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Community Empowerment in Application of Solar-Powered Automatic Irrigation For Chilli Farming on a Rainfed Rice

Heri Ardiansyah[1*], Rohmatin Agustina[2]

[1]Department of Computer Engineering, Faculty of Engineering, Science, and Education, Universitas Muhammadiyah Lamongan, Lamongan, Indonesia

[2]Department of Agrotechnology, Faculty of Agriculture, Universitas Muhammadiyah Gresik, Gresik, Indonesia

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Abstract The low productivity of rainfed lowland rice during the dry season, a critical factor in reduced farmer income and compromised food security, has been effectively addressed by a community team through the introduction of an automatic solar-powered irrigation system. This innovative approach, encompassing group discussions, construction of the irrigation system, and training in chilli cultivation with the new technology, has significantly enhanced crop yield and farmer income. Specifically, the technology has doubled farmers' earnings outside the rainy season, with chilli cultivation yielding 6.75 t/ha and generating IDR46,182,061 in income. The economic viability of this technology is underscored by its positive net present value (NPV) of IDR154,918,858, an internal rate of return (IRR) of 36%—surpassing the 6% discount rate—a profitability index (PI) of 1.99, and a payback period (PP) of 2.5 years. The overwhelming positive response from farmers, with 53% planning to adopt this technology in the upcoming dry season, either individually or in collaboration, highlights its effectiveness in not only boosting income but also in fostering a positive attitude towards innovative cultivation practices in challenging conditions.

1. INTRODUCTION

A rainfed rice field is a rice field with a watering system that depends on rainfall for its productivity (Singh, 2018). The productivity of rainfed rice fields was generally low because of high water evaporation, degraded soil, natural disasters such as drought or flood, and low water arrangements (Bastia et al., 2021; Kukal et al., 2014). This condition turned the rainfed rice fields extravagant to labor use since the farmer should be replanting more often compared to irrigated rice fields caused by rare water supply. The productivity increase of rainfed rice field can be obtained by farming intensification (Kleijn et al., 2019) and farming mechanization.

These farming efforts were important to be done, so that the rainfed rice fields could be more productive. Unfortunately, rainfed rice farming can only take place during the rainy season, as opposed to the dry season when farmers leave the land uncultivated. According to the rainfed rice cultivation calendar, planting usually occurs twice a year, sometimes only once.

The current situation directly affects the income of rainfed rice farmers, as farming is their sole means of livelihood. Rainfed rice farmers will only earn income if they engage in planting activities. Otherwise, they will have no earnings. In the past, the main food crops that were grown were rice and corn. However, with most farmers owning land that is less than one hectare, it became unprofitable to cultivate these crops. This situation resulted in a decrease in food production.

The farmer group's entrepreneurs conducted a community service activity using automatic irrigation technology powered by solar energy for efficient plant watering. One solution to the problem of water conservation during crop farming in the dry season for rainfed rice could be to implement a water conservation procedure. This could help farmers effectively manage their water usage. For dry season crop farming, the preferred watering system technology is drip irrigation (Kondaveti, 2021; Singh & Singh, 2000).

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*Corresponding author: Heri Ardiansyah
Departement of Computer Engineering, Faculty of Science, Technology and Education, Universitas Muhammadiyah Lamongan, Jl. Raya Plalangan, Plosowahyu Km 02, Lamongan, 62218
Email: hery24@gmail.com

A smart irrigation system can be created using an intelligent algorithm that determines the ideal volume and timing of watering based on each plant's specific needs. (Prasojo et al., 2020 ; Shanthiya, 2018) with additional solar energy for electrical control of the system (Uddin et al., 2012). The crop that can be chosen for its high economic value is the chili plant (Iverson et al., 2014). One of the effective conservation methods is the cultivation system that uses mulch made from organic matter like straw, which is waste from previous cultivation (Qin et al., 2022).

Our community service project involved collaborating with a group of farmers called Gemah Ripah in Klitih Village, Wajik Sub-district, Lamongan District, Lamongan Regency. The group is composed of 80 farmers who collectively own 30 hectares of rice fields. The number of farmers actively involved in this activity is 60. In their rainfed rice fields, farmers typically grow rice and other crops. During the first rainy season from November to February, rice cultivation takes place while during the second rainy season from March to June, some farmers plant corn while others continue to grow rice in fields close to the river. In contrast, from the first to the second dry season, most farmers do not cultivate their land, except for those fields near the riverside, where crops such as corn, beans, sorghum, or tobacco are still grown. On average, rice cultivation yields 4-5 t/ha, while corn yields 5-6 t/h.

The goal of this project is to empower the team to implement a previously designed solar-powered automatic irrigation system alongside the farmer's group. This system will be utilized in the cultivation of chilli crops during the dry season, which has historically resulted in unproductive fields. By implementing this technology, it is expected that the income of farmer households will increase. The success of this project will be measured by the ability of the solar-powered irrigation system to effectively grow and produce chillies in rainfed rice fields during the dry season. The hope is that this project will create a profitable opportunity for farmers.

2. METHOD

The community empowerment program was conducted in Wajik Village, Klitih Subdistrict, Lamongan Regency from July to November 2022. The program was carried out in partnership with the Gemah Ripah Farmers Group, which has 80 members, and involved 60 farmers during the community empowerment activities. The aim was to construct a solar-powered automatic irrigation system on the hamlet's land, which could be further utilized by other members of the farmer group. The activities were comprised of knowledge transfer and discussion, designing and implementing the irrigation system, training in its use, and evaluation. At the start of the program, an announcement was made to the farmer group via a Focus Group Discussion (FGD), which involved community partners, the Gemah Ripah farmer group, community leaders, the village government, and related agricultural offices. The FGD was held at every stage of the program to evaluate each activity and prepare improvements for the next one. The hope was that the program would increase the farmers' commitment and foster collaboration among all partners.

2.1 Knowledge transfer and discussion

The implementation of an automatic irrigation solar-powered system for rainfed rice fields has been completed for a group of 60 farmers in Klitih Village. The majority of these farmers grow rice. The project began with a focussed group discussion (FGD) involving farmer group administrators, the hamlet's officials, and community leaders (Figure 1). The purpose of this FGD was to explain the aims and objectives of the project, which consisted of constructing a solar-powered automatic irrigation system for cultivating chili plants. During the FGD, the placement of the irrigation equipment and its implementation was discussed. It was decided that the solar-powered irrigation equipment should be placed in the paddy fields belonging to Dusun Klitih.

Figure 1 . Community empowerment in implementing solar-powered automatic irrigation for chili plants: (a) knowledge transfer; (b) FGD

A major challenge faced by rice farmers in this area is the limited farming opportunities available to them as rice can only be grown during the rainy season. During a group discussion, the idea of using bunds to cultivate horticultural crops and exploring options for farming during the dry season was brought up as a way to increase income for rainfed rice farmers. However, water availability remained a significant challenge for crop cultivation during the dry season. To address this issue, the FGD participants were informed about the potential of drip irrigation as an alternative to traditional watering methods. Drip irrigation has proven to be an efficient way to meet the water needs of crops. Additionally, it was suggested that chili plants could be a profitable alternative for dry season cultivation due to their high economic value.

2.2 Design of automatic solar-powered irrigation system and Implementation through building the construction of an automatic irrigation system

The implementation of the automatic system was voluntary organized by the farmer group and the community empowerment team. The materials needed for the manufacture of a solar-powered automatic irrigation system were 7 m^3 of sand, 7 m^3 of coral, 150 kg of cement, 50 watts of solar panels, 45 mAh battery, 50 m of cable, 1 Arduino, 100 m of irrigation hose, 900 l clean water, 200 meters of ¾ inch PVC pipe, 72 irrigation drips, 15 ϴ iron 8 mm (@12 m), 1 inch at 3.5 m height supporting pole. The construction tools needed are hoes, soldering iron, plywood, scaffolding, and a screwdriver. The materials needed for chili cultivation are the seeds of the Dewata 72 variety, 10 kg NPK Mutiara fertilizer, and 30 kg manure.

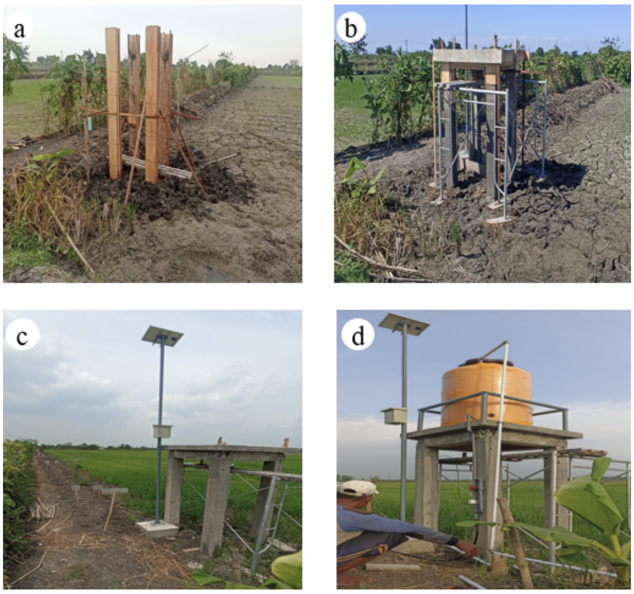

Figure 2 . Stages of construction of a concrete deck of solar-powered automatic irrigation: (a) casting of poles; (b) casting of deck; (c) making of solar power source; (d) installation of water reservoir

Figure 3 . Installation of water installations with automation: (a) Installation of pipes for water flow from water sources to water reservoirs; (b) Installation of automation; (c) drip irrigation; (d) Installation of drip irrigation with irrigation automation in chili cultivation

To build an automated solar-powered irrigation system, we must follow several steps. The first is constructing a concrete deck (Figure 2). The second is installing pipes to transport water from the source to the irrigation reservoirs (Figure 3). The third is setting up an automated solar irrigation system that follows rules based on time and water volume. The last is using the technology to enhance the cultivation of chili plants.

In order to operate an automatic irrigation system (Figure 4), a photovoltaic solar panel captures sunlight energy and converts it into electrical energy, which is then stored in a battery (A). This stored energy powers the microcontroller and electric faucet (B). The microcontroller is responsible for opening the electric faucet for varying durations, based on the specific water needs of the plants. It has been determined that 50 liters of water is required for 500 drip points, and the faucet must be opened for 40 seconds to achieve this. The system is scheduled to water the plants twice a day, at 7:00 AM and 1:00 PM and additionally, the water reservoirs should be replenished every three days.

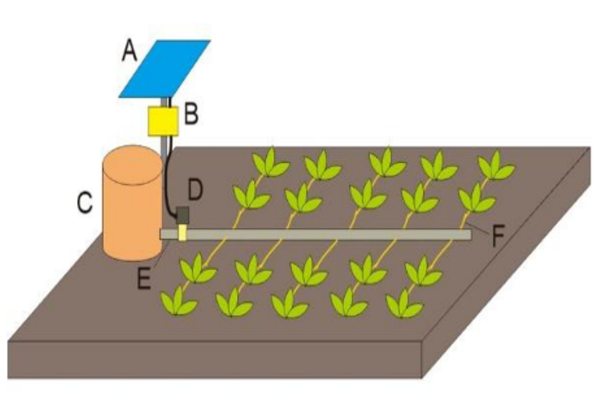

Figure 4 . Prototype of Solar-Powered Automatic Irrigation on rainfed rice. A. Solar panels; B. Battery & Controller; C. Water reservoir; D. Electric faucet; E. PVC pipe; F. Drip hose

2.3 The training in using the solar-powered automatic irrigation system

Farmers took advantage of an automatic irrigation system once it was built. The training was organized to teach the participants how to use the technology properly (Figure 5). The procedure for using this technology were (1) turning on the electrical system and making sure the LED indicator was on or flashing, (2) checking that there was enough water supply in the water tank to create pressure and allow water to flow down, (3) before turning on the system, ensure that water can flow through all drip lines by manually opening the water supply using the emergency lever provided, (4) once the check-up procedure is complete, the system is ready to operate. All stages of this procedure should be customized to suit the farmers' cultivation activities, making their work easier in the end.

Cultivation of chili plants is planted in rice field bunds as a border plant. The process of chili planting typically begins with sowing the seeds in a pot tray. After about three weeks, the small chili plants are then transplanted, with one plant being placed per planting hole at a depth of 10 cm and with a spacing of 50 x 70 cm.

To maintain the health and productivity of the chili plants, it was important to fertilize and weed them regularly. In terms of fertilizing, it was recommended to apply fertilizer three times throughout the planting process – once at the age of two weeks after planting, again during the maximum vegetative period, and finally when the flowers appear. The fertilizer used was typically NPK at a dose of 200 kg/ha during planting.

As for weed cleaning, this was typically done manually by pulling out any unwanted weeds. It was also important to control pests to ensure the health and productivity of the chili plants. Biological agents were often used for pest control, and they were typically applied on a weekly basis.

Finally, harvesting is a gradual process, with physiologically ripe chilies being picked as they reach their full potential. These chilies are usually characterized by their bright red color. By following these guidelines, one can ensure a healthy and productive crop of chili plants.

During the dry season, cultivating plants with limited water can be a challenge. Chili growers often face constraints in the early stages of planting due to the need for water, which is not always supported by the microclimate of the plants. The average air temperature in this phase can reach between 35°C and 38°C, which is why plant embroidery is often applied. However, during the advanced vegetative growth phase, the plant can adjust to the temperature of its microenvironment until harvest. By cultivating chili plants during the dry season, farmers can increase their income by 100% as there has never been any cultivation during this time before. Chili prices begin to rise in November, making it a profitable time for the farmers.

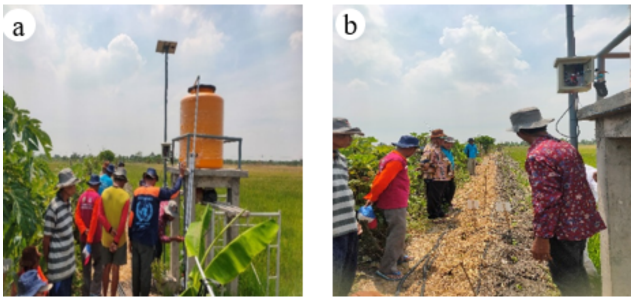

Figure 5 . Training on the use of solar-powered automatic irrigation on chili plants: (a) training on automatic irrigation equipment (b) training on chili cultivation

3. RESULT AND DISCUSSION

3.1 Evaluation of activities

An evaluation was conducted by distributing questionnaires to 42 respondents who were the members of participating farmer groups. The assessment comprised determining the percentage of knowledge transformation regarding irrigation systems in rainfed rice fields, evaluating the farmers' knowledge before and after the activity, and assessing the sustainability of implementing a solar-powered automatic irrigation program in rainfed fields. The Likert scale criteria were used to measure the farmers' answers to the questions, which were categorized as very weak (score 1), weak (score 2), adequate (score 3), strong (score 4), and very strong (score 5). The data analysis was carried out using SPSS software version 26.

The feasibility of farming with a solar irrigation system on rainfed fields during the dry season was evaluated through the use of Net Present Value (NPV) (Zizlavsky, 2014) and internal Rate of Return (IRR) (Sullivan et al., 2015) approaches. When the NPV value exceeds 0 and the IRR is greater than the discount rate (DR), and this it indicates that the investment is viable. The payback period (PP) is a way to measure the amount of time it takes to repay business capital (Kashmir & Jakfar, 2019). A viable investment is one with a PP of less than 10 years. The potential value of an investment can be determined by its profitability index (PI) (Chen, 2021). Investment feasibility can be determined by the PI value, which should be greater than 1. The following formula was used for the measurement:

Net Present Value

$$NPV = \sum \left(\frac{X_n}{(1+i)^n} - X_0 \right)$$

X_0 = Initial Investment
i = Interest rate (discount rate)
n = Cash flow timing
NPV = Net Present Value

Internal Rate of Return

$$IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2} + (i_2 - i_1)$$

NPV_1 = NPV Positive
NPV_2 = NPV Negative
i_1 = Interest rate that produces a positive NPV
i_2 = Interest rates that result in a negative NPV
IRR = Internal rate of return

Payback Period

$$PP = n + \frac{x_0 - x_n}{x_s - x_n} \times 1 \text{ year}$$

n = The last year where the net cash flow is still negative (not able to cover x_0)
x_0 = Initial investment
x_n = Cumulative amount of cash flows up to year-n
x_s = Cumulative sum of cash flows up to n+1 year
PP = Payback period

Profitable Index

$$PI = 1 + \frac{NPV}{x_0}$$

NPV = Net present value
x_0 = Initial investment
PI = Profitable index

3.2 Discussion

Figure 6 are the results obtained from the questionnaire evaluating the activity. According to the FGD results, after participating in the program, farmers' knowledge about irrigation system technology in rainfed rice fields increased to 90% (Figure 8). Before the program, they only knew 6% about drip irrigation and 54.8% about automatic irrigation. Figure 7 shows that 55% of farmers gained knowledge about solar-powered automatic irrigation systems through this program. Farmers were directly involved in various activities, such as socialization, FGD, building irrigation systems together, and practicing cultivation of chilies with this system. Among the farmers, 32.5% obtained this knowledge from various sources, including mass media (5%), agricultural services (2.5%), online media (12.5%), farmer groups (7.5%), and colleagues in farmer groups (5%) (Figure 7). The village government did not provide enough information about this irrigation system technology to farmer groups, but they were supportive and facilitated all programs from the government and NGOs. However, 12.5% of farmers still did not understand this technology due to limited access.

According to Figure 6, all farmers surveyed found the program to be highly beneficial. They reported gaining a better understanding of irrigation technology and increasing their income from chili cultivation during the dry season using this technology. As a result, more farmers expressed interest in cultivating crops during the dry season, with 53% planning to use this technology in the next dry season (Figure 9).

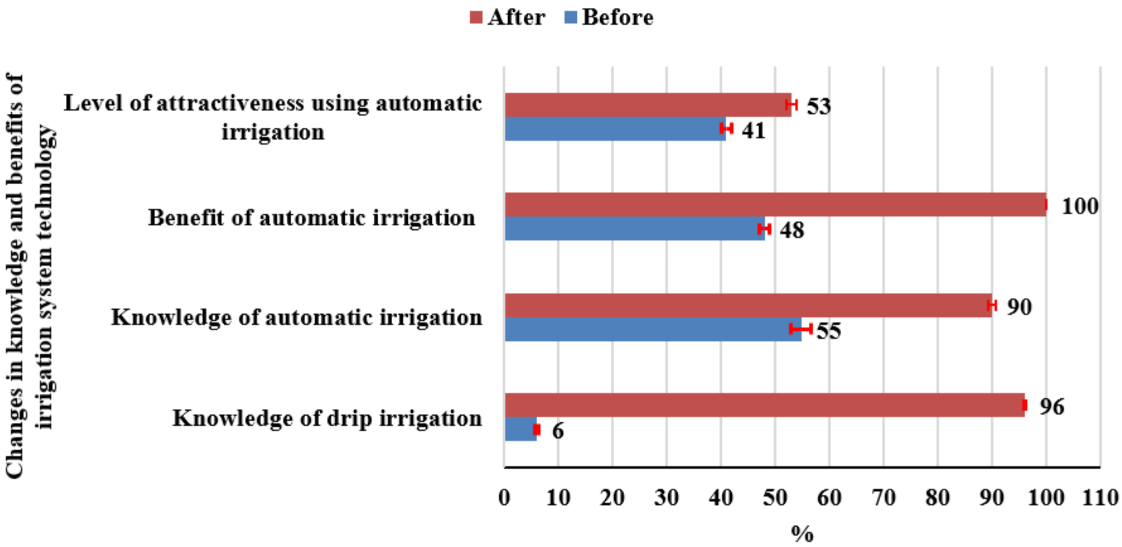

Figure 6 . Percentages of changes in farmers' knowledge of solar-powered automatic irrigation systems

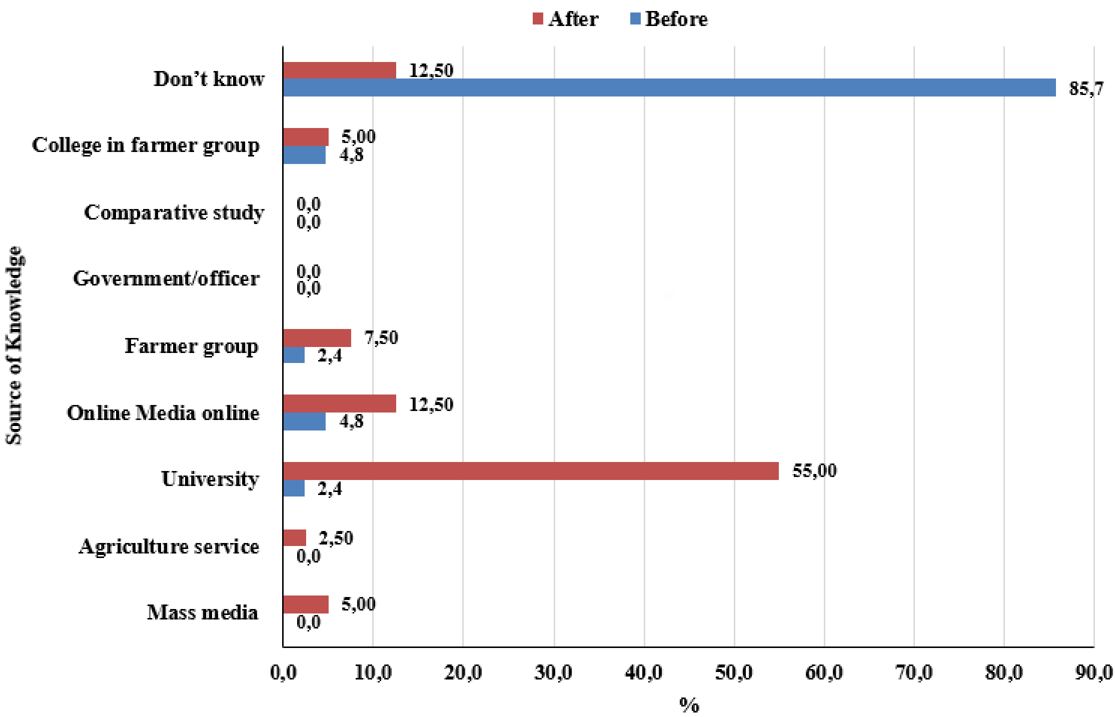

Figure 7 . Percentage of farmers' sources of knowledge related to solar-powered automatic irrigation systems

	Amount	Unit	Price (Rp)	Unit	Total (Rp)
1.Solar irrigation system equipment					10,000,000
Total A					10,000,000
2. Material					
2.1Chili seeds, spacing 50 x 70 cm	12.7	Wrap	72,500	Wrap	918,333
2.2 Manure	30.0	t/ha	2,500	kg	75,000,000
2.3 Urea Fertilizer	570.0	kg/ha	9,500	kg	5,415,000
2.4 SP 36 Fertilizer	997.5	kg/ha	10,000	kg	9,975,000
2.5 KCL fertilizer	855.0	kg/ha	12,500	kg	10,687,500
2.4 Seedling polybags 10 x 10 cm	73.7	kg	25,000	kg	1,842,105
Total B					103,837,939
3.Labor					
3.1 Nursery	4.0 People ♂	2 working days	150,000	HOK ♂	600,000
3.2 Planting	10.0 People ♂	1 working day	150,000	HOK ♂	1,500,000
	30.0 People ♂	1 working day	120,000	HOK ♀	3,600,000
3.3 Maintenance	40.0 People ♂	20 times work @ 2 people	150,000	HOK ♂	6,000,000
	80.0 People ♀	20 times work @ 4 people	120,000	HOK ♀	9,600,000
3.4 Harvesting	12.0 People ♂	6 times work @ 2 people	150,000	HOK ♂	1,800,000
	24.0 People ♀	6 times work @ 4 people	120,000	HOK ♀	2,880,000
3.5 Tillage	30.0 People ♂	3 times work @ 10 people	150,000	HOK ♂	4,500,000
Total C					30,480,000
4. Yield					
4.1 Chili fruit 400 g/p	6750.0	kg/ha	30,000	kg	202,500,000
Total D					202,500,000
5. Sewa Lahan					12,000,000
Total E					12,000,000
Total cost (A + B + C + E) ~ Initial investment ….. F					156,317,939
Income 1 season (D - (A+B+C+E)) …... G					46,182,061
Cash Flow 1 season (D- (B+C+E))					56,182,061
R/C (D/F)					1.3

Figure 8 . Analysis of chili farming with an automatic irrigation system in rain-fed paddy fields in the dry season in an area of 1 ha

Figure 9 . Rainfed paddy fields: (a) before the construction of solar-powered automatic irrigation; (b) after the construction of solar-powered automatic irrigation.

Rainfed rice fields were previously left uncultivated during the dry season, resulting in no income for farmers. However, with the implementation of a solar-powered automatic irrigation system, farmers could now cultivate crops and generate income during the dry season. According to the farming analysis results in Figure 8, chili farming on drip irrigation with a one ha area yielded an income of IDR46,182,061 per growing season.

This means that even after incurring costs for creating the solar-powered irrigation system and moving crops, farmers could still benefit greatly from cultivation during the dry season. The RC ratio also confirmed the feasibility of this business, with a ratio greater than 1.

Table 1 . Evaluation of the feasibility of farming with an automatic solar irrigation system in the dry season in rainfed rice fields in an area of 1 ha for 5 years

nth year	Cash in Flow	Cash Flow Cumulatif	Discount Factor (1/(1=i)n̂)	Present Value (XT) atau (PV)	Net Cash Flow
0	-IDR156,317,938.60	-	1	-IDR156,317,938.60	-IDR156,317,938.60
1	IDR56,182,061.40	IDR56,182,061.40	0.943396226	IDR53,001,944.72	-IDR100,135,877.19
2	IDR89,932,061.40	IDR146,114,122.81	0.88999644	IDR80,039,214.49	IDR40,353,245.61
3	IDR50,557,061.40	IDR320,353,245.61	0.792093663	IDR97,967,777.09	IDR164,035,307.02
4	IDR123,682,061.40	IDR320,353,245.61	0.792093663	IDR97,967,777.09	IDR164,035,307.02
5	IDR50,557,061.40	IDR370,910,307.02	0.747258173	IDR37,779,177.33	IDR214,592,368.42
BEP					**2.20**
NPV					**154,918,858.69**
IRR					**36%**
PI					**1.99**

According to Table 1, using an automatic solar irrigation system for farming during the dry season in one hectare of rain-fed rice fields for five years is both practical and profitable. This was supported by the fact that the net present value (NPV) was greater than zero, and the internal rate of return (IRR) value was greater than the DR value (6%), and the profitability index (PI) was greater than one. Based on the calculations, the payback period (PP) for this farming project was 2 years and 5 months. This was within a reasonable timeframe of less than 10 years to recoup the initial investment.

3.3 Substainbility and prospect

The sustainability of the automatic solar-powered irrigation system which enhance the productivity of rainfed lowland rice during the dry-season is a main factor in its long-term success (Toga, 2020). This system addresses critical issues such as reduced farmer income and compromised food security, which are prevalent in many agricultural communities. The sustainability of this approach lies in its use of solar power, a renewable energy source, which reduces dependence on non-renewable energy resources and minimizes environmental impact (Niaz et al., 2022). Additionally, the system's ability to significantly increase crop yield and farmer income ensures its continued use and maintenance, as it becomes an integral part of the farming process. The training provided to farmers in chili cultivation and system operation further ensures that the knowledge and skills required to maintain and effectively use the system are disseminated within the community, fostering self-reliance and long-term sustainability.

The prospects for this technology is high promising, given its demonstrated ability to double farmers' earnings outside the rainy season. The success in chili cultivation, yielding 6.75 t/ha and generating substantial income, serves as a compelling model for other crops and regions facing similar challenges (Alam et al., 2010; Burney et al., 2010; Jo et al., 2021; Portugal et al., 2020). The economic viability of the system, which indicated by its positive NPV, high IRR, favorable PI, and short PP, makes it an attractive option for farmers and investors alike. These financial indicators suggest that the system is not only a viable solution for the immediate challenges, but also a profitable long-term investment, encouraging its adoption and expansion.

Furthermore, the positive response from the farming community, with over half of the farmers expressing interest in adopting the technology, indicates a significant shift in attitudes towards innovative agricultural practices. This shift is crucial for the widespread adoption and success of such technologies. As more farmers adopt this system, there is potential for a ripple effect, leading to broader changes in agricultural practices that favor sustainability and resilience. This community-led approach, coupled with the tangible benefits observed, which is most likely to inspire similar initiatives in other regions, potentially leading to a paradigm shift in how dry-season agriculture is approached.

Looking ahead, the prospects for scaling up this technology are substantial. Its adaptability to different crops and environments, combined with the growing global emphasis on sustainable agriculture, positions it well for broader implementation. Governments, NGOs, and private entities looking to invest in sustainable agricultural technologies may find this model particularly appealing (Alam et al., 2010; Larbodiere et al.,2020; Pretty et al., 2011). Moreover, as climate change continues to impact traditional farming seasons and methods, technologies like this solar-powered irrigation system will become increasingly vital. They offer a way to mitigate some of the adverse effects of climate change on agriculture, ensuring food security and stable farmer incomes in the face of environmental challenges. In summary, the sustainability and prospects of this solar-powered irrigation system are not only promising for the communities currently using it, but also hold significant potential for transforming agricultural practices globally.

4. CONCLUSION

The implementation of this program has been successful in providing farmers with alternative irrigation methods for crop cultivation in the dry season. By utilizing solar-powered automatic irrigation installations, farmers could increase their income by 100% during the dry season.

Through the use of this technology, the results of chili cultivation during the program yielded 6.75 t/ha with an income of IDR46,182,061. Based on the calculations, it has been established that utilizing this technology for farming was a viable option. This was because it yielded a positive net present value (NPV) of IDR154,918,858, an internal rate of return (IRR) of 36% which is higher than the discount rate of 6%, a profitability index (PI) of 1.99, and a payback period (PP) of 2.5 years, which falls within 10 years. All farmers participated in the program stated that it was very beneficial. The benefits they received comprised their increased knowledge about irrigation technology, increased income from chili cultivation during the dry season, and the adoption of attitudes suitable for planting during the dry season. As a result, 53% of farmers planned to continue cultivating crops using this technology, either independently or in groups with other farmers.

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CONFLICT OF INTERESTS

The authors declares there is no conflict of interest

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