 28 (1), 1–39. doi:10.1146/annurev.ps.28.020177.000245

Sovetova, N. P. (2021). Rural territories' digitalization: from theory to practice. *Ekonom. Sots. Perem.* 14 (2), 105–124. doi:10.15838/esc.2021.2.74.7

Stupina, A. A., Rozhkova, A. V., Olentsova, J. A., and Rozhkov, S. E. (2021). Digital technologies as a tool for improving the efficiency of the agricultural sector. *IOP Conf. Ser. Earth Environ. Sci.* 839 (2), 022092. doi:10.1088/1755-1315/839/2/022092

Su, M., Feng, S. Y., Lu, H. L., and Fan, P. (2021). Farmers'domestic waste disposal behavior:moderating effects based on big five personality traits. *Resour. Sci.* 43 (11), 2236–2250. doi:10.18402/resci.2021.11.08

Tang, L., Luo, X. F., and Zhang, J. B. (2021). Environmental policies and farmers' environmental behaviors: administrative restriction or economic incentive. *China Popul. Resour. Environ.* 31 (6), 147–157. (in Chinese).

Van der, M. M., Kirsten, J. F., and Trienekens, J. H. (2017). Information sharing as a safeguard against the opportunistic behavior of South African Karoo Lamb farmers. *Agr. Econ.* 48 (S1), 101–111. doi:10.1111/agec.12389

Wang, X., Wang, S., and Zhang, Y. (2022). The impact of environmental regulation and carbon emissions on green technology innovation from the perspective of spatial interaction: empirical evidence from urban agglomeration in China. *Sustainability* 14, 5381. doi:10.3390/SU14095381

Wei, O., Wei, J., Li, X., Giubilato, E., and Critto, A. (2016). Long-term agricultural non-point source pollution loading dynamics and correlation with outlet sediment geochemistry. *J. Hydrol.* 540, 379–385. doi:10.1016/j.jhydrol.2016.06.043

Winsten, J. R., Baffaut, C., Britt, J., Borisova, T., Ingels, C., and Brown, S. (2011). Performance-based incentives for agricultural pollution control: identifying and assessing performance measures in the United States. *Water Policy* 13 (5), 677–692. doi:10.2166/wp.2011.055

Wu, H., and Ge, Y. (2019). Excessive application of fertilizer, agricultural non-point source pollution, and farmers' policy choice. *Sustainability* 11 (4), 1165. doi:10.3390/su11041165

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

Yang, C., Ji, X., Cheng, C., Liao, S., Obuobi, B., and Zhang, Y. (2024). Digital economy empowers sustainable agriculture: implications for farmers' adoption of ecological agricultural technologies. *Ecol. Indic.* 159, 111723. doi:10.1016/j.ecolind.2024.111723

Yang, H. (2018). Family clans and public goods: evidence from the new village beautification project in South Korea. *J. Dev. Econ.* 136, 34–50. doi:10.1016/j.jdeveco.2018.09.001

Yu, L., Liu, W., Yang, S., Kong, R., and He, X. (2022). Impact of environmental literacy on farmers' agricultural green production behavior: evidence from rural China. *Front. Environ. Sci.* 10, 990981. doi:10.3389/fenvs.2022.990981

Yu, T., and Yu, F. W. (2019). The impact of cognition of livestock waste resource utilization on farmers' participation willingness in the context of environmental regulation policy. *Chin. Rural. Econ.* 35 (8), 93–110. doi:10.1016/j.cjpre.2021.04.019

Zerrer, N., and Sept, A. (2020). Smart villagers as actors of digital social innovation in rural areas. *Urban Plan.* 5 (4), 78–88. doi:10.17645/up.v5i4.3183

Zhang, L., Li, X., Yu, J., and Yao, X. (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, L., Wang, Z., Chai, J., Fu, Y., Wei, C., and Wang, Y. (2019). Temporal and spatial changes of non-point source N and P and its decoupling from agricultural development in water source area of middle route of the South-to-North Water Diversion Project. *Sustainability* 11 (3), 895. doi:10.3390/su11030895

Zhang, W., Gao, P., Chen, Z., and Qiu, H. (2023). Preventing agricultural non-point source pollution in China: the effect of environmental regulation with digitization. *Int. J. Env. Res. Pub. He.* 20 (5), 4396. doi:10.3390/ijerph20054396

Zhang, W., He, Q., and Wang, H. (2024). Design and study on the landscape morphology of urban greenways from a low-carbon perspective: a case study of Fuzhou urban greenways. *J. Biot. Res.* 18, 140–153.

Zhang, Y., Lu, X., Zou, Y., and Lv, T. (2022). Nudging strategies for arable land protection behavior in China. *Int. J. Environ. Res. Public Health.* 19, 12609. doi:10.3390/ijerph191912609

Zhao, J., Liu, L., Qi, J., and Dong, J. (2022). Study on the influence of environmental regulation on the environmentally friendly behavior of farmers in China. *Front. Environ. Sci.* 10, 1009151. doi:10.3389/fenvs.2022.1009151