Impact of Farmers' Irrigation Behavior Objectives on Irrigation Water Use Efficiency: A Case Study of Shaya County (Postprint)

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Abstract

Agricultural water use has consistently accounted for the vast majority of total water consumption, serving as a fundamental input factor for agricultural production development. However, the complex climatic environment has posed tremendous challenges to agricultural water use, making the contradiction between supply and demand of agricultural water resources even more pronounced. From a micro-level perspective, this study explores the impact of irrigation behavior target preferences on irrigation water use efficiency, aiming to optimize and select approaches for improving agricultural water use efficiency and maximize agricultural benefits under resource and environmental constraints. Taking traditional farmers in Shaya County, Xinjiang as the research subject, a stochastic frontier model is constructed to measure agricultural production technical efficiency and derive irrigation water use efficiency; subsequently, a Tobit model is employed to examine the influence of irrigation behavior target preferences and other factors on irrigation water use efficiency. The results indicate that the average agricultural production technical efficiency of farmers is 0.824, and the average irrigation water use efficiency is 0.560; neither agricultural production technical efficiency nor irrigation water use efficiency has achieved full technical efficiency, leaving room for improvement. The study of influencing factors reveals that age, education level, proportion of agricultural income to total income, irrigation area, perception of water scarcity, village cadre status, participation in training, preference for profit maximization, and preference for water conservation have significant positive effects on irrigation water use efficiency; the proportion of water-consuming crop planting area to total sown area and preference for reducing labor input have significant negative effects on irrigation water use efficiency; agricultural labor force, proportion of water-saving irrigation area to total irrigation area, water cost, preference for timely irrigation, and sustainable development have no significant impact on irrigation water use efficiency, and water cost exerts a negative effect on the improvement of irrigation water use efficiency. To improve irrigation water use efficiency, the following policy recommendations are proposed: enhance farmers' water-saving awareness, adjust planting structure, and improve the irrigation water pricing mechanism.

Full Text

Influence of Farmers' Irrigation Behavior Goals on Irrigation Water Efficiency: A Case Study of Xayar County

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Abstract

Agricultural water consumption currently accounts for the vast majority of total water use and serves as the fundamental input element for agricultural production and development. However, the complex climate environment poses enormous challenges to agricultural water use, making the contradiction between supply and demand of agricultural water resources increasingly prominent. This study examines micro-level dynamics by investigating how irrigation behavior goal preferences affect irrigation water use efficiency, aiming to optimize and select approaches for improving agricultural water efficiency to maximize agricultural benefits under resource and environmental constraints. Focusing on traditional farmers in Xayar County, Xinjiang, we constructed a stochastic frontier model to measure agricultural production technical efficiency and derived irrigation water efficiency values. We then employed a Tobit model to explore the impacts of irrigation behavior goal preferences and other factors on irrigation water efficiency. The results indicate that the average technical efficiency of agricultural production is 0.824, with an average irrigation water efficiency of 0.560. Neither agricultural production technical efficiency nor irrigation water efficiency has reached the level of full technical efficiency, leaving considerable room for improvement. Analysis of influencing factors reveals that age, education level, proportion of agricultural income in total household income, irrigated area, awareness of water scarcity, village cadre status, participation in training, preference for profit maximization, and preference for water conservation have significant positive effects on irrigation water efficiency. Conversely, the proportion of water-consuming crop planting area to total sown area and preference for reducing labor input exert significant negative effects. Agricultural labor force, proportion of water-saving irrigation area to total irrigated area, water use cost, preference for timely irrigation, and sustainable development orientation show no significant effects, with water use cost actually playing a negative role in improving irrigation water efficiency. To enhance irrigation water efficiency, we propose the following policy recommendations: strengthen farmers' water-saving awareness, adjust planting structures, and improve the irrigation water pricing mechanism.

Key words: irrigation behavior; goal preference; influencing factors; irrigation water efficiency; Xayar County

1 Introduction

Water resource protection, development, and utilization are crucial for sustainable development and national economic operation, significantly impacting the orderly conduct of human production activities and the effective safeguarding and improvement of people's living standards. Xinjiang, located in the hinterland of the Eurasian continent, features a typical arid climate. According to the 2021 Xinjiang Water Resources Bulletin, Xinjiang's total water resources amount to 801.0×10^8 m^3, with per capita water resources of 2938.19 m^3. In 2020, Xinjiang's total water consumption reached 549.93×10^8 m^3, with agricultural water use accounting for over 95% of the total, and farmland irrigation water comprising more than 90% of agricultural water use. This means farmland irrigation water exceeds 85% of Xinjiang's total water consumption. The 2020 China Water Resources Bulletin indicates that Xinjiang's farmland irrigation water effective utilization coefficient is 0.574, suggesting substantial potential for improvement. In contrast, economically developed regions such as Beijing, Tianjin, and Shanghai have irrigation water utilization coefficients above 0.7. This disparity underscores the arduous task of further improving agricultural irrigation water efficiency in Xinjiang.

Agricultural water-saving irrigation technology is particularly important for agricultural output, and enhancing irrigation water efficiency is required by both Xinjiang's agricultural sustainable development policy system and practical needs. Although Xinjiang's high-efficiency water-saving irrigation area has increased annually, water efficiency has not significantly improved, indicating that improving water efficiency through water-saving technology alone has encountered bottlenecks. Consequently, it is necessary to investigate from the perspective of farmers' own management behavior goals and deeply explore how farmers' irrigation behavior goals affect irrigation water efficiency.

Recent research on irrigation water efficiency primarily focuses on three aspects: definition, measurement, and influencing factors. Regarding definition, scholars define irrigation water efficiency as the ratio of potential (minimum) agricultural water input required to achieve optimal technical efficiency to actual agricultural water input, based on a multi-factor agricultural production framework. From a technical efficiency perspective, irrigation water efficiency is defined as the ratio of the minimum possible irrigation water amount to actual irrigation water amount, holding other inputs and outputs constant.

For measurement, scholars primarily employ parametric and non-parametric methods, namely Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). Many scholars use macro and micro data with SFA models to measure agricultural production technical efficiency and subsequently calculate irrigation water efficiency. Others use DEA models to directly measure agricultural water efficiency, while some employ both methods simultaneously.

Regarding influencing factors, scholars generally agree that farmers' endowments, household characteristics, technology and irrigation infrastructure conditions, natural conditions, and policy environments affect irrigation water efficiency. However, literature directly examining how farmers' irrigation behavior goals affect irrigation water efficiency is relatively scarce, mainly focusing on how farmers' production behavior goals influence production activities. Since agricultural irrigation constitutes a crucial part of agricultural production, existing research on farmers' production behavior goals provides valuable references for this study.

1.1 Study Area Overview

Xayar County is located in southern Xinjiang and features a typical continental arid desert climate characterized by dry conditions, low rainfall, high agricultural water consumption, and relative water scarcity. The county primarily grows grain crops and cotton. Due to harsh climate conditions and poor irrigation conditions, the contradiction between water supply and demand is particularly acute. Since 2020, Xayar County has vigorously implemented high-efficiency water-saving projects, using southern Xinjiang's high-efficiency water-saving income-increasing pilot projects as a breakthrough to promote large-scale construction of high-standard farmland.

1.2 Data Sources

In March 2022, research team members distributed questionnaires and conducted household interviews. We randomly selected 210 typical farm households from Yingmaili Town, Hailou Town, Hongqi Town, Gulebage Town, and Tuoyibaoledi Town. A total of 210 questionnaires were distributed, with 200 valid questionnaires recovered, yielding a 95.24% validity rate.

1.3 Methodology

1.3.1 Mechanism Analysis According to Ajzen's Theory of Planned Behavior, individual behavioral intentions are highly correlated with actual behavior. Farmers' behavioral goals can fully reflect their intentions, and different behavioral goals indicate different intentions. As irrigation behavior constitutes part of production activities, the goals farmers pursue during irrigation correspond to those in their overall production activities.

Irrigation behavior goals evolve over time and with environmental factors. In initial stages, farmers pursue yield increases. When livelihood needs are met, they reduce costs to improve agricultural income. When water shortage risks are high, they tend to avoid risks and obtain timely irrigation. Farmers with higher off-farm income focus more on leisure and reducing labor input. While achieving economic goals, they also consider social responsibility and respond to water conservation calls to gain respect and recognition. New-generation farmers pay greater attention to environmental protection and sustainable development. Based on this analysis, this study proposes diversified farmers' irrigation behavior goals: profit maximization, timely irrigation, risk avoidance, reduced labor input, increased leisure time, water conservation, gaining respect, and sustainable development.

From a management perspective, efficiency refers to the ratio of different inputs to outputs over a period, including producing a certain output at minimum cost or maximizing output at a certain cost. Efficiency is inversely proportional to input and directly proportional to output. Irrigation water use efficiency decreases as irrigation volume increases. The specific effect of farmers' irrigation behavior goal preferences on irrigation water efficiency depends on the relative magnitude of input and output changes.

Farmers preferring profit maximization focus on reducing production costs and increasing yields. To reduce irrigation costs, they decrease water use to improve water efficiency. Farmers preferring timely irrigation and risk avoidance pay more attention to whether crops receive timely irrigation during critical growth periods and improve irrigation water efficiency through effective water resource management and rational allocation. Farmers preferring reduced labor input and increased leisure time may face labor scarcity or have fewer agricultural workers, focusing more on labor allocation efficiency. They increase other production factor inputs to substitute for labor, leading to less attention to water costs in irrigation input and consequently reducing irrigation water efficiency.

From Maslow's hierarchy of needs, esteem and self-actualization are growth needs. When basic needs are satisfied, people pursue higher-level needs. Farmers preferring water conservation and gaining respect have typically satisfied basic needs and seek to become water-saving irrigation models to gain others' respect. They consciously constrain irrigation behavior and adopt high-efficiency water-saving measures to increase output while reducing water use, thereby improving irrigation water efficiency. Farmers preferring sustainable development focus more on irrigation's ecological environmental impacts. Excessive groundwater use and flood irrigation cause soil salinization and water waste, which are detrimental to agricultural sustainability. To achieve sustainable development goals, farmers may adopt water-saving irrigation technologies, reduce traditional irrigation frequency, and decrease groundwater use to improve irrigation efficiency.

1.3.2 Stochastic Frontier Method This study aims to analyze factors affecting irrigation water efficiency. We adopt the stochastic frontier production function method developed by Battese and Coelli (1995) to measure farmers' irrigation water efficiency. Irrigation water efficiency values are derived from parameter estimation and error term calculations of the agricultural production technical efficiency measurement equation. First, we construct a production function model to measure agricultural production technical efficiency.

Let Y_i represent the output of the i-th farmer. The stochastic frontier production function is expressed as:

$$Y_i = f(X_{ij}, W_i; \beta) \cdot \exp(v_i - u_i)$$

where X_{ij} is the j-th input factor (excluding irrigation water) for the i-th farmer; W_i is the irrigation water volume for the i-th farmer; β represents parameters to be estimated; v_i is a random error term following an independent normal distribution, representing uncontrollable factors in agricultural production such as climate change and measurement errors; and u_i is a management error term representing technical inefficiency loss, which follows a half-normal distribution. v_i and u_i are independent of each other and of other input variables. When technical efficiency loss $u_i = 0$, the estimated result $\hat{Y}_i$ represents the maximum possible output achievable under full technical efficiency for the i-th farmer.

Farmers' agricultural production technical efficiency (TE_i) is the ratio of actual output to maximum possible output under full technical efficiency, which can be estimated through the error term ($v_i - u_i$). The calculation formula is:

$$TE_i = \frac{Y_i}{\hat{Y}_i} = \frac{f(X_{ij}, W_i; \beta) \cdot \exp(v_i - u_i)}{f(X_{ij}, W_i; \beta) \cdot \exp(v_i)} = \exp(-u_i)$$

Following Kopp's (1981) definition of irrigation water efficiency (TEW_i), it is expressed as:

$$TEW_i = \frac{\hat{W}_i}{W_i} = \exp(-u_i \cdot \beta_w)$$

where $\hat{W}_i$ is the minimum irrigation water volume achievable by the i-th farmer under current technology; and β_w is the elasticity impact value of irrigation water variables on agricultural output.

1.3.3 Tobit Model The irrigation water efficiency in this study ranges between 0 and 1, representing censored data. Using Ordinary Least Squares (OLS) for estimation would incorporate nonlinear terms into the disturbance term for either the entire sample or subsamples after removing outliers, leading to inconsistent estimates. To address this issue, this study employs the limited dependent variable Tobit model based on maximum likelihood estimation to estimate parameters and analyze the impact of different irrigation goal preferences on irrigation water efficiency.

We use various influencing factor indicators as independent variables and the measured irrigation water efficiency values as dependent variables to scientifically quantify their impacts within the Tobit framework. The specific model is formulated as:

$$TEW_i = \begin{cases} \delta_0 + \sum_k \delta_k Z_{ki} + \xi_i & \text{if } \delta_0 + \sum_k \delta_k Z_{ki} + \xi_i > 0 \\ 0 & \text{if } \delta_0 + \sum_k \delta_k Z_{ki} + \xi_i \leq 0 \end{cases}$$

where Z_{ki} represents the k-th independent variable affecting the i-th farmer's irrigation water efficiency, including individual farmer characteristics, household production and operation features, and other factors; δ_0 is the constant term to be estimated; δ_k represents parameters to be estimated; and ξ_i is an error term following a normal distribution.

2 Empirical Analysis

2.1 Variable Selection and Descriptive Analysis for Irrigation Water Efficiency Calculation

Following Wang Xueyuan's (2008) research, we select input-output variables using per-unit-area data to separate variable input factors in agricultural production from land resources, enabling precise reflection of irrigation water efficiency. According to Xu Lang et al. (2012) and production realities, and considering the wide variety of agricultural products with difficulty in measuring different crop yields using uniform standards, we select per-unit-area agricultural output value (calculated from various crop yields and market prices) as the output indicator. We choose per-unit-area seed input (calculated from average seed input per hectare and seed prices), chemical input (mainly including fertilizer and pesticide inputs), machinery input (including tillage, sowing, and harvesting costs), labor input (calculated from household agricultural labor force and average working days), and irrigation water volume (calculated from irrigation frequency and water volume per irrigation) as agricultural production input indicators .

2.2 Variable Selection and Descriptive Analysis for Influencing Factors

Since this study's agricultural irrigation water efficiency is measured based on agricultural production technical efficiency using sample data from Xayar County, we exclude natural conditions from the influencing factors selection. Instead, we focus on farmers' irrigation behavior goal preferences and explore their impact on irrigation water efficiency. Referencing existing research and agricultural production realities, we consider various factors from farmer characteristics, household features, and production and operation characteristics. Building on previous studies, we expanded research variables to focus not only on external factors but also on internal goal preferences affecting irrigation water efficiency. The importance ranking of goal preferences follows Chai Jun's (2008) research using paired comparison methods .

2.3 Analysis of Agricultural Production Technical Efficiency and Irrigation Water Efficiency

We used Frontier 4.1 software to calculate agricultural production technical efficiency and irrigation water efficiency (Table 3). Technical efficiency results show that most farmers' agricultural production technical efficiency exceeds 0.7, yet none achieve full technical efficiency. The average agricultural production technical efficiency is 0.824, with a maximum value of 0.987. Frequency distribution reveals that 42.86% of farmers have technical efficiency values below the group average, and 30.50% exceed 0.9, indicating substantial variation in agricultural production technical efficiency among farmer groups.

Irrigation water efficiency measurements show more dispersed and volatile values compared to technical efficiency. The average irrigation water efficiency is 0.560, with a minimum of 0.053 and maximum of 0.987, demonstrating strong heterogeneity primarily caused by differences among individual farmers. Frequency distribution shows that 47.40% of farmers have irrigation water efficiency below the sample average, with those between 0.3-0.8 accounting for 80.52%, indicating extremely serious water waste and substantial water-saving potential. This heterogeneity suggests that analyzing farmers' irrigation water efficiency across different individual characteristics is highly valuable .

2.4 Analysis of Influencing Factors of Farmers' Irrigation Water Efficiency

To deeply explore underlying causes affecting irrigation water efficiency, we used the Tobit model for parameter estimation to analyze how different irrigation goal preferences influence irrigation water efficiency (Table 4).

Individual and Household Characteristics. Farmers' age shows a significant positive effect on irrigation water efficiency ($P < 0.01$). With accumulated experience, older farmers can more accurately grasp crop growth cycles and effectively manage irrigation water to improve crop water satisfaction and promote irrigation water efficiency. Education level significantly positively affects irrigation water efficiency ($P < 0.01$). Higher education helps farmers understand new agricultural technologies and management models, enabling rational agricultural production and scientific irrigation to enhance irrigation water efficiency.

The proportion of agricultural income in total income significantly positively affects irrigation water efficiency ($P < 0.01$). Farmers relying primarily on agricultural income pay more attention to saving water resources and controlling costs to improve irrigation water efficiency. Irrigated area significantly positively affects irrigation water efficiency ($P < 0.01$). Results show that scaled agricultural operations can improve land leveling and planning, promote large-scale planting, and concentrate more production factors to enhance efficiency. Therefore, water resource utilization is higher under scaled farmland management.

Agricultural labor force negatively affects irrigation water efficiency, but not significantly. As labor hiring costs rise, increased labor input raises agricultural production costs and negatively impacts irrigation water efficiency. However, in the relatively economically backward study area, farmers increase agricultural output value through labor input, which improves irrigation water efficiency and weakens the negative impact, resulting in an insignificant regression result.

Production and Operation Characteristics. The proportion of water-consuming crop planting area to total sown area significantly negatively affects irrigation water efficiency ($P < 0.01$). Under the same output, water-consuming crops require more water resources, and required water volume increases with the proportion of water-consuming crop area, reducing irrigation water efficiency.

The proportion of water-saving irrigation area to total irrigated area positively affects irrigation water efficiency, but not significantly. As the proportion of water-saving irrigation area increases, irrigation water efficiency also improves. The insignificant result may be due to insufficient data, as most farmers still use flood irrigation technology, and farmers' understanding and application of water-saving irrigation technology remain immature, preventing them from achieving maximum benefits during operation.

Water use cost negatively affects irrigation water efficiency, but not significantly. This may relate to local conditions in the survey area, where some towns have relatively backward farmland water conservancy facilities that cannot accurately calculate irrigation water volume, and management methods charging by acreage cannot reflect water resource value. Additionally, subsidy policies reduce farmers' water costs, creating a false impression of lower expenses.

Goal Preferences. Different irrigation behavior goal preferences have different effects on irrigation water efficiency. Preference for profit maximization significantly positively affects irrigation water efficiency ($P < 0.05$). The regression coefficient indicates that when farmers consider this goal more important, they tend to reduce costs and inputs to improve water use efficiency.

Preference for timely irrigation and risk avoidance has no significant effect on irrigation water efficiency. The likely reason is that in the study area, most farmers lack autonomy, with irrigation timing determined by farmers' water use cooperatives without obvious patterns, making regression results insignificant.

Preference for reducing labor input and increasing leisure time significantly negatively affects irrigation water efficiency ($P < 0.01$). The probable reason is that as economic levels improve, farmers pay more attention to leisure and entertainment, and the survey includes many elderly farmers who urgently need to reduce labor input, leading to inadequate agricultural production and irrigation management and reduced irrigation water efficiency.

Preference for water conservation and gaining others' respect significantly positively affects irrigation water efficiency ($P < 0.05$). The likely reason is that farmers are constrained by water-saving awareness during water use, and some regions commend and reward farmers with obvious water-saving effects, encouraging farmers to integrate water-saving concepts throughout the water use process and ultimately improve irrigation water efficiency.

Awareness of water scarcity significantly positively affects irrigation water efficiency ($P < 0.01$). Farmers aware of water shortages enhance protection consciousness and use water resources cautiously. Conversely, farmers lacking awareness of irrigation water scarcity often have psychological tendencies toward unrestricted use and comfort priority, making it difficult to constrain extensive irrigation behavior and resulting in low irrigation water efficiency.

Village cadre status is crucial for improving irrigation water efficiency, with significant positive effects ($P < 0.01$). As village committee members, cadres understand agricultural policies and apply them in practice, using new technologies and methods to increase yields, reduce costs, and improve crop growth environments, thereby enhancing irrigation water efficiency. In special bilingual environments, village cadres with bilingual abilities have particular advantages in performing duties and acquiring water-saving knowledge. Although ordinary farmers are influenced by village cadres when using water resources, their irrigation water efficiency is lower due to insufficient understanding and implementation capacity for water-saving policies.

Participation in training significantly positively affects irrigation water efficiency ($P < 0.01$). Farmers acquire advanced production knowledge through training and put it into practice, making training play an important role in irrigation. The survey shows that most farmers actively participate in water-saving irrigation training during their free time, with frequent sessions featuring practical and targeted content. Professionally trained farmers possess more technical knowledge and practical experience, enabling more effective water resource utilization.

Preference for sustainable development has no significant effect on irrigation water efficiency. The possible reasons are that few sample farmers prefer this goal, or sustainable development requires future-oriented concerns while farmers focus more on current production needs. In actual production, they may not necessarily follow sustainable development concepts to guide water use, nor can this ensure water-saving effects.

3 Discussion

3.1 Irrigation Water Efficiency

This study shows that the average irrigation water efficiency of sample farmers in Xayar County is 0.560, lower than Geng Xianhui et al.'s (2014) measurement of 0.668 based on Xinjiang cotton farmer data and Wang Xiaojuan et al.'s (2005) measurement of 0.62 based on Shijin Irrigation District winter wheat production data, but higher than Wang Xueyuan's (2010) measurement of 0.466 based on Chinese provincial data and Xu Lang et al.'s (2012) measurement of 0.43 based on wheat data from Mengcheng County, Anhui Province. The differences likely stem from different survey areas and output specifications. Since 2020, Xayar County has continuously promoted high-standard farmland construction and high-efficiency water-saving income-increasing pilot projects, implementing intelligent drip irrigation systems with obvious water-saving effects. After land leveling, moderate-scale operations have improved agricultural mechanization levels and corresponding irrigation efficiency. Regarding output indicators, scholars typically focus on single crops, but our survey found most farmers cultivate diverse products including walnuts, cotton, corn, and wheat, making unified measurement difficult. Therefore, we used final agricultural product output value as the output indicator. Water consumption differences among various crops directly affect irrigation water efficiency. Considering multiple crops better reflects actual agricultural production characteristics.

3.2 Influencing Factors of Irrigation Water Efficiency

Our findings indicate that water use cost negatively affects irrigation water efficiency, but not significantly, which differs from other scholars' conclusions that irrigation costs positively correlate with irrigation water efficiency. Additionally, research shows that within certain price ranges, elasticity exists between water price and water consumption volume, with water price effects on water demand only becoming apparent when reaching critical points. Given the currently low irrigation water prices in the survey area, their role in stimulating farmers to improve irrigation water efficiency is limited.

Preference for profit maximization and water conservation positively affect irrigation water efficiency, consistent with Kibirige and Singh's (2021) conclusions, while preference for reducing labor input has negative effects, contrary to their findings. The main reason is that due to real-world constraints, farmers in the survey area lack the capacity to efficiently utilize other resources. Furthermore, preferences for timely irrigation and sustainable development have no significant effects on irrigation water efficiency, suggesting that while goal preference indicators are representative, they have limitations and require improvement in future research.

4 Conclusions and Recommendations

4.1 Conclusions

This study measures irrigation water efficiency and empirically analyzes the impact of irrigation behavior goal preferences on irrigation water efficiency using the Tobit model. The conclusions are:

1) In 2022, the average irrigation water efficiency of farmers in Xayar County was 0.560. From the frequency distribution, 47.40% of farmers had irrigation water efficiency values below the sample average, with those between

0.3-0.8 accounting for 80.52%. This indicates extremely serious water waste among farmers and substantial water-saving potential. The minimum value was only 0.053, with a maximum of 0.987, showing strong heterogeneity.

2) Age, education level, proportion of agricultural income in total income, irrigated area, awareness of water scarcity, village cadre status, participation in training, preference for profit maximization, and preference for water conservation have significant positive effects on irrigation water efficiency. The proportion of water-consuming crop planting area to total sown area and preference for reducing labor input have significant negative effects. Agricultural labor force, proportion of water-saving irrigation area to total irrigated area, water use cost, preference for timely irrigation, and sustainable development have no significant effects, with water use cost playing a negative role in improving irrigation water efficiency. Therefore, irrigation water efficiency can be improved by enhancing water scarcity awareness, promoting training, encouraging profit maximization and water conservation goals, appropriately reducing water-consuming crop planting areas, and improving water pricing mechanisms.

4.2 Policy Recommendations

Based on these findings, we propose the following recommendations:

1) **Strengthen farmers' water-saving awareness.** This study shows that when farmers recognize water scarcity, their irrigation water efficiency improves. Therefore, scientific publicity and guidance should help farmers fully understand current water shortage situations and water resource characteristics. Additionally, farmers' preference for water conservation and gaining respect improves water efficiency. We should improve water-saving model selection and reward mechanisms, create a positive water-saving atmosphere, and encourage farmers' irrigation behavior goal preferences to align with "water conservation and gaining respect," thereby transforming water awareness into behavior and ultimately improving irrigation water efficiency.

2) **Adjust planting structure and reduce the proportion of water-consuming crops.** Research results show that the proportion of water-consuming crop planting area to total sown area negatively correlates with irrigation water efficiency. Crop planting structures should be optimized and adjusted to improve irrigation water utilization efficiency, while fully considering market factors to achieve increased agricultural product value and farmers' income.

3) **Improve the irrigation water pricing mechanism.** Research shows that water use cost has no significant effect on irrigation water efficiency, likely due to the lack of perfect irrigation water measurement facilities in the survey area, leading to water fees charged by irrigated area, which is

not conducive to forming water-saving awareness. Additionally, subsidy policies weaken water price's economic leverage effect. Therefore, it is necessary to establish a supply measurement facility system, improve the agricultural price formation mechanism and water-saving reward mechanism, implement agricultural irrigation fee standards, establish a village-level accounting confirmation system, and implement progressive pricing above quotas, classified pricing, and end-of-channel pricing for tertiary and quaternary canal systems.

References

[1] Xu Lang, Chen Linghong. Analysis of water efficiency and influencing factors of agricultural irrigation in over exploitation area of groundwater[J]. Yellow River, 2020, 42(7): 145-150.

[2] Zhao Liping, Li Dengjuan, Hou Delin, et al. Tempo spatial variations of agricultural water use efficiency measurements in Hubei Province from 2003 to 2016[J]. Journal of Water Resources & Water Engineering, 2020, 31(5): 240-247.

[3] Liang Jingxi, Zhang Ankang, Xu Yaowen, et al. Evaluation of irrigation water use efficiency based on method set and DEA model in Heilongjiang Province[J]. Agricultural Research in the Arid Areas, 2019, 37(6): 124-131.

[4] Luo Chong, Jiang Bo, Zhang Wenqi, et al. Analysis of the spatial and temporal differences in irrigation water efficiency and its water saving potential in Heilongjiang Province[J]. Jiangsu Agricultural Sciences, 2017, 45(23): 254-257.

[5] Wang Xueyuan. Comparative study on irrigation water use efficiency of provinces and regions in China based on DEA and SFA methods[J]. Statistics & Decision, 2010(8): 44-47.

[6] Wang Xueyuan, Zhao Liange. Agricultural water efficiency and the causal factors: A stochastic frontier analysis based on Chinese provincial panel data: 1997—2006[J]. Issues in Agricultural Economy, 2008, 29(3): 10-18, 110.

[7] Tong Jinping, Ma Jianfeng, Wang Huimin, et al. Research on agricultural total factor water use efficiency and its influencing factors in China[J]. On Economic Problems, 2014(6): 101-106.

[8] Kopp R J. The measurement of productive efficiency: A reconsideration[J]. The Quarterly Journal of Economics, 1981, 96(3): 477-503.

[9] Liu Weizhe, Chang Ming, Wang Xiqin. Irrigation water efficiency based on stochastic production frontier and influencing factors: An empirical study of wheat in Guanzhong Region, Shaanxi[J]. Chinese Journal of Eco-Agriculture, 2018, 26(9): 1407-1414.

[10] Xu Lang, Chen Jie, Liu Chen. Comparison of irrigation efficiency of smallholder farmers and new agricultural operators and influencing factors[J]. Resources Science, 2021, 43(9): 1821-1833.

[11] Liu Weizhe, Wang Xiqin. Impact of farmers scarcity perception and overdrawn cognition on efficiency of groundwater irrigation: Based on the survey data of 457 farmer households in groundwater overdraft area of Hebei Province[J]. Chinese Journal of Eco-Agriculture, 2021, 29(5): 929-936.

[12] Chang Ming, Wang Xiqin, Jia Baozhen. Driving factors and spatiotemporal differentiation of irrigation water use efficiency in China[J]. Resources Science, 2019, 41(11): 2032-2042.

[13] Yu Miao, Wang Weizhen, Liu Meiran, et al. Analysis on water use efficiency and influencing factors of agricultural irrigation under the background of water price reform[J]. Heilongjiang Agricultural Sciences, 2019(7): 133-139.

[14] Liu Yihang. A study on the differences of agricultural production efficiency of farmers of different scales and influencing factors: An empirical analysis based on DEA-Tobit model[J]. Ecological Economy, 2021, 37(5): 113-118.

[15] Geng Xianhui, Zhang Xiaoheng, Song Yulan. Measurement of irrigation water efficiency and analysis of influential factors: An empirical study based on stochastic production frontier and cotton farmers data in Xinjiang[J]. Journal of Natural Resources, 2014, 29(6): 934-943.

[16] Berkhout E D, Schipper R A, Kuyvenhoven A, et al. Does heterogeneity in goals and preferences affect efficiency? A case study of farm households in northern Nigeria[J]. Agricultural Economics, 2010(41): 265-273.

[17] Kibirige D, Singh A S. Efficiency and goals of smallholder sugarcane farmers in Eswatini (Swaziland)[J]. Journal of Agricultural Studies, 2021, 9(3): 123-152.

[18] Xu Lang, Huang Ying. Measurement of irrigation water efficiency and analysis of influential factors: An empirical study of Mengcheng County in Anhui Province[J]. Resources Science, 2012, 34(1): 105-113.

[19] Zhang Hui, Zhang Kai, Chen Bing, et al. Effects of different irrigation rates on cotton growth and yield formation in Xinjiang[J]. Arid Zone Research, 2022, 39(6): 1976-1985.

[20] Chai Jun. Study on the relationship between herdsman's production behavior and grassland degradation in Xinjiang[D]. Beijing: Chinese Academy of Agricultural Sciences, 2008.

[21] Battese G E, Coelli T J. A model for technical inefficiency effects in a stochastic frontier production function for panel data[J]. Empirical Economics, 1995(20): 325-332.

[22] Xu Lang, Hu Lihong. Maize irrigation water efficiency and its influencing factors in well irrigation district: A case study of farmer data in Hua County of Henan Province and Juye County of Shandong Province[J]. Jiangsu Agricultural Sciences, 2017, 45(10): 296-300.

[23] Wang Xiaojuan, Li Zhou. Analysis of irrigation water efficiency and influencing factors[J]. Chinese Rural Economy, 2005(7): 11-18.

[24] Wang Wenhao, Cao Hongxia, Cai Huanjie. Relationship between irrigation water price and irrigation water consumption[J]. Journal of Irrigation and Drainage, 2013, 32(1): 82-85.

[25] Chen Guanqiao. The impact of agricultural insurance on agricultural output: A case study of prefecture level cities in Guangdong Province[D]. Guangzhou: Guangdong University of Finance & Economics, 2022.

[26] Berbel J, Gomez Limon J A. The impact of water pricing policy in Spain: An analysis of three irrigated areas[J]. Agricultural Water Management, 2000, 43(2): 219-238.

[27] Huffaker R, Whittlesey N, Michelsen A, et al. Evaluating the effectiveness of conservation water pricing programs: Reply[J]. Journal of Agricultural and Resource Economics, 1998, 23(2): 571-572.

Note: Figure translations are in progress. See original paper for figures.