Comparative Investigation of Performance for Off-Grid Solar Pump for Further Application in Agriculture Farms: A Case Study in Thailand

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Abstract. *Thailand's agricultural sector, with its substantial farming population, relies heavily on irrigation from small canals to sustain the cultivation of crops such as rice, corn, cassava, and sugarcane, which are replanted at various intervals throughout the year. This study evaluates the efficiency and economic viability of a direct-coupled solar water pumping system without storage, utilizing three distinct types of DC pumps—centrifugal, reciprocating, and submersible—each with a power rating of 750 W. The field tests were conducted concurrently under controlled conditions in a specific rural area in Thailand, with each pump connected to 3×340 W photovoltaic (PV) panels. The performance analysis revealed that the centrifugal pump achieved the highest efficiency, followed by the reciprocating pump, with the submersible pump ranking last. However, despite its lower efficiency, the submersible pump demonstrated the shortest payback period of 1.7 years, compared to 2.2 years for the centrifugal pump and 3.0 years for the reciprocating pump. These findings highlight the importance of selecting the appropriate pump type based on specific irrigation requirements and system design, as each pump offers unique advantages for different solar water pumping applications and areas.*

Keywords:

PV water pumping, Renewable energy, Solar-powered pump, DC pump, Photovoltaic

1. Introduction

Thailand is where the farthest of the population is engaged in agriculture, including rice, corn, cassava, and sugarcane which are replanted more than once, causing the need for plants to grow all year. The water pump system in most agricultural areas in Thailand still uses the internal combustion engine as the power source. However, fossil fuel prices and agriculture production costs have increased dramatically, and its loss may occur accordingly. For this reason, the Thai government has issued a policy to encourage the agricultural sector to adopt renewable energy technology to reduce dependence on fossil fuels composed of biogas fuel and solar energy, our focus is on repurposing the organization to align with the Green Economy of the BCG model [1, 2]. In the case of biogas fuels, it is used as a direct replacement for fossil fuels in internal combustion engines. Still, in production, a fermentation process must be involved, thus increasing the cost of the system, which may not be suitable for smaller systems. Disparate with a PV panel, the price per kWh unit is getting cheaper daily and higher efficiency. In addition, it is ideal for the terrain of Thailand with a relatively high irradiance intensity curve throughout the year, and importantly, it has an uncomplicated installation.

In Thailand, agricultural irrigation was traditionally carried out by directly drawing water from small irrigation canals into farming plots, as illustrated in Figure 1. A direct-coupled solar PV water pumping system has become popular among Thai farmers due to its simplicity [3], [4], [5], and it can be used with both AC and DC-type water pumps. Although AC pumps are generally less expensive than DC pumps, they require an inverter to convert DC power to AC, which increases overall system costs. While AC water pumps are smaller, DC pumps are more efficient and versatile [4 – 6].

Solar-powered irrigation systems utilize various types of DC pumps, each offering distinct advantages and limitations depending on the specific system design and irrigation requirements. Centrifugal pumps, including submersible variants, are commonly chosen for their simplicity and effectiveness in high-flow, low-pressure applications such as flood irrigation. However, their performance can be affected by factors like solar irradiation and rotational speed, with efficiency often decreasing under high-pressure conditions [5], [7[, [9].

Reciprocating pumps, driven by DC motors, are well-suited for small-scale systems where high pressure and precise flow control are required. Despite their effectiveness, these pumps are typically more complex and demand regular maintenance. Submersible pumps, designed for underwater operation, are particularly advantageous for deep-well irrigation, offering high efficiency and low noise levels. However, their higher initial costs and greater maintenance needs can be significant drawbacks [8].

Additionally, Brushless DC (BLDC) motor pump sets have emerged as a promising alternative, delivering enhanced efficiency and cost savings compared to traditional submersible pumps [7].

This study aims to evaluate the efficiency of a direct-coupled DC solar water pumping system for the agricultural sector in Thailand by testing three types of pumps: centrifugal, reciprocating, and submersible. Each pump, having comparable power ratings, will be installed at the same location. The tests will be conducted simultaneously on the same day, utilizing water supply pipes of similar size and length. The study will encompass a performance analysis of the three pumps as well as an economic cost evaluation.

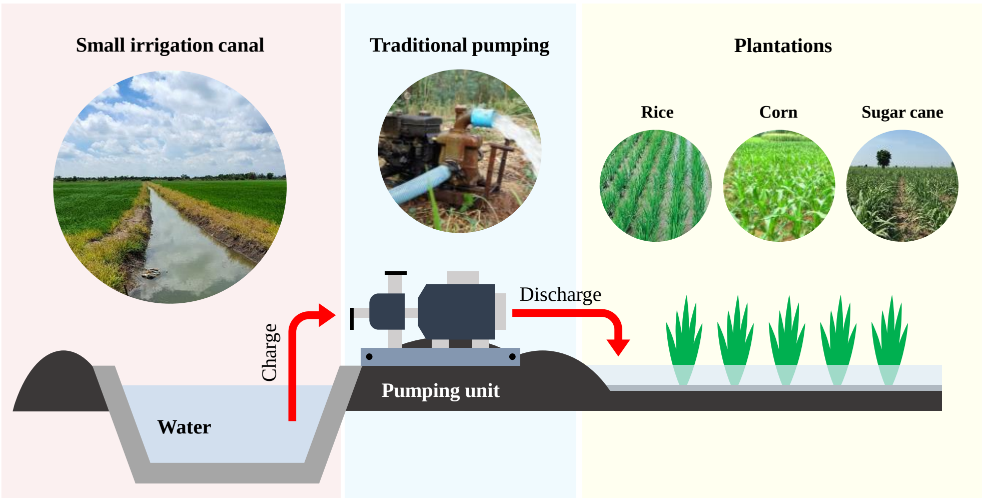


Fig. 1 Irrigation of common agricultural crops in Thailand.

2. Methodology

The performance of the direct-coupled PV-powered DC water pumping system without storage, which can be shown as a simple schematic in Figure 2, depends on the following parameters [10 – 13]:

- Solar irradiation (Sir);
- Ambien Temperature (T);
- Measured PV array output voltage (V_{pv});
- Measured PV array output current (I_{pv});
- Total head (H_T);
- Flow rate (Q);
- Power (P) and
- Photovoltaic (PV)

The system efficiencies (η_{system}) can be calculated as

$$\eta_{system} = P_{out} / P_{in} \qquad (1)$$

Where $P_{PV} = P_{in}$, and $P_{Hydraulic} = P_{output}$, as shown in Fig. 2.

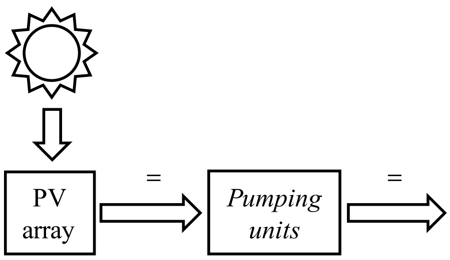


Fig. 2. Basic direct-coupled PV-powered DC water pumping system without storage

The measured voltage by the PV panel multiplied by the current gives the PV output power. That will become the input power of the pump system. The PV input power (P_{PV}) can be calculated as

$$P_{PV} = V_{PV} \times I_{PV} \quad (2)$$

Where V_{PV} is the measured voltage of the PV panel, and I_{PV} is the measured current of the PV panel.

The hydraulic power of pumping units ($P_{Hydraulic}$) can be calculated as

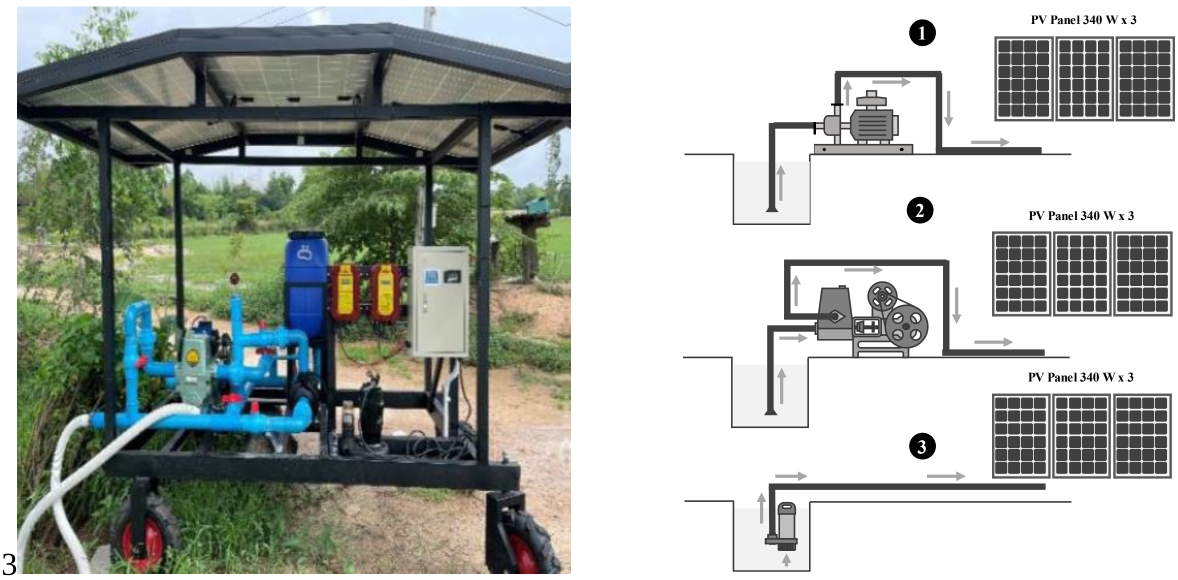
$$P_{Hydraulic} = \gamma Q H_T \quad (3)$$

Where γ is the specific weight of water (kN/m^3), Q is the flow rate (m^3/s), and H_T is the total head.

From Equations (2) and (3), the equations can be rewritten as follows:

$$\eta_{system} = \gamma Q H_T / V_{PV} I_{PV} \quad (4)$$

3. Experimental Setup



(a) (b)

Fig. 3. (a) The proposed three types of PV solar pumping prototypes installed, (b) Schematic experimental setup diagram of the proposed a solar pumping system using three different pumps: 1) Centrifugal pump set, 2) Reciprocating pump, and 3) Submersible pump.

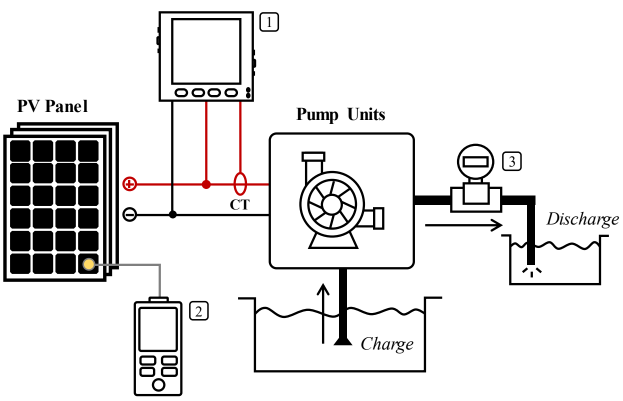


Fig. 4. The measuring setup for the three solar pump systems, 1) Digital power meter, 2) Water flow meter, and 3) Solar irradiance meter.

The proposed solar water pumping system as shown in Figure 3 was tested to determine the efficiency in rice fields at Thap Than Subdistrict, Thap Than District, Uthai Thani Province, located in the central region of Thailand (15.45587N, 99.87965E). The experimental setup as in Figure 3 consisted of stand-alone pumping systems with three different pumps, each with three solar panels in series, The input voltage, and the input current from the three PV panels were measured with a digital power meter (Schneider-PM2300 model, Germany) for taking and recording the data every 30 minutes. The solar irradiation intensity and ambient temperature were measured with a solar irradiance meter (SEAWARD-SS200R model, United Kingdom), which can log data in the device's memory. The flow meter (Yf-dn50 G2, China) was mounted on the pump outlet pipe. The measuring setup for the three solar pump systems utilized in this study is shown in Figure 4. The specifications of the three pumps are shown in Table 1.

In our research, we conducted field tests independently to ensure that the results align with the irradiation and climate of Thailand. The efficiency test of the three proposed types of solar water pumps was conducted under the following testing conditions:

- Input power from PV panel = 3 x 340 watts.
- Water pipes of the same size and length.
- Testing done on the same date and at the same time.

Table 1 Specifications of the three pumps

Type	Models	Motor Power (kW)	Statics head (m)	Outlet (inch)
Centrifugal	JODAI DC 750W, LHF20/14-96/750	750	25	2
Reciprocating	NEW-MAKKO and Brushless DC motor, LMT750-DC	750	12	2
Submersible	JODAI DC 750W, LIQDX14.5/25-96/750-2	750	25	2

4. Results and Discussion

This section evaluated the field performance of three water pumping units equipped with solar PV panels under identical temperature and irradiation conditions. Figure 5 illustrates the average solar irradiation (S_{ir}) and average ambient temperature (T) results. The system measurements were taken over three days from April 1 to 3, 2022, during predominantly sunny conditions with few clouds. The peak irradiation intensity reached 1,177 W/m^3 around noon, with an average of 716 W/m^3.

The average ambient temperature was 35 °C, reaching a maximum of 43 °C. It is important to note that variations in solar radiation affect the output voltage (V_{pv}) of the solar panels, as higher radiation levels increase V_{pv} while excess heat decreases it.

The pumping unit's input voltage (V_{in}) is supplied by the solar panel (V_{pv} = V_{in}). The V_{in} curves of the three different types of DC pumps can be seen in Figure 6, which suggests that the voltage and power sources (P_{in}) for each pump were roughly identical. The three pumps showed a less than 1% average voltage fluctuation.

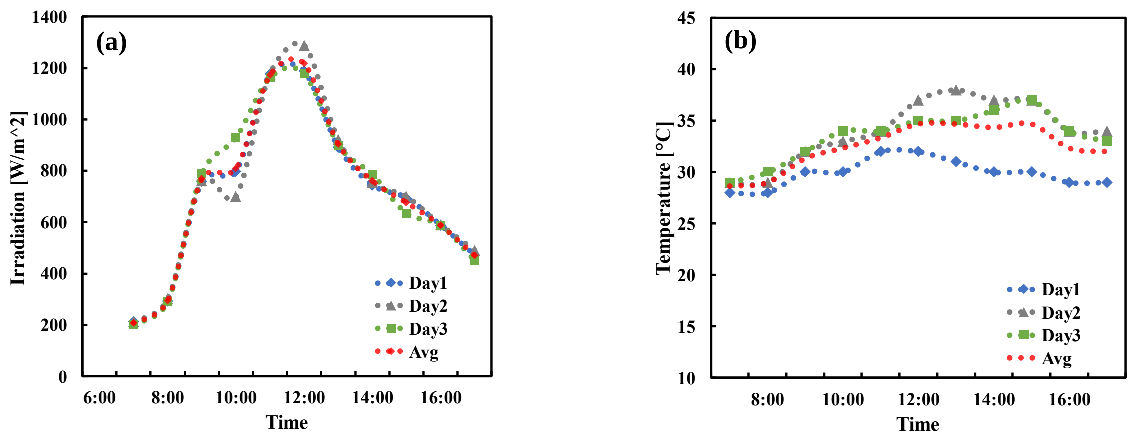


Fig. 5. (a) Solar irradiation and (b) Solar ambient temperature.

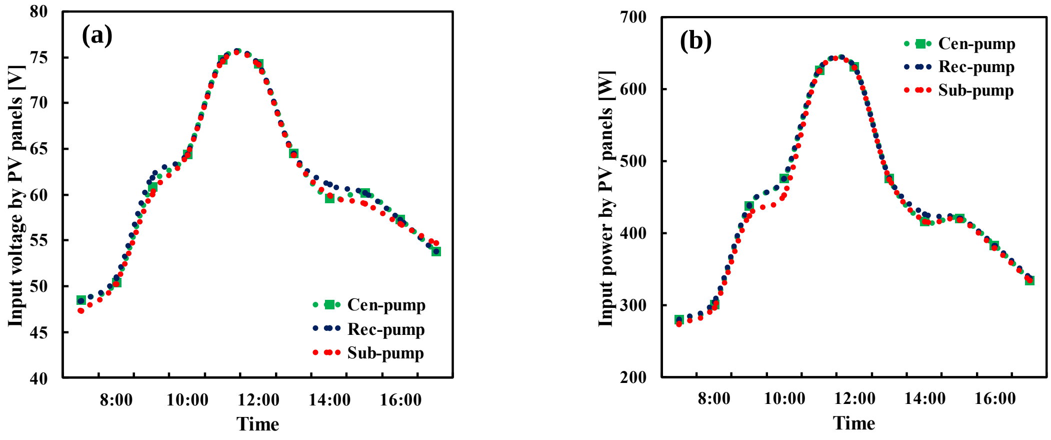


Fig. 6. (a) Input voltage and (b) input power by PV panels.

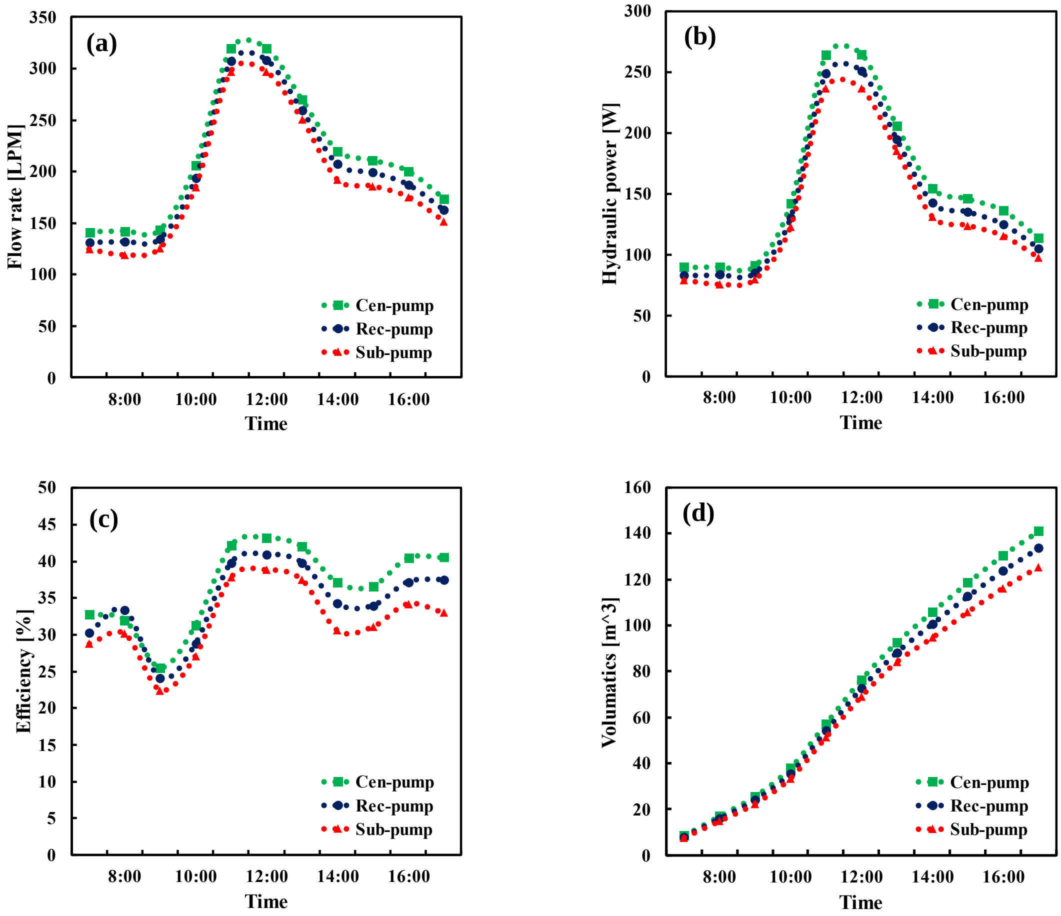


Fig. 7. Performance of pumping units, a) Flow rate, b) Hydraulics power, c) System efficiency and d) Volumatic of pump per day.

Table 2 The economic identification of the three pumps

Specification, items	Unit	Centrifugal	Reciprocating	Submersible
Installed PV power	W_p	1020	1020	1020
Specific module price	USD/W_p	0.11	0.11	0.11
Specific pump price	USD/W_p	0.37	0.57	0.23
Cost of installation	USD	57	57	57
Total initial installation cost	USD	451	601	341
Total operating cost	USD	4	2	2
Input energy by PV	kWh/year	1726.75	1667.55	1738.43
Payback period	years	2.2	3.0	1.7
Output hydraulic energy	kWh/year	620.56	579.46	535.70

The three pumps have the same total head (Ht) due to identical pipe size and length. The flow rate (Q) in equation (4) determines the hydraulic power of the pump system, which directly impacts system efficiency. Fig. 7(b) illustrates the average hydraulic power of the pumping unit system. In Fig. 7(c), the system efficiency is presented, showing that centrifugal pumps were the most efficient, followed by the reciprocating pump, and the submersible pump was the least efficient in this experimental design. The efficiency achieved will determine the water volume obtained during different periods, as illustrated in Fig. 7(d). The conditions were set so that irradiation patterns were consistent throughout the year, with an assumed 10% system unavailability due to maintenance and low irradiation. The output hydraulic energy of the three pumping systems is detailed in Table 2.

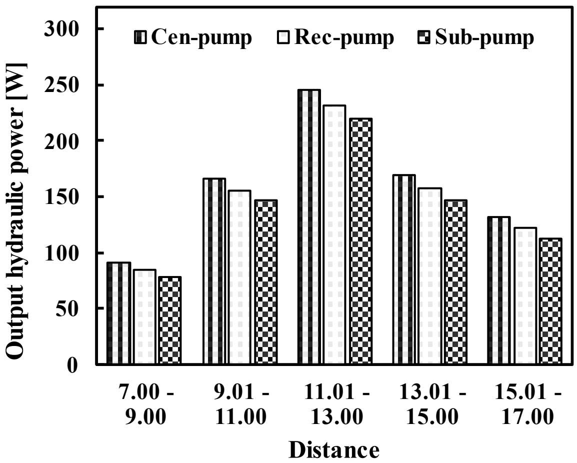


Fig. 8. The average output hydraulic power is used every two hours of pumping units.

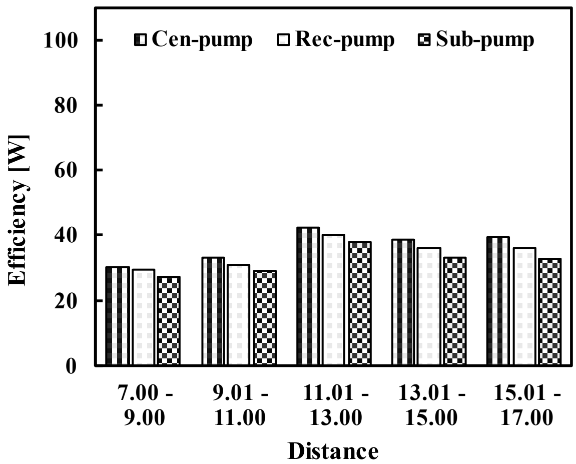


Fig. 9. System efficiency every two hours of pumping units.

The hydraulic output power of the three pumps was analyzed at two-hour intervals between 07:00 and 17:00, as illustrated in Figure 8. The data clearly shows that the submersible pump consistently exhibits the lowest average output power across all intervals, while the centrifugal pump demonstrates the highest average output power. This observation is consistent with the efficiency diagram presented in Figure 9, which indicates that the submersible pump maintains the lowest efficiency throughout the entire period, whereas the centrifugal pump achieves the highest efficiency, followed by the piston pump.

We conducted an economic analysis of three different pumps in this study [14 – 17]. Table 2 provides a summary of the annual operating costs and expenses for PV panels, structures, and pumps. The main operating cost is pump maintenance, assuming a service life of 10 years. The pump system is designed to run for 10 hours per day, totaling 36,500 hours of operation, while the PV panels can be used for more than 80,000 hours. It's important to note that the PV panels and structure may require minor repairs after the project is completed and can be utilized again.

When comparing the cost of using electricity from PV panels to the cost of purchasing electricity at a rate of 0.12

USD, the annual costs for the centrifugal pump, the reciprocating pump, and the submersible pump are 207.24 USD, 200.11 USD, and 208.61 USD, respectively. As a result, the payback periods for the three water pumps in the study are 2.2 years, 3.0 years, and 1.7 years, respectively.

5. Conclusion

In this study, we examined the effectiveness of a direct-coupled DC solar water pumping system using three different types of DC pumps for the agriculture sector in Thailand. The field test will be conducted under specific conditions in a rural area in Thailand. The three pumps were all 750 W in size and were paired with 3×340 W PV panels.

The test results indicated that the efficiency values of the three pumps, when sorted in descending order, were as follows: centrifugal pumps, reciprocating pumps, and submersible pumps, respectively. However, despite the efficiency rankings, the submersible pump had the shortest payback period of 1.7 years, the centrifugal pump came in second at 2.2 years, and the reciprocating pump had the longest payback period at 3.0 years.

Based on the findings of this research, several key conclusions can be drawn: First, for achieving more speedy water pumping, a centrifugal pump emerges as the most effective option. Second, when prioritizing rapid return on investment, a submersible pump is the optimal choice. Lastly, if both high-speed pumping and swift payback are desired, the centrifugal pump remains the preferred solution.

It's important to note that because the material's hardness was not considered during this test, the lifespan of some of the pumps may differ from what was expected. However, the selection of the appropriate pump type should be based on specific irrigation requirements and system design, as each pump offers distinct benefits for different solar water pumping applications.

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