

ENHANCING FARM-LEVEL WATER EFFICIENCY AND CLIMATE RESILIENCE THROUGH AN INTELLIGENT IRRIGATION MANAGEMENT PLATFORM (iFARM)

AMÉLIORATION DE L'EFFICIENCE D'UTILISATION DE L'EAU À L'ÉCHELLE DE L'EXPLOITATION ET DE LA RÉSILIENCE CLIMATIQUE GRÂCE À UNE PLATEFORME INTELLIGENTE DE GESTION DE L'IRRIGATION (iFARM)

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ABSTRACT

Improving water use efficiency is necessary to sustain agricultural productivity and resilience under climate uncertainty. However, irrigation practices in rural Thailand still depend on farmer experience and conventional practices. This study presents the development of iFarm (Intelligent Farm), a smart irrigation management platform designed to improve water use efficiency, economic performance, and climate resilience at the farm level. The platform was developed and evaluated in agricultural areas of the Klong Suan Mak and Klong Klung river basins in Thailand, where the irrigation water availability is affected by climate variability. The system integrates IoT-based automated irrigation control, weather and rainfall forecasts, and satellite-derived information to estimate soil moisture depletion and determine irrigation requirements across 18 pilot farms.

Results from pilot fields indicated that iFarm improved irrigation system performance and water use efficiency. The average irrigation efficiency achieved across the study plots was 70%. During the rainy season of 2024 and the dry season of 2024–2025, water productivity was higher than 0.1 USD per cubic meter, which is higher than the national agricultural average of 0.06 USD per cubic meter reported in Thailand. These improvements were achieved through reductions in over-irrigation, minimization of water losses, and improved alignment between crop water demand and irrigation supply. Economic analysis highlights the feasibility and scalability of the iFarm system. The average installation cost was approximately 440 USD per plot, with an estimated payback period of 2.27 months. An ex-ante economic analysis indicated that the system is economically viable when operational efficiency is fully functional and farmer adoption rates exceed 40%. Under these conditions, the project generated a net present value (NPV) of 147,000 - 150,000 USD, benefit–cost ratios ranged from 3.51 to 3.54, and the internal rate of return was approximately 34%, indicating long-term economic potential.

Overall, iFarm provides an effective framework for evaluating and improving irrigation practices at the farm levels through the integration of technological innovation with decision-support platforms tailored to farmers' needs. The results indicate that iFarm is a feasible and scalable platform to improve water use efficiency, reduce production costs, and boost sustainable water resource management in climate-vulnerable areas.

Keywords: intelligent farm, irrigation management platform, water use efficiency.

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RÉSUMÉ

L'amélioration de l'efficacité d'utilisation de l'eau est nécessaire pour préserver la productivité agricole et la résilience face à l'incertitude climatique. Cependant, les pratiques d'irrigation dans les zones rurales de Thaïlande reposent encore sur l'expérience des agriculteurs et sur des pratiques conventionnelles. Cette étude présente le développement d'iFarm (Intelligent Farm), une plateforme intelligente de gestion de l'irrigation conçue pour améliorer l'efficacité d'utilisation de l'eau, les performances économiques et la résilience climatique à l'échelle de l'exploitation. La plateforme a été développée et évaluée dans des zones agricoles des bassins des rivières Klong Suan Mak et Klong Klung, en Thaïlande, où la disponibilité de l'eau d'irrigation est affectée par la variabilité climatique. Le système intègre une commande automatisée de l'irrigation fondée sur l'Internet des objets (IoT), des prévisions météorologiques et pluviométriques ainsi que des informations dérivées des satellites, afin d'estimer l'épuisement de l'humidité du sol et de déterminer les besoins d'irrigation dans 18 exploitations pilotes.

Les résultats obtenus dans les parcelles pilotes indiquent qu'iFarm a amélioré les performances du système d'irrigation et l'efficacité d'utilisation de l'eau. L'efficacité moyenne de l'irrigation atteinte dans l'ensemble des parcelles étudiées était de 70 %. Pendant la saison des pluies 2024 et la saison sèche 2024–2025, la productivité de l'eau a dépassé 0,1 USD par mètre cube, soit une valeur supérieure à la moyenne agricole nationale de 0,06 USD par mètre cube rapportée en Thaïlande. Ces améliorations ont été obtenues grâce à la réduction de la surirrigation, à la diminution des pertes d'eau et à une meilleure adéquation entre les besoins en eau des cultures et l'apport d'irrigation. L'analyse économique met en évidence la faisabilité et l'évolutivité du système iFarm. Le coût moyen d'installation était d'environ 440 USD par parcelle, pour une période de récupération estimée à 2,27 mois. Une analyse économique ex ante a indiqué que le système est économiquement viable lorsque l'efficacité opérationnelle est pleinement assurée et que le taux d'adoption par les agriculteurs dépasse 40 %. Dans ces conditions, le projet a généré une valeur actualisée nette (VAN) de 147 000 à 150 000 USD, des ratios avantages-coûts compris entre 3,51 et 3,54, et un taux de rendement interne d'environ 34 %, ce qui indique un potentiel économique à long terme.

Dans l'ensemble, iFarm fournit un cadre efficace pour évaluer et améliorer les pratiques d'irrigation à l'échelle de l'exploitation, en intégrant l'innovation technologique à des plateformes d'aide à la décision adaptées aux besoins des agriculteurs. Les résultats indiquent qu'iFarm est une plateforme viable et évolutive permettant d'améliorer l'efficacité d'utilisation de l'eau, de réduire les coûts de production et de renforcer la gestion durable des ressources en eau dans les zones exposées aux aléas climatiques.

Mots-clés : Ferme intelligente; Plateforme de gestion d'irrigation; Efficacité de l'utilisation de l'eau.

1. INTRODUCTION

In Thailand, significant changes in rainfall patterns, atmospheric temperature and increasing frequency of extreme climatic events were recorded recently (Supharatid, 2016, Gunathilake et al., 2020). Extreme weather and climate can have a wide range of physical and environmental impacts (Supharatid, 2016). Among these, drought in Thailand has a great impact on agriculture and water resources, as agriculture remains one of the most important economic sectors and a major source of income in the country (Franzetti et al., 2017, Khadka et al., 2024). Drought is one of the major uncertainties faced by farmers, as it can severely affect agricultural activities by reducing soil moisture, causing crop water stress, limiting crop growth, and reducing crop quality and productivity (Pak-Uthai and Faysse, 2018).

As drought not only affects agriculture but also economic stability, the environment, and people's livelihoods (Pak-Uthai and Faysse, 2018, Khadka et al., 2024). Mitigation strategies are required to address these problems in both the short- and long term, such as better groundwater management; cloud seeding operations; watershed management; irrigation development; better irrigation allocation,

scheduling, and planning; forest conservation and reforestation; and strengthening stakeholder cooperation (Seebonruang, 2015, Chengot et al., 2025, de Oliveira-Júnior et al., 2025). In addition, the adoption of smart water management technologies and climate-resilient agricultural practices can play a crucial role in enhancing drought tolerance and long-term resilience.

Smart farming refers to the concept of applying new technologies and innovation to improve precision and efficiency of farm operations (Wolfert et al., 2017). Its primary objectives are to reduce the use of agricultural inputs, lower production costs, increase both the quantity and quality of agricultural outputs, and minimize risks associated with farming activities. Technologies and innovations related to smart farming include the Internet of Things, Global Positioning System (GPS), Geographic Information Systems (GIS), remote sensing, big data analysis, and cloud computing (Wolfert et al., 2017, Bersani et al., 2022, Soussi et al., 2024). These technologies facilitate real-time monitoring and control of farming systems to support data-driven farm management decisions. Based on numerous studies, farms that have implemented these technologies have seen significant increase in productivity compared to farms that still use traditional practices (Goedde et al., 2020, Khan et al., 2021, Duguma and Bai, 2024).

In Thailand, although early concerns were raised regarding the impact of climate variability and water scarcity on agricultural production and water resources (Lebel et al., 2010), limited attention has been given to the practical implementation of specific adaptation measures in farm conditions. Existing studies on smart irrigation have only focused on IoT-based architecture, prototype development, or isolated automation components, with limited emphasis on fully integrated decision-support platforms that combine real-time weather monitoring, crop water demand estimation, and automated irrigation control (Boonchieng et al., 2018, Suanpang and Jamjuntr, 2019, Tiammee et al., 2019). With the increasing interest in smart farming, numerous innovations, service providers, and academic programs related to smart agriculture have emerged in Thailand, such as Farmdee-Mesok (Raksapatcharawong and Veerakachen, 2025), DSmart Farming (Thepbandit et al., 2026), and Ricult (Magazine, 2025).

While basin-scale intelligent water management systems such as iWASAM have demonstrated the potential to improve irrigation allocation and water distribution efficiency, translating these benefits into actionable farm-level irrigation management remains a critical challenge (Donjadee et al., 2025). There is still a lack of intelligent farm-level platforms that effectively bridge large-scale water management strategies with site-specific irrigation decision-making and automated on-farm control. This issue is often challenging due to farmers' lack of instruments for proper irrigation scheduling and reliance on personal experience. Therefore, this study aims to develop and evaluate an intelligent irrigation management platform (iFarm) that extends the iWASAM concept from basin-scale water allocation to farm-level implementation while contributing to more sustainable water resource management. The iFarm architecture was designed to integrate data from multiple sources, including iWASAM, Radar4Flood, and other API-based systems, to analyze soil moisture in the form of soil moisture depletion. This information is utilized to support irrigation decision-making and helps farmers to determine when to irrigate and how much water should be supplied.

2. MATERIALS AND METHODS

2.1 Study area

This study was conducted in the Klong Suan Mak River Basin and adjacent Klong Klung River Basin in Kamphaeng Phet Province, Northern Thailand. This area was selected as the study site due to its agricultural importance and its vulnerability to water availability fluctuations caused by climate variability, making it a suitable location for evaluating smart irrigation management strategies. The Klong Suan Mak basin has been the focus of previous water management development through the implementation of the iWASAM (Intelligent Water Allocation Scheduling and Monitoring) platform (Donjadee et al., 2025), which supports basin-scale irrigation scheduling and water allocation management. Building upon this foundation, the present study extends the application of irrigation management from basin-level decision support to farm-level precision irrigation through the development of the iFarm platform. Pilot implementation was conducted across 19 pilot farms

representing different crop types and irrigation conditions (“**Figure 1.**”). These pilot farms provided an opportunity to assess the adaptability and operational performance of the iFarm platform under real farming conditions.

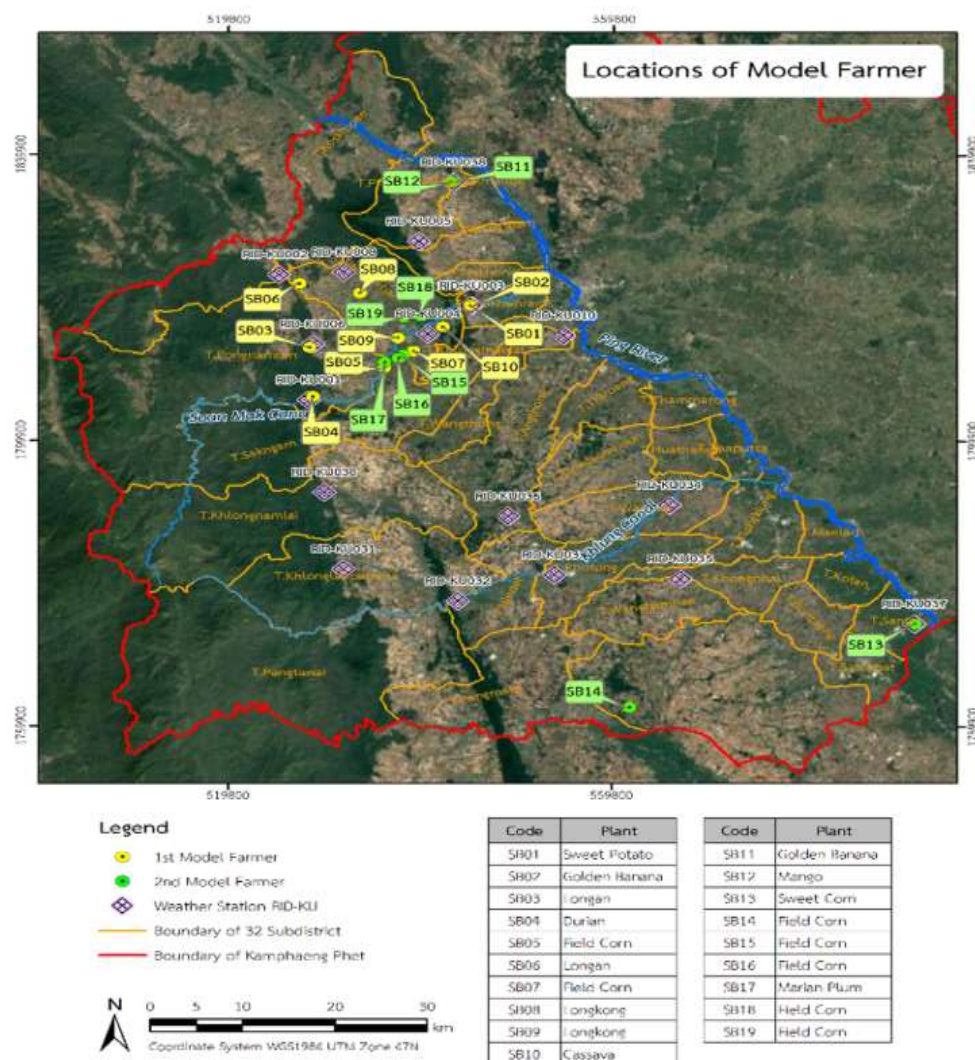


Figure 1. illustrates the location of the model farmer within the Klong Suan Mak and Klong Klung River Basins.

2.2 Development of iFarm platform

The iFarm (intelligent Farm) platform was conceptualized as a smart irrigation management system that integrates rainfall monitoring (Radar4Flood), weather forecasting (TMD API), real-time crop water requirements (IrriSAT and iWASAM), and IoT-based irrigation automation to support precision irrigation at the farm level. The system consists of four main components, including iWASAM-iDSS (iWASAM-irrigation decision support system), iControl (automated irrigation control system), the iFarm application, and farmers as shown in “**Figure 2.**”.

iWASAM-iDSS is responsible for estimating crop water requirement, scheduling irrigation, and assessing soil moisture depletion. The iFarm mobile application provides the farmer interface for monitoring irrigation status, receiving irrigation recommendations, and remotely managing irrigation operations. iControl is an IoT-based hardware control unit developed by the research team to execute automated irrigation commands, including pump activation and motorized valve operation.



Figure 2. illustrated iFarm architecture.

2.4 Irrigation scheduling algorithm

The irrigation scheduling process in iFarm follows a data-driven decision framework. The irrigation decision process is a daily analysis of soil water balance. Soil moisture depletion, $d(t)$, is calculated by the system using **equations 1 to 3**, where crop evapotranspiration (ET_c), effective rainfall, irrigation application, and previous soil water status are derived from the iWASAM platform. Then, the iDSS used the calculated depletion value to ascertain whether irrigation is needed.

$$d'(t) = \text{Max} [d(t-1) + ET_c(t) - R, d_{\min}] \quad (1)$$

$$R = \text{Max} [ER(t), R^* + R_{rd}] \quad (2)$$

$$d(t) = \text{Min} [\text{Max} \{d(t-1) + \text{Actual } ET_c(t) - V(t) - R(t), d_{\min}\}, d_{\text{limit}}] \quad (3)$$

Where:

- $d'(t)$ = estimated soil moisture depletion on day (t), before irrigation application.
- $d_{\min}$ = the minimum allowable soil moisture depletion from field capacity.
- $d(t-1)$ = soil moisture depletion at the end of the day (t-1) used for estimating $d'(t)$ on day (t).
- $d(t)$ = soil moisture depletion at the end of the day (t) used for estimating $d(t+1)$ on the following day.
- $ET_c(t)$ = crop evapotranspiration on day (t), derived from iWASAM.
- Actual $ET_c(t)$ = actual crop water use, calculated as $(K_c \times ET_o)$, where (ET_o) is derived from weather data collected by the RID-KU automatic weather station through iWASAM.
- R = rainfall that is calculated from the expected rainfall ($ER(t)$).
- $R(t)$ = the actual rainfall collected from the nearest automated weather station.
- $ER(t)$ = the expected rainfall for day (t), obtained from iWASAM.
- R^* = the actual rainfall accumulated from 07:00 to the irrigation decision time.
- R_{rd} = predicted rainfall forecast from Radar4Flood
- $V(t)$ = the actual volume of irrigation water applied to the crop, measured using a bypass flow meter.

The recommendation can be viewed by farmers on the iFarm application, and irrigation can be triggered remotely through iControl that operates the pump and motor valve. Water delivery is checked continually using a bypass flow meter. The recorded bypass flow is converted to total irrigation volume using a calibration coefficient, allowing real-time monitoring of water application. The irrigation stops automatically when the defined irrigation volume is attained, which corresponds to the re-establishment of the soil moisture to the field capacity ($d(t) = 0$). The irrigation decision framework uses soil moisture depletion ($d(t)$) as the primary control variable, which is defined as the difference between soil moisture at field capacity (FC) and the current soil moisture content (q), expressed in **equation 4**.

$$d = FC - q \quad (4)$$

When the soil moisture is at field capacity, ($d = 0$).

When the soil moisture is lower than field capacity, ($d > 0$).

When the soil moisture is higher than field capacity, ($d < 0$).

In irrigation management, soil moisture depletion (d) is a key parameter used to support irrigation scheduling and help answer two important questions for farmers: When should irrigation be applied and how much water should be applied.

2.5 System performance

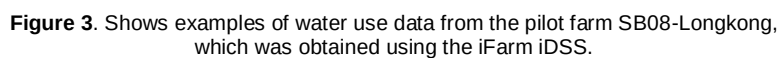
The analysis was carried out to assess the potential of the iFarm platform to reduce irrigation water use and to keep the water delivery to the crop near the estimated crop water requirement in the pilot farms. The performance of the iFarm platform was evaluated based on water use efficiency; energy consumption; labor use associated with irrigation management and field operation; and crop yield. The results were compared with traditional farming practices that are currently used by pilot farmers. A cost-benefit analysis, Net Present Value (NPV), Benefit-Cost Ratio (BCR), Internal Rate of Return (IRR), and payback period were used to assess the effectiveness and economic viability of the iFarm system.

3. RESULTS AND DISCUSSIONS

3.1 System implementation and performance

At present, the iFarm has been implemented in a total of 18 pilot farms, identified as SB01-SB03 and SB04-SB19, as shown in **"Figure 1."**. The first group of pilot farms consists of nine plots (SB01-SB03 and SB05-SB10), which gradually commenced operation in September 2024. The second group of nine pilot farms (SB01-SB19) began implantation from August 2025 forward. The location of all 18 pilot farms within the Klong Suan Mak and Klong Klung River Basin is illustrated in **"Figure 1."**. As of 22 May 2026, a total of 13 cultivation cycles had been completed and harvested, while an additional 18 cultivation cycles were still under ongoing testing and monitoring.

During the growing season, the system continuously recorded and stored soil moisture depletion ($d(t)$), estimated crop evapotranspiration (ETc), rainfall, irrigation suggestion status, irrigation volume applied, and soil water balance updated after irrigation on the iDSS database as shown in **"Figure 3."**. However, farmers are still the most important component of the iFarm architecture. Unlike fully autonomous irrigation systems, iFarm operational architecture is human-in-the-loop, where farmers are in control over irrigation operations. This is consistent with the study from Tachaboon et al. (2025), which demonstrates that a user centered approach may turn fragmented data into timely and actionable insights.



The observed improvement is consistent with previous studies that have demonstrated the benefit of smart irrigation technologies and decision support systems. For example, Wood et al. (2020) reported that the use of sensor-based irrigation scheduling resulted in a 49% reduction in consumptive water use. Similarly, Cáceres et al. (2021) reported that their proposed predictive controller boosted irrigation efficiency from 76.2 to 94.3% compared to traditional irrigation practices. Overall findings consistently show that data-driven irrigation scheduling can significantly enhance water-use efficiency.

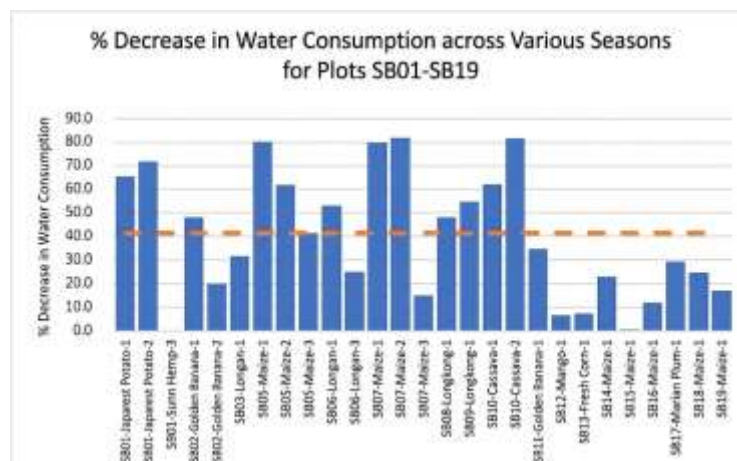


Figure 4. The percentage of water reduction in the pilot farms

3.3 Economic feasibility and technology adoption

Economic analysis indicated that iFarm is economically viable for farm-level implementation. The average investment cost per plot for the systems across the pilot farms, including the irrigation control system, communication devices, sensors, and installation costs, was around 440 USD. The economic benefits were significant with labor saving, enhanced irrigation management, and a reduction in operational costs. This resulted in a quick return on the initial investment with an average payback period of around 2.3 months. Crops with relatively high market value and rapid economic returns generally demonstrated superior financial performance following the adoption of the iFarm platform. This indicates that under normal operation, farmers could recover their investment in a single cropping season. The short payback period found in this study is consistent with previous findings on smart farm irrigation. For example, Bazaluk et al. (2022) reported that the payback period varied depending on crops and farm area, ranging from 3 to 12 months for corn, wheat, and rapeseed. Similarly, Champness et al. (2023) found that implementing smart-sensed automation in rice production can reduce the payback period from 7 to 4 years.

An ex-ante economic impact assessment was conducted to evaluate the long-term benefits of adopting the iFarm platform across the study area. The assessment considered a 20-year evaluation period (2024-2044). Results indicated that the project becomes economically viable when system effectiveness reaches 100% and the technology adoption rate exceeds 40%. In this case, the estimated net present value (NPV) ranged from 147,000 to 150,000 USD, and the benefit–cost ratio (BCR) was estimated to be between 3.51 and 3.54. This indicates that the economic advantages exceed the cost. The internal rate of return (IRR) was consistently assessed at approximately 34%, which is higher than usual discount rates used in agricultural investment analysis.

A similar conclusion has been found in other smart farming research. For example, Pereira et al. (2022) determine that investment in smart farms is economically feasible with an NPV of €49,960 (58,265.85 USD) and an IRR of 6% and that the initial capital investment could be fully paid back during the project's lifetime. These findings also aligned with previous studies on the adoption of smart farming technologies, which can generate positive economic returns when operational benefits, cost savings, and productivity are improved over time (Srivetbodee and Igel, 2021, Giua et al., 2022, Georgopoulos et al., 2023).

There are two main mechanisms that can explain the favorable economic performance of iFarm. First, the system reduces irrigation management costs by replacing labor-intensive irrigation practices with automated irrigation control. Under conventional irrigation management, farmers typically incur labor costs for irrigation operations, either through daily wages or hourly payments. In contrast, the automated system operates primarily through electricity consumption, resulting in lower operating

costs and reduced labor requirements. Second, iFarm contributes to improved crop productivity by supplying water according to crop demand and soil moisture conditions. By avoiding both under-irrigation and over-irrigation, the system helps maintain optimal growing conditions, thereby supporting higher yields and improved crop quality. More precise irrigation management also reduces water losses and improves overall resource-use efficiency.

CONCLUSION

This study presents the development and field implementation of iFarm (intelligent Farm), which is designed to improve water use efficiency and climate resilience at the farm level. The platform utilized the iWASAM platform in converting real-time water management information into an irrigation decision support system at the farm level. The results showed that the iFarm can integrate multiple data sources from iWASAM to facilitate automated irrigation scheduling and field monitoring. iFarm enhanced the performance of irrigation systems, with an average irrigation efficiency of 70%. Water productivity was higher than 0.1 USD per cubic meter for both the 2024 rainy season and the 2024-2025 dry season, which is better than the national agricultural average of 0.06 USD per cubic meter. This study achieved these improvements by reducing over-irrigation and water losses. Economic studies also confirmed that the iFarm is feasible and scalable.

The average installation cost was approximately 440 USD per plot with an estimated payback period of approximately 2.27 months. An ex-ante economic analysis also found a positive economic return when the adaptation rate was above 40%. The short payback period also highlights the affordability of the device and helps reduce financial barriers to technology adoption among small farmers. These results indicated that the integration of automated irrigation control with data-driven irrigation scheduling can provide technical and economic benefits. In addition to the immediate saving in labor needs, which are more relevant given the water scarcity and climate uncertainty, the system also results in more efficient use of water and better farm management. In these conditions, the project generated positive net present values of 147,000 - 150,000 USD, benefit–cost ratios between 3.51 and 3.54, and a consistent internal rate of return of 34%. This emphasizes the ability of iFarm to contribute to both farm profitability and sustainable water resource management in climate-vulnerable agricultural regions.

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