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Research Article

Experimental Studies on Aerobic Rice Cultivation with Solar Photovoltaic Powered Micro-Irrigation System

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Abstract: A water saving technology and less water consuming rice production system without any compromise with the decline in yield are the urgent necessity of the present scenario of increasing water scarcity and achieving food security for the fast growing population of the world. One such crop growing practice, introduced recently is through aerobic method of rice cultivation which has been developed as a promising and viable technology for the situation where uncertainty in assured irrigation and irregularity of rainfall prevail. Submergence of rice field continuously with water for longer period in a crop growing season in traditional method of rice cultivation is now a major concern for global warming due to the emission of most potent greenhouse gas i.e. methane to the atmosphere. Shifting from flooded to non-flooded method of rice cultivation may therefore be the need of the hour to address the above issues. Efficient water management through micro- irrigation, particularly by drip irrigation in non-flooded, unsaturated or un-puddled rice cultivation system may be a viable option. An attempt is therefore made to develop a portable solar photovoltaic powered drip irrigation system for aerobic rice cultivation. There may be the saving of 40-45 % of water for irrigation purpose compared to the conventional method. The pay- back period of the setup is estimated to be 4 years and monthly income of Rs. 4000/- throughout the year can be achieved by adopting aerobic rice cultivation in 1 acre (0.4 ha) of land.

Keywords: Solar photovoltaic system, Micro-irrigation, Water use efficiency, Aerobic rice cultivation, Greenhouse gases mitigation, solar pump.

INTRODUCTION

Sustainability of rice production in the present context of fast growing population is a big challenge before all of us with respect to achieving food security and controlling over the increased concerns of water scarcity, energy crisis and global warming due to the emission of greenhouse gases through anthropogenic activities particularly in the agricultural sector. In order to attain self-sufficiency in food grain, the production and productivity of rice crop alone play a crucial role not only for our state Odisha but also for India, Asia and the world as well, as rice is the principal food of more than 60 % of the world's population and around 90 % of the rice area worldwide is in Asia and low land rice fields produce about 75 % of the world's rice supply (Singh *et al.*, 2010). Agriculture too in Odisha to a considerable extent means growing rice. It is the staple food for almost the entire population of Odisha and therefore, the state economy is directly linked with the improvements in production and productivity of rice (Anon, 2014). Rice production practices mostly followed in the state are through wet and low land cultivation, covering about 80 % of the total rice area and the methods of cultivation are usually transplanting of seedlings and broadcasting of sprouted seeds in the puddled soil. In the above method of cultivation, the field remains either in fully or partially flooded condition most of the time of the growing season, creating favourable environment for emission of methane, which is one of the principal and potent greenhouse gases relative to global warming potential of 25 times higher than that of CO_2 and accounts for one-third of the current global warming phenomenon (Gag *et al.*,, 2011). Rice cultivation is a major source of atmospheric CH_4 and contributes about 10-20 % of total methane emission to the atmosphere (Pathak and Agarwal, 2012). The environmental experts have now recognized and expressed in intergovernmental panel on

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climate change (IPCC, 2010) that the submerged rice fields are the most significant contributors of atmospheric methane (Jain *et al.,* 2004). According to the current estimate, the production of rice needs to be enhanced by around 70 % to meet the demands for ever-increasing population by 2030 and thus making rice cultivation, a potential major cause of growing atmospheric methane (Singh 2010).

Aerobic rice cultivation where fields remain unsaturated or nearer to saturation throughout the season like an upland crop offers an opportunity to produce rice with less water (Patel 2010). Aerobic and upland rice are both grown under aerobic condition, however, the former is under controlled water management system but latter is not (Parthasarathi *et al.,* 2012). Aerobic rice is a new cropping system in which specially developed varieties are directly seeded in well-drained, un-puddled and unsaturated soil conditions for most of the crop growing period. The rice is grown like an upland crop with adequate inputs and supplementary irrigation when rainfall is insufficient. Aerobic rice varieties are bred by combining the draught resistance of upland varieties with high yielding characteristics of low land cultivars. Some of the suitable varieties like CRDhan-200 (pyari), Naveen and Annada are also available in our state Odisha. Aerobic rice is therefore grown with the use of external inputs such as supplementary irrigation and fertilizers with an aim to maintain the productivity at par with the traditional production system without compromise with yield decline. The micro-irrigation in general and drip irrigation in particular has received considerable attention from researchers, policy makers, economists etc. for its perceived ability to contribute significantly to ground water resources development, agricultural productivity, economic growth and environmental sustainability (Singh *et al.,* 2010). Currently, our state has around 1.38 lakhs (35 %) grid based (electric) and 2.47 lakhs (65 %) diesel irrigation pump sets. However, erratic grid supply of electricity and high cost of diesel pumping continue to remain as a big problem for the farmers. The rising cost of using diesel for powering irrigation pump sets are often beyond the means of small and marginal farmers. Consequently, the lack of required amount of water often leads to poor growth of plants, thereby, reducing yields and income. Hence, use of conventional diesel/gasoline powered pumping systems poses an economic risk to the farmers. Scientific studies reveal that timely and required amount of water availability for the crop favours the increase in the yield by 10-15 % (Narale *et al.,* 2013). The burning of petroleum fuels also creates threats by polluting environment and causing global warming by releasing a considerable amount of CO_2 into the atmosphere. The continuous exhaustion of limited stocks of conventional energy sources and their environmental impacts have, therefore, forced researchers, planners, and policy makers to search for the reliable, environment-friendly and cost effective energy resources to power water pumping system in a sustainable manner. Hence to keep pace with the growing demands of energy and acute shortage of water, solar photovoltaic water pumping device may be integrated with drip irrigation system for rice cultivation in addressing the issues of food security under climate change scenario (Gopal *et al.,* 2013). Thus an integrated approach of water saving technology and reliable source of energy along with the reduced greenhouse gases emissions from the conventional method of rice cultivation has been thought up in the proposed study to achieve food security of the nation. An attempt is therefore made to study the feasibility and performance of solar photovoltaic powered drip irrigation system in aerobic rice cultivation.

MATERIALS AND METHODS

Design and development of solar photovoltaic (SPV) drip irrigation system has been made for cultivating paddy in 1 acre (0.4 ha) of land to achieve secured irrigation and to improve water use efficiency mostly in aerobic method of cultivation. The details of the design and developments are mentioned below. The experiments were carried out during the year 2017-18 in OUAT farm, Bhubaneswar, Odisha, which lies at the latitude of 20 ^{0} 15$^'$ N and longitude of 85 ^{0} 52$^'$ E and coming under warm and humid climatic condition. Paddy was cultivated in rabi and summer seasons. The soil type of the experimental site is sandy loam and the climate of the study area is humid and sub tropical in nature.

The Cost Estimate for Solar Photovoltaic Powered Drip Irrigation System

1.	Solar PV Module of 1000 watt @ Rs. 50 per w_p	= Rs. 50,000
2.	1 hp DC motor with pump set	= Rs. 80,000
3.	Mounting structure	= Rs. 15,000
4.	Civil works/Balance of system	= Rs. 20,000
5.	Drip set up for 1-acre land	= Rs. 35,000
6.	**Total**	**= Rs. 2, 00,000**

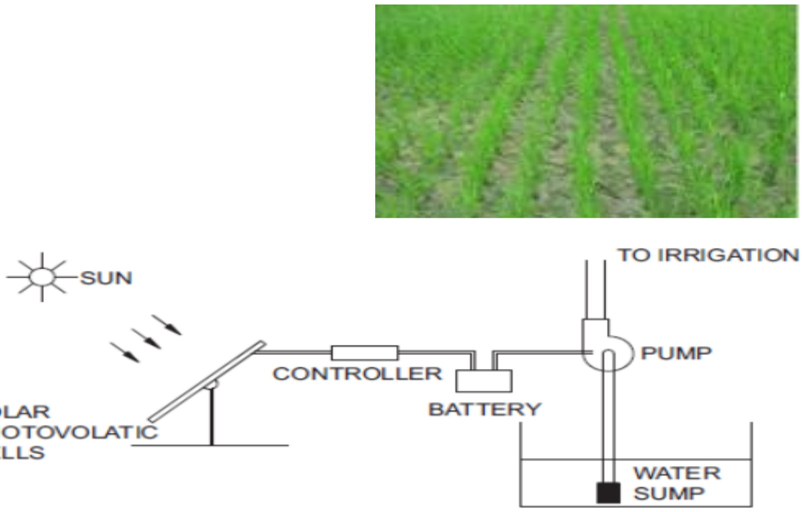

Fig1: Experimental Set-up for Solar Water Pumping Based Drip Irrigation in Aerobic Rice

Hourly Cost of Operation of Various Water Pumping Devices

Information for Cost Analysis

1. Cost of 1 hp electric pump set = Rs. 7,000
2. Cost of 1 hp diesel pump set = Rs. 10,000
3. Cost of 1 hp PV powered pump set = Rs. 1,00,000
4. Prevailing interest rate may be taken as 10 %
5. Efficiencies of motor varies from 70-80 % (70 % taken)
6. Efficiencies of pump varies from 70-80 % (70 % taken)
7. Efficiencies of diesel engine varies from 30-40 % (40 % taken)
8. Useful life of PV panel varies from 20-25 years (can be taken 22 years)
9. Useful life of diesel engine pump set = 8 years
10. Useful life of electric pump set = 8 years
11. Maintenance cost of PV system with drip as 0.5 per cent of total capital cost per year
12. Maintenance cost of diesel engine pump set as 10 per cent of total capital cost per year
13. Maintenance cost of electric pump set as 10 per cent of total capital cost per year
14. Annual working hours of diesel, electric pump sets and PV system be 500 hours
15. One hp engine consumes about 250ml. diesel per hour (present cost of diesel Rs. 60/lit)
16. One unit of electric energy (1 kWh) = Rs. 5.00
17. Salvage value of diesel pump set be taken as 20 % of capital cost
18. Salvage value of electric pump set be taken as 20 % of capital cost
19. Salvage value of PV powered pump set be taken as 5 % of capital cost
20. Operator's time spent in the proposed system be 1 hr/day (labour charge Rs. 250/day)
21. Energy consumption (kWh) of electric pump set = (BHP) / (motor efficiency x pump efficiency) x 0.746 x 1 hour
22. Cost per hour of operation of diesel pump set = (BHP) / (motor efficiency x pump efficiency) x fuel consumed in litres/hour/BHP x cost of fuel/lit

(i) Hourly operating cost of PV powered water pumping device with drip system

Fixed Cost

(a) Depreciation

D = (C-S)/ (L x H) where C= capital cost; S = Salvage Value; L = Useful life of device; H= Annual working hour

Putting the values of all necessary data, D= Rs. 17.27/hour

(ii) Interest (I) = (C + S)/(2) x (Interest rate/100) x (1/H) = Rs. 21/hour

Insurance and taxes and housing are not applicable

Total fixed cost = 17.27 + 21 = Rs. 38.27/hour

Variable Cost

(b) Fuel cost = Nil

(ii) Lubricants = Nil

(iii) Repair and maintenance = (C) x (0.5/100) x (1/H) = Rs. 2/hour

(iv) Operator's wages Rs. 250/8 = Rs. 31.25/hour

Total variable cost = 2 + 31.25 = Rs. 33.25/hour

Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = **Rs. 71/hour**

(ii) Hourly operating cost of diesel pump set

Fixed Cost

(i) Depreciation

D = (C-S)/ (L x H) where C= capital cost; S = Salvage Value; L = Useful life of device; H= Annual working hour

Putting the values of all necessary data, D= Rs. 2.0/hour

(ii) Interest (I) = (C + S)/(2) x (Interest rate/100) x (1/H) = Rs. 1.2/hour

Insurance and taxes and housing are not applicable

Total fixed cost = 2.0 + 1.2 = Rs. 3.20/hour

Variable Cost

(i) Fuel cost = (1)/(0.4 x 0.7) x 0.25 x 60 = Rs. 53.57/hour

(ii) Lubricants = 20 % of cost of fuel = Rs. 10.71/hour

(iii) Repair and maintenance = (C) x (10/100) x (1/H) = Rs. 2.0/hour

(iv) Operator's wages Rs. 250/8 = Rs. 31.25/hour

Total variable cost = 53.57 + 10.71 + 2.0 + 31.25 = Rs. 97.53/hour

Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = **Rs. 100/hour**

(iii) Hourly operating cost of electric pump set

Fixed Cost

(i) Depreciation

D = (C-S)/ (L x H) where C= capital cost; S = Salvage Value; L = Useful life of device; H= Annual working hour

Putting the values of all necessary data, D= Rs. 1.4/hour

(ii) Interest (I) = (C + S)/(2) x (Interest rate/100) x (1/H) = Rs. 0.84/hour

Insurance and taxes and housing are not applicable

Total fixed cost = 1.4 + 0.84 = Rs. 2.24/hour

Variable Cost

(i) Energy consumption (kWh) = (1) / (0.7 x 0.7) x 0.746 = 1.52 kWh

(ii) Electric energy cost = 1.52 x 5 = Rs. 7.6/hour

(iii) Lubricants = 20 % of cost of fuel = Rs. 1.52/hour

(iv) Repair and maintenance = (C) x (10/100) x (1/H) = Rs. 1.4/hour

(v) Operator's wages Rs. 250/8 = Rs. 31.25/hour

Total variable cost = 7.6 + 1.52 + 1.4 + 31.25 = Rs. 41.77/hour

Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = **Rs. 44/hour**

RESULTS AND DISCUSSION

The results of the experiment conducted during the course of the study are presented in this section. Rice is one of the most important and major crops in Odisha and is grown in an area of 40 lakh ha in kharif season and only 2.5 lakh ha in rabi season, (Agricultural Statistics, 2012, Govt. of Odisha). Kharif rice is entirely monsoon-fed. The area for rice cultivation during rabi season has not been covered widely due to lack of assured irrigation causing most of the cultivable land to remain unutilized. The yield of rice from the areas during rabi season is not satisfactory due to erratic supply of grid electricity for operating irrigation pumps. Farmers are also not interested to use diesel pump sets due to frequent rise in the cost of diesel fuel. Hence captive power and water source along with water saving technology for rice cultivation are the only alternative for the resource poor farmers of the state. The harnessing of solar energy for electricity generation through PV system is a viable option in the state due to abundant availability of solar radiation in about 300 days in a year. The variety chosen for the study was CR Dhan-200 (Pyari). This variety of rice was cultivated for the present study in order to evaluate the effectiveness of the developed solar PV drip irrigation device with respect to production and productivity, without depending upon conventional source of energy and flooded system of watering practice. The cost of cultivating rice in 1 acre of land has been mentioned in order to know the annual profits out of it and its pay-back period. Similarly, the mitigation of greenhouse gases with the use of the developed set-up has been estimated compared with traditional diesel and electric pump sets for its contribution in combating global warming and climate change and thus achieving sustainable agriculture.

Cost-Benefit Calculation of Aerobic Rice Cultivation in 1Acre (0.4 ha) Land

(i) Cost of Cultivation in 1.0 Acre Land

Sl. No.	Name of operation	Implements used	No. of operation	Man-hr/Ac	Operation cost (Rs.)	Input (kg)	Cost of input (Rs.)	Total cost (Rs.)
1	Tillage	Tractor drawn rotavator	1	2	1200	-	-	1200
2	Seed					20 kg		500
3	Direct line sowing (by rope method)		1	8	31.25/hour			250
4	Manures and Fertilizer	FYM Gromer Potash	Once Twice Twice			1 tractor load 100 kg 100 kg	1500 1000 1000	1500 1000 1000
5	Interculture (cono weeder)	Manual	Thrice	16	31.25/hour			1500
6	Plant protection	Knapsack sprayer	Thrice	2	31.25/hour	Pesticides	2000	2062
7	Irrigation	Solar PV powered drip system	45 (2 days interval)	1	Rs. 51/hour			2295
8	Harvesting	Hired Reaper	Once	1				750
9	Threshing	Pedal thresher	Once	50-60 kg/hr	Six man days			1500
TOTAL COST								**13,557 ≈ 13,500**

(ii) Benefit

Yield of paddy in aerobic rice practice = 2.5 tones/acre; By- product yield = 1.5 tones/acre; Returns from paddy @ Rs. 1350/quintals = 33,750; Returns from by-product @ Rs. 250/ quintal = 3,750; Total returns = 33,750 + 3,750= Rs. 37,500; Net gain = Rs. 37,500– Rs. 13,500 = Rs. 24,000 (kharif) ; Net gain = Rs. 37,500– Rs. 13,500 = Rs. 24,000 (rabi) ; Total gain from 1 acre of aerobic rice cultivation in a year = Rs. 48,000; Monthly income from aerobic rice cultivation with assured water supply = Rs. 48,000/12 = Rs. 4000 per month

Simple payback period = (Initial investment cost) / (Net annual gain) = 2, 00,000/48,000 = 4.1 years ≈ 4 years

Estimation for Mitigation of CO_2 Emission by Use of Solar Photovoltaic Powered Water Pumping System

The existing diesel and electric pump sets in the state of Odisha is 2.47 lakhs ad 1.38 lakhs respectively in the power rating range of 1-5 hp. Taking the average power rating of both diesel and electric pump sets as 3 hp, the amount of emissions of CO_2 are as follows;

- One hp engine consumes about 250 ml of diesel per hour
- Burning of 1 litre of diesel releases 3 kg of CO_2 to the atmosphere
- The average carbon dioxide emission for electricity generation from coal based thermal power plant is approximately 1.58 kg of CO_2 per kWh at the source.
- Annual working hours of diesel and electric pump sets can be taken 500 hours
- Annual CO_2 emissions from 2.47 lakhs diesel pump sets to be 30 crore kg in our state
- Annual CO_2 emissions from 1.38 lakhs electric pump sets to be 25 crore kg in our state
- Total annual electrical energy consumption from 1.38 lakhs electric pump sets can be saved in the tune of 15 x 10^7 kWh (saving around 15 crore units of electricity costing about Rs. 75 crores/annum)
- Total annual diesel consumption from 2.47 lakhs diesel pump sets can be saved in the tune of 10 x 10^7 litres of diesel (saving around Rs. 600 crores/annum)

Estimation for Mitigation of CH_4 Emission by Shifting from Anaerobic to Aerobic Rice Cultivation

Rice fields have been identified as a major source of atmospheric methane. The global methane emission rate from rice fields was recently estimated to be 40 Tg/year (1 Tg = 10^{12} g) which accounts for about 8 % of the total methane emission. The reduction in the amount of methane emission from the conventional method of rice cultivation is estimated as follows;

- On an average, 50 kg methane is emitted from 1 hectare of transplanted rice crops in one crop growing season.
- Annual Area under rice cultivation in the state Odisha is 4.0 million hectares (both kharif and rabi).
- Annual Area under rice cultivation in India is 43.0 million hectares (both kharif and rabi).

- Mitigation of CH_4 emissions through aerobic rice cultivation is 0.2 million tones and 2.15 million tones per annum in Odisha and India respectively.

CONCLUSION

A portable solar photovoltaic powered drip-irrigation system for aerobic rice cultivation in warm and humid climate of Odisha appears to be a viable proposition looking into the present day's concerns of water scarcity and energy crisis in agricultural sector. The following conclusions may be drawn from the study.

(i) Monthly income of Rs. 4000/- throughout the year may be possible by adopting aerobic rice cultivation in 1 acre of land both during rabi and summer seasons.
(ii) The small and marginal farmers of the state may be attracted to adopt solar photo voltaic powered water pumping system as the hourly operating cost is Rs. 71/hour and Rs. 44/hour for electric pump set and Rs. 100/hour for diesel pump set.
(iii) Pay- back period of the proposed set up is 4 years, due to which, it may be easily accepted by the small and marginal farmers of the state in spite of its high initial cost.
(iv) Total annual CO_2 emissions can be mitigated by 0.55 million tones with the replacement of existing diesel and electric pump sets in our state by the adoption of a reliable solar photo voltaic powered system in irrigation sector.
(v) Total annual CH_4 emissions can be mitigated by 0.2 million tons from 4.0 million hectares' rice fields in Odisha
(vi) Total annual electrical energy consumption from 1.38 lakhs electric pump sets can be saved in the tune of 15 x 10^7 kWh (saving around 15 crore units of electricity costing about Rs. 75 crores/annum)
(vii) Total annual diesel consumption from 2.47 lakhs diesel pump sets can be saved in the tune of 10 x 10^7 litres of diesel (saving around Rs. 600 crores/annum)

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