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Technical Note

Development of a Solar Energy Operated Weeder for Wetland Paddy Crop

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A B S T R A C T

A solar energy operated two-row weeder was developed for weeding in wetland paddy crop. Its major components are power source, power transmission system, weeding wheels, and a float. The power source comprised a DC motor, solar panel, and power storage unit with maximum power point tracker and motor controller. Solar panel/power storage unit through a motor controller supplied power to the DC motor and it was transmitted to the shaft of the weeding wheel through a dog clutch. A pair of wheels attached with jaw tooth and plane blades at wheel circumference was used for carrying out weeding and movement of the weeder in the field. A float was used to prevent sinkage of the weeder in soft soil which, in turn, ensured stability during operation. The developed weeder could do weeding at a rate of 0.06 ha per hour with field efficiency, weeding efficiency, and plant damage of 83.3 %, 83 % and 2-3 %, respectively. As compared to cono-weeder, the cost of weeding was 41.2 % lower due to higher field capacity and fewer labor requirements. Annual use less than 4.13 ha for the developed weeder was found uneconomical for carrying out weeding. The developed powering system comprising solar photovoltaic panels could supply power to do weeding continuously for 2 hours with a maximum discharge of 20 % from the battery.

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1. INTRODUCTION

India has been cultivating rice on about 438 lakh ha agricultural land that produces about 113 million tonnes each year [1]. The rice cultivating farmers face losses in the production due to various reasons, among which weeds are the major one which compete with the main crop for nutrients, sunlight, spaces, water, etc. and the main crop gets weakened leading to lower grain productivity. De Dutta [2] reported a reduction in yield of rice in unweeded plots due to weed growth as much as 34 %, 45 %, and 67 % in transplanted rice, direct-seeded rainfed lowland rice, and upland rice, respectively. Gunasena and Arceo [3] reported that rice was very sensitive to weed competition in the first three weeks after seeding and failure to control weeds in this period could reduce the yield by 50 %. It was also reported that weed competition period up to 45 days after sowing (DAS) significantly affected the yield of wetland paddy [4].

Most of the traditional Indian farmers follow different methods of weeding such as manual hand weeding, weeding with some tools, weeding with push-pull weeders, and power weeders. Parthasarathi and Negi [5] reported that under lowland conditions in India, the labor requirement for hand weeding was 200-250 h/ha, whereas in row seeded or transplanted rice, it took about 50-60 h/ha using manually operated mechanical weeders depending upon weed infestation and soil conditions. Khan and Diesto [6] designed a push type cono-weeder for paddy crop which uprooted and buried the weeds in one pass without making back-forth movement. They reported that the machine required labor about 120 man-h/ha saving half the time of operation compared to that of manual weeding. Remesan et al. [7] evaluated performance of a rotary weeder and a cono-weeder in wetland paddy conditions and compared the same with hand weeding. It was reported that the time required for hand weeding per hectare with male and female operators was 333.3 h and 399.8 h on average, respectively. The average time required by male labor to carry out weeding per hectare with rotary and cono-weeder was 47.7 h and 41.0 h, respectively, on average as compared to 80.7 and 76.3 h with female labor. Hossen et al. [8] designed and developed a weeder to carry out weeding in lowland as well as upland conditions, which used hoe as the weeding tool with an overall width of 120 mm. The average effective field capacity and degree of weeding were reported as 0.034 ha/h and 90 % in the lowland and 0.027 ha/h and 83 % in upland conditions, respectively.

Ambujam [9] developed a rotary paddy weeder powered by a 1 kW engine. This weeder operated at a depth of 70 mm and weeding efficiency, actual field capacity, and performance index were reported as 80 %, 0.022 ha/h, and 587, respectively, with an average fuel consumption of 0.86 l/h. The cost of weeding with this power weeder was Rs.503/ha as compared to Rs.438/ha with hand weeding.

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Victor and Verma [10] developed 0.373 kW petrol engine powered wet-land paddy weeder, which consisted of prime mover, belt and pulley transmission system, 4 L-shaped weeding blades, two traction wheels, and a gauge wheel. With 200 mm width of weeder when operated in paddy field with standing water of 50-70 mm, the field capacity was found to be between 0.04 to 0.06 ha/h with the weeding efficiency of 90.5 % and field efficiency of 71 %. The cost of the weeding was reported as Rs. 882/ha. Alizadeh [11] evaluated the performance of four types of mechanical weeders in paddy crop: single-row conical weeder (W1), two- row conical weeder (W2), rotary weeder (W3), and power weeder (W4) and compared their performances with hand weeding (W5). Among the mechanical weeders, the highest (84.33 %) and lowest (72.80 %) weeding efficiency rates were obtained with power weeder and rotary weeder, respectively. The damaged plants were observed to be 3.83 % with mechanical weeders as compared to 0.13 % with hand weeding. The cost of weeding with W1, W2, W3, and W4 as compared to W5 was reduced by 15.70, 38.51, 22.32, and 48.70 %, respectively.

Deshmukh and Tiwari [12] conducted a study on the impact of different types of weeders in System of Rice Intensification (SRI) where plant-to-plant and row-to-row spacings were maintained at 250 mm. They reported that cono-weeder and rotary weeder were suitable for weeding in wetland conditions and twin wheel hoe in dry-land condition adopting SRI methods. In SRI, the rotary weeder was found to be the best weeder with a field capacity of 0.18 per ha/day/labour and cost of weeding of Rs. 500/ha with 50 % saving in time.

Ojomo et al. [13] studied the performance of a 1.5 kW petrol engine powered weeding machine with three types of cutting blades (flat, spike tooth and curved blades). At 16 % soil moisture content, the highest average weeding efficiency of 76.62 % was obtained with the spike tooth blade followed by 71.84 % with the curved blade and 68.56 % with the flat blade. Olaoye et al. [14] developed a 3.73 kW petrol engine operated rotary power weeder. It consisted of a frame, rotary hoe (disc), tines, power unit, and transmission unit. The field capacity of the rotary power weeder was reported to be 0.071 ha/h with a weeding efficiency rate of 73 %. The cost of weeding with this machine was Rs. 12,600 per year against Rs. 56,000 per year when weeding manually.

Said et al. [15] evaluated the performance of a power operated single row paddy weeder and compared it with manual weeders such as cono-weeder and Ambika paddy weeder. The weeding efficiency and percent tiller damaged for power operated single-row paddy weeder, cono-weeder, and Ambika paddy weeder were reported as 74.50 %, 72.45 %, 83.87 % and 1.15 %, 0.52 %, 0.75 %, respectively. The average time required for weeding one hectare of the field was 12.82 h, 62.50 h, and 47.62 h for power operated weeder, cono-weeder, and Ambika paddy weeder, respectively. They suggested the application of power operated paddy weeder for carrying out weeding in paddy field from 15 days after transplanting up to 45 days with an interval of 10 days.

Shakya et al. [16] developed a cono-weeder that consisted of two conical rotors of 100 mm diameter with serrated bladed weeding unit at 30° blade angle and compared its performance with the TNAU (Tamil Nadu Agricultural University) cono-weeder comprising two conical drums with alternative smooth and serrated blades on it. The weeding efficiency, plant damage, and soil handled with the developed cono-weeder were reported as 87.77 %, 4.58 %, 6.5 m^3/h, respectively, as compared to 77.41 %, 9.17 %, 4.54 m^3/h, with TNAU cono-weeder. The average value of performance indices for the developed cono-weeder and TNAU cono-weeder obtained was 2300 and 1153.60, respectively.

Kunnathadi et al. [17] developed a self-propelled cono-weeder powered by a 0.9 kW engine with specific fuel consumption of 650 g/kWh. The average field capacity of this weeder when operated at a speed of 2.0-3.0 km/h was reported as 0.1 ha/h. with a weeding efficiency at par with that of the manual cono-weeder operating twice in 15 and 30 days after transplanting.

Seerangurayar et al. [18] evaluated performance of one 3-row and two 2-row commercially available power weeders powered by 1.5 kW, 1.3 kW, and 1.3 kW petrol engines, respectively, for carrying out weeding in paddy crop in south India and compared it with the manual weeding. Out of these two 2-row weeders, one (1.3 kW engine) was fitted with wheels and the other had 'L'-type blade as weeding element. The weeding efficiency, plant damage, field capacity, and field efficiency for these weeders were found to be in the range of 60.8-64 %, 1.2-2.7 %, 0.074-0.131 ha/h, and 76-78 %, respectively. The highest field efficiency, weeding efficiency, and plant damage among the 2-row weeders were found for weeder fitted with 'L'-type blades. The field capacity observed with 3-row power weeder was highest (0.131 ha/h) followed by 2-row 'L'-type blades weeder (0.091ha/h) and 2-row wheel type weeder (0.074 ha/h). The cost of weeding with power weeders as compared to manual weeding was reduced by 56 to 64 % with a saving of time up to 95 to 97 %.

Sirmour and Verma [19] developed and evaluated a single-row 1.49 kW petrol engine powered weeder for paddy crop. 'L' type weeding blades were arranged in a rotating disc for weeding and the working width of this weeder was made adjustable between 140 mm and 250 mm. The performance of weeder was studied in the field using three sets of blade (i.e., 4, 6, and 8 numbers) at a depth 30 to 80 mm and at a rotor speed of 176 rpm. It was reported that power requirement for weeding after 15 days of sowing was maximum with 8 blades, i.e., 380 W, followed by 313 W with 6 blades and, then, 290 W with 4 blades. The average fuel consumption of power weeder was reported as 0.55 l/h with a maximum field capacity of 0.054 ha/h and weeding efficiency of 88.62 %. Use of these weeders could save 60 % cost of weeding and 65 % time required for carrying out weeding as compared to manual weeding.

The push-pull weeders and cono-weeders are mostly used by the marginal and small farmers, which are efficient in removing weeds, but with low field capacity and high drudgery to the operators. These manual weeders require longer time as well as much labor for carrying out weeding in paddy crop as frequent machine cleaning and rest for the operator are required during weeding. The power (engine operated) weeders produce much vibration, create noise pollution, and also cause environmental pollution due to burning of fossil fuel. The working elements used in the power weeders were mostly 'L'-type blades, which were good in uprooting weeds in the wet-land condition, but poor in burying weed in the soil. Hence, the addition of weeds to the soil to enhance its organic manure is not possible and there is a possibility for the regrowth of the weeds from the weed residue left. The existing weeding blades are also prone to frequent clogging with weeds, which create problem in smooth operation and consume unnecessary energy in cleaning the clogged working elements. To overcome these difficulties, a suitable weeder powered by solar energy is very much required. Though a few solar energy operated tillers and weeders were developed [20-22] for tilling in dryland for carrying out weeding operation in maize and ground nut crops, their applicability to wetland where the soil is soft and standing water is available is not known. Hence, an attempt was made to develop an effective and non-polluting weeder for carrying out weeding in the wetland paddy field.

2. EXPERIMENTAL

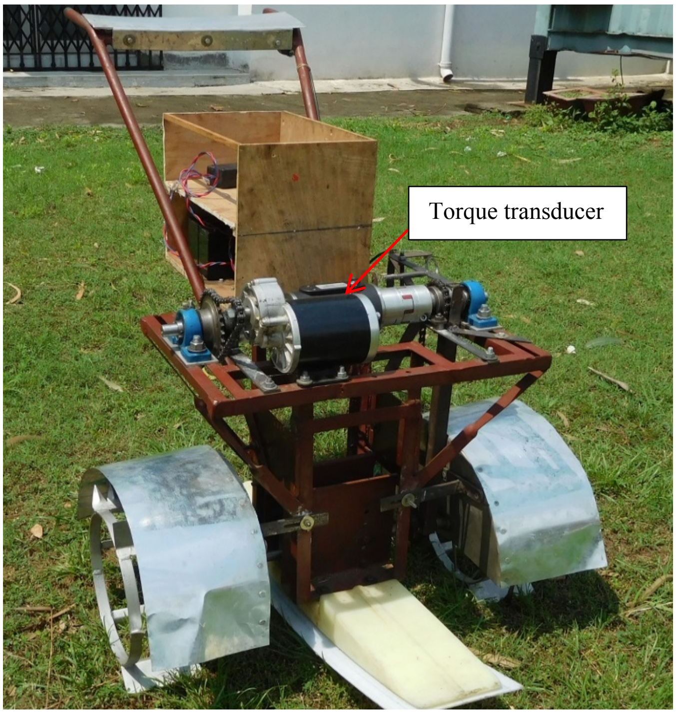
2.1. Development of power weeder

A two-row wetland paddy weeder, as shown in Figure 1(a), was developed. It comprised the main frame with a wooden box, a prime mover, transmission system, two weeding wheels, and a float. A DC motor of 450 W and 480 rpm with controller was used to supply power to the weeding wheels using a chain and sprocket transmission system. This DC motor was fixed on the main frame, and was used as the prime mover for carrying out weeding operation. Chain-sprocket transmission was used to transmit power from the motor to a clutch shaft and, subsequently, from the clutch shaft to shaft fitted with weeding wheels at both of the ends at 1:3 and 1:1 reduction ratios, respectively. A dog clutch arrangement was provided to disconnect the power flow from motor to the rotating wheel while taking a turn from one row to the adjacent row during field operation. The developed paddy weeder was fitted with cage wheel type weeding wheels of 250 mm diameter and 125 mm width so that both forward movement and weeding operation could be done simultaneously. On the periphery of each of the wheels, three jaw tooth and three plane blades were arranged alternatively at equal spacing (Figure 1 (b)). The jaw-toothed blades were used to uproot the weeds and the plain blades helped to cut and bury the weeds in the soil. The blade angle of the weeding elements was kept at 30° for effective weeding operation. A float was attached to the bottom of the weeder to support its weight and stabilize it during operation in the wet and muddy soil conditions. It also prevented the weeder from sinking into the muddy soil during operation. During operation, the float was sliding on the middle row with rotating weeding wheel on either side. The weeding elements provided on the wheel could cut and bury the weeds into the soil up to a maximum depth of 70 mm. The weeder had a provision to operate the machine at three different depths such as 30 mm, 50 mm, and 70 mm by adjusting the gap between float and axle of the weeding wheel. This weeder can operate in different row-to-row spacing conditions for paddy crop such as 200 mm, 250 mm, and 300 mm. Power requirement for carrying out weeding operation with this type weeder in actual wetland field condition was studied and, then, a suitable powering system comprising Solar Photo-Voltaic (SPV) panels was designed and developed to operate the weeder.

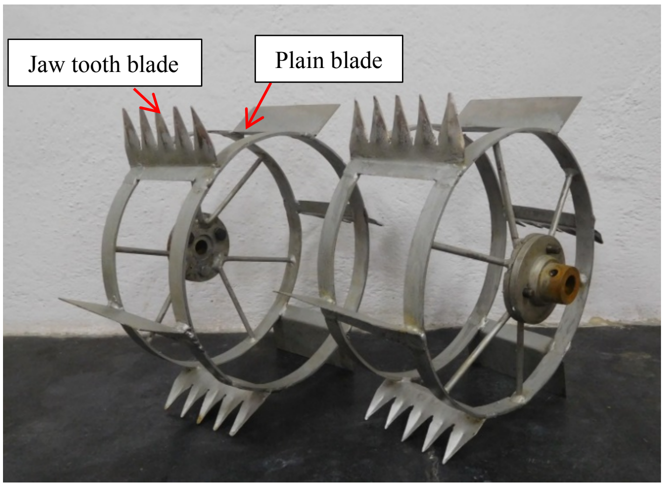
2.2. Power requirement of the weeder for carrying out weeding

A 100 Nm torque transducer (Datum make) was attached to the main shaft for power transmission, as shown in Figure 1(a). After measuring the torque required with this transducer and speed of the weeding wheel during weeding operation, the power requirement of the weeder was computed, i.e., product of torque and angular speed. A photograph of the developed weeder during field operation for measurement of torque and speed is shown in Figure 2. The DC motor used as the power source to operate the weeder was receiving power from batteries (inside the wooden box, Figure 2). A data displaying and storing device called Datum Universal Interface (DUI) was employed to acquire speed and torque data from the transducer during operation of the weeder. The operator used the handle for guiding the implement during operation in between the rows.

Clutch actuating lever was provided with the handle so that the operator could easily disconnect power supply to the weeding wheels for taking a turn from one row to the adjacent row. The torque transducer measured the torque and speed requirement during weeding operation and transmitted that to DUI for storing data using a simple pen drive for future usage.



(a) The developed weeder



(b) Cage wheel with weeding elements

Figure 1. The developed wetland paddy weeder

2.3. Development of solar energy operated wetland paddy weeder

The solar energy operated wetland paddy weeder comprised a stand-alone solar photo voltaic (SPV) system that supplied power to the two weeding wheels for weeding operation. The power flow in the stand-alone SPV system used in the developed weeder is shown in Figure 3.

Figure 2. The developed wetland paddy weeder

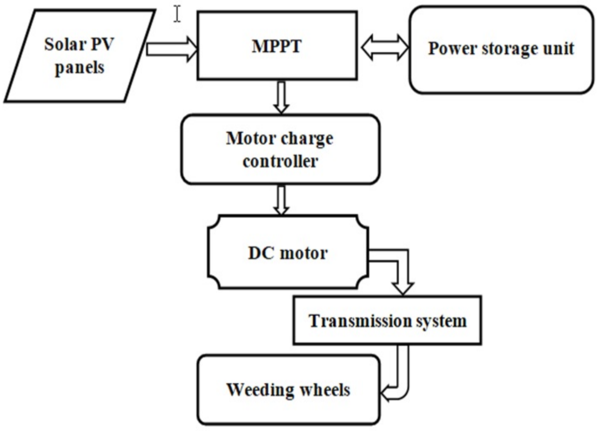


Figure 3. Flow chart for power flow in the stand-alone SPV system

2.3.1. Development of the SPV powering system for the weeder

The powering system for the developed weeder comprised four components, namely DC motor, power storage (battery), power source (solar PV panels), and controllers.

2.3.1.1. Selection of DC motor

In this SPV powering system, the DC motor has a major role as the prime mover for the paddy weeder. Considering the maximum torque and speed requirement to carry out weeding operation as obtained in the field (30 N.m and 350 W, respectively, considering 20 % reserve), a DC motor of 450 W was selected and its specifications are summarized in Table 1. As the speed required for carrying out weeding operation was 150 rpm but the rated speed for DC motor was 480 rpm, a chain-sprocket transmission with a speed reduction of 3:1 was used. The fabricated model with the DC motor was applied in the wetland field condition using batteries and the current and voltage required for this operation were measured. Based on these requirements, battery size was decided.

Table 1. Specifications of DC motor for weeder

Sl. No.	Parameters	Values
1.	Rated power, W	450
2.	Rated voltage, V	24
3.	Actual speed, rpm	480
4.	No load current, A	2.5
5.	Full load current, A	24
6.	Rated torque, kg.cm	90
7.	Motor weight, kg	5.6

2.3.1.2. Selection of battery

During the field operation of the weeder, the voltage and current required for carrying out weeding were measured to be 24 V DC and 10 to 13 A, respectively. Taking an operating time of 6 hours per day with 3 hours autonomy and a battery discharge rate of 0.6, the battery capacity was determined using Eq. 1.

Size of battery (A-h) =

$$\frac{\text{Total Watthours required per day} \times \text{Days of autonomy}}{\text{Discharge rate of battery} \times \text{nominal battery voltage}(V)} \tag{1}$$

Battery capacity (A-h) = $\frac{(24 \times 13 \times 6) \times 3}{24 \times 0.6 \times 24}$ =16.25 A-h

As 24 VDC and 20 A-h Lithium-ion battery was available in the market, which is light in weight and easy to use. Hence, this was selected for this purpose and its specifications are given in Table 2.

Table 2. Specifications of the battery (Lithium-ion battery)

Sl. No.	Parameters	Values
1.	Nominal voltage, V	24
2.	Capacity, Ah	20
3.	Depth of discharge, %	50
4.	No. of batteries	1
5.	Efficiency, %	90

2.3.1.3. Selection of solar PV panel

The size of solar PV panel is basically decided considering two factors: daily solar radiations available during the operation period (solar peak hour) and the energy required to carry out weeding. Weeding operation is generally carried out during March to April and September to October for paddy crops in Rabi and Kharif seasons, respectively. Solar radiation available at Kharagpur (22.35° N, 87.23° E) for Rabi and Kharif seasons during these periods is about 5.5 to 6 kWh/m^2/day. Hence, the peak solar hour for this location is 5.5 to 6 h/day (@1000 W/m^2). The average power required for carrying out weeding operation was in the range of 300 W in the wetland paddy field condition. The size of solar panel was decided using Eq. 2.

Solar panel size =

$$= \frac{\text{Energy consumption per day}\left(\frac{\text{Wh}}{\text{day}}\right)}{\text{Peak sun hour}\left(\frac{\text{h}}{\text{day}}\right)} = \frac{\mathbf{300 \times 6}}{\mathbf{5.75}} = 313.04\ \text{W}_\text{p} \tag{2}$$

Hence, two flexible solar PV panels, each with 160 Wp, were selected for this powering system and the panels were connected in series to give the desired output. The specifications of these panels are summarized in Table 3.

Table 3. Specifications of flexible solar panel selected

Sl. No.	Parameters	Values
1.	Nominal max. power (P_{max}), W	160
2.	Optimum operating voltage (V_{mp}), V	19.60
3.	Optimum operating current (I_{mp}), A	8.20
4.	Open circuit voltage (V_{oc}), V	21.60
5.	Short circuit current (I_{sc}), A	9.80
6.	Conversion efficiency, %	19.0

2.3.1.4. Selection of controllers

Solar charge controller and DC motor controller were included in this developed powering system.

Solar charge controller

The output of the solar panel was about 39.20 V DC and 8.20 A, which did not match with the load requirement; hence, to address the problem, a device called solar charge controller was used. Because of higher efficiency of Maximum Power Point Tracker (MPPT) charge controller over the Pulse Width Modulation (PWM) type charge controller [23], it was selected to be coupled with the solar panels for getting maximum current and voltage output. The specifications of the MPPT selected for use are given in Table 4. The controller not only maximized the power from the panel to match with the load operating point but also prevented the power over flow to the DC motor, which might damage it. The advance controller MPPT had also a provision to display and store the power, voltage and current data of the solar panel, battery, and load through solar monitor software using a personal computer.

Table 4. Specifications of solar MPPT charge controller

Sl. No.	Parameters	Values
1.	Model	TRIRON3210N
2.	System voltage, VDC	12/24
3.	Maximum PV open circuit voltage, V	100
4.	Rated charge/discharge current, A	30
5.	Maximum rated charge power, W	390W (12V), 780W (24V)
6.	Battery voltage range, V	Aug-32
7.	Efficiency, %	99.5

DC motor controller

A DC motor charge controller was selected based on the maximum current requirement during weeding operation and by controlling its power input from the SPV powering system, the speed of the DC motor was regulated during weeding operation. The specifications of the selected DC motor controller are summarized in Table 5.

Table 5. Specifications of DC motor controller

Sl. No.	Parameters	Values
1.	Output power for 24 V(max.), W	960
2.	Range of operating voltage, V	10-50
3.	Peak current, A	40
4.	Adjustable speed range, %	5-100
5.	Operating temperature, ºC	-20 to 40

2.4. Performance evaluation of the Solar Energy Operated Weeder (SEOPW)

Performance of the developed two-row SEOPW was evaluated in wetland paddy fields with 20-30 mm standing water, available in the Research Farm of Indian Institute of Technology Kharagpur, India. It comprised two major parts:

• Performance of the paddy weeder in the field

• Performance of the SPV powering system developed for the SEOPW

2.4.1. Field performance of the paddy weeder

Field performance of the developed paddy weeder was evaluated following the procedure outlined in Indian standard for testing manual weeders [24] and it was compared with that of a manual push-pull type cono-weeder. The following parameters were measured:

Effective field capacity was computed by measuring the total time required to carry out weeding in plots of size 15×10 m. It included time loss during turning. Theoretical field capacity was calculated by multiplying the width of weeding by the forward speed of the weeder during operation.

Field efficiency of the weeder was computed using Eq. 3:

$$\text{Field efficiency } = \frac{\text{Actual field capacity}}{\text{Theoretical field capacity}} \times 100 \quad (3)$$

Plant damage percentage was computed using Eq. 4.:

$$\text{Plant damage (\%)} = \frac{\text{Number of plants damaged in a plot}}{\text{Total number of plants in the plot}} \times 100 \quad (4)$$

Weeding efficiency was computed using Eq. 5:

Weeding efficiency =

$$\frac{\text{Total no. of weeds present before weeding} - \text{Total no.no.of weeds present fter weedingg}}{\text{Total no. of weeds present before weeding}} \times 100 \quad (5)$$

2.5. Economic analysis of weeding with SEOPW

The initial costs of SEOPW and conventional cono-weeder are Rs. 60,000 and Rs. 2,000, respectively. Cost of weeding in paddy crop with conventional cono-weeder and SEOPW was computed following the Indian Standard IS-9164 [25]. The useful life of the SEOPW as well as cono-weeder was considered as 8 years with an annual use and 250 h. Fixed costs of the weeders were computed considering the salvage value of SEOPW and cono-weeder as Rs. 3000 and Rs. 100, respectively (following a straight method), interest (7 % per annum), insurance, taxes (2 % of average purchase price of weeders), and housing cost (1.5 % average price of weeders). The operating cost of SEOPW included the cost of batteries, the cost of electricity for recharging the batteries, lubricant cost, operator's wages, and repair and maintenance charges. The labor cost for carrying out weeding was computed using a daily wage of unskilled labor as Rs. 350. Labor required for weeding in paddy crop using SEOPW and cono-weeder was recorded. The cost of weeding in paddy crop with SEOPW and cono-weeder was compared. Break Even Analysis of SEOPW was computed and it is defined as the minimum area required to be weeded using the SEOPW per year to have economic advantage over weeding with conventional cono-weeder. The break-even point for the SEOPW was estimated using Eq. 6.

Break even point (ha/year) =

$$\frac{\text{Annual fixed cost of weeding with SEOPW } \left(\frac{\text{Rs}}{\text{year}}\right)}{\text{Cost of weeding with conoweeder } \left(\frac{\text{Rs}}{\text{ha}}\right) - \text{Cost of weeding with SEOPW} \left(\frac{\text{Rs}}{\text{ha}}\right)} \quad (6)$$

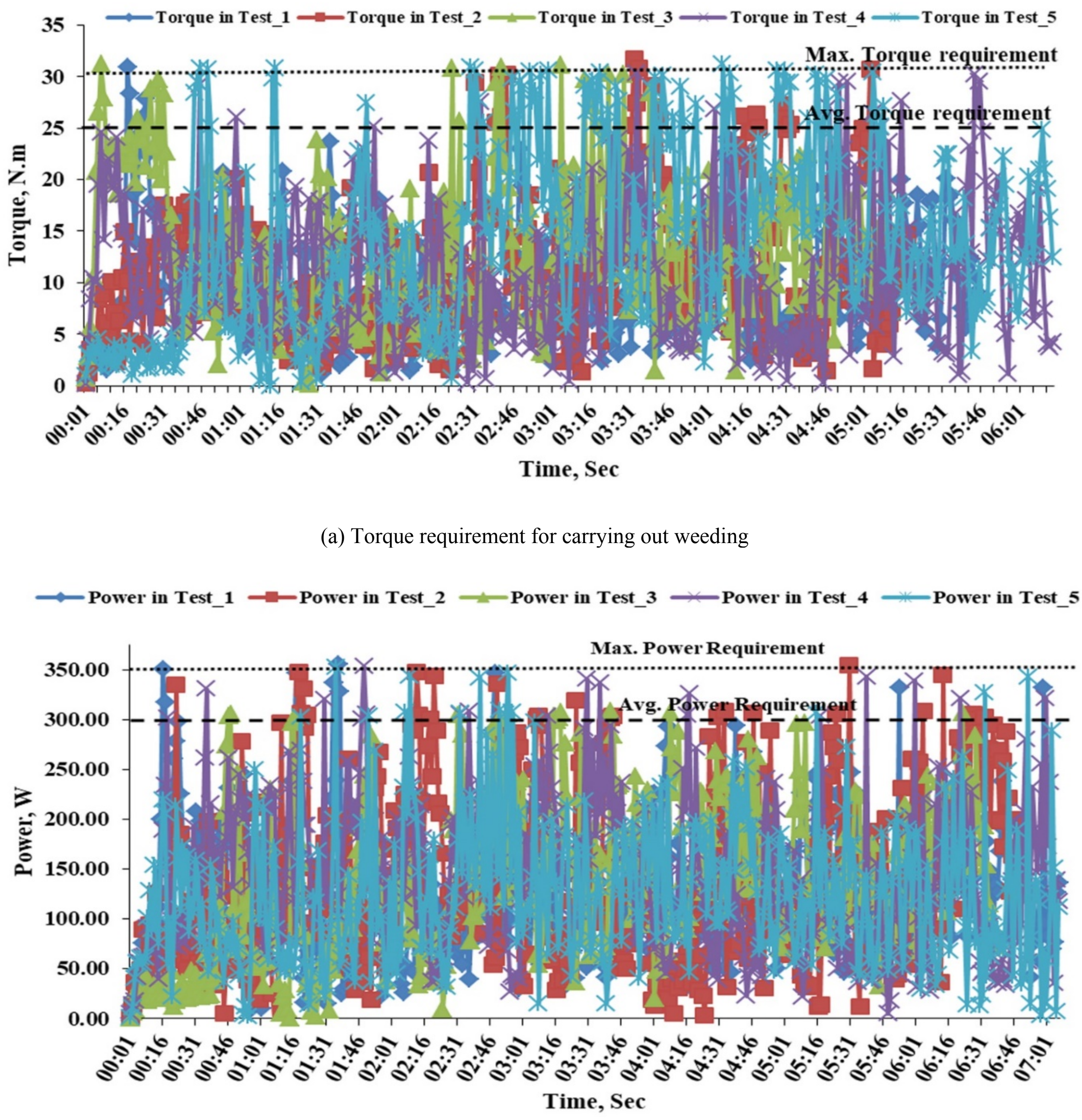
3. RESULTS AND DISCUSSION

3.1. Determination of torque and power requirement of the weeder

Experiments were carried out in the wetland paddy field using a pair of weeding wheels with alternative three jaw toothed and plain blades on its periphery at a speed of 150 rpm. Both torque and power requirement while carrying out weeding operation were recorded with the help of torque transducer and DUI. A sample plot of these parameters with time is shown in Figure 4 (a and b). From these figures, maximum torque and power required to carry out weeding operation in the wetland condition were found to be 30 N.m and 350 W, respectively. The average torque and power requirement of the weeder to carry out weeding were found to be 25 N.m and 300 W, respectively. Based on these experimental results, a solar PV powering system was designed and developed.

3.2. Developed solar energy operated paddy weeder

The developed Solar Energy Operated two-row Paddy Weeder (SEOPW) is shown in Figure 5 and its detail specifications are given in Table 6.



(a) Torque requirement for carrying out weeding

(b) Power requirement for carrying out weeding

Figure 4. Torque and power requirement for carrying out weeding operation in the wetland paddy field

1. Solar panels; 2. Panel holding frame; 3. Stand for frame; 4. DC motor; 5. Transparent protection; 6. Main frame; 7. Float; 8. Mud guard; 9. Weeding wheel; 10. Weeding elements; 11. Rotating shaft; 12. ON/OFF switch; 13. Speed regulator; 14. Clutch lever; 15. Handle; 16. MPPT; 17. Battery

Figure 5. The developed solar energy operated paddy weeder (SEOPW)

Table 6. Specifications of the developed two-row SEOPW

Sl. No.	Particulars	Details
1.	Overall dimension (l×w×h), mm	1450×950×700
2.	Capacity of DC motor, W	450
3.	Rated speed of motor, rpm	480
4.	Rated torque of motor, N.m	8.95
5.	Speed of weeding wheel, rpm (m/s)	125 (1.64), 150 (1.96), 175 (2.30)
6.	Depth of operation, mm	30 - 70
7.	Suitable for row space, mm	200, 250, 300 (Adjustable)
8.	Dimension of float (l×w×h), mm	1000×200×55
Details of weeding mechanism		
9.	Type	Cage wheel type
10.	Width of the weeding wheel, mm	125
11.	Diameter of the weeding wheel, mm	250
12.	Weeding element	Plain and jaw toothed blade
13.	Total no. of plain and jaw-toothed blades	6 (3 each type)
14.	No. of jaws per blade (jaw-toothed blade)	5
15.	Dimension of blades (w×h×t), mm	125×50×2
16.	Lug angle of blades, degree	30

3.3. Performance of the developed SEOPW

A photograph of the developed weeder during operation in the field is shown in Figure 6. In the paddy field, indigenous local weeds and aquatic weeds mainly were found, as shown in Figure 7(a). In Figure 7(b), it can be clearly seen that the developed SEOPW not only uprooted the weeds in between the rows but also buried the uprooted weeds in muddy soil with its weeding elements. Some paddy plants were partly damaged while carrying out weeding as well as taking turn at the headland, which could be avoided with a skilled operator. All the performance parameters measured are summarized in Table 7 and are compared with those obtained with a manually operated cono-weeder.

Figure 6. Field testing of the developed SEOPW

(a) Before weeding

(b) After weeding

Figure 7. Field condition before and after the weeding operation with the developed SEOPW

Table 7. Performance of the developed weeder and cono-weeder

Sl. No.	Variables	SEOPW	Manual cono-weeder
1.	Actual field capacity, ha/h	0.06	0.034
2.	Field efficiency, %	83.3	60.2
3.	Labour requirement, man-h/ha	17-19	29-30
4.	Plant damage, %	2-3	4-5
5.	Weeding efficiency, %	83-85	75-77

In Table 7, it can be seen that the actual field capacity of the developed SEOPW was 0.06 ha/h and it was 1.78 times higher than that of the manually operated cono-weeder due to higher width of coverage. The SEOPW could perform weeding with higher field capacity (76.47 %), weeding efficiency (10.4 %), and field efficiency (38.37 %) with lower plant damage (45 %).

There was a saving of 12 man-h labor requirement per hectare as compared to manually operated cono-weeder. This was due to higher cutting width and powered weeding wheels for which the operator had to take less rest during weeding operation unlike the cono-weeder.

3.4. Performance of the developed SPV powering system

Performance of the developed SPV powering system was evaluated during weeding operation for a period of two hours (from 10 AM to 12 PM). Different parameters such as power consumption by the weeder, battery power (recharge/ discharge), solar panel output power, and the corresponding solar intensity during the operation period were recorded with the help of the MPPT and Personal Computer (PC) with solar energy data monitoring software. The solar radiation data were measured with the help of an automatic electronic Pyranometer. All the recorded data stored in the PC are plotted in Figure 8. In this Figure, it can be seen that power required for carrying out weeding operation (shown as vertical bars) is varying from 195 W to 300 W. This much power was required to be provided by the SPV powering system. During this weeding period, the solar intensity was varying in the range of 700 to 825 W/m^2 and power supplied by the solar panels for carrying out weeding operation was about 195 W to 225 W. Thus, there was mismatch between the power required for carrying out weeding and the power available from the SPV powering system. Hence, this mismatch was overcome by drawing power from the battery. The battery power available during this period, shown in Figure 8, was characterized as negative as the power of battery was discharged during the weeding operation. However, the discharge amount from the battery was not a high amount for the selected battery capacity. The charge of battery was 100 % before the operation and after two hours of operation, about 20 % got discharged from the battery. During weeding operation, when the power requirement for weeding was reduced due to resting or turning of the weeder, the power output from the panel was used to charge the battery.

3.5. Cost of weeding in wetland

The cost analysis of the developed weeder vis-a-vis cono-weeder was carried out and the details are given in Table 8.

The costs of weeding and labor requirement to carry out weeding with SEOPW and conventional cono-weeder were computed to be Rs. 3607 per ha and 17 man-h per ha, respectively, as compared to Rs. 6133 per ha and 29 man-h per ha with conventional cono-weeder. Although the initial cost of the developed weeder was higher than the manual cono-weeder, the operational cost for the developed weeder per hectare was about 41.2 % lower than that of the manual push-pull type cono-weeder. This was due to higher field capacity and fewer labor requirements with the developed SEOPW. Thus, weeding with SEOPW would save money, time, and energy of farmers and increase the productivity. Break-even point for the SEOPW was computed as 4.13 ha/year and annual use below this area was found uneconomical for weeding with SEOPW.

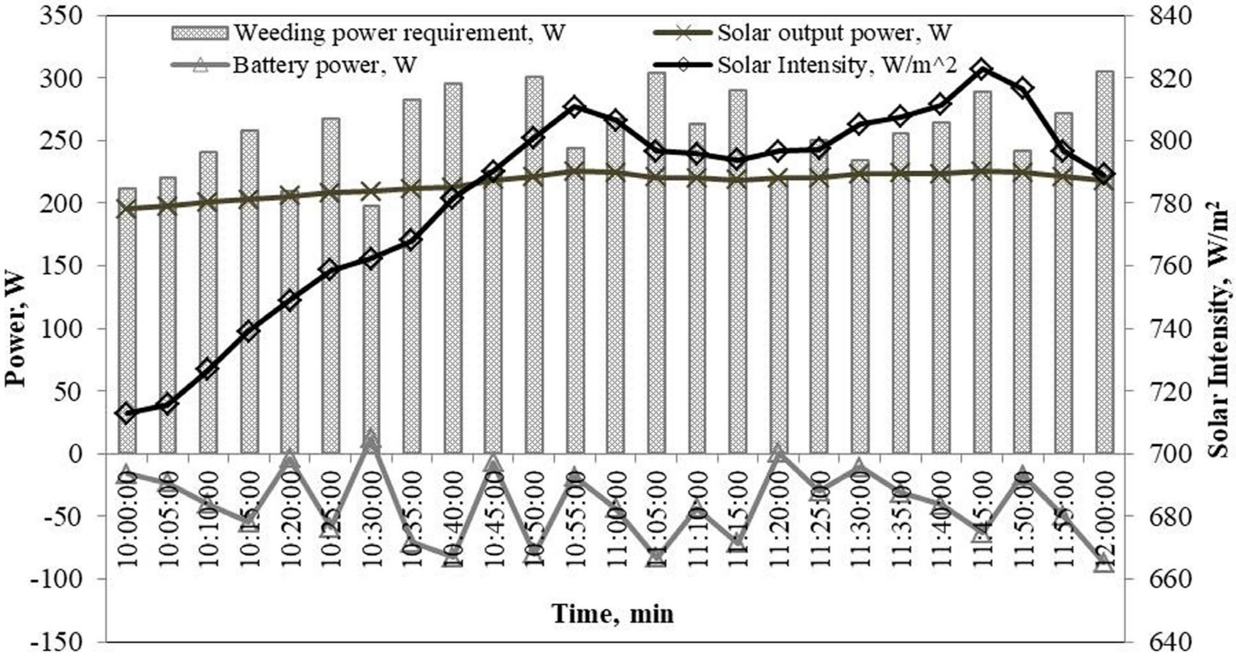


Figure 8. Performance of the developed SPV powering system during weeding operation on 10th March 2020 in the Research Farm of IIT Kharagpur

Table 8. Details of cost analysis of SEOPW and Cono-weeder and their comparison

Sl. No.		Parameters	SEOPW	Cono-weeder
1.		**Fixed cost**		
	i.	Initial cost, Rs.	60000	2000
	ii.	Useful life, years	8	8
	iii.	Annual use, hour	250	250
	iv.	Salvage value, Rs.	3000	100
	v.	Depreciation cost per hour, Rs./h	28.5	0.95
	vi.	Interest on capital (@ 7 % per annum) per hour, Rs./h	8.82	0.29
	vii.	Average purchase price of machine, Rs.	31500	1050
	viii.	Insurance and taxes per hour (@ 2 %), Rs./h	2.52	0.08
	ix.	Housing per hour (@ 1.5 %), Rs./h	1.89	0.06
2.		**Total Fixed cost, Rs./h (USD/h)**	**41.73 (0.572)**	**1.39 (0.019)**
3.		**Variable cost**		
	i.	Field capacity, ha/h	0.06	0.034
	ii.	Daily hours of operation, h	6	7
	iii.	Repair and maintenance cost per hour, Rs/h	24	0.8
	iv.	Man-hour required per ha	17	29
	v.	Cost of battery per hour (Replacement of battery in every 3 years), Rs/h	9	-
	vi.	Cost of labor per hour, Rs/h	141.67	207.14
	vii.	Total cost of weeding per hour, Rs	216	209
4.		**Cost of weeding operation, Rs/ha (USD/ha)**	**3607 (49.47)**	**6133 (84.11)**

4. CONCLUSIONS

Application of solar energy in carrying out weeding in paddy crop is an excellent attempt to mechanize paddy cultivation where access to continuous supply of electricity and availability of conventional fossil fuel are remote. The following specific conclusions are drawn from the study conducted:

• The developed two-row SEOPW had a field capacity 1.78 times that of a manual drawn cono-weeder with 41 % fewer labor requirements, 10.5 % higher field efficiency, and 45 % lower plant damage.

• The developed powering system for operating the weeder using solar photovoltaic could charge the battery in less than 2 hours when the solar intensity available was above 450 W/m^2. The weeder with a fully charged battery was continuously operating for a maximum period of 2 hours without recharging.

• The operating cost of the developed SEOPW was Rs 3607 (49.47USD) per ha as compared to Rs 6133 (84.11 USD) with cono-weeder. This was due to its higher field capacity and fewer labor requirements. In order to make the weeding operation with SEOPW economical as compared to cono-weeder, the minimum area required for weeding is 4.13 ha/year.

From the experiments conducted, it was finally concluded that the developed weeder was successful in carrying out weeding in the paddy crop using solar energy with higher field capacity and field efficiency and also with fewer manpower requirements than the commonly used manual drawn cono-weeder.

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REFERENCES

1. Annual report, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, New Delhi, India, (2018), 4. (https://agricoop.nic.in/sites/default/files/AR_2018-19_Final_for_Print.pdf).
2. De Dutta, S.K., Principles and practices of rice production, John Wiley and Sons, USA, (1981), 469-472. (https://books.google.co.in/books?hl=en&lr=&id=Yxa5Sz_Puv4C&oi=fnd&pg=PR1&ots=pVZjBecXID&sig=XzxhlyopXDW7ux6VWtgLRM9rIu0&redir_esc=y#v=onepage&q&f=false).
3. Gunasena, H.P. and Arceo, L.M., "Weed control studies with butachlor in direct seeded rice in Shri Lawlea", ***Proceedings of 8th Asian Pacific Weed Science Society Conference***, Bangalore, India, (1981), 27-29. (https://www.isws.org.in/Documents/Proceedings_of_conference/1981_8th_Asian-Pacific_Weed_Science_Society_Conference_Proceedings_(Volume2).pdf).
4. Sathyamoorthy, K. and Kandasamy, O.S., "Critical period of crop weed competition in different rice culture (lowland transplanted and wet seeded rice)", Summary and Research Achievements, AICRPWC (ICAR), Coimbatore Centre, Tamil Nadu Agricultural University, Coimbatore, India, (1998). (https://www.academia.edu).
5. Parthasarathi, M.N., "Control of rice weed with butachlor", ***Proceedings of Weed Science Conference, Indian Society of Weed Science***, Andhra Pradesh Agricultural University, Rajendranagar, India, (1977), 179-180. (https://www.isws.org.in).
6. Khan, A.V. and Diesto, M., "Push type cono weeder for small rice farms", ***Investigation Intelligence***, Vol. 23, (1987), 236-237. (http://ijaast.com/publications/vol6issue12/V6I1201).
7. Remesan, R., Roopesh, M.S., Remya, N. and Preman P.S., "Wet land paddy weeding-A comprehensive comparative study from south India", ***Agricultural Engineering International: The CIGR E-Journal***, Vol. 9, (2007), 1-21. (https://hdl.handle.net/1813/10717).
8. Hossen, M.A., Islam, M.S., Huda, M.D., Zami, M.A., Bhuyan, M.G.K. and Nath, B.C., "Design and development of a weeder for both lowland and upland conditions", ***AMA-Agricultural Mechanization in Asia Africa and Latin America,*** Vol. 42, No. 2, (2011), 56. (http://www.shin-norin.co.jp/english/pdf/VOL_42_NO2_SPRING_2011.pdf#page=56).
9. Ambujam, N.K., "Performance evaluation of power weeder", ***Agricultural Mechanization in Asia, Africa & Latin America***, Vol. 24, (1993), 16-18. (https://www.cabdirect.org), (Accessed: 12 June 2016).
10. Victor, V.M. and Verma, A., "Design and development of power-operated rotary weeder for wetland paddy", ***Agricultural Mechanization in Asia Africa and Latin America***, Vol. 4, (2003), 27-29. (https://www.researchgate.net/publication/285531721_Design_and_Development_of_Power-operated_Rotary_Weeder_for_Wetland_Paddy), (Acessed: 10 May 2016).
11. Alizadeh M.R., "Field performance evaluation of mechanical weeders in the paddy field", ***Scientific Research and Essays***, Vol. 6, (2011), 5427-5434. (https://academicjournals.org/article/article1380826459_Alizadeh.pdf).
12. Deshmukh, G. and Tiwari R.K., "Impact of weeders for weed management in system of rice intensification (SRI)", ***Indian Journal of Weed Science***, Vol. 43- No. 3-4, (2011), 243-244. (https://www.indianjournals.com/ijor.aspx?target=ijor:ijws&volume=43&issue=3and4&article=029).
13. Ojomo, A.O., Ale, M.O. and Ogundele, J.O., "Effect of moisture content on the performance of a motorized weeding machine", ***IOSR Journal of Engineering (IOSRJEN)***, Vol. 2, No. 8, (2012), 49. (http://iosrjen.org/Papers/vol2_issue8%20(part-1)/G0284953.pdf), (Acessed: 12 May 2016).
14. Olaoye, J.O., Samuel O.D. and Adekanye, T.A., "Performance evaluation of an indigenous rotary power weeder", ***Energy and Environmental Engineering Journal***, Vol. 1, No. 1, (2012), 94-97. (https://eprints.lmu.edu.ng/123/1/2012.Performance%20Evaluation%20of%20an%20Indigenous%20Rotary%20Power%20Weeder.pdf), (Accessed: 10 June 2017).
15. Said P.P, Shukla A. and Sahu K.R., "Field performance of power operated paddy weeder in comparison with manual weeders", ***Advancements in Life Sciences***, Vol. 5, (2016), 2200-2203. (http://www.als-journal.com/archive/).
16. Shakya, H.B., Parmar, M.R., Kumpavat, M.T. and Swarnkar, R., "Development and performance evaluation of manually operated cono-weeder for paddy crop", ***International Refereed Journal of Engineering and Science***, Vol. 5, No. 7, (2016), 6-17. (http://www.irjes.com/Papers/vol5-issue7/B570617.pdf).
17. Kunnathadi, M., Jayan, P.R. and Abraham. C.T., "Development and testing of self-propelled cono-weeder for mechanized rice cultivation", ***Indian Journal of Weed Science***, (2016), 25-28. (https://www.indianjournals.com/ijor.aspx?target=ijor:ijws&volume=48&issue=1&article=005).
18. Seerangurayar, T., Shridar, B., Kavitha, R. and Manickavasagan A., "Performance evaluation of power weeders for paddy cultivation in south India", ***AMA, Agricultural Mechanization in Asia, Africa and Latin America***, Vol. 48, No. 4, (2017), 76-81. (https://www.shin-norinco.com), (Accessed: 18 July 2018).
19. Sirmour, A., and Verma, A., "Design and development of single row power weeder for rice", ***Journal of Crop and Weed***, Vol. 14, No. 1, (2018), 163-169. (https://www.cropandweed.com/archives/2018/vol14issue1/14.1.30.pdf).
20. Waghmode, R.S., Shinde, S.R., Dixit, A.K., Chanchure, A.A., Jadhav, K.H. and Gudur, S.E., "Solar power tiller", ***International Journal of Engineering Science & Advanced Technology***, Vol 5, No. 3, (2015), 149-156. (https://www.ijesat.org/Volumes/2015_Vol_05_Iss_03/IJESAT_2015_05_03_01.pdf).
21. Kumari S., Mehta, A.K. and Meena, S.S., "Development and performance evaluation of solar operated power weeder", ***International Research Journal of Engineering and Technology (IRJET)***, Vol. 06, No. 7, (2019), 1340-1342. (https://www.irjet.net/archives/V6/i7/IRJET-V6I7479.pdf).

22. Kachhot, A.R., Dulawat, M.S. and Vadher, A.L., "Development of solar operated walking type power weeder", ***Agricultural Science and Green Energy***, Vol. 2, No. 2, (2021), 30-41. (https://agrilscience.com/wp-content/uploads/2021/02/2-2-5.pdf).

23. Laguado–Serrano, M. A., Luna Paipa, E.A., Bustos–Márquez, L.F. and Sepulveda–Mora, S.B., "Performance comparison between PWM and MPPT charge controllers", ***Scientia et Technica***, Vol. 24, No. 1, (2019), 6-11. (https://www.redalyc.org/journal/849/84959429001/84959429001.pdf).

24. Anonymous, Indian Test Code, IS: 7927, "Method of field testing for manually operated paddy weeder", Bureau of Indian Standard (Indian Standard Institution), New Delhi, India, (1975). (https://archive.org/details/gov.in.is.7927.1975), (Acessed: 10 July 2016).

25. Fagiolari, L. and Bella, F., "Carbon-based materials for stable, cheaper and large-scale processable perovskite solar cells", ***Energy & Environmental Science***, Vol. 12, No. 12, (2019), 3437-3472. (https://doi.org/10.1039/C9EE02115A).