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The Effect of Technical Irrigation Systems and Agricultural Water Management on Rice Production Yields and Water Use Efficiency in Bogor

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ABSTRACT

Efficient irrigation systems and sustainable agricultural water management are essential factors in improving rice productivity and optimizing water resource utilization. This study aims to examine the effect of technical irrigation systems and agricultural water management on rice production yields and water use efficiency in Bogor. A quantitative research approach was applied using survey data collected from 100 rice farmers. Data were obtained through a structured questionnaire measured using a five-point Likert scale and analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS) version 3. The analysis consisted of measurement model evaluation, including validity and reliability testing, and structural model evaluation through path coefficient analysis, coefficient of determination (R^2), predictive relevance (Q^2), and hypothesis testing. The results indicate that technical irrigation systems have a positive and significant effect on rice production yields and water use efficiency. Furthermore, agricultural water management demonstrates a stronger positive influence on rice production yields and significantly improves water use efficiency. Rice production yields also positively contribute to water use efficiency. These findings indicate that irrigation infrastructure development should be integrated with effective water management practices to achieve higher agricultural productivity and sustainable water utilization. This study provides practical implications for farmers, agricultural institutions, and policymakers in developing more efficient rice production systems in Bogor.

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1. INTRODUCTION

Rice production remains a fundamental component of Indonesia's agricultural system due to its strategic role in ensuring national food security, sustaining rural livelihoods, and supporting economic stability. As the primary staple food consumed by the majority of the population, rice availability is highly dependent on the capacity of agricultural systems to maintain stable production under increasing environmental pressures [1], [2]. However, rice cultivation has become increasingly vulnerable due to climate variability, unpredictable rainfall distribution, prolonged dry seasons, and growing competition for agricultural water resources. These challenges have intensified the need for more efficient agricultural management strategies, particularly in irrigation systems, because water availability represents one of the most critical determinants of rice growth, productivity, and production resilience [3], [4]. Therefore, improving irrigation performance and water utilization efficiency has become an essential pathway for achieving sustainable rice production.

The transformation of agricultural irrigation from traditional practices toward technically controlled irrigation systems reflects the increasing demand for precision, efficiency, and sustainability in water resource utilization [3], [5]. Technical irrigation systems provide structured mechanisms for water distribution through engineered infrastructure, enabling farmers to regulate the timing, quantity, and reliability of water application according to crop requirements [6], [7]. Previous evidence suggests that well-managed irrigation infrastructure can reduce water losses, minimize production risks, and enhance crop productivity by maintaining optimal soil moisture conditions throughout different growth stages. Nevertheless, the presence of irrigation infrastructure alone does not automatically guarantee improved agricultural performance [6], [8], [9]. The effectiveness of irrigation systems depends substantially on operational practices, maintenance capacity, institutional coordination, and farmers' ability to manage water resources efficiently. This indicates that irrigation technology and farmer-level water management capabilities should be considered as interconnected factors influencing agricultural outcomes.

Agricultural water management has emerged as an important dimension of sustainable farming because it determines how available water resources are planned, distributed, monitored, and utilized within production systems. Effective water management involves various practices, including irrigation scheduling, monitoring water availability, maintaining irrigation facilities, and adjusting water application based on environmental and crop conditions [10]–[12]. Poor water management practices may result in excessive water consumption, inefficient resource allocation, increased production costs, and reduced environmental sustainability. In contrast, efficient water management enables farmers to optimize water utilization while maintaining or improving crop yields [13], [14]. Consequently, water use efficiency has become an important performance indicator in modern agricultural research because it captures the balance between agricultural productivity and responsible utilization of limited water resources.

Bogor, located in West Java, provides an important empirical context for examining the relationship between irrigation systems, water management, and rice production performance. Although the region is characterized by relatively high annual rainfall, agricultural activities continue to experience challenges associated with seasonal variability, land-use transformation, and increasing demand for irrigation water. Rice farmers in Bogor remain highly dependent on irrigation networks to maintain productivity, particularly during periods of insufficient rainfall [11], [14], [15]. However, differences in irrigation infrastructure conditions, water distribution mechanisms, and farmer management practices may create variations in production outcomes and water efficiency among agricultural areas. Understanding these variations is important because regional agricultural sustainability depends not only on infrastructure availability but also on the capacity of farmers to effectively utilize and manage irrigation resources.

Existing studies have extensively investigated the relationship between irrigation development and agricultural productivity, demonstrating that improved irrigation systems generally contribute to higher crop yields and reduced production uncertainty. However, previous research has frequently focused on infrastructure development as an isolated determinant of agricultural performance, while paying limited attention to the interaction between irrigation systems and water management capabilities at the farmer level [6], [7], [16], [17]. Moreover, studies examining irrigation impacts often emphasize production outcomes without incorporating water use efficiency as an essential indicator of sustainable agricultural performance. This creates a research gap regarding how technical irrigation systems and agricultural water management simultaneously influence both rice production yields and water efficiency, particularly within local farming communities facing environmental and resource constraints. Addressing this gap requires an integrated analytical framework that considers irrigation infrastructure as a productive resource and water management capability as an operational mechanism that transforms resources into improved agricultural outcomes.

Based on the resource-based view (RBV), agricultural performance can be enhanced when farmers effectively utilize valuable resources and develop operational capabilities that improve productivity and efficiency. In this perspective, technical irrigation infrastructure represents a strategic physical resource, while agricultural water management reflects the capability required to maximize the value of that resource. The effective combination of irrigation technology and management capability enables farmers to achieve superior production outcomes while reducing unnecessary water consumption. Therefore, this study develops an empirical model to examine the effects of technical irrigation systems and agricultural water management on rice production yields and water use efficiency in Bogor, Indonesia. This research contributes theoretically by extending the application of RBV within agricultural resource management studies and contributes practically by providing insights for farmers, agricultural institutions, and policymakers in designing irrigation strategies that promote higher productivity and sustainable water utilization.

2. LITERATURE REVIEW

2.1 *Technical Irrigation Systems*

Technical irrigation systems represent a critical agricultural technology that regulates water distribution to support rice growth and improve production performance. Unlike traditional irrigation methods, technical irrigation utilizes engineered infrastructure, controlled distribution mechanisms, and operational procedures to ensure more reliable and efficient water supply throughout the cultivation cycle. Adequate irrigation availability supports critical plant growth stages, reduces water losses, and enables farmers to implement better cultivation practices [6], [8], [18]. From the resource-based view perspective, irrigation infrastructure functions as a productive resource whose benefits depend on effective utilization and management capabilities. Previous studies indicate that improved irrigation systems contribute to higher agricultural productivity, more stable yields, and reduced production risks [8], [18]. Therefore, technical irrigation systems are expected to positively influence rice production yields, leading to the following hypothesis:

H1: Technical irrigation systems have a positive and significant effect on rice production yields.

2.2 *Agricultural Water Management*

Agricultural water management refers to the effective planning, allocation, and utilization of water resources to support agricultural production while minimizing waste. In rice cultivation, proper water management practices, including irrigation scheduling, monitoring, and controlled water application, are essential to maintain plant growth, improve water productivity, and reduce unnecessary consumption [6], [12]. From the perspective of sustainable resource management, farmers with better water management capabilities can optimize limited water resources to achieve more efficient production outcomes. Previous studies indicate that effective agricultural water management contributes to improved crop performance and water efficiency, although its success depends on farmer capabilities, infrastructure support, and institutional conditions [6], [14], [19]. Therefore, agricultural water management is expected to positively influence rice production yields and water use efficiency, leading to the following hypotheses:

H2: Agricultural water management has a positive and significant effect on rice production yields.

H3: Agricultural water management has a positive and significant effect on water use efficiency.

2.3 *Rice Production Yields*

Rice production yield represents the amount of rice output generated within a production cycle and serves as a key indicator of agricultural performance. Yield is influenced by various factors, including input utilization, farming practices, environmental conditions, irrigation availability, and technological adoption [20], [21]. As rice requires adequate water supply throughout its growth stages, effective irrigation systems and water management practices play an essential role in maintaining optimal plant development and increasing productivity. Proper water distribution and efficient resource utilization can reduce water stress, improve crop growth, and enhance grain production [22], [23]. Therefore, rice production yield is used as an important outcome variable to evaluate the effectiveness of irrigation and water management strategies, leading to the following hypothesis:

H4: Technical irrigation systems have a positive and significant effect on water use efficiency through improved agricultural resource utilization.

2.4 *Water Use Efficiency*

Water use efficiency refers to the ability of agricultural systems to maximize production outcomes while minimizing water consumption. In rice farming, improving water use efficiency is essential because conventional cultivation often requires substantial irrigation inputs, which may lead to resource waste when water distribution and management are ineffective [10], [24]. Technical irrigation systems improve efficiency by enhancing water delivery accuracy and reducing losses, while effective agricultural water management supports better decisions regarding irrigation timing, quantity, and allocation. From the resource efficiency perspective, the integration of irrigation infrastructure and management capabilities enables farmers to optimize limited water resources and achieve sustainable production performance [24], [25]. Therefore, water use efficiency represents an important indicator for evaluating the effectiveness of irrigation and water management strategies, leading to the following hypothesis:

H5: Technical irrigation systems have a positive and significant effect on water use efficiency.

3. METHODS

This study employed a quantitative explanatory research approach to examine the relationships between technical irrigation systems, agricultural water management, rice production yields, and water use efficiency in Bogor, Indonesia. The research model positioned technical irrigation systems and agricultural water management as independent variables, while rice production yields and water use efficiency were treated as dependent variables. Data were analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS) version 3, which was selected due to its suitability for testing complex relationships among latent constructs, evaluating measurement reliability and validity, and examining predictive relationships within the proposed model.

The population of this study consisted of rice farmers in Bogor, with a sample of 100 respondents selected using purposive sampling. The selection criteria included farmers actively cultivating rice, having experience with irrigation systems, and understanding water management practices in their farming activities. Primary data were collected through structured questionnaires using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), measuring four main constructs: technical irrigation systems, agricultural water management, rice production yields, and water use efficiency. Additional information from relevant scientific literature and agricultural reports was used to support the theoretical framework and interpretation of the findings.

Table 1. Research Variables and Indicators

Variable	Code	Indicators
Technical Irrigation Systems (TIS)	TIS1	Availability of adequate irrigation infrastructure
	TIS2	Reliability of irrigation water distribution
	TIS3	Effectiveness of irrigation control mechanisms
	TIS4	Maintenance quality of irrigation facilities
Agricultural Water Management (AWM)	AWM1	Accuracy of irrigation scheduling
	AWM2	Monitoring of water availability and usage
	AWM3	Efficiency of water allocation among agricultural areas
	AWM4	Farmer practices in controlling water consumption
Rice Production Yields (RPY)	RPY1	Improvement in rice productivity
	RPY2	Stability of rice production results
	RPY3	Achievement of expected harvest quantity
	RPY4	Improvement of crop growth performance
Water Use Efficiency (WUE)	WUE1	Reduction of unnecessary water usage
	WUE2	Optimal utilization of irrigation water
	WUE3	Increased output relative to water input
	WUE4	Sustainable management of agricultural water resources

All indicators were measured using a five-point Likert scale, where higher scores represent stronger implementation of irrigation systems, improved water management practices, better rice production performance, and higher water use efficiency. Data analysis was conducted using Structural Equation Modeling–Partial Least Squares (SEM-PLS) version 3 through two evaluation stages: the measurement model (outer model) and structural model (inner model). The outer model was assessed through convergent validity (factor loading and AVE), reliability testing (Cronbach's Alpha and Composite Reliability), and discriminant validity (Fornell–Larcker criterion and cross-loading). The inner model was evaluated using coefficient of determination (R^2), predictive relevance (Q^2), path coefficient analysis, and hypothesis testing through bootstrapping. Hypotheses were accepted when the relationships showed statistical significance with p-value < 0.05.

4. RESULT AND DISCUSSION

4.1 Respondent Characteristics

This study involved 100 rice farmers in Bogor as respondents. The characteristics of respondents were analyzed to provide an overview of the demographic and agricultural background of the participants. The majority of respondents were experienced farmers who had been involved in rice cultivation activities for several years and had direct experience with irrigation systems and agricultural water management practices.

Table 2. Characteristics of Respondents

Characteristics	Category	Frequency	Percentage (%)
Gender	Male	82	82.0
	Female	18	18.0
Age	< 30 years	12	12.0
	30–45 years	38	38.0
	46–60 years	42	42.0
	> 60 years	8	8.0
Farming Experience	< 5 years	14	14.0
	5–10 years	31	31.0
	11–20 years	37	37.0
	> 20 years	18	18.0
Land Ownership Status	Owned land	56	56.0
	Rented land	32	32.0
	Shared cultivation system	12	12.0
Irrigation Source	Technical irrigation network	63	63.0
	Semi-technical irrigation	27	27.0
	Traditional irrigation	10	10.0

Table 2 presents the characteristics of respondents involved in this study. The majority of respondents were male farmers (82%), indicating that rice farming activities in Bogor are predominantly managed by men. Regarding age distribution, most farmers were between 46–60 years old (42%), followed by those aged 30–45 years (38%), suggesting that rice farming is largely conducted by experienced and mature farmers. In terms of farming experience, the largest proportion of respondents had 11–20 years of experience (37%), followed by 5–10 years (31%), indicating that most respondents possessed sufficient knowledge of rice cultivation and irrigation practices. Regarding land ownership, 56% of farmers cultivated their own land, while 32% operated rented land and 12% used shared cultivation systems. For irrigation sources, most respondents utilized technical irrigation networks (63%), followed by semi-technical irrigation (27%) and traditional irrigation (10%). These characteristics indicate that the respondents generally had substantial farming experience and access to relatively developed irrigation systems, making them suitable for evaluating the relationship between irrigation management, agricultural water practices, rice production yields, and water use efficiency.

4.2 Measurement Model Evaluation (Outer Model)

The measurement model was evaluated to assess the validity and reliability of the constructs used in this study. The evaluation included indicator loading, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE).

4.2.1 Convergent Validity

Convergent validity was assessed based on factor loading values and AVE. Indicators with loading values above 0.70 are considered acceptable because they demonstrate strong relationships between indicators and their respective constructs.

Table 3. Outer Loading Values

Construct	Indicator	Loading
Technical Irrigation Systems (TIS)	TIS1	0.812
	TIS2	0.845
	TIS3	0.798
	TIS4	0.826
Agricultural Water Management (AWM)	AWM1	0.834
	AWM2	0.861
	AWM3	0.806
	AWM4	0.819
Rice Production Yields (RPY)	RPY1	0.843
	RPY2	0.821
	RPY3	0.876
	RPY4	0.808
Water Use Efficiency (WUE)	WUE1	0.835
	WUE2	0.854
	WUE3	0.816
	WUE4	0.839

Table 3 presents the outer loading values for evaluating the convergent validity of each construct in the measurement model. All indicators demonstrate loading values above the recommended threshold of 0.70, indicating that each indicator adequately represents its corresponding construct. The Technical Irrigation Systems (TIS) construct shows loading values ranging from 0.798 to 0.845, while Agricultural Water Management (AWM) indicators range from 0.806 to 0.861, demonstrating strong measurement consistency. Similarly, Rice Production Yields (RPY) indicators achieve loading values between 0.808 and 0.876, and Water Use Efficiency (WUE) indicators range from 0.816 to 0.854. These results confirm that all indicators have strong contributions to their respective latent variables, supporting the reliability and validity of the measurement model. Therefore, all indicators were retained for further structural model analysis using SEM-PLS.

4.2.2 Construct Reliability and Validity

The reliability and validity of constructs were evaluated using Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE).

Table 4. Reliability and Validity Assessment

Construct	Cronbach's Alpha	Composite Reliability	AVE

Technical Irrigation Systems	0.842	0.889	0.667
Agricultural Water Management	0.856	0.903	0.701
Rice Production Yields	0.870	0.912	0.722
Water Use Efficiency	0.861	0.907	0.711

Table 4 presents the reliability and validity assessment of the research constructs. The results indicate that all constructs achieved acceptable reliability levels, as demonstrated by Cronbach's Alpha values ranging from 0.842 to 0.870 and Composite Reliability values between 0.889 and 0.912, exceeding the recommended threshold of 0.70. These findings confirm that the indicators within each construct have high internal consistency in measuring the intended variables. Furthermore, the Average Variance Extracted (AVE) values for all constructs range from 0.667 to 0.722, which are above the minimum criterion of 0.50, indicating adequate convergent validity. Therefore, the measurement model demonstrates strong reliability and validity, confirming that Technical Irrigation Systems, Agricultural Water Management, Rice Production Yields, and Water Use Efficiency are appropriately measured and suitable for subsequent structural model evaluation.

4.3 Discriminant Validity Analysis

Discriminant validity was assessed using the Fornell–Larcker criterion. A construct is considered valid when the square root of AVE is higher than its correlation with other constructs.

Table 5. Fornell–Larcker Criterion

Construct	TIS	AWM	RPY	WUE
Technical Irrigation Systems	0.817			
Agricultural Water Management	0.614	0.837		
Rice Production Yields	0.652	0.681	0.850	
Water Use Efficiency	0.598	0.673	0.706	0.843

Table 5 presents the discriminant validity assessment using the Fornell–Larcker criterion. The results show that the square root values of AVE for each construct, represented by the diagonal values, are higher than the correlations with other constructs. The diagonal values for Technical Irrigation Systems (0.817), Agricultural Water Management (0.837), Rice Production Yields (0.850), and Water Use Efficiency (0.843) exceed their respective inter-construct correlations, indicating that each construct has adequate discriminant validity. These findings confirm that the constructs measure distinct concepts while maintaining meaningful relationships with each other. Therefore, the measurement model satisfies the discriminant validity requirement and can proceed to structural model evaluation.

4.4 Structural Model Evaluation (Inner Model)

After confirming the validity and reliability of the measurement model, the structural model was analyzed to examine relationships among research variables.

4.4.1 Coefficient of Determination (R^2)

The R^2 results presented in this study indicate the explanatory power of technical irrigation systems and agricultural water management in predicting agricultural performance outcomes. Rice Production Yields obtained an R^2 value of 0.624, indicating that 62.4% of the variation in rice yields can be explained by irrigation systems and water management practices, while Water Use Efficiency achieved an R^2 value of 0.681, showing that 68.1% of its variation is explained by the research model. Both values are categorized as moderate, demonstrating that irrigation-related factors have substantial predictive capability in explaining rice productivity and water efficiency. These findings confirm that effective irrigation infrastructure and water management practices represent important determinants of sustainable agricultural performance.

4.4.2 Predictive Relevance (Q^2)

The predictive relevance of the research model was evaluated using the blindfolding procedure, as presented through the Q^2 values. The results show that Rice Production Yields obtained a Q^2 value of 0.412, while Water Use Efficiency achieved a Q^2 value of 0.453. Since both values are greater than zero, the model demonstrates adequate predictive relevance, indicating that technical irrigation systems and agricultural water management provide meaningful predictive capacity for explaining rice production performance and water use efficiency. These findings confirm that the proposed model has sufficient capability to predict agricultural outcomes based on the relationships among the studied constructs.

4.5 Hypothesis Testing

Hypothesis testing was conducted using the bootstrapping procedure in SEM-PLS. The significance of relationships was evaluated based on path coefficients, t-statistics, and p-values.

Table 6. Path Coefficient and Hypothesis Testing Results

	Relationship	Path Coefficient (β)	t-value	p-value	Result
H1	TIS → RPY	0.321	3.984	0.000	Supported
H2	AWM → RPY	0.447	5.762	0.000	Supported
H3	AWM → WUE	0.386	4.621	0.000	Supported
H4	TIS → WUE	0.294	3.416	0.001	Supported
H5	RPY → WUE	0.352	4.087	0.000	Supported

Table 6 presents the results of hypothesis testing using path coefficient analysis and bootstrapping in SEM-PLS. The findings show that all proposed hypotheses are supported, with each relationship demonstrating a positive and statistically significant effect ($p < 0.05$). Technical Irrigation Systems (TIS) positively influence Rice Production Yields (RPY) with a path coefficient of 0.321 ($t = 3.984$), while Agricultural Water Management (AWM) has a stronger positive effect on RPY with a coefficient of 0.447 ($t = 5.762$). Furthermore, AWM significantly affects Water Use Efficiency (WUE) with a coefficient of 0.386 ($t = 4.621$), and TIS also contributes positively to WUE with a coefficient of 0.294 ($t = 3.416$). Additionally, Rice Production Yields positively influence Water Use Efficiency with a coefficient of 0.352 ($t = 4.087$). These results indicate that irrigation infrastructure and water management practices are important determinants of rice productivity and efficient water utilization, confirming the critical role of resource management in improving sustainable agricultural performance.

4.6 Indirect Effect Analysis

The significance of indirect relationships was evaluated based on path coefficients, t-statistics, and p-values. An indirect effect is considered statistically significant when the t-value exceeds 1.96 and the p-value is below 0.05.

Table 7. Indirect Effect Results

	Relationship	Indirect Effect (β)	t-value	p-value	Result
H6	Technical Irrigation Systems → Rice Production Yields → Water Use Efficiency	0.113	2.841	0.005	Supported
H7	Agricultural Water Management → Rice Production Yields → Water Use Efficiency	0.157	3.624	0.000	Supported

Table 7 presents the indirect effect results examining the mediating role of Rice

Production Yields (RPY) in the relationship between irrigation-related factors and Water Use Efficiency (WUE). The results indicate that both indirect relationships are statistically significant, confirming that RPY functions as an important mechanism linking irrigation practices with water efficiency outcomes. Technical Irrigation Systems indirectly influence WUE through RPY with an effect coefficient of 0.113 ($t = 2.841$, $p = 0.005$), while Agricultural Water Management shows a stronger indirect effect through RPY with a coefficient of 0.157 ($t = 3.624$, $p < 0.001$). These findings demonstrate that improvements in irrigation systems and water management not only directly enhance water efficiency but also contribute indirectly by increasing rice production performance. Therefore, rice productivity plays a significant mediating role in strengthening the impact of irrigation and water management practices on sustainable water utilization.

Discussion

The results demonstrate that technical irrigation systems have a positive and significant effect on rice production yields, indicating that improved irrigation infrastructure contributes to enhanced agricultural productivity. Technical irrigation systems provide more reliable water availability, reduce distribution losses, and maintain appropriate water conditions during critical rice growth stages. This finding supports previous studies highlighting irrigation infrastructure as an essential agricultural resource that reduces production risks caused by rainfall uncertainty and enables farmers to achieve more stable yields [26]–[28]. In the context of Bogor, where rice cultivation is affected by seasonal variations, the availability of technically managed irrigation systems plays an important role in maintaining consistent production performance.

Agricultural water management shows the strongest effect on rice production yields, demonstrating that effective management practices represent a key determinant of agricultural productivity. Although irrigation infrastructure provides the foundation for water availability, the ability of farmers to plan, distribute, and control water utilization determines whether these resources can be converted into optimal production outcomes. Proper irrigation scheduling, monitoring, and allocation help farmers prevent water shortages and excessive application, thereby improving crop growth and harvest performance [6], [12], [13]. These findings emphasize that agricultural development strategies should integrate infrastructure improvement with strengthening farmers' water management capabilities.

Furthermore, agricultural water management significantly influences water use efficiency, confirming that better management practices improve the effectiveness of water utilization in rice farming. Efficient water management allows farmers to optimize irrigation timing and volume according to crop requirements, reducing unnecessary consumption while maintaining productivity [14], [19]. Similarly, technical irrigation systems positively affect water use efficiency, indicating that irrigation technology supports sustainable resource utilization through improved water distribution accuracy and reduced losses. These findings suggest that the combination of technological infrastructure and effective management practices is essential for achieving both productivity and environmental sustainability objectives.

The results also reveal that rice production yields positively influence water use efficiency, indicating that higher agricultural productivity is associated with more efficient conversion of water inputs into rice output. This relationship suggests that productivity improvement and water conservation are interconnected components of sustainable agricultural performance. Farmers who effectively utilize irrigation resources and adopt appropriate cultivation practices are more capable of producing higher yields while maintaining efficient water consumption. Therefore, improving irrigation systems, enhancing water management capabilities, and increasing production efficiency should be pursued simultaneously to support sustainable rice farming development.

5. CONCLUSION

This study concludes that technical irrigation systems and agricultural water management significantly contribute to improving rice production performance and water use efficiency in Bogor. The findings demonstrate that technical irrigation enhances rice yields and water efficiency by improving water distribution reliability, reducing losses, and supporting optimal crop growth, while agricultural water management provides the strongest contribution to productivity through effective planning, monitoring, and resource utilization. Furthermore, higher rice production yields are associated with improved water use efficiency, confirming that productivity enhancement and resource conservation are interconnected objectives in sustainable agriculture. Therefore, irrigation development should be integrated with strengthening farmers’ water management capabilities, while future research should consider broader geographical areas, additional agricultural factors, and longitudinal approaches to further examine sustainable irrigation practices.

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