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Impact of Farm Pond Based Solar Powered Micro Irrigation Systems on Enhancing Water Use Efficiency and Crop Productivity in Rainfed Areas

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ABSTRACT

Solar-powered pumps provide sustainable irrigation solutions for farmers in India, particularly in rainfed regions. Farm ponds-based solar-powered micro-irrigation systems have emerged as promising technologies for sustainable agriculture. Irrigation is a crucial factor in enhancing food production, improving land productivity, and supporting the livelihoods of smallholder farmers. This study was conducted at KVK-Ranga Reddy, ICAR–Central Research Institute for Rainfed Agriculture (CRIDA), Hyderabad, in a 6.0 ha micro-watershed at the Hayatnagar Research Farm. The system comprises a farm pond with a capacity of 750 m³ lined with a 600-micron HDPE sheet, and connected to a solar-powered irrigation system. This photovoltaic (PV) system operates with a 5 HP pump set consisting of 16 solar panels, a 440 V system voltage, and a 3.73 kW power rating, and is equipped with low and high-voltage protection. The performance of various micro-irrigation systems was evaluated in naturally fertile soils. Drip irrigation achieved the highest water use efficiency (90–95%), followed by rain pipe irrigation (80–85%), micro-sprinklers (75–80%), and mini-sprinklers (70–80%). Compared to traditional methods, adopting these technologies resulted in 20–30% higher crop yields, 40–60% water savings, a 40% reduction in labor costs, and up to a 100% increase in cropping intensity. Overall, integrating farm ponds with solar-powered micro-irrigation systems is a sustainable and scalable model for enhancing productivity and water use efficiency in rain-fed areas.

Keywords: *Watershed, Farm, Pond, Solar energy, Micro irrigation , Vegetable.*

INTRODUCTION

Rainfed agriculture is predominant in the arid, semi-arid, and sub-humid regions of India, where it supports nearly 55% of agricultural land and sustains 81% of the rural poor. Farmers in these regions are highly dependent on rainfall, leading to subsistence farming and low productivity. Solar-powered irrigation systems are a clean technology option for irrigation that allows solar energy to pump water, replacing fossil fuels as an energy source, and reducing greenhouse gas (GHG) emissions from irrigated agriculture. The sustainability of solar-powered irrigation systems largely depends on how water resources are managed. The present work describes an attempt to develop a solar-powered micro-irrigation system with strategies to address the limitations of drip irrigation for smallholder farmers. These include development of a low-pressure micro-irrigation system, an adequate pumping scheme for taking water from small-scale water collection ponds and introduction of an economical and efficient alternative micro-irrigation system by achieving a perfect match between the available water and the area available for extensive small-scale vegetable production. While developing this system, due consideration has been given to the techno-socio-economic status of small and marginal farmers in these areas. The Government of India promotes solar irrigation under the PM-KUSUM scheme, which aims to ensure farmer energy security while meeting national climate commitments by increasing the share of renewable energy capacity. Farm ponds (capacity <1000 m³, depth <4 m) are an effective means of harvesting rainwater, which can be recycled as life-saving irrigation to stabilize yields in rainfed areas (Anbumoji *et al,* 2001). The main barriers to realizing the potential of water harvesting and recycling in rainfed agriculture in India are the economic and technical means to lift the water and distribute it in the field. Namara *et al* 2007 and Raza *et al* 2022 in their studies in the states of Maharashtra and Gujarat, found a significant positive impact of ownership of wells and high-horsepower pumps on the likelihood of adoption of micro-irrigation technologies.

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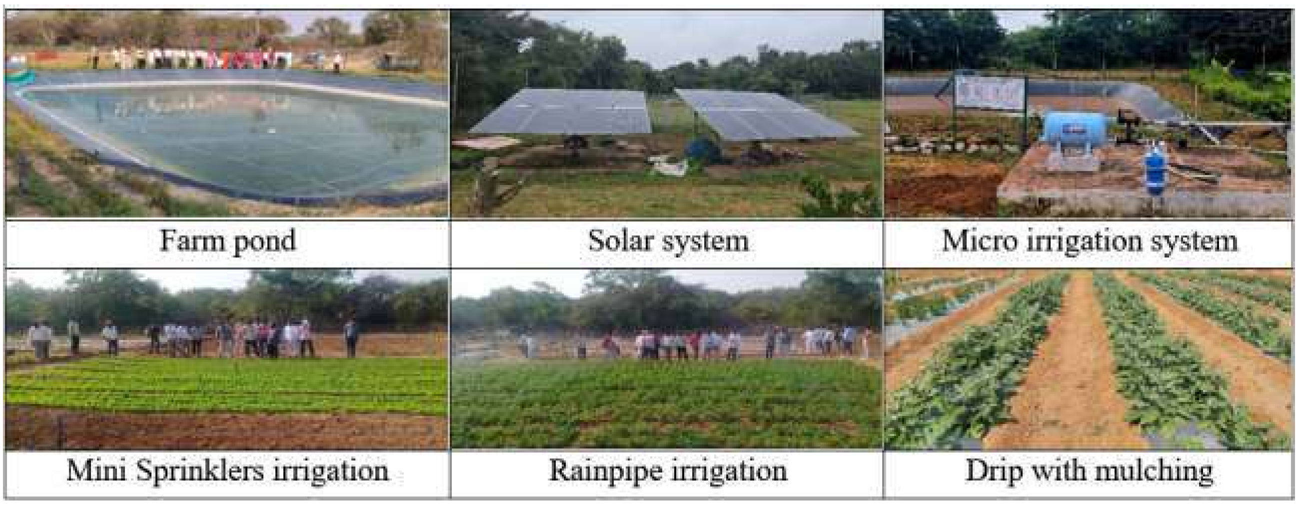

Fig. 1: Demonstration area of Solar-powered micro-irrigation systems

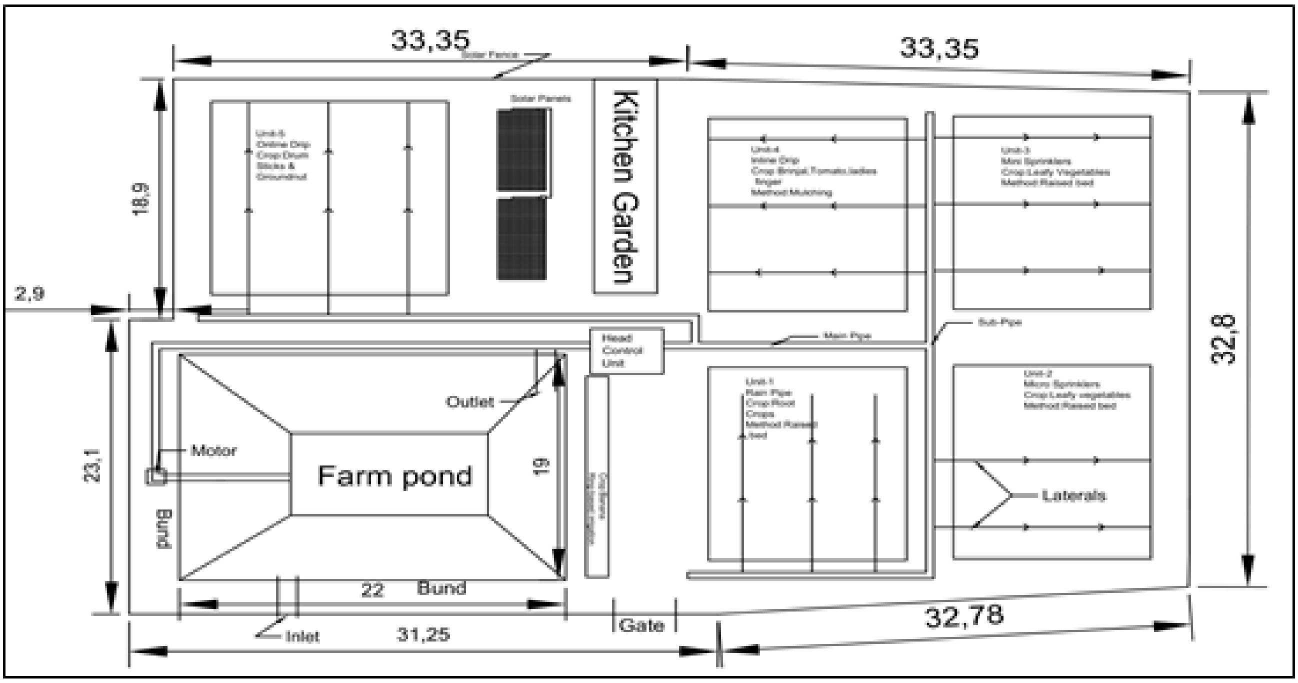

Fig. 2: Development of a farm pond-based solar-powered micro-irrigation system

This directly or indirectly indicates that energy cost is a major factor in irrigation. Several energy-efficient interventions in micro-irrigation have been reported in the literature, such as bucket kits (Fandika *et al,* 2012), IDE low-cost drip irrigation (Pollack *et al,* 1997a; Van Westhorp *et al,* 2004), drum kit (Carlberg *et al,* 2007; Kulechow and Weatherhead, 2005), gravity-fed micro-irrigation (Bhatnagar and Srivastava, 2003; Kumar *et al,* 2009), and the Pepsi system (Verma *et al,* 2004). Micro-irrigation methods are widely considered to be the most effective and efficient irrigation method (Keller and Bleisner, 1990). Several studies have been conducted in the past to demonstrate high water use efficiency and water productivity. Some studies from the Indian subcontinent have indicated a 20-50% increase in the average yield of various crops such as cotton, sugarcane, grapes, tomatoes, and bananas (Indian National Committee on Irrigation and Drainage, 1994; Sivanappan, 1994). In practice, these methods are often associated with capital intensity and, therefore, are largely unaffordable for large farmers and small farms as these systems are not available in large-scale commercial agriculture. However, these technologies have been obtained through technological and innovative interventions to make low-cost micro-irrigation systems viable (Pollack *et al,*

S. No.	Details of the cropping system
1	Model watershed Catchment area: 6 hectares
2	Pongamia & Jatropha crops: 2.3 hectares
3	Mango, custard apple & guava crops: 2.7 ha
4	Fodder and other crops: 0.8 hectares
5	crops and vegetables: 0.2 hectares
6	Using pond water, Crop area under farm pond: 15 to 20% of total

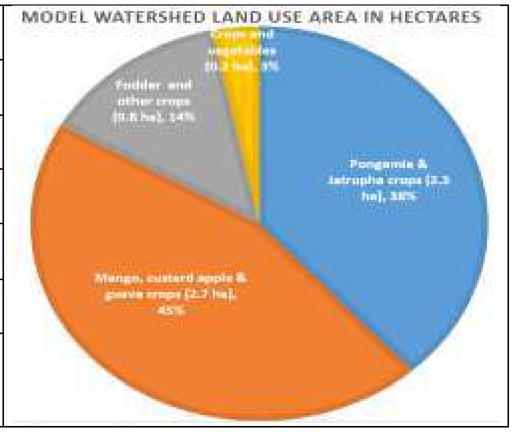

Fig. 3: Model watershed cropping system in the catchment

1997b; Verma *et al,* 2004; Upadhyay, 2003; Tiwari *et al*, 2023; Ravanashree *et al* 2024). The most perceived constraint under general constraints was observed to be difficulty in maintenance of DIS, regularly and the problem of blocking the drippers due to salt or other impurities in the water (Yadav *et al,* 2017). The results of study on watermelon revealed that the yield of watermelon increased under drip irrigation and fertigation compared to the conventional surface irrigation and soil application of fertilizer (Nisha *et al,* 2020). Drip fertigation using water soluble fertilisers along with silver-black plastic mulching can be effectively used for attaining higher production and early harvest in bitter gourd variety Preethi in Kerala (Abraham *et al,* 2018).

Micro-irrigation in Indian rainfed agriculture has been promoted with single or mixed objectives, as listed by Namara *et al* (2007), (i) to protect irrigated agriculture from water scarcity crises, (ii) to increase household income and ultimately reduce poverty, and (iii) to increase water productivity to address the issue of food and nutritional security. Namara *et al* (2007), using data from a random sample of 448 farmers in the Indian states of Maharashtra and Gujarat, found that farmers with groundwater and high-capacity pumps (6.6 hp vs 3.8 hp and 4.01 hp vs 0.6 hp) adopted drip irrigation more than non-adopters in Maharashtra and Gujarat, respectively. A carry-and-irrigate scheme was introduced in Andhra Pradesh in 2005 under the state-funded Micro Irrigation Project (now TSMIP scheme), where farmers are supplied with five sprinkler heads, sufficient to cover 0.4 hectares of land, to improve water use efficiency (Renjini et al. 2021). However, these systems are over-exploiting the groundwater in the region. Hence the present study was conducted to investigate the impact of land use on water yield in farm pond-based solar-powered micro-irrigation systems with various crops,

MATERIALS AND METHODS

Krishi Vigyan Kendra-Ranga Reddy has established a 6.0-hectare micro-watershed at the ICAR-CRIDA Research Farm, Hayathnagar, to investigate the impact of land use on water yield in farm pond-based solar-powered micro-irrigation systems with various crops, as shown in Figure 1.

Location of study

The research was conducted at KVK Farm (located at 17°37_N and 78°48_E) of ICAR-Central Research Institute for Rainfed Agriculture (ICAR-CRIDA), Hyderabad, South-Central India. The location typically represents Rainfed agricultural conditions in semi-arid regions, with Alfisols and Vertisols being the predominant soil types in the region. The average annual rainfall in this region is 750 mm. About 80% of this rainfall occurs during the monsoon months (June 15 to October 15), enabling various crops to be cultivated, are shown in Figure 2. However, second and third crops are also practiced in the area with intensive irrigation facilities (mostly groundwater).

Construction of farm pond

A 750 m^3 farm pond (top: 21 m x 19 m, bottom: 11 m x 10 m, depth: 3.5 m, side slope: 1:1) was constructed and lined with a 600 micron thickness HDPE sheet for supplementary irrigation of various crops.

Establishment of solar pump system

In solar-powered micro irrigation systems, electricity is generated by solar photovoltaic (PV) panels and used to operate pumps to capture, lift and distribute irrigation water. The maximum power (Wp)

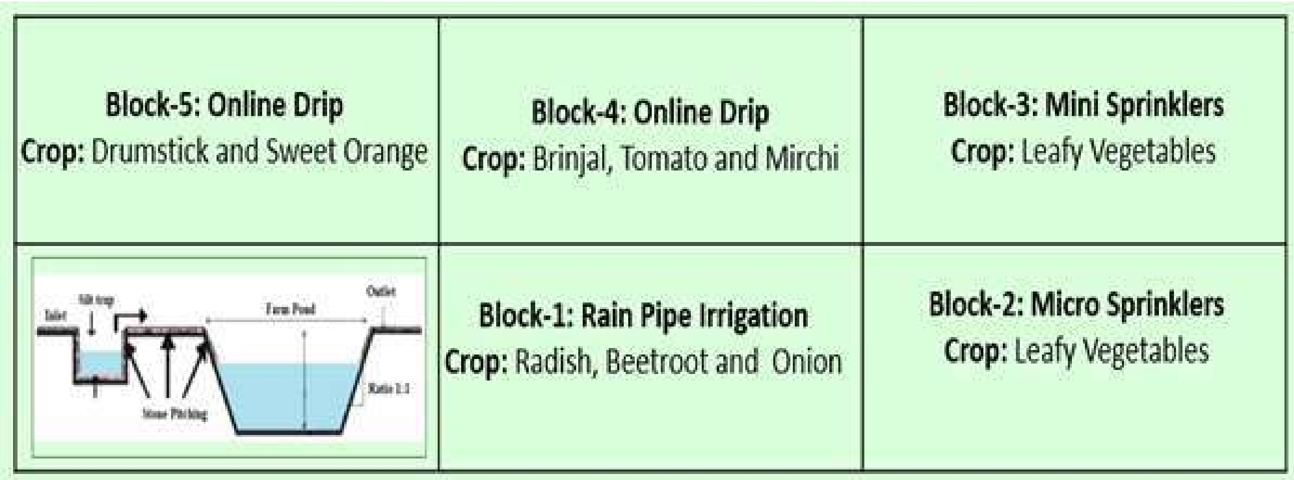

Fig. 4: farm pond and Cropped area with MI Systems divided into five parts

of the solar panel in the solar system is 5280 Wp (watt peak), the total number of panels is 16, an AC motor, capacity 5HP / 3-phase, easy & low maintenance, running at 440 volts & 3730 watts (3.73kw) system power with under and over-voltage protection.

Development of a micro-irrigation system

In the farm pond area, it is necessary to use the harvested water efficiently by selecting crops and cropping systems based on profitability and irrigation requirements. Various micro irrigation systems have been set up in five blocks of 0.2 ha in five blocks of the farm pond area, which save water by 50% to 90%. With the available water, more land can be irrigated and modern irrigation systems are used to increase water use efficiency. The novelty of this developed system lies in the management of natural forces for maximum benefits. The developed system operates using a pump unit. This pump operates using electricity generated from solar power. The provision microirrigation system was another novel idea implemented in this invention, which reduced the overall material cost of the irrigation system as compared to the conventional drip-based irrigation system. The conventional drip-based irrigation system employs a dripper connected to the laterals and thus one lateral pipe is required for every row of crop. The present system with star-configured micro-tube enables the lateral to command two rows of crops and thus reduces the requirement of lateral pipe up to 50%. Thus, the above-mentioned facts establish the novelty of the present development of solar power-operated micro-irrigation systems to address the issue of water use efficiency coupled with energy in agriculture and the environment.

Considering the issues discussed earlier, the irrigation system developed by integrating three broad components, namely, a solar power generation system, a water lifting system and water distribution using water-emitting devices operated through gravity. The complete setup of the system is presented and the detailed technical description is provided in Table 1. The solar power generation unit consists of a solar panel and the components were selected after considering the suitability and compatibility to achieve high efficiency and better economy. The solar panels can generate 5280 watts of power from solar energy, shown in Table 1. The power is directly used to lift water from the mono block pump set. The water was lifted to a farm pond with a capacity of 750 m^3.

The catchment area and crop area in the model watershed

In the model watershed area, the 6.0-hectare catchment area was divided into four parts. As shown in Figure 3, Pongamia and Jatropha crops were cultivated in the upper part (2.3 hectares), mango, custard apple, and guava crops in the middle part (2.7 hectares), fodder crops in the lower part (0.8 hectares), and crops and vegetables in the area adjacent to the pond (0.2 hectares). However, this water distribution system is most suitable for vegetable cultivation in a small field of 0.2 hectares. The farm pond provides a constant pressure to the solar-powered irrigation system and ensures maximum uniformity in water usage. The total cost of this system is INR 7.3 Lakhs. The cost of various components is presented in Table 2.

Farm crop area

Selection of crops and cropping systems is done based on profitability and irrigation demands and increases the water productivity of the cultivated area. Various micro irrigation systems were set up in five

Table 1: Component-wise minimum specifications.

Sr. No.	Components	Specification details
1	Solar Energy System	Category: high efficiency Total number of panels = 16 Each panel Volages = 36 Volts Total Voltage produced: 576 Volts (16 x 36 V = 576 Volts Each panel Power output: 330W Total Power output: 16 x 330 = 5280 Watts Watts = Volts x Amps Current generated through panels = 9.16 Amps Dimension: length and width preferably be less than 1200mm (windvelocity point of view) Maximum wind load: 60 m/s
2	Water -lifting Monoblock pump	Motor type: AC Motor Motor Capacity: 5 HP / 3-Phase Motor Power: 440 volts & 3730 watts (3.73kw) Maximum Current Rating:10 Amps Pump type: Mono Block Pump Set Total Head: Up to 10 meters Water Output: 76500 to 1 Lakh litters per day
3	Water Source Farm Pond	Farm pond Capacity: 750 m3, Top Dimensions of the pond: 21 m x 19 m, Bottom Dimensions of the pond: 11 m x 10 m, Depth of the pond: 3.5 m, Side slope of the pond: 1:1
4	Micro irrigation system	Rain pipe: discharge rate 172 lph/meter, water saving with the irrigation system 80 to 85% Micro Sprinklers: discharge rate 120 lph, water saving with the irrigation system 75 to 80% Mini Sprinklers: discharge rate 180 lph, water saving with the irrigation system 70 to 80% In-Line Drip: discharge rate 4 lph, water saving with the irrigation system > 90% On-Line Drip: discharge rate 10 lph, water saving with the irrigation system 90%
Note: By utilizing the capacities in the above table, we can cultivate an area of approximately 10 to 15 acres.		

blocks of 0.2 hectares in the farm pond area, which demonstrated various options of micro irrigation systems with suitable crops, are shown in Figure 4. These systems were developed for technology transfer to create awareness among farmers on saving energy, increasing crop productivity and enhancing water productivity.

Performance study on Micro-Irrigation Systems for various crops

In this research, demo field installed different micro-irrigation systems were installed for various crops Rain pipe, Micro Sprinklers, Mini Sprinkler, In-Line Drip and On-Line Drip, as shown in Table 3.

RESULTS AND DISCUSSIONS

Solar-powered micro irrigation systems make irrigation possible in remote areas. Micro irrigation systems can be connected to a solar system to further improve crop yields. The water production can be invested once every year to grow multiple crops in seasons and then used for years to come with zero maintenance costs (free sunlight). It is eco-friendly. No need for a grip connection. No need to pay electricity bills. No need for fuel. It is durable, requires minimal maintenance and contributes in reducing carbon emissions and pollution.

Table 2: Cost of developed irrigation system (conversion: INR 90 = 1$).

Sr.No	Items detailed capacities	Cost INR
1	Solar system with a monoblock 5 HP pump set	3.5 Lakh
2	Micor Irrigation Systems	1.5 Lack
3	A solar fence for protection against wild boars, covering an area of 0.2ha	2.0 Lakh
4	Civil work and other miscellaneous	0.8 Lakh
	Total Cost of the system in the model watershed area (Rs.)	7.8 Lakh

Table 3: The details of the Micro-Irrigation Systems for various crops.

Type of Irrigation	Discharge rate of each system	Type of Crops	Method of cultivation	Area of crop (m2)	No. of discharge units
Rain pipe	172 lph/meter	Radish	Raised bad	80	125 holes/ m
		Onion	Raised bad	80	
Micro Sprinklers	120 lph	Fenu Greek Leaves	Raised bad	55	10
		Coriander leaves	Raised bad	55	10
		Purslane	Raised bad	55	10
Mini Sprinklers	180 lph	Garden sorrel	Raised bad	55	8
		Spinach	Raised bad	55	8
		Kenaf Leaves	Raised bad	55	8
In-Line Drip	4 lph	Red bhindi	Mulching	55	60
		Tomato	Mulching	55	60
		Chilly	Mulching	55	60
On-Line Drip	10 lph	Sweet orange	Flat	75	20
		Drumstick	Flat	75	30

Field-level benefits for farmers on solar-powered irrigation systems

Solar energy is widely abundant and has gained high importance because of active global interests in climate change mitigation. In total 72% of CO_2 contributes to human-emitted greenhouse gases, the share of fossil fuel combustion is the maximum and substituting diesel power pumps with solar-powered pumps can considerably reduce carbon emissions. Because of using clean, renewable energy from the sun, the Solar Powered Irrigation Systems are considered resilient to climate change. Solar photovoltaic and solar thermal are the two major groups of solar water pumping systems. Their performance is influenced by factors like the influence of solar radiation, source and amount of water, water storage conditions and duration of use system. The possible effects of elements in the Solar Powered Irrigation Systems, such as local climate, irrigation area, irrigation method, characteristics of the well or any other water source, and crop types, as well as designing the photovoltaic pumping system to achieve optimum efficiency, are well documented in several previous studies on solar-powered irrigation. A solar-powered irrigation systems are environmentally friendly, and low maintenance is required. The micro hydel power is sometimes technically and financially not feasible in the complex terrain of the region, so a solar-powered system is preferred for ease of installation and maintenance. The system comprises components like Photovoltaic modules, a Pump controller and a Pumping unit. The power requirement of Solar Powered Irrigation Systems depends on factors like discharge required (Q), total dynamic head (TDH), the sum of suction and delivery heads and pump efficiency. Details of different types of solar photovoltaic systems and their effective performance parameters are well documented in the literature. Solar-powered irrigation System has wide applications in the agriculture sector, e.g. solar water pumping/lifting for raising crops and stock water, lighting systems, solar dryers, solar air and water heaters, and solar greenhouses at the farm level. Owing to the limited availability of electricity and high prices of diesel, photovoltaic-based pumping of water has gained much importance.

Water productivity

The seasonal water used (SWU) for each crop irrigated by buried pipe with riser irrigation system

Table 4: Field-level benefits for farmers on solar-powered irrigation systems.

Type of Irrigation	Type of Crops	Crop duration (days)	CWR (mm)	Crop yield on micro irrigation (q/ha)	Crop yield on flood irrigation (q/ha)	WP (t/ha/mm)	Discharge (lph)	% of Water saving than farmer practices
Rain pipe	Radish	90	600	170	109	17	3784	80 to 85%
	Onion	120	450	125	80	12.5	3784	
Micro Sprinklers	Fenu Greek Leaves	25	160	45	30	4.5	1200	75 to 80%
	Coriander leaves	25	160	45	30	4.5	1200	
	Purslane	25	160	45	30	4.5	1200	
Mini Sprinklers	Garden sorrel	25	160	45	30	4.5	1800	70 to 80%
	Spinach	25	160	45	30	4.5	1800	
	Kenaf Leaves	25	160	45	30	4.5	1800	
In-Line Drip	Red bhindi	100	500	135	87	13.5	240	> 90%
	Tomato	100	700	200	128	20	240	
	Chilly	140	500	210	134	21	240	
On-Line Drip	Sweet orange	365	750	15-40 (t/ha/y)	18	27	200	90%
	Drumstick	365	550	15-17 (t/ha/y)	12	16	300	

under the studied reservoir system was calculated from the information of average discharge rate (Q), total number of irrigations (N), time of each irrigation (T) and area of plot (A) using the following relationship:

Seasonal water use (SWU)=N×Q×TA-------- (1)

The crop yield per unit water utilization is generally described in terms of water productivity (Mollah 2004), and it is determined by using the formula:

WP=YWR ----- (2)

where WP = water productivity (kg/ha/mm), Y = crop yield (kg/ha) and WR = total amount of water used in the field for the crop (mm). the details crop water requirement and productivity are shown in Table 4 below.

The table above illustrates water savings of 70 to 95% in solar-powered irrigation systems by using different types of irrigation methods compared to traditional methods, and the water productivity for various crops has also been calculated. As shown in Table 4, the water productivity for different crops was observed to range from 4.55 to 17 tonnes per millimeter per hectare.

CONCLUSION

Farm pond-based solar-powered micro-irrigation systems significantly reduce costs, minimize losses, increase productivity, and enhance farmers' profitability in rainfed agriculture. This system has introduced satisfactory performance in cultivating various crops under rainfed conditions. The adoption of this technology has enabled year-round cultivation of crops and vegetables, resulting in 20–30% higher yields compared to traditional methods, 40–60% savings in irrigation water, 40% labor savings, and an increase in cropping intensity to 250–300%. Applying the right amount of water at the right time improved crop health, leading to a significant increase in yield. Farmers' income increased. The system is more durable and easier to maintain, with both the solar pump and the drip system operating for extended periods with minimal maintenance. These findings highlight the potential of integrating farm ponds with solar-powered micro-irrigation systems as a replicable and sustainable solution to enhance resource use efficiency, productivity, and livelihoods in rainfed agricultural systems.

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