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A New Solar-Powered Rice-Fish Farming System for Yield Improvement

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Abstract

Rice-fish farming is widely practiced all over the world, but since some areas lack irrigation, diesel pumps are often needed. Solar-powered irrigation systems (SPIS) are considered to be a more sustainable option than traditional pumps, but are more costly to set up, limiting their use to direct rice irrigation. This study intended to integrate solar-powered pumps in the irrigation system and investigate its viability through the following: establish an appropriate motor size, determine solar panel tilt, and compare with traditional irrigation pumping. The system was comprised of a positive displacement-type solar pump, photovoltaic panels, a charge controller, a battery, and an elevated, lined water impounding system for aquaculture. Tilt angles varying between 5 and 10 degrees were tested by measuring the current drawn from the photovoltaic panels. Three motor sizes were used and compared based on flow rate and volume of water pumped per full 100Ah battery, and the effect of the water impounding system along with raising tilapia on the growth of rice was determined. Results revealed that a 200-watt motor pumps the most water per full battery charge, and that the monthly computed panel tilt had the highest harvested energy. Furthermore, solar-powered rice-fish culture gave a higher yield compared to traditional diesel-pump irrigation, and calculations on the system's economic feasibility show a benefit-cost ratio of 1.26 and a payback period of 2.87 years.

Keywords: Rice-fish culture, solar-powered irrigation system aquaponics

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Rice-fish cultivation is widely practiced around the world, especially in Asia, with countries developing their own methodology and techniques to address various constraints unique to their area (Halwart and Gupta, n.d.). The practice has numerous monetary, social, and ecological advantages. Even with a decrease of 10% in the area of the rice field committed for the fish shelter, “there is an increase in the yield of rice by 14-48% in addition to a fish yield of 51-74 kilograms (kg)/ha; in fact, rice-fish cultivation in the Philippines gives a 27% net return as revealed from the study of Sevilleja of CLSU in 1992” (Guerrero, 2018).

In rice-fish culture, a steady stockpile of water from an artificial system or underground source is critical, with irrigation water, ground water, spring and other water sources often used when uncontaminated by pesticides (FAO, 2001).

Pumps are needed in areas not serviced by the National Irrigation Authority (NIA). Diesel pumps are widely used, but the cost is prohibitive, needing at least 15,000 pesos per hectare for each cropping cycle (Bacongco, 2019).

Solar powered irrigation systems (SPIS) are gaining popularity in the Philippines but are still expensive because most of these systems operate only when irrigation is needed. As a result, a big system is required to supply the needed volume of water at once, with the cost for SPIS irrigation methods taking about nine years to be equal to that of conventional pumps. After this time, the costs of conventional pumping systems would then exceed the PV solar panel systems (Niajalili, et al. 2017).

To fully utilize the SPIS, this study intended to integrate it with rice-fish culture. Water pumped by SPIS was channeled to the lined, elevated pond raised with red tilapia before irrigating the field below. This study also investigated the optimum motor size and tilt angle, and conducted a cost and return analysis.

Materials and Methods

Description of the study area

The study was conducted at a rainfed rice field in Purok 3-A, Brgy. Mesaoy, New Corella, Davao del Norte. The soil texture of the experimental site was found to be silt loam, and its topography was determined suitable for check basin irrigation. Individual plots were situated inside a close-growing rice field so that the actual growing can take place in the site.

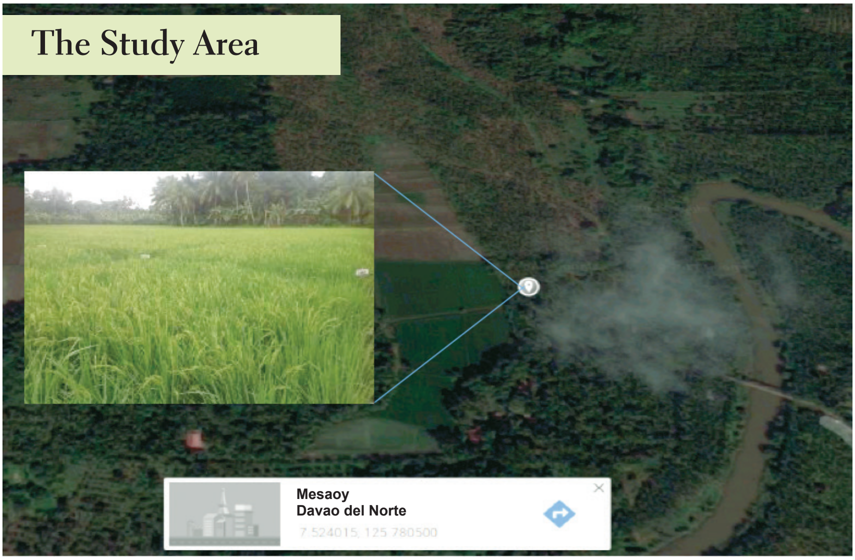

Figure 1. Study area, satellite view.

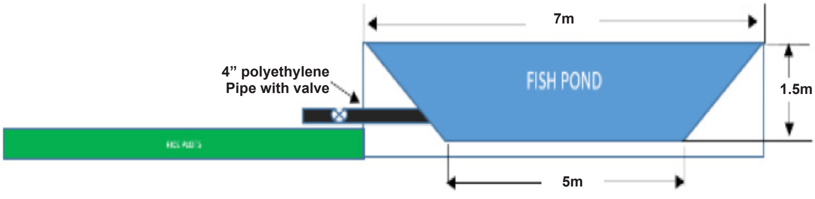

Figure 2. Fish pond and rice plot diagram.

Pump selection

The pump used in the study is a positive displacement screw type with a motor mounted on the tripod. The motors available had capacities of 200, 300, and 550 watts, directly coupled to the pump by bolts and nuts.

Construction of shallow tube well and fish pond

A 70-ft. well was dug above the field to facilitate gravitational delivery of water during irrigation. A 7m x 5m x 1.5m lined impounding was also constructed between the well and the field. The impounding has an output pipe that leads to the field, which is controlled by a shut off valve. The impounding was where tilapia was raised following a standard stocking density.

Figure 3. Construction of the water impounding system.

Construction of the rotating solar panel mounting and installation

The solar panel mount was made from a 2" metal pole as its support column and a 1" angle bar for the panel holder, which in turn was attached to a 1" shaft (see figure on next page). Both ends of the 1" shaft were attached to a pillow block to allow for tilt adjustment, and both ends were locked in place to fix panel tilt and avoid sudden rotation. This was installed following a north-south orientation.

Figure 4. The Constructed Solar Panel Mount

The Solar Charging System

A 100-Ah, 12-V battery was used to store the energy harvested by the panels and power the pump. This battery was charged by a 300-watt, 12-volt monocrystalline solar panel connected in parallel series through a 40-amps solar charge controller.

Figure 5. Solar Battery and Charge Controller

Motor size selection

Three motor sizes (200, 300, 550 watts) were used and were laid out in Complete Randomized Design (CRD). Water discharge of 3 varying pump sizes was gathered at 0 m head elevation, and the motors' battery life duration for every full charge was recorded.

Solar panel monthly tilt selection

Site coordinates were obtained through geotagging. The optimal monthly solar panel tilt was calculated following Malicdem's formula, and its solar insolation compared to ±5 and ±10 degrees.

The panel tilt was manually adjusted at every level using a protractor positioned in the horizontal axis of the solar panel mounting rails. This was performed randomly and quickly to ensure no cloud cover can cause biased data to succeeding runs, and in the case of cloud cover appearing, the experiment was suspended and rescheduled. The energy harvested by the panels at different tilt angles was measured using Fluke 302+ Digital Clamp Meter AC/DC multimeter. This was replicated three times.

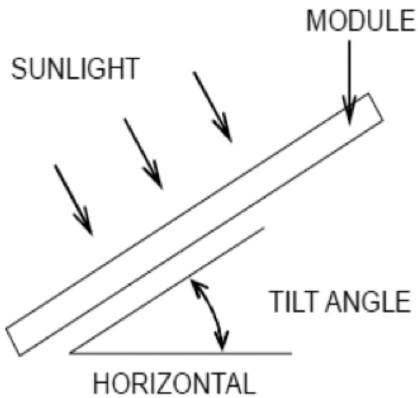

Figure 6. The solar panel and tilt angle location

Evaluating system service capacity

The amount of water irrigated was recorded, and the system's theoretical and actual field capacity was calculated using the rice water requirement of related studies.

Comparing the system with conventional pumping

The experiment was laid out in a split plot design. The type of irrigation was selected as the main plot, with the irrigation source service as subplots. Treatments were replicated three times (see Table 1, next page).

Table 1. Experimental Layout Used in Comparing the Two Systems

SUBPLOTS (Irrigation Source)	MAINPLOTS (Type of Irrigation)	
	AWD	FLOODING
Solar Pump-Water Impounding	Treatment 1	Treatment 2
Diesel Pump from Well	Treatment 3	Treatment 4

Experimental site preparation and conditioning

The rice variety used in this study was NSIC Rc120, which has an average yield of 4.8 tons and a maximum yield of 5.1 tons (PhilRice-Department of Agriculture). The experimental area was prepared using wetland tillage, following the PhilRice Philippine Rice Production Training Manual of 2007. The manual also includes dike repair, field unit irrigation, primary tillage operations, land-soaking for 5-7 days, harrowing 2-3 times at a 5-7 day interval, and field leveling.

Seedbed plots 1-1.5m wide, spaced 40m apart, and raised at about 5cm were prepared one day before sowing. Seed preparation, fertilization, and transplanting were done by following the PhilRice Manual.

Fertilizer application

The fertilizer application rates used were based on soil laboratory analysis results. Fertilizer application was uniform to all treatments, with each treatment receiving the same amount of fertilizer to avoid biased data.

Observation well fabrication, installation, and use

For controlled irrigation, an observation well was made from a plastic tube 25 cm long with a 10 cm diameter, which was fabricated and installed following the PhilRice Manual of 2007. During wet season, irrigation involved flooding the field until the water reached the topmost portion of the tube, while during the dry season, water was applied until it reached 5 cm above the ground or until its level reached the circumferential line marked for the wet season.

Irrigation was done again using controlled irrigation when there was no more visible water in the observation well, and needed to be started in the field based on the observation well 30 days or four weeks after planting. During the tillering period, it was important that flooding was not done continuously, and that a 5-cm depth of standing water was maintained in the paddy during flowering. The last irrigation was done one week before harvest.

Figure 7. Experimental Site

Alternate wetting and drying

After irrigation, water depth is expected to gradually decrease. When water level drops to about 15 cm below the surface of the soil, irrigation should be applied to re-flood the field to a depth of about 5 cm. From one week before to a week after flowering, the field should be kept flooded, topping up to a depth of 5 cm as needed. After flowering, during grain filling and ripening, the water level is allowed to drop again to 15 cm below the soil surface before re-irrigation.

AWD was implemented 1-2 weeks after transplanting. When weeds were present, AWD would be postponed for 2-3 weeks to assist weed suppression by the ponded water and improve herbicide efficacy; local fertilizer recommendations for flooded rice could be used.

The following data were gathered:

Plant height. The data on plant height was measured from ten (10) samples established in a plot, from plant base to panicle.

Number of productive tillers. This was taken 75 days after emergence.

Grain yield. The rice production after the research was recorded in tons per hectare.

Fish yield. Fish raised in the impounding were harvested after 5 months.

Project cost. All costs incurred were recorded as input to benefit-cost analysis.

Benefit Cost Analysis

The benefit cost ratio (BCR) is the ratio of project benefit to project cost. This involves taking the sum of a project's total discounted benefit throughout its entire duration, and dividing it by the project's total discounted costs.

In calculating BCR, it was assumed that the study would use two cropping seasons for 3 years, from the assumption that the battery use could reach 3 years' service life.

It was also assumed in the analysis that there was no rain water addition, with only pumped water used. The benefits considered were rice and tilapia yield at a discount rate of 15%, with palay price being Php 17.00/kg.

$$BCR = \frac{[\sum B_1/(1+d)^1]}{[\sum C_1/(1+d)^1]} \text{ summed over } 1 = 0 \text{ to } n \text{ years}$$

Equation 1. Benefit Cost Ratio Formula

Statistical Analysis

Analysis of variance (ANOVA) was performed. To determine which treatment means had a significant effect over the other treatments, Tukey's Studentized Range or Honest Significant Difference (HSD) Test was used.

Results and Discussion

The Constructed Solar Powered Irrigation with Aquaculture System

The experimental unit was composed of three 12-volt, 100-watt mono-crystalline panels, a 12-volt 100 Ah-battery, and a 40-ampere charge controller. The pump installed was a positive displacement-screw type pump with a replaceable motor mounted on a tripod, and is locally available.

Pump motors with three different capacities were used: 200, 300, and 550 watts. A 1.5m x 7m x 5m water impounding, located 1.5m above the rice field and 1m below the pump outlet was constructed with red tilapia grown at a stocking density of 25 fish/m^3. The system would continue to pump water to the reservoir to be utilized for land preparation of the succeeding cropping, and a shut-off valve was used to control the flow of water from the reservoir to the field through gravity.

Figure 8. The Constructed Irrigation System

Pump motor size selection

Three motor sizes were selected for testing. The highest motor power (550 watts) had the highest flow rate at 1063.33 liters per hour and the lowest motor power (200 watts) had the lowest flow rate at 808.67 liters per hour. However, 200 watts motor can operate for 2.99 hrs per 1 full charge of a 100-Ah battery thereby pumping out 2414 liters of water. The 200-watt motor had the highest volume of water pumped per 1 full charge compared to the other two motor sizes. This was because the volume of water discharges was dependent on the outlet pipe of the diameter of the pipe where the screw pump trapped the water towards the outlet. The motor size is not directly proportional to its total water pumped (see Table 2).

Table 2. Flow Rates and Volume of Water Pump Using Different Motors

Motor Power	Flow rate (lph)**	Volume of water pumped per 1 full charge**
200 watts	808.67[c]	2414.00[a]
300 watts	902[b]	1806.33[b]
550 watts	1063.33[a]	1160.33[c]

** Significant at 1% level of probability using Tukey Test.
Means with the same letter superscripts are not significantly different.

Optimal solar panel tilt

The energy received by the solar panel mainly depends on its solar irradiation incident. However, the major shortcoming of solar power is its low conversion rate, usually between 16 - 18%. One way to overcome this is to fix the solar panels properly to obtain maximum energy from the sun (Louzazni, Aroudam, and Yatimi, 2013). The computed panel tilt angle has the highest current flow reaching an average of 40.77 amperes, compared to ±5 and ±10 degrees during the duration of the study. This is because solar panels are most effective when facing perpendicular to the sun's rays. However, the sun does not stay exactly where it is as the earth rotates. "The sun moves from east to west at varying inclinations respective from north to south, depending on the month of the year. This is brought about by the earth's axial tilt, which is currently at 23.4°," meaning the sun goes east to west "at a north-south variance of 46.8 degrees" (Malicdem, 2015) throughout the year. The computed tilt is the optimal angle that keeps the panel almost perpendicular to the sun.

Table 3. The Current Flow for Different Panel Tilts

	Current Flow (Amperes)			
Tilting Angle	December *	January*	February*	March*
T1 (-5 degrees)	34.26[c]	34.43[c]	34.93[c]	34.5[c]
T2 (-10 degrees)	37.80[b]	37.33[b]	37.9[b]	37.67[b]
T3 (Computed)	41.05[a]	40.4[a]	41.33[a]	40.33[a]
T4 (+5 degrees)	37.06[b]	37.43[b]	37.83[b]	37.93[b]
T5 (+10 degrees)	34.23[c]	34.16[c]	34.53[c]	34.6[c]

* Significant at 5% level of probability using Tukey Test
Means with the same letter superscripts are not significantly different.

Comparison of conventional pumping and solar pumping using different Irrigation Regimes

Number of productive tillers. Plots that were irrigated through flooding from the fishpond (T2) had the highest number of productive tillers, averaging at about 25.37. For the irrigation sources, solar pump-fishpond water had a higher number of productive tillers, compared to diesel pump from well. This is because rice-fish culture has a fertilizing effect from the fish excrement, which increases nutrient availability for rice crops (Shugen, 1995). This was also the result of the study conducted by Tsuruta, Yamaguchi, Abe and Iguchi in 2010, where they found out that the NO_3–N concentration in rice-fish plots was higher than that in rice-only plots, indicating that the increase in NO_3–N concentration resulted from the excretion of unutilized food nutrients by the fish. In the case of the irrigation type used, flooding irrigation had a higher number of tillers compared to alternate wet and drying methods. This is because higher water application indicates a higher amount of nitrate in the plots (Table 4).

Table 4. Average Number of Tillers

SUBPLOTS (Irrigation Sources)	MAINPLOTS (Types of Irrigation)		
	AWD	FLOODING	Ave. for Irrigation Sources
Solar Pump-Fish Pond	T1= 23.06	T2= 25.37	24.21*
Diesel Pump from well	T3= 21.55	T4= 23.93	22.74*
Ave. for Types of Irrigation	22.30*	24.65*	

* Significant at 5% level of probability using Tukey Test

Rice yield. It was found out that plots that were irrigated by flooding with water that was solar-pumped to the fishpond (T2) had the highest yield (5,187.26 kg), and that fishpond water, as an irrigation source, had a higher yield compared to well water. This is in conjunction with the result of the tiller number analysis.

The same plots and sources of water had the highest number of productive tillers and yield. This subscribes to the result of the study conducted by Tsuruta et. al in 2010 which showed that rice yield in the rice-fish plots was 20% higher than that in the rice-only plots (see Table 5).

Table 5. Average Yield of Each Plot at 14% Moisture Content

SUBPLOTS (Irrigation Sources)	MAINPLOTS (Types of Irrigation)		
	AWD (kg/ha)	FLOODING * (kg/ha)	Ave. for Irrigation Sources
Solar Pump-Fishpond*	T1= 5058.17	T2= 5187.26	5122.72*
Diesel Pump from well*	T3= 4513.77	T4= 4700.38	4607.08*
Ave. for Types of Irrigation	4785.97*	4943.82*	

* Significant at 5% level of probability using Tukey Test; cv= 11%

System capacity

Based on the data gathered, the 200-watt pump can operate at an average of 4.66 hrs/day, pumping a total volume of 3.774 m^3/day, but can only irrigate 947 m^2 using AWD (0.86 m3/m2). This pump service area is relatively small during drought phenomena. However, the solar pump had no CO_2 emissions, compared to about 1.11 kg CO_2/m^3 of water a day when using diesel pumps.

Cost comparison of the system and conventional pumping

The two pump types were compared. The initial capital cost in the construction of the solar irrigation system was 50,000 pesos. Annual labor costs in operating the solar pump, minor dust cleaning accumulated in the panel, and feeding the fish were estimated at about 5,000 pesos. The total operating cost of the solar pump amounted to 27,000 pesos, without need for fuel and maintenance costs unlike the diesel pump. Due to the solar pump's small service area, the annual profit was much lower compared to that of the diesel pump. The solar pump had a payback period of 2.87 years, while the diesel pump had only 0.77 years. The computed BCR was 1.26 and 2.3, respectively.

Table 6. Annual Cost Analysis of the Solar Irrigation and Conventional Pumping

		Solar Pumping	Diesel Pumping
Initial capital costs		50,0000.00	25,000.00
Annual operating costs	Variable Cost		
	Labor	5,000	3,600
	Fuel and maintenance		10,000
	Feeds	10,000.00	
	Subtotal	15,000.00	13,600
	Fixed Cost		
	Interest on capital (10%)	5,000	1,500
	Depreciation	7,000	3,000
	Subtotal	12,000	4,500
	Total Operating Cost	27,000	18,100
Revenue	Tilapia	30,000	0
	Rice yield	7,380	50, 650
	Total Revenue	37,380	50,650
Annual Profit		10,380	32,550
Payback period		2.87 years	0.768 years
BCR (3 years)		1.26	2.3

The area considered in calculating the yield of solar pump was 947 m^2 and 1 hectare for diesel pump.
Two cropping seasons every year were considered in the calculation.
Palay price was 15.40/kg
Rice yield considered for T1= 5058.17 and T3= 4513.77

Summary

The study was conducted to introduce a new concept of an irrigation system suited to almost all rain-fed rice production areas and to solve irrigation problems. The system utilized technological advancements in harnessing solar energy to power irrigation pumps and adopted the concept of water impounding projects and shallow tube wells implemented by the Philippine government. Different motor sizes, varying solar panel tilts, and various irrigation methods and sources were evaluated.

The highest amount of water pumped daily was found using the 200-watt motor. Monthly computed panel tilt had the highest harvested energy in terms of recorded current flow. Another finding of the study was that water pumped by the solar pump to the reservoir where tilapia was raised had a higher yield compared to water pumped by a diesel pump from a well. Flooding irrigation also had a higher yield compared to alternate wet and dry irrigation, though the system can only irrigate 947 m^2 and is dependent on effective rainfall to irrigate 9,403 m^2. The solar system and the diesel pump had BCRs of 1.26 and 2.3, respectively, after 3 years.

Conclusion

The irrigation system can run at optimum efficiency when the 200-watt motor is used, utilizing the monthly computed tilt to harvest maximum solar energy. Reservoir pond water can increase rice production by almost 20% the production of conventional diesel pumping. However, the system is not suitable for rice production due to its low service area capacity, but can be tried for high value crops.

Recommendation

A comparative study of solar powered systems with battery storage and direct-panel powered pumps is recommended in order to ascertain the advantages and disadvantages of these systems. In addition, the system can also be used in similar studies using high value crops.

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