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The influence of the industrial organization on farmers' willingness to adopt water-saving irrigation technologies: a perspective of organizational support

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ABSTRACT

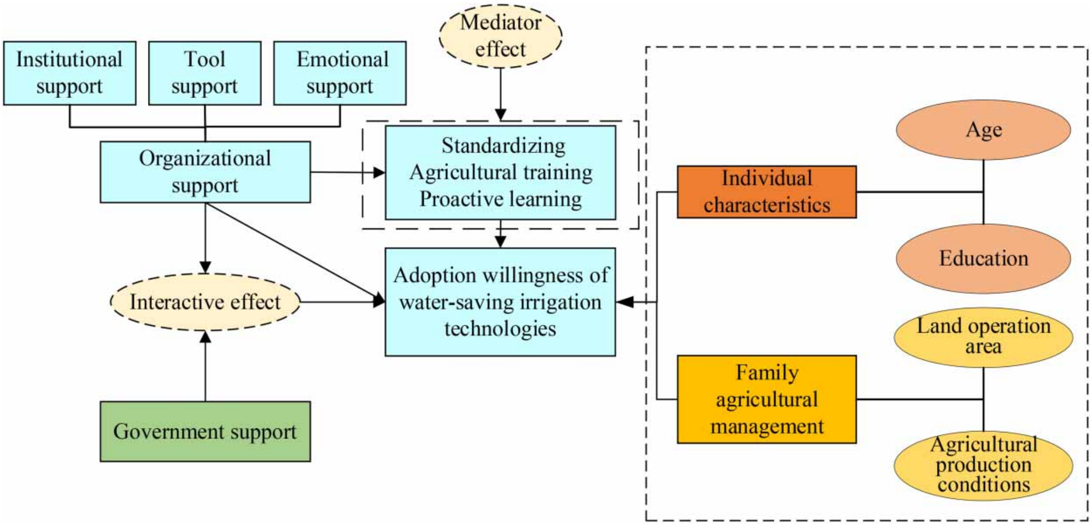
Water scarcity and inefficiency hinder China's sustainable agriculture. Water-saving irrigation (WSI) technology, as a crucial means to improve water efficiency, has relatively low adoption rates. In this context, this study utilizes survey data from 1,178 farmers in the Yellow River Basin in China, employing both the Binary Probit model and the Iv-Probit model to deeply explore the influence and mechanism of industrial organizations on farmers' willingness to adopt WSI technology. Our study shows that organizational participation behavior and degree of organizational support can effectively enhance farmers' willingness to adopt WSI technology. Organizational support indirectly enhances farmers' willingness to adopt WSI technology by standardizing production, providing agricultural training, and being proactive in learning agricultural techniques. Furthermore, organizational support has a significant impact on farmers with low education, young age, large land management areas, and poor agricultural production conditions. Our study also found that organizational support and government support can play a synergistic role in promoting farmers' willingness to adopt WSI technology. Therefore, it is necessary to strengthen the cultivation of industrial organizations, improve the governance structure of industrial organizations, strengthen the institutional guarantee of industrial organizations, and pay attention to the heterogeneity of farmer groups when leveraging the role of industrial organizations.

Key words: Agricultural training, Organizational support, Proactive learning, Standardizing, Water-saving irrigation technologies

HIGHLIGHTS

- Organizational participation behavior and organizational support degree can effectively promote farmers' willingness to adopt water-saving irrigation technology.
- Standardizing, agricultural training, and proactive learning play an intermediary role in the influence of industrial organizations on farmers' willingness to adopt water-saving irrigation technology.

GRAPHICAL ABSTRACT



INTRODUCTION

Water scarcity and low utilization efficiency pose significant constraints to the sustainable development of agriculture in China (Liu *et al.*, 2022; Shi *et al.*, 2022). Agriculture accounts for approximately 63.1% of the total water consumption in the country, yet the irrigation water use efficiency stands at a mere 0.54, exhibiting a substantial gap compared to developed nations (Geng *et al.*, 2019). The suboptimal efficiency in agricultural irrigation contributes to issues such as water wastage and agricultural non-point source pollution (Chen & Mu, 2022). In a bid to promote sustainable agricultural development, the Chinese government has emphasized the widespread adoption of water-saving irrigation (WSI) technologies. The Central Document No. 1 of 2023 proposed to promote efficient WSI and promote deep water saving and water control in agriculture in the Yellow River Basin. However, the application of WSI technologies in agricultural production remains limited, with low enthusiasm among farmers. Therefore, enhancing farmers' willingness to adopt WSI technologies and expediting their dissemination carry crucial implications for improving agricultural water efficiency, alleviating China's water resource crisis, and fostering sustainable agricultural development.

WSI technologies aim to enhance agricultural irrigation efficiency by effectively utilizing natural precipitation and irrigation water, thereby improving the economic, social, and ecological benefits of agricultural production. These technologies include drip irrigation, micro-sprinkler irrigation, mulching irrigation, and channel seepage irrigation. Current scholarly discussions on factors influencing the adoption of WSI technologies primarily cover aspects such as inherent endowments, farmer cognition, risk preferences, operational characteristics, social networks, and policy factors (Liu *et al.*, 2008; Zhang *et al.*, 2019; Xu *et al.*, 2023; Wang *et al.*, 2024; Zhang & Song, 2024). Farmers' application of these technologies is a decision based on self-endowments, cost–benefit considerations, and risk assessment. Constraints such as plot and usage scale limitations and high costs make it impractical for individual farmers to adopt these technologies. Additionally, as these are complex and high-risk technologies, the adoption of WSI technologies requires a significant investment of time and effort from farmers, posing substantial resistance. Finally, based on the positive externalities of technology, the spillover of benefits leads to low enthusiasm among farmers to adopt (Liu, 1996; Wan & Cai, 2021).

In recent years, the government has prioritized the cultivation of new agricultural management entities to integrate farmers into the agricultural industry chain, ensuring effective alignment with the market. As of the end of May 2022, there were 2.225 million registered farmers' professional cooperatives nationwide, influencing nearly half of all farming households. Industrial organizations, such as agricultural cooperatives, serve as vital channels for the integration of small-scale farmers into modern agriculture. By establishing a linkage mechanism of 'shared risks and shared benefits' with farmers, these organizations consolidate dispersed farmers, stimulate collective action, and play a coordinating role in the production processes of the agricultural product industry chain (Li & Lu, 2020). The rapid development of industrial organizations in China has created opportunities to promote the adoption of WSI technologies among farmers. Numerous scholars have found that organizational behavior theory can be applied across various fields, yielding positive outcomes. Demirhan & Onur Ince (2018) demonstrated that different organizations can exert significant public influence by uniting their members, affecting public opinion, improving civic culture, and guiding decision-making processes. Lee *et al.* (2024) found that social support from intermediary organizations plays a crucial role in enhancing innovation capabilities, which in turn significantly impacts residents' subjective well-being. Furthermore, organizational support and humanistic care within companies have been shown to be highly effective in improving employee performance and well-being (Kurtessis *et al.*, 2017). Workplace environmental risks are a prominent source of stress for geological surveyors. A survey conducted by Tao *et al.* (2023) revealed that different dimensions of perceived organizational support play distinct roles in stress management; emotional support directly alleviates occupational stress, while instrumental support buffers the impact of risk perception on occupational stress. Meluch (2021) conducted semi-structured interviews with 31 cancer patients, indicating that community cancer health organizations can alleviate stress for cancer patients. While organizational support can yield positive outcomes across various domains, it does not necessarily benefit or favor every member. The critical factor lies in the operational mechanisms of the organization and the internal realization of fairness and autonomy. As organizational behavior studies evolve, incorporating fairness into the analytical framework has become a direction for expanding the theory of collective action within organizations. In developing countries, faced with the challenges of public resource management, secondary organizations such as federations and cooperatives have emerged as a complementary force to governments, gradually becoming more formalized. Nepal's Forest Act of 1993 supported the establishment of Community Forest User Groups, granting them management rights, income distribution rights, and government funding to enhance their capabilities. The government provided training and exchange programs to facilitate the improvement of these groups in areas such as forestry management, business development, organizational management, and leadership, while also promoting democratic governance (Paudel *et al.*, 2012). In Brazil, Indonesia, Peru, and other regions, collective payment mechanisms have been introduced to protect tropical forests, but they face challenges related to collective action, such as the 'free-rider' problem. To address these challenges, individual incentives, sanctions, and strengthened government enforcement have become crucial in enhancing the efficiency, effectiveness, and equity of collective action for ecosystem services (Naime *et al.*, 2022).

Focusing on the adoption of technology by farmers, existing research confirms that organizational support may have a positive influence on farmers' technological adoption. Narrod *et al.* (2009) found that in studies on the quality and safety of agricultural products in Kenya and India, organizations effectively promoted the adoption of green agricultural production technologies to meet the quality and safety requirements of developed countries, enhancing attractiveness to consumers. Based on case studies of five fresh horticultural product supply chains, Boselie *et al.* (2003) discovered that industrial organizations not only enhance farmers' technological competitiveness and reduce transaction costs but also assist in the integration of technology-adopting farmers into the agricultural retail chain. Ainembabazi *et al*. (2017) found that the stronger the service function of farmer organizations, the shorter the waiting time for farmers' technology adoption.

The existing body of research provides a relatively comprehensive foundation for this paper, serving as a valuable reference and source of inspiration. However, there are opportunities for further expansion in the following areas: First, existing studies on the factors influencing the adoption of WSI technology have largely neglected the role of agricultural industry organizations, particularly the indirect impacts arising from different functional dimensions of organizational support. There is a distinct lack of systematic theoretical and mechanistic analysis in this domain. Second, although some research has explored the relationship between these factors, there is a dearth of discussion on the interplay between government support and organizational support. It remains to be seen whether organizational support can serve as a substitute for government support or if there is a complementary effect between the two. Third, current research findings lack contextual differentiation, especially in terms of distinguishing between different household management characteristics. Differences in household management characteristics lead to variations in motivations and determinants for technology investment, and failure to account for these differences can result in inaccurate conclusions. Consequently, this paper utilizes micro-level survey data from 1,178 households in the Yellow River Basin, adopting an organizational support perspective, to explore the effects of industrial organizations on farmers' willingness to adopt WSI technologies.

Compared to previous research, this paper may offer innovations in the following aspects: First, this study draws upon organizational behavior theory by linking organizational behavior with farmers' psychology and attitudes, thereby advancing the application of organizational behavior theory in the adoption of agricultural technology. The research not only confirms the impact of organizational participation on farmers' willingness to adopt WSI technology but also employs factor analysis to construct measurement indicators for organizational support across three dimensions: institutional support, tool support, and emotional support. This further explores the influence of the degree of organizational support on farmers' willingness to adopt WSI technology. Second, in terms of mechanistic research, this study verifies the impact of organizational support on farmers' willingness to adopt WSI technology through three mechanisms: standardized production, agricultural training, and proactive learning of agricultural techniques. Third, this study further analyzes the interactive relationship between government support and organizational support in influencing farmers' willingness to adopt WSI technology. Fourth, by considering not only the heterogeneity of farmers but also the quantity and quality characteristics of family land management, this paper further investigates variations in the effects of organizational support among different categories of groups (educational attainment and age) and different operational characteristics (land operation area and agricultural production conditions). This aims to explain differences in farmers' willingness to adopt technologies and propose targeted promotion strategies.

Implementation background of agricultural industrial organizations in China

Based on organizational behavior theory, members who join organizations benefit from organizational support, enabling them to alleviate fear through cooperation and collective action, thereby achieving outcomes unattainable individually. Agricultural industrial organizations in China are spontaneously formed, mutual-aid, functional, autonomous cooperative organizations of farmers. These organizations are formed by agricultural producers for the purpose of economic self-help, owned and democratically managed by members, ensuring equal access to economic benefits. Among these, farmers' professional cooperatives represent the most significant form of agricultural industrial organizations, playing a crucial role in the development of modern agriculture.

Historically, the development of agriculture in China has relied heavily on governmental policy support, a strategy that is unsustainable in the long run. In contrast to government support, agricultural cooperatives embody the characteristics of shared benefits and collective risk-bearing. This mutual-aid and autonomous nature helps prevent farmers from becoming overly dependent on external support. Regarding technology adoption, cooperatives do not impose mandatory participation on their members. Instead, they act as facilitators, providing support to help farmers overcome the challenges associated with adopting new technologies. Within the organizational structure of cooperatives, farmers retain the autonomy to decide whether to adopt WSI technologies and have the right to choose the type of technology that best suits their needs. Additionally, smallholder family farming has been the fundamental mode of agricultural operation in China for a long period. However, smallholders often face challenges such as low education levels, poor production skills, and outdated mindsets. Thus, smallholders need to strengthen their capacities through mutual cooperation, fostering joint development. This collaborative approach enhances their self-development capabilities, gradually transforming them into specialized households, leading to a virtuous cycle of autonomous development. Consequently, agricultural industrial organizations could potentially serve as an alternative to government policy support.

Organizational support not only reduces over-reliance on the government but also ensures farmers' independent decision-making through internal institutional design and external governmental oversight, ensuring equitable rights for all members. On the one hand, the establishment of agricultural cooperatives should adhere to the principle of voluntary membership, allowing farmers to freely join or withdraw, ensuring equal status for all members. It is essential to create a 'democratic association' characterized by democratic management and oversight, reflecting the farmers' wishes and demands. This ensures that farmers genuinely benefit from their participation, with organizational surpluses being proportionately redistributed based on members' transactions with the cooperative. On the other hand, the formation and operation of cooperatives are regulated and supervised by the government. According to the 'Law of the People's Republic of China on Farmers' Specialized Cooperatives,' the election and voting processes in members' assemblies are governed by an equal voting system. The amount of a member's investment does not directly correlate with their voting rights within the cooperative; each member is entitled to one basic vote, and no one can restrict or deprive this right. All members should enjoy equal rights to information, expression, participation, and decision-making within the organization and have equal access to the various services provided by the cooperative.

In the decision-making process, cooperatives prioritize collective interests over individual interests. This principle ensures a relatively fair distribution of benefits within agricultural cooperatives. In the rural social environment, which is deeply rooted in strong geographical bonds, interpersonal interactions, and reciprocal cooperation are long term and complex. The interaction between cooperative members is a process of multiple games. Even if, in certain decisions, some members' interests must be temporarily sacrificed for the overall benefit, these members can be reasonably and promptly compensated through flexible and diverse means in subsequent or future cooperations. This compensation could include resource allocation, granting of priority rights, direct economic compensation, or psychological support.

The Chinese government is vigorously promoting the development of agricultural industrial organizations to enhance the degree of farmer organization and effectively address the contradiction between small-scale production and large-scale markets.

Theoretical analysis and research hypotheses

WSI technologies encompass various techniques, including drip irrigation, micro-sprinkler irrigation, canal seepage irrigation, and plastic film mulching. WSI technologies not only help mitigate secondary soil salinization, enhance water resource efficiency, and reduce labor input, leading to increased productivity and income, but also facilitate the acceleration of agricultural mechanization, industrialization, and modernization. However, substantial upfront investment, long payback periods, high maintenance costs, and the risk of pipeline blockage due to improper operation pose challenges, constrained by soft constraints in mindset and hard constraints in economics, discouraging individual farmers' adoption. Agricultural industrial organization is a kind of professional operation transaction coordination mechanism for farmers, which is the means of coordination or contractual relationship between farmers and relevant enterprises or cooperative organizations in order to realize specialized production (Huang, 2018). Farmers' willingness to adopt technology is influenced by various factors, with economic benefits being a primary concern for rational economic actors. According to the 'interactionist perspective,' individuals' psychological cognition also influences their behavioral intentions. Industrial organizations offer a new pathway for incentivizing farmers' technological demands (Bikkina *et al.*, 2018). Through providing support and assistance to farmers, enhancing their technological awareness and production income, and reducing production costs and technology adoption costs, technologies that individual farmers find impractical or unwilling to adopt can be realized within the organization.

Organizational support is a critical factor in farmers' willingness to contribute to the organization. Coined by American psychologist Eisenberger *et al.* (1990), 'organizational support' reflects members' perceptions and beliefs about how the organization values their contributions and cares about their interests. Members who perceive organizational support are more likely to feel a responsibility toward the organization's development and contribute to achieving its goals (Farh *et al.*, 2007). Measurement of organizational support lacks unified indicators and evaluation methods, and is still in the exploratory stage, initially employing Eisenberger's single-dimensional concept. Later, McMillan (1997) proposed that the Eisenberger perceived organizational support measure focused on emotional support, ignoring the demand for equipment, information, tools, resources, and other aspects. Chinese research on organizational support dimensions has mainly focused on refining support content and sources (Ling *et al.*, 2006). In terms of support functions, organizational support includes crucial dimensions such as institutional support, tool support, and emotional support. Institutional support provides farmers with standardized technical specifications and stable production-sales relationships, while tool support influences the availability of agricultural inputs, information, and technology for farmers and market access for products. Emotional support acts on the formation of trust, reciprocity, and quality commitment psychology in industrial organizations. Organizational support theory and psychological contract theory assume that when members perceive more support in the organization, they engage in reciprocal behavior, repaying the support through efforts and improved performance (Yang *et al.*, 2015).

Institutional support provides farmers with the establishment of production standards, brand management, and contractual regulations. To meet the growing demand for high-quality agricultural products, industrial organizations offer specialized services and engage in the procurement, processing, and sales of agricultural products as agreed upon, thereby promoting brand certification. On the one hand, industrial organizations stimulate the demand for WSI technologies by implementing production standards among farmers. On the other hand, signing contracts, reducing sales risks, establishing standardized production norms, realizing brand management, attracting more consumers to buy, and increasing the willingness to pay at a premium, will have a positive impact on farmers' income (Liu & Di, 2013). The adoption of new technologies involves certain financial thresholds. As farmers' income increases, their enthusiasm for adopting resource-saving technologies in the production process continues to rise, thereby achieving higher and more stable agricultural income (Zhu *et al.*, 2015; Zuo, 2016).

Tool support comprises material support, personnel support, information support, and technical support (Aryee & Chay, 2001). Through training, it helps farmers reduce production costs, technology adoption costs, and maintenance costs, primarily playing a demonstrative and supportive role. First, due to risk avoidance, some farmers tend to adopt excessive fertilization or pesticide application behaviors, resulting in additional production costs (Ji *et al.*, 2016). Agricultural cooperatives and other industrial organizations invite agricultural experts and local agricultural extension personnel to provide technical guidance and training to members.

They standardize the input dosage and application frequency of pesticides and fertilizers, effectively allocating production factors, avoiding resource waste, and reducing costs, to some extent, addressing farmers' capacity deficiencies and saving production costs (Cai, 2013; Wan & Cai, 2021). Second, given the fragmented nature of Chinese land, constrained by plot and scale limitations, individual farmers often cannot bear the high costs of adopting WSI technologies. The core of controlling farmer behavior in industrial organizations lies in collective action. It can change the production and management patterns of small farmers by connecting them to work collectively, reducing technology adoption costs through centralized pipeline installation, and achieving economies of scale. Finally, the late-stage maintenance of WSI facilities requires more professional attention (Guo *et al.*, 2022). Industrial organizations provide training to farmers, conveying technical points, standardizing the application of technology, and operating post-maintenance of pipelines, reducing the late-stage repair costs of technology adoption and thus increasing the willingness to adopt WSI technologies.

Emotional support brings trust, care, and respect to farmers (Shore & Wayne, 1993), helping satisfy farmers' social and psychological needs (Newman *et al.*, 2012). When farmers perceive emotional care from the organization and feel satisfied, they are more likely to focus on the organization and exert more effort for its benefit (Ling *et al.*, 2006; Yang *et al.*, 2015). The stronger the received emotional support, the higher the likelihood of voluntarily implementing pro-environmental behaviors. It primarily manifests as a guiding role: mutual trust and reciprocal behavior between organizations and farmers enhance farmers' sense of social responsibility, facilitate changes in farmers' thoughts and subjective consciousness, promote farmers' acceptance of the modernization transformation of agricultural production methods, and increase farmers' enthusiasm for actively learning agricultural technology. It not only reduces the perception of risks associated with technology adoption but also helps farmers understand the importance of WSI technologies in water conservation, fertilizer reduction, labor savings, and yield improvement. To ensure a more enduring and stable material foundation, eliminate future concerns, and compensate for the opportunity cost of labor input, farmers intensify their technical investment in agricultural production, thereby enhancing their willingness to adopt WSI technologies.

Therefore, the institutional support provided by industrial organizations achieves a premium on farmers' product income by promoting standardized production, thereby enhancing farmers' revenue (Zhang & Shi, 2022). The tool support offered by industrial organizations, including training, facilitates the rational allocation of factors, improves the scientific nature of farming, and achieves savings in technology adoption costs and production costs. The emotional support provided by industrial organizations reduces the perception of technological risks and encourages farmers to actively engage in learning agricultural techniques. Overall, organizational support helps farmers overcome economic constraints and cognitive constraints, increasing the willingness to adopt WSI technologies. Based on the above analysis, the following hypotheses are proposed:

Hypothesis H1: Organizational participation increases farmers' willingness to adopt WSI technologies.
Hypothesis H2: Organizational support enhances farmers' willingness to adopt WSI technologies.
Hypothesis H3: Organizational support increases willingness to adopt WSI technologies by promoting standardized production.
Hypothesis H4: Organizational support increases willingness to adopt WSI technologies by encouraging farmers to participate in agricultural training.
Hypothesis H5: Organizational support increases willingness to adopt WSI technologies by promoting farmers' proactive learning of agricultural techniques.

The impact pathway of organizational support on farmers' adoption of WSI technologies is illustrated in Figure 1.

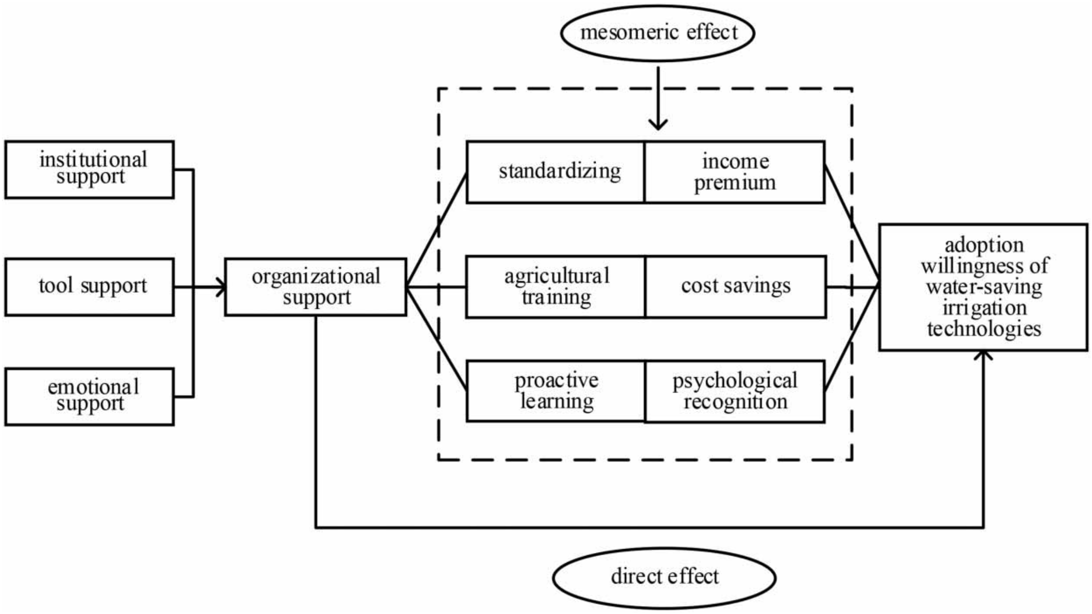


Fig. 1 | The influence path of organizational support on farmers' adoption willingness of WSI technology.

METHODS

Data sources

This study focuses on the Yellow River Basin, the second-largest river basin in China and the largest in northern China. Several considerations led to the selection of the Yellow River Basin as the research area. First, the Yellow River Basin is among the most water-scarce regions, with the most pressing issue being the shortage of water resources. The Yellow River, with only 2% of China's river runoff, supports 12% of the population, irrigates 15% of the arable land, and generates 14% of the country's GDP. Therefore, studying agricultural water-saving issues in the Yellow River Basin is highly representative. Second, the Yellow River Basin exhibits diverse topography, ranging from high mountains to plains, and its precipitation patterns vary significantly across regions. This complex natural environment fosters rich ecosystems and unique cultural landscapes, making the Yellow River Basin a microcosm of China's broader geographical and environmental conditions. Consequently, our research not only benefits the water resource utilization in the Yellow River Basin but also offers valuable insights for the development of water-saving technologies in other regions of China. Thirdly, to achieve sustainable water resource utilization in the Yellow River Basin, the Chinese government strongly advocates the widespread adoption of efficient WSI technologies, improvement of water-saving engineering systems, and vigorous support for the development of water-efficient agricultural facilities. Therefore, this study examines farmers' willingness to adopt WSI technologies in the Yellow River Basin. This analysis is both a practical necessity for the intensive use of water resources and a critical measure to ensure national food security.

In 2021, our research team conducted a survey of farmers in three provinces within the Yellow River Basin: Shaanxi, Gansu, and Ningxia. The data were collected using a combination of typical sampling, stratified sampling, and random sampling methods. Considering differences in policy implementation, socioeconomic factors, etc., two counties (districts) in Shaanxi Province (Pucheng County and Chengcheng County), two counties (districts) in Gansu Province (Linze County and Minle County), and one city in Ningxia (Qingtongxia City) were selected. This involved 5 counties and 14 towns. The one-on-one survey method was employed, covering aspects such as participation in industrial organizations, the degree of support provided by industrial organizations (cooperatives or enterprises) to farmers, and farmers' willingness to adopt relevant WSI technologies. A total of 1,283 questionnaires were collected, and after organizing and excluding invalid responses, and interpolating to address some missing values, 1,178 valid questionnaires were obtained, achieving an effective rate of 91%. Specifically, there were 417, 429, and 332 valid questionnaires from Shaanxi, Gansu, and Ningxia provinces, respectively.

Model specification

The dependent variable is 'Willingness to adopt WSI technologies for agricultural production,' which is a binary variable ranging from 0 to 1. Defining it as a discrete variable aims to avoid multicollinearity issues in the identification process. In linear models, personal characteristics would 'linearly' influence the dependent variable (Lu *et al.*, 2013), leading to multicollinearity problems. Brock & Durlauf (2001) found that in non-linear models such as Probit and Logit, multicollinearity issues can be circumvented. Based on the model fit, this paper opts for the Binary Probit model. It is assumed that the adoption behavior of farmers is determined by the following equation:

$$\text{Probit}(\text{adopt}_i = 1) = \Phi(\alpha_i \text{support}_i + \beta_i \text{individual}_i + \chi_i \text{household}_i + \partial_i \text{gov}_i) \tag{1}$$

The subscript i denotes the ith surveyed household. The dependent variable is a binary variable indicating the willingness to adopt WSI technologies (0–1 variable). If the household is willing to adopt WSI technologies, the value is 1; otherwise, it is 0. 'Support' is the core variable in this study, encompassing organizational participation behavior and organizational support degree. 'Individual,' 'household,' and 'gov', respectively, represent individual characteristics, household characteristics, and government support.

Variable selection

(1) *Dependent variable*: Farmers' willingness to adopt WSI technologies, derived from respondents' answers to the survey question 'Are you willing to adopt WSI technologies for agricultural production?' If willing, assign a value of 1; otherwise, 0.
(2) *Independent variables*: Organizational participation behavior and organizational support degree. Organizational participation behavior is measured by asking farmers, 'Are you involved in industry organizations (such as cooperatives or enterprises)?' If involved, assign a value of 1; otherwise, 0. Additionally, this study quantifies the organizational support degree using Likert's five-level scale. Following the organizational support questionnaire developed by Eisenberger *et al.* (1990) and adjusted by Ling *et al.* (2006) with a focus on three dimensions: institutional support, tool support, and emotional support, the average value is computed as the composite indicator of organizational support degree. Specific meanings and statistical features are presented in Table 1.
(3) Control variables: To mitigate potential interference from other factors influencing farmers' willingness to adopt WSI technologies, this paper borrows from existing literature (He *et al.*, 2018) and selects individual characteristics of farmers (including gender, age, health status, educational attainment, and risk preference), household operational features (share of income from agriculture, land operation area, conditions of agricultural production), and government support as control variables. Additionally, provincial variables are controlled to avoid estimation bias due to regional differences.

Descriptive statistics

The average value of farmers' willingness to adopt WSI technologies in the sample is 0.61; 34% of farmers participate in industry organizations. Since farmers' specialized cooperatives are the most important organizational form

Table 1 | Organizational support degree measure and descriptive analysis.

Variant	Meaning and assignment	
Organizational support	Institutional support	Cooperatives, businesses, and other organizations that have contracts or agricultural orders with me: 1 = None, 2 = Rarely, 3 = Generally, 4 = More often, 5 = Frequently
		Cooperatives, enterprises and other organizations set standards for me in agricultural production: 1 = None, 2 = Seldom, 3 = Average, 4 = More, 5 = Frequently
		Cooperatives, enterprises and other organizations provide me with brand certification services and trademarks: 1 = None, 2 = Seldom, 3 = Generally, 4 = More, 5 = Frequently
		Cooperatives, businesses, and other organizations provide me with marketing services: 1 = None, 2 = Rarely, 3 = Fairly, 4 = More, 5 = Frequently
	Tool support	Cooperatives, enterprises and other organizations provide me with the agricultural resources I need for production: 1 = None, 2 = Rarely, 3 = Generally, 4 = More often, 5 = Frequently
		Organizations such as cooperatives and businesses provide me with market information: 1 = No, 2 = Rarely, 3 = Generally, 4 = More often, 5 = Frequently
		Cooperatives, businesses and other organizations provide me with agricultural training and technical guidance: 1 = None, 2 = Rarely, 3 = Generally, 4 = More often, 5 = Frequently
		Organizations such as cooperatives, businesses, etc. provide me with financial support or guarantees for loans: 1 = None, 2 = Rarely, 3 = Generally, 4 = More often, 5 = Frequently
	Emotional support	Cooperatives, businesses, and other organizations respect my various decisions in melon production: 1 = very little respect, 2 = no respect, 3 = average, 4 = respect, 5 = very much respect
		Organizations such as cooperatives, businesses, etc. trust me a lot: 1 = very distrustful, 2 = distrustful, 3 = average, 4 = trustful, 5 = very trustful
		Organizations such as cooperatives give me guidance and help when I encounter problems in production: 1 = never, 2 = don't care, 3 = generally, 4 = concerned, 5 = very concerned
		Organizations such as cooperatives never engage in fraudulent practices in the distribution of agricultural funds or the acquisition of products: 1 = strongly disagree, 2 = disagree, 3 = fairly agree, 4 = agree, 5 = strongly agree

in agricultural industrial organizations, in the actual research, the industrial organization samples existing in the form of cooperatives account for the majority. There is significant variation in organizational support levels, ranging from a minimum of 0.41 to a maximum of 4.58. Surveyed farmers exhibit the following characteristics: more males than females, primarily due to the sample being mostly household heads; mostly middle-aged farmers; predominant education level is junior high and technical secondary, reflecting an ageing population and relatively low education levels, consistent with rural realities; most farmers exhibit risk-averse tendencies. There is considerable variation in the percentage of agricultural income at the household level, with an average land cultivation size of 14.51 mu, and agricultural production conditions surpass the median. Furthermore, to evaluate whether the adoption of WSI technologies brings economic and environmental benefits, we conducted interviews with farmers in the surveyed regions who have already adopted these technologies. Using a five-point Likert scale (1–5), we assessed various outcomes. The average perceived effectiveness of reducing per-mu costs was 3.62, the perceived effectiveness of increasing per-mu yields was 3.78, and the perceived effectiveness of improving product quality was 3.79, all of which are above the median value of 3. Therefore, most farmers who adopt these technologies believe that WSI yields substantial economic benefits. The average perceived effectiveness of improving soil quality was 3.75, and the average effectiveness of enhancing the ecological environment was 3.85, both above the median value of 3. Additionally, 64% of the farmers considered the ecological improvement to be useful or very useful. This further substantiates the significant practical importance of the Chinese government's promotion of WSI technologies. Specific meanings and descriptive statistics are provided in Table 2.

RESULTS

Impact of industrial organizations on farmers' adoption of WSI technologies

Beyond verifying the impact of farmers' organizational participation behavior on the willingness to adopt WSI technologies, an accurate evaluation of the developmental effectiveness of industrial organizations involves assessing their actual service-driving role. Therefore, the core independent variables in this study encompass organizational participation behavior and organizational support degree. Regression results are presented in Table 3. The results indicate that organizational participation behavior passes the significance test at a 1% confidence level, meaning that, under unchanged conditions, participating in industrial organizations enhances farmers' willingness to adopt WSI technologies. Similarly, the organizational support degree also passes the significance test at a 1% confidence level, suggesting that, with other conditions remaining constant, organizational support increases farmers' willingness to adopt WSI technologies. Hence, Hypotheses H1 and H2 are confirmed.

Specifically, industrial organizations stimulate the demand of farmers to adopt WSI technologies through regulated production standards and help farmers to comply with the unified quality management standards of agricultural products to improve the quality of agricultural products to achieve income premium (Yuan *et al.*, 2018; Li & Lu, 2020). Through training, industrial organizations reduce the later maintenance costs of WSI technologies and guide the proper dosage and frequency of elements, mitigating farmers' capacity constraints and saving production costs. Connecting scattered farmers for collective operations, industrial organizations lower the costs of technology adoption. Small farmers, receiving care and respect from organizations, build trust, fostering farmers' proactive learning of agricultural techniques and elevating their willingness to adopt WSI technologies.

Among the control variables, only the health status, educational attainment, and share of income from agriculture had a significant negative effect on the willingness to adopt WSI technology. The government support variables had a significant positive effect on the willingness to adopt WSI techniques. In addition, the regional virtual variables are significant, indicating that the willingness to adopt WSI technology has regional differences. The possible reason is that the government policies and social atmosphere vary from place to place.

Notably, the marginal effect of organizational participation behavior (0.099) exceeds that of organizational support degree (0.040). This suggests that the current level of support from industrial organizations has a relatively limited impact range and strength. In other words, while participating in industrial organizations increases farmers' willingness to adopt WSI technologies, effectively enhancing the degree of organizational support would further elevate farmers' willingness to adopt these technologies.

Examination of the mechanism by which organizational support degree affects farmers' willingness to adopt WSI technologies

Previous analyses delineated organizational support levels across three dimensions: instrumental, institutional, and emotional. Drawing on the methodology of Wen & Ye (2014), this study utilizes an intermediate effects model for mechanistic analysis. In this paper, the mechanism variables of agricultural training, standardized production, and proactive learning of agricultural technology representative organization tool, and institutional and emotional support are selected for verification. The analysis results are presented in Table 4.

Table 2 | Descriptive statistics.

Variable name	Meaning and assignment	Average value	Standard deviation	Minimum value	Maximum values
Willingness to adopt	Are you willing to adopt WSI technologies for agricultural production? 1 = Yes; 0 = No	0.61	0.487	0	1
Organizational participation behavior	Are you involved in industrial organizations (organizations such as cooperatives or businesses)?1 = Yes; 0 = No	0.34	0.475	0	1
Organizational support degree	Summed and averaged	1.49	1.488	0.416	4.583
Gender	Sex of head of household: 1 = male; 0 = female	0.94	0.241	0	1
Age	Age of head of household (years)	57.46	10.275	19	89
Health status	Health status of the head of the household: 1 = unable to take care of himself/herself; 2 = able to take care of himself/herself with a long-term chronic illness; 3 = frail with minor illnesses, 4 = healthy; 5 = very healthy	4.02	0.856	1	5
Educational attainment	Educational level of the head of household: 1 = illiterate; 2 = elementary school; 3 = middle school and secondary school; 4 = high school; 5 = college; 6 = bachelor's degree; 7 = master's degree	2.58	0.951	1	7
Risk preference	If you had an asset, what type of investment would you prefer: 1 = high risk and high return; 2 = average risk and average return; 3 = lower risk and lower return; 4 = stable return without any risk	3.24	0.928	1	4
Share of income from agriculture	Ratio of agricultural income to total household income (%)	0.51	0.329	0.009	1
Land operation area	(mu)	14.51	16.558	0.7	360
conditions of agricultural production	Additive synthesis	11.42	2.085	4	15
	Soil quality: 1 = very bad; 2 = bad; 3 = fair; 4 = better; 5 = very good				
	Condition of field roads: 1 = very bad; 2 = bad; 3 = fair; 4 = better; 5 = very good				
	Land level: 1 = very bad; 2 = bad; 3 = fair; 4 = better; 5 = very good				
Government support	Whether the government has carried out sensitization activities related to farmland management strategies: 1 = yes; 0 = no	0.47	0.500	0	1
Gansu	1 = yes; 0 = no	0.36	0.481	0	1
Ningxia	1 = yes; 0 = no	0.28	0.450	0	1
Mediation variables					

(*Continued.*)

Table 2 | Continued

Variable name	Meaning and assignment	Average value	Standard deviation	Minimum value	Maximum values
Standardizing	Degree of standardization of production: 1 = very bad; 2 = bad; 3 = fair; 4 = better; 5 = very good	3.08	1.153	1	5
Agricultural training	Participation in agricultural training? 1 = Yes; 0 = No	0.23	0.423	0	1
Proactive learning	How often do you take the initiative to learn from and seek help in agricultural technology? 1 = Never; 2 = Occasionally; 3 = Generally; 4 = Often; 5 = Frequently	2.16	1.232	1	5

Results from Models (1), (2), and (3) demonstrate that organizational support has a mechanism of influencing farmers' willingness to adopt WSI technologies through standardized production, explaining 39.27% of the total effect. Results from Models (1), (4), and (5) reveal that organizational support has a mechanism of indirectly increasing farmers' willingness to adopt WSI technologies by promoting participation in training, explaining 38.86% of the total effect. Results from Models (1), (6), and (7) demonstrate that organizational support has a mechanism of indirectly increasing farmers' willingness to adopt WSI technologies by promoting proactive learning of agricultural techniques, explaining 16.46% of the total effect. Hypotheses H3, H4, and H5 are confirmed.

Organizational support incentivizes the adoption of WSI technologies by promoting standardized production and agricultural training, achieving product premiums and cost savings. It also overcomes soft constraints on farmers' adoption intentions by stimulating proactive learning of agricultural techniques, raising awareness, and increasing willingness to adopt WSI technologies.

Heterogeneity analysis

Considering the heterogeneity of peasant household characteristics and household management characteristics, this paper divides the average educational level and age of the sample farmers according to the average value. Table 5 shows that the influence of organizational support on the adoption willingness of farmers in different groups (educational attainment and age) and different management characteristics (land operation area and agricultural production conditions) is very different. Among them, organizational support has a significant impact on the less educated and young farmers. The adoption willingness of farmers with large land management areas and poor agricultural production conditions is significantly affected by organizational support. Farmers with large operating areas often need more water resources to irrigate their crops, and with more resources and capital, they can more easily bear the cost of adopting WSI technology and also have the motivation and ability to introduce advanced technologies to improve yield and efficiency. Farmers with poor agricultural production conditions are faced with more urgent production problems and need to introduce advanced technology faster to improve production conditions. On the contrary, farmers with good roads are already able to meet their needs under traditional irrigation methods, so there is no urgent need to introduce WSI technology, or there is a resource curse.

Robustness tests

Sample selection

Due to the long investment return cycle and high risks associated with WSI technologies, the production behavior of elderly individuals tends to shift from rational small-scale farming to ethical small-scale farming. The goals in agricultural production transform from profit maximization to risk minimization. For the elderly, the benefits

Table 3 | Impact of industrial organizations on farmers' willingness to adopt WSI technology.

	(1) Willingness to adopt		(2) Willingness to adopt	
	Probit model	**Marginal effect**	**Probit model**	**Marginal effect**
Organizational participation behavior	0.286***	0.099		
	(0.11)	0.037		
Organizational support degree			0.116***	0.040
			(0.04)	0.013
Gender	−0.253	−0.088	−0.243	−0.084
	(0.18)	0.061	(0.18)	0.061
Age	−0.005	−0.002	−0.004	−0.001
	(0.00)	0.002	(0.00)	0.002
Health status	0.221***	0.077	0.227***	0.079
	(0.05)	0.017	(0.05)	0.017
Educational attainment	−0.148***	−0.052	−0.151***	−0.052
	(0.05)	0.016	(0.05)	0.016
Risk preference	0.061	0.021	0.060	0.021
	(0.04)	0.015	(0.04)	0.015
Share of income from agriculture	−0.390***	−0.135	−0.402***	−0.139
	(0.15)	0.050	(0.15)	0.050
Land operation area	0.001	0.000	0.001	0.000
	(0.00)	0.001	(0.00)	0.001
Conditions of agricultural production	−0.067***	−0.023	−0.073***	−0.025
	(0.02)	0.008	(0.02)	0.008
Government support	0.467***	0.162	0.460***	0.159
	(0.09)	0.029	(0.09)	0.029
Gansu	0.418***	0.145	0.381***	0.132
	(0.15)	0.050	(0.14)	0.050
Ningxia	0.833***	0.290	0.854***	0.296
	(0.13)	0.044	(0.13)	0.044
Constant term	0.359		0.312	
	(0.49)		(0.49)	
N	1,178		1,178	
Prob $> \chi^2$	0.0000		0.0000	
Pseudo R^2	0.0881		0.0900	

Note. ***, **, and * indicate that the estimates are significant at the 1, 5, and 10% levels, respectively, and robust standard errors are in parentheses.

of WSI technologies in the later stages of their remaining agricultural production years are challenging to offset the investment costs. Therefore, the promotion of WSI technologies should primarily target the labor force of appropriate age. To test the robustness of empirical results, this study excludes samples of male farmers aged 60 years and above and female farmers aged 55 years and above. After controlling for other variables, the

Table 4 | Mechanism test of organizational support degree on farmers' willingness to adopt WSI technology.

	(1) Willingness to adopt	(2) Standardizing	(3) Willingness to adopt	(4) Agricultural training	(5) Willingness to adopt	(6) Proactive learning	(7) Willingness to adopt
Organizational support degree	0.116***	0.163***	0.070*	0.067***	0.071*	0.101***	0.105***
	(0.04)	(0.03)	(0.04)	(0.01)	(0.04)	(0.03)	(0.04)
Standardizing			0.281***				
			(0.04)				
Agricultural training					0.724***		
					(0.11)		
Proactive learning							0.190***
							(0.04)
Control variables	YES						
N	1,178	1,178	1,178	1,178	1,178	1,178	1,178
R^2		0.279		0.262		0.142	
Pseudo R^2	0.0900		0.1216		0.1165		0.1090
Prob> χ^2	0.0000		0.0000		0.0000		0.0000

Note. *** and * indicate that the estimates are significant at the 1 and 10% levels, respectively, and robust standard errors are in parentheses.

Table 5 | Heterogeneity analysis of organizational support degree on farmers' willingness to adopt WSI techniques.

	(1) Age		(2) Educational attainment		(3) Land operation area		(4) Conditions of agricultural production	
Willingness to adopt	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Organizational support degree	0.057	0.149***	0.028	0.120***	0.136**	0.086	0.056	0.151***
	(0.06)	(0.05)	(0.10)	(0.04)	(0.05)	(0.05)	(0.05)	(0.06)
Control variables	YES							
N	578	600	159	1018	375	803	582	596
Pseudo R^2	0.1409	0.0648	0.1222	0.0881	0.1186	0.0935	0.1148	0.0751
Prob> χ^2	0.0000	0.0000	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000

Note. *** and ** indicate that the estimates are significant at the 1 and 5% levels, respectively, and robust standard errors are in parentheses.

Binary Probit regression is rerun, and the results, as shown in (1) of Table 6, are consistent with those in Table 3. Even after excluding the elderly samples, the degree of organizational support remains significant through significance tests. This confirms that organizational support significantly increases farmers' willingness to adopt WSI technologies.

Variable replacement

Furthermore, this study employs factor analysis to reconstruct the variable of organizational support degree, testing the robustness of regression results. Using factor analysis, the Kaiser–Meyer–Olkin value for the

Table 6 | Regression results of organizational support degree on farmers' willingness to adopt WSI technology after excluding elderly samples and replacing variables.

Variable name	(1) Exclusion of older persons Willingness to adopt	(2) Substitution of variables Willingness to adopt
Organizational support degree	0.135***	
	(0.04)	
Level of organizational support (factor synthesis)		0.175***
		(0.05)
Control variables	YES	
N	745	1,178
Prob> χ^2	0.0000	0.0000
Pseudo R^2	0.0870	0.0903

Note. *** indicates that the estimates are significant at the 1% level, and robust standard errors are in parentheses.

organizational support degree variable is calculated as 0.949, and Bartlett's sphericity test's approximate chi-square is 32,747.099 (sig = 0.000). Passing the 1% level of significance, the suitability for factor analysis is confirmed. The cumulative variance contribution rate is 89.902%, indicating that the extracted common factors effectively reflect the information of the original variables. As observed in (2) of Table 6, the organizational support degree variable passes significance tests at the 1% confidence level, with a positive direction. This result corroborates the main conclusion of the study, emphasizing that a stronger organizational support degree corresponds to a higher willingness among farmers to adopt WSI technologies.

Endogeneity analysis

Participation in industrial organizations significantly influences farmers' willingness to adopt WSI technologies. However, farmers' participation in industrial organizations is not a completely random choice; it is typically influenced by individual characteristics, family features, and regional factors. The resulting self-selection issue may introduce bias into the model estimates. Considering the endogeneity issue resulting from measurement errors and missing variables, to ensure the correctness of the results, this study introduces the average organizational support degree of other respondents in the same village, excluding the interviewed individual, as an instrumental variable for the organizational participation behavior. The rationale behind this choice is that within the same village, an individual farmer's organizational participation behavior is related to the organizational support degree of other farmers in that village. Simultaneously, the organizational support degree of other farmers in the village is not directly related to the individual's willingness to adopt WSI technologies. Therefore, it is strictly exogenous. Table 7 provides the Wald test results for the exogeneity hypothesis 'H_0:$\rho = 0$,' with a p-value of 0.000. Thus, organizational participation behavior can be considered an endogenous explanatory variable at the 1% significance level. The first-stage F-value is 325.19, indicating that the instrumental variable is not weak. In this study, the number of instrumental variables chosen equals the number of endogenous explanatory variables, eliminating the need for an over-identification test. Through the Iv-Probit(1) regression, the instrumental variable for organizational participation behavior achieves a significance level of 1%, demonstrating its strong explanatory power for organizational participation behavior and satisfying the instrument variable relevance assumption. After considering endogeneity, the conclusion remains valid that participation in industrial organizations promotes farmers' willingness to adopt WSI technologies.

Table 7 | Regression results of organizational participation behavior on farmers' willingness to adopt WSI techniques after the introduction of instrumental variables.

	(1) Organizational participation behavior	(2) Willingness to adopt
Organizational participation behavior IV	2.117***	
	(0.16)	
Organizational participation behavior		0.699***
		(0.15)
Control variables	YES	
N	1,178	1,178
Prob> χ^2	0.0000	0.0000
ar^2	0.7686	
$F(12, 1160)$	325.19	
Prob > *F*	0.0000	

Note. *** indicates that the estimates are significant at the 1% level, and robust standard errors are in parentheses.

Further analysis: The synergistic effect of agricultural industry organization support and government support

Industrial organizations are autonomous grassroots organizations of farmers, while the government functions as an authoritative administrative body. To validate the influence of organizational support and government support on farmers' willingness to adopt WSI technologies, we incorporated an analysis of the synergistic effects between these supports. For ease of comparison, we attach (1) of Table 3 to (1) of Table 8.

The results show that the coefficient for government support is 0.467 and the coefficient for organizational support is 0.286, both significant at the 1% level. This indicates that both government and organizational support can enhance farmers' willingness to adopt WSI technologies. We included an interaction term for government

Table 8 | Interactions of organization support with government support.

	(1) Willingness to adopt		(2) Willingness to adopt	
	Probit model	Marginal effect	Probit model	Marginal effect
Interactive item			0.348**	0.120
			(0.17)	0.059
Organizational participation behavior	0.286***	0.099	0.109	0.037
	(0.11)	0.037	(0.14)	0.048
Government support	0.467***	0.162	0.352***	0.121
	(0.09)	0.029	(0.10)	0.035
Control variables	YES			
N	1,178		1,178	
Prob> χ^2	0.0000		0.0000	
Pseudo R^2	0.0881		0.0907	

Note. *** and ** indicate that the estimates are significant at the 1 and 5% levels, respectively, and robust standard errors are in parentheses.

support and organizational support based on (1) of Table 8. The interaction term's coefficient is 0.348, significant at the 5% level. Although the coefficient for organizational support becomes insignificant after adding the interaction term, the results still demonstrate a combined effect. This suggests that government support provides a beneficial complement to organizational support. While government support is more effective, it also imposes additional fiscal burdens, which may not be sustainable in the long term. International organizations impose stringent restrictions on government aid and subsidies, and there is significant international skepticism regarding China's agricultural subsidies. Given this context, seeking low-cost alternatives is necessary. Our research offers potential insights into this issue. Therefore, the Chinese government can develop agro-industrial organizations based on the use of subsidized micro-permit space as a viable way to promote technology.

DISCUSSION

Long-term effects of organizational support on farmers' adoption of WSI technology

This study demonstrates that joining industrial organizations can enhance farmers' willingness to adopt WSI technologies. However, whether this influence is sustainable in the long run remains inconclusive. Due to the lack of long-term panel data, this study cannot empirically verify the long-term impact of industrial organizations, which is a limitation that needs to be addressed in future research. Nevertheless, insights can be drawn from the institutional design of industrial organizations and the characteristics of WSI technologies.

WSI technologies require substantial initial investment and have relatively long payback periods, deterring small farmers from adopting them. In China, smallholder farming will continue to dominate for the foreseeable future. The short-sighted behavior of farmers and financial constraints hinder the adoption of such technologies, adversely affecting the sustainable use of agricultural water resources. By analyzing the influence of organizational support on farmers' willingness to adopt WSI technologies, this study connects organizational behavior theory with farmers' psychology and attitudes, promoting the application of organizational behavior in technology adoption. This approach provides new pathways for farmers to adopt technologies, enriching both behavioral economics and organizational behavior studies. Our research shows that both organizational participation behavior and the degree of organizational involvement significantly increase farmers' willingness to adopt WSI technologies, similar to the findings of Jia *et al.* (2024), which indicate that farmers' participation in collective actions positively impacts decisions regarding terracing, WSI, and afforestation. Cooperatives strengthen farmers by uniting them, helping them overcome financial constraints associated with technology adoption. Through training, cooperatives enhance farmers' overall skills and capabilities, playing a supportive role in promoting productive investments. Cooperatives provide cognitive guidance and improve farmers' capabilities, aiding in their gradual self-development (Hoffmann, 2018). Although WSI technologies require substantial initial investment, their long lifespan means that once adopted with cooperative support, farmers are likely to use them for an extended period. Our field surveys indicate that farmers who have adopted WSI technologies generally perceive positive outcomes and significant economic benefits. As rational economic agents, farmers are thus motivated to adopt these technologies long-term. The impact of WSI technologies is profound and comprehensive, enabling cooperatives to guide farmers toward sustainable development and get rid of the poverty trap.

The economic impact of WSI technology

While industrial organizations can enhance farmers' willingness to adopt WSI technologies, the actual economic benefits and potential income increases require further empirical testing. As rational economic agents, farmers' continued use of WSI technologies hinges on their economic viability. This study further analyzes the impact of adopting these technologies on farmers' incomes. Table 9 verifies the influence of WSI technology adoption on per-mu income (take logarithmic). Considering potential endogeneity issues, we used the frequency of

Table 9 | The influence of WSI technology adoption on the per-mu income.

	(1) Farmers' per-mu income	(2) Adopt behavior	(3) Farmers' per-mu income
Adopt behavior	0.157***		2.038**
	(0.06)		(0.81)
Communicate your agricultural techniques with others		0.029***	
		(0.01)	
Control variables	YES		
N	1,178	1,178	1,178
R^2	0.044	0.050	

Note. *** and ** indicate that the estimates are significant at the 1 and 5% levels, respectively, and robust standard errors are in parentheses.

communication about WSI technologies with others as an instrumental variable for adoption. The results indicate that adopting WSI technologies significantly increases farmers' per-mu income, demonstrating substantial economic benefits.

Environmental impact of WSI technology

This study analyzes the influence of industrial organizations on farmers' willingness to adopt WSI technologies and further discusses the economic benefits and long-term adoption potential. However, it does not empirically verify the environmental impacts of these technologies. Existing research suggests consensus on several aspects of the environmental benefits of WSI technologies. They conserve water, protect water resources, and efficiently utilize resources. Techniques like drip and sprinkler irrigation prevent soil compaction and salinization caused by traditional flood irrigation, improve soil structure, and enhance soil fertility, significantly contributing to environmental protection. Moreover, these technologies reduce the incidence of pests and diseases, lowering the use of pesticides and fertilizers, thereby alleviating environmental pressure and reducing ecological risks in agricultural production, further improving food safety.

Although the environmental benefits of WSI technologies are widely recognized, current assessments are primarily based on objective measurements through natural experiments, posing challenges for quantification from economic and sociological perspectives. Therefore, analyzing the environmental impacts of these technologies using social science and economic methodologies remains a future direction for research.

SWOT analysis of the promotion of WSI technologies under the development strategy of industrial organization

Given the low adoption rates of WSI technologies among farmers, a significant challenge to efficient agricultural water resource utilization persists. To effectively harness the potential of industrial organizations, stimulate farmers' enthusiasm for adoption, and promote WSI technologies, we have drawn upon the research findings of Srivastava & Chinnasamy (2021) to conduct a Strength–Weaknesses–Opportunities–Threats (SWOT) analysis of the promotion of WSI technologies under the strategic framework of industrial organization development. This analysis aims to better identify key issues and challenges (Table 10).

Based on the above analysis, WSI technologies are crucial for improving water resource efficiency and ensuring sustainable agricultural development. The Chinese government actively promotes these technologies through financial subsidies and tax incentives. However, challenges such as low farmer acceptance, high initial costs, and fragmented land pose significant barriers. The rise of industrial organizations presents new opportunities

Table 10 | SWOT analysis of the promotion of WSI technologies under the development strategy of industrial organization.

Strength	Weakness
• WSI technologies effectively reduce water waste, maintain ecological balance, promote crop growth, and enhance agricultural yields and quality.	• The initial investment costs of WSI technologies are relatively high, including expenses for equipment procurement, installation, and maintenance.
• The Chinese government strongly supports WSI technologies, implementing policies to encourage the development and adoption of these technologies.	• Small and fragmented landholdings in rural China limit the effective application and scalability of WSI technologies.
• WSI technologies in China have become relatively mature, with high stability and reliability.	• Farmers have a low acceptance of WSI technologies due to information barriers and the constraints of traditional practices.
Opportunity	**Threat**
• Agricultural organizations can centralize resources and planning, improving the adoption rate of WSI technologies.	• Some organizations face issues like poor management, lack of transparency, and unequal benefit distribution.
• Government support for cooperatives provides essential policy, financial, and technical backing for promoting WSI technologies.	• Members of industrial organizations often have relatively low levels of education and specialized knowledge.
• The successful models of agricultural industrial organizations offer replicable experiences and strategies for promoting WSI technologies in other regions.	• Resource disparities among members of industrial organizations may lead to unequal distribution of resources, potentially causing conflicts within the organization.

for the promotion of WSI technologies by integrating resources, reducing costs, and increasing adoption rates. The Chinese government also provides strong support for the development of these organizations. As the models of industrial organizations mature and successful experiences are disseminated, the application of WSI technologies is likely to expand. Nevertheless, challenges such as poor management, low member quality, and resource disparities within industrial organizations may affect the effectiveness of technology promotion and the stability of these organizations. Therefore, it is essential to strengthen the standardization of industrial organizations, improve service levels, enhance member quality, and ensure the effective promotion of WSI technologies, thereby supporting sustainable agricultural development.

Policy recommendations

In view of the above analysis, we put forward the following suggestions to better promote farmers' willingness to adopt WSI technology through industrial organizations.

- *Fostering industrial organizations and encouraging farmer participation:* To bolster the cultivation of industrial organizations, efforts should be made to increase their quantity and improve service levels to meet diverse needs. Awareness campaigns should be employed to encourage more farmers to join these organizations, facilitating effective alignment between farmers and industrial organizations. Attention should be given to the development of various dimensions of industrial organizations. This includes promoting farmers' active participation in standardized production, enhancing their management capabilities and agricultural production techniques, and strengthening the connection between industrial organizations and farmers. Such measures will enhance institutional support, emotional support, and tool support provided by industrial organizations.

- *Improving governance structures and operational norms*: It is essential to advance the establishment of robust governance structures within cooperatives, ensuring that farmers maintain a central role within these organizations, and to enhance the management level and operational efficiency of cooperatives. Institutional designs should be implemented to safeguard farmers' interests within cooperatives, such as establishing benefit distribution mechanisms and setting up farmer rights protection funds.
- *Strengthening institutional safeguards for industrial organizations*: Legislation should be enacted to clearly define the legal status of cooperatives, ensuring their rights as independent legal entities. The founding regulations of cooperatives should be thoroughly reviewed, and their operations monitored and evaluated to ensure that their development aligns with farmers' interests and prevents them from becoming tools that harm farmers' interests. The government should establish a dispute resolution mechanism for cooperatives, providing farmers with convenient and efficient means to resolve conflicts and protect their legal rights.
- *Considering farmer heterogeneity in the role of industrial organizations*: When leveraging the role of industrial organizations, the heterogeneity of the farmer population should be considered, and differentiated strategies should be implemented for different groups. Financial assistance should be provided to small farmers with poor agricultural production conditions. Meanwhile, large farmers with better production conditions should be offered professional agricultural planning and management consulting services to increase the attractiveness of technical investments.

CONCLUSION

The findings are summarized as follows: First, organizational participation behavior significantly and positively influences farmers' willingness to adopt WSI technologies. Addressing potential endogeneity concerns, constructing instrumental variables, and conducting robustness tests using the Iv-Probit model reveal that organizational participation behavior has a higher marginal contribution to farmers' willingness to adopt WSI technologies. Construct the degree of organizational support variable from different support dimensions, and the study found that organizational support plays a significant role in promoting farmers' willingness to adopt WSI technology. This conclusion is still true after using factor analysis to reconstruct the organizational support degree variable and eliminate the elderly sample. Second, mechanism analysis indicates that organizational support degree, through enhancing the standardization of farmers' production, participation in agricultural training, and proactive learning of agricultural techniques, indirectly increases farmers' willingness to adopt WSI technologies. Third, the analysis of individual heterogeneity reveals that for farmers with lower educational levels and younger age, an organizational support degree significantly promotes their willingness to adopt WSI technologies. The analysis of the heterogeneity of the quantity and quality characteristics of family agricultural management shows that for farmers with large land operation areas and poor agricultural production conditions, the degree of organizational support has a significant effect on their willingness to adopt WSI technology. Last, organizational support and government support can play a joint role in promoting farmers' willingness to adopt WSI technology. Both form a useful complement.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Y. D. and Q. L. conceived the study; Y. D. and J. C. proposed the methodology and edited the manuscript; Y. D. collected and analyzed the data. All the authors have approved the final manuscript.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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