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Design and development of single row power weeder for rice

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ABSTRACT

Weed control is one of the most difficult tasks on an agricultural farm. Weeding by mechanical devices reduces the cost of labour and also saves time. In order to assess the possibility of mechanization of the weeding operation, a power operated single row active weeder are designed and developed in the Faculty of Agricultural Engineering, IGKV, Raipur. From the design point of view- power source (engine), cutting blades shaft were the important components of single row power weeder for rice. Average working speed of operation was found as 2.45 km hr^{-1}. The average fuel consumption of power weeder was found as 0.55 l hr^{-1}. The maximum field capacity was found 0.054 ha hr^{-1}. The working width of the developed machine may be adjustable between 140 mm to 250 mm. The weeding efficiency was observed as 88.62 per cent under single row active power weeder. The saving in cost of weeding was 60 per cent and saving in time was 65 per cent compared to manual weeding.

***Keywords*:** Blade, power weeder, rice, rotor speed, transmission

Weed control is one of the most difficult tasks in agriculture that accounts for a considerable share of the cost involved in agriculture production. Weeds compete with crop plants for nutrients and other growth factors and in the absence of an effective control measure, consume 30 to 40 per cent of applied nutrients resulting in significant yield reduction. In India, about 4.2 billion rupees are spent every year for controlling weeds for production of major crops. Weeding with the use of manual tools requires high labour force. Mechanical weeders are used to complete the weeding operation in due time at less cost. Environmental pollution caused by chemical is also reduced by the use of mechanical weeder.

Pitoyo *et al.* (2000) reported the development of a power weeder for mechanical control of weeds in the rice field. The machine is driven by two strokes engine 2 hp/6500 rpm. The machine performance was 15 h/ha capacity at travelling speed 1.8 km hr^{-1}, the mass of the machine was 24.5 kg. Victor *et al.* (2003) reported that a rotary power weeder reduce the drudgery and ensure a comfortable posture of the operator during weeding and increases production as, field capacity and weeding efficiency of the rotary power weeder were 0.0712 ha/h and 73 per cent respectively. In order to assess the possibility of mechanization of the weeding operation, the power operated single row active weeder was designed and developed considering the optimum shape, size and location of cutting blades, evaluation of its performance, optimisation of dimensions of machine for better performance.

MATERIALS AND METHODS

A manually operated power weeder was designed for weeding of mechanical and manual transplanting of rice. From the design point of view- power source (engine), cutting blades shaft were the important components of single row power weeder for rice.

Power requirement

Assumption

Soil resistance has a considerable effect upon the power requirement of weeder. Also, width of cut and speed of operation influences power requirement of weeder. For calculating power requirement of the weeder, maximum soil resistance was taken as 0.5 kgf/cm^2. The speed of operation of the weeder was considered as 0.7 ms^{-1} to 1.0 ms^{-1}. Total width of coverage of cutting blades was in the range of 12 to 30 cm. The depth of operation was considered as 3 to 8 cm, transmission efficiency is 82 per cent.

$$P_d = \frac{\text{SR x d x w x v}}{75}\,\text{hp}$$

where,

SR = soil resistance, kgf/cm^2
d = depth of cut, cm
w = effective width of cut, cm
v = speed of operation, ms^{-1}

Hence, power requirement is estimated as

$$P_d = \frac{0.5 \times 8 \times 30 \times 1}{75}\,\text{hp} = 1.6\ \text{hp} = 1.26\ \text{kW}$$

Total power required

The total power required is estimated as 1.95 hp as follows

$$P_t = \frac{\text{Pd}}{\eta} = \frac{1.6}{0.82} = 1.95\ \text{hp} = 1.56\ \text{kW}$$

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where,

Pd = Power required to dig the soil:

η = Transmission efficiency.

Thus, a prime mover of 1.49 kW (2 hp) was required for this weeder.

Power transmission system of worm and worm gear

The following table shows the various proportions for worm and worm gear arrangement in term of the axial pitch (P_a = 6.08) in mm.

Table 1 : Proportion of worm

S.No.	Particulars
1.	Normal pressure angle
2.	Pitch circle diameter for the worms integral with the shaft
3.	Pitch circle diameter for worms bored to fit over the shaft
4.	Maximum bore of the shaft
5.	Hub diameter
6.	Depth of tooth
7.	Addendum

Table 2 : Proportions for worm gear

S.No.	Particulars	Value
1.	Normal pressure angle	14 ½^0
2.	Outside diameter	Dg + 1.0135 Pa = 71.78mm
3.	Throat diameter	Dg + 0.636 Pa = 69.49 mm
4.	Face width	2.38 Pa + 6.5 = 20.97mm
5.	Radius of face gear	0.882 Pa+14 = 19.36 mm
6.	Radius of gear rim	2.2 Pa +14 = 27.38mm

Torque transmitted by the shaft

$$T = \frac{P \text{ x } 60 \text{ x}10^3}{2 \text{ x } \pi \text{ x } N}$$

where,

P = power, kW

T = torque transmitted by the shaft, Nm

N = revolutions per minute

Considering engine speed as 6000 rpm and engine power 1.49 kW we get torque as 2.37 Nm.

Diameter of the flexible shaft

For designing the rotor shaft, the maximum tangential force which can be endured by the rotor should be considered. The maximum tangential force occurs at the minimum of blades tangential speed is calculated by the following (Bernacki *et al*., 1972)

$$K_g = \frac{C_s \text{ x } 75 \text{ x } N_c \text{ x}\eta_c \text{ x } \eta_z}{u}$$

Where,

Ks = Maximum tangential force, kg,

Cs = Reliability factor (1.5 for non-rocky soils and 2 for rocky soils),

Nc = Power of engine, hp,

η_c = Traction efficiency for the forward rotation of rotor shaft as 0.9,

η_z = Coefficient of reservation of engine power (0.7-0.8),

u = Minimum tangential speed of blades

Tangential peripheral speed, u, can be calculated using the following equation:

$$u = \frac{2 \text{ x } \pi \text{ x } N \text{ x } R}{6000}$$

where,

N = Revolution of rotor, rpm, and

R = Radius of rotor, cm

After substituting values for revolution of rotor shaft (176 rpm) and its radius as 16 cm in equation (3.14), tangential peripheral speed was obtained as 2.94 ms^{-1}.Using the tangential peripheral speed and other parameters in equation (1), the maximum tangential force was determined to be 55.10 kg.

The maximum moment on the rotor shaft (M_s) is calculated through the following:

M_s= Ks x R

With rotor shaft radius of 16 cm, moment acting on it was 881.6 kg-cm.

The yield stress of rotor made from rolled steel (AISI 302) was 520 MPa. The allowable stress on the rotor (ôall) was calculated by the following equation (Mott, 1985) :

$$\tau_{all} = \frac{0.577 \text{ x } k \text{ x } \text{x}\sigma_y}{f}$$

where,

τ_{all} = Allowable stress on rotor shaft, kg.cm^{-2},

k = Coefficient of stress concentration (0.75),

f = Coefficient of safety (1.5), and

σ_y = Yield stress, 520 MPa

By substituting above values in the following equation, rotor shaft diameter was calculated as:

$$D = \sqrt[3]{\frac{16 \times Ms}{\tau all \times \pi}}$$

D =14.3 mm

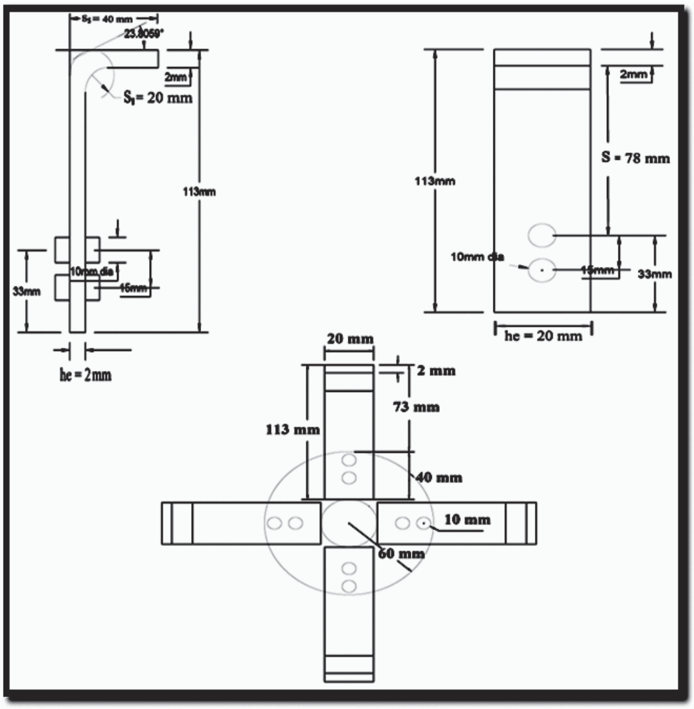

Fig. 1 : Specification of blade

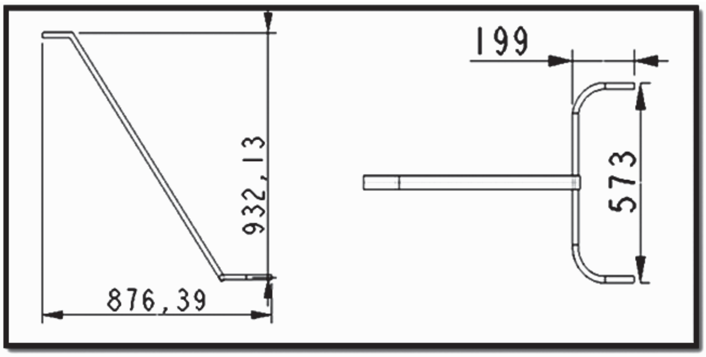

Fig. 2: Design of handle

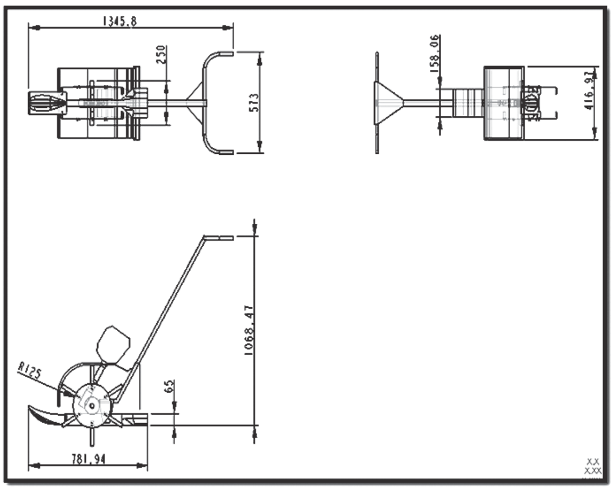

Fig.3: 2-D diagram of the developed machine

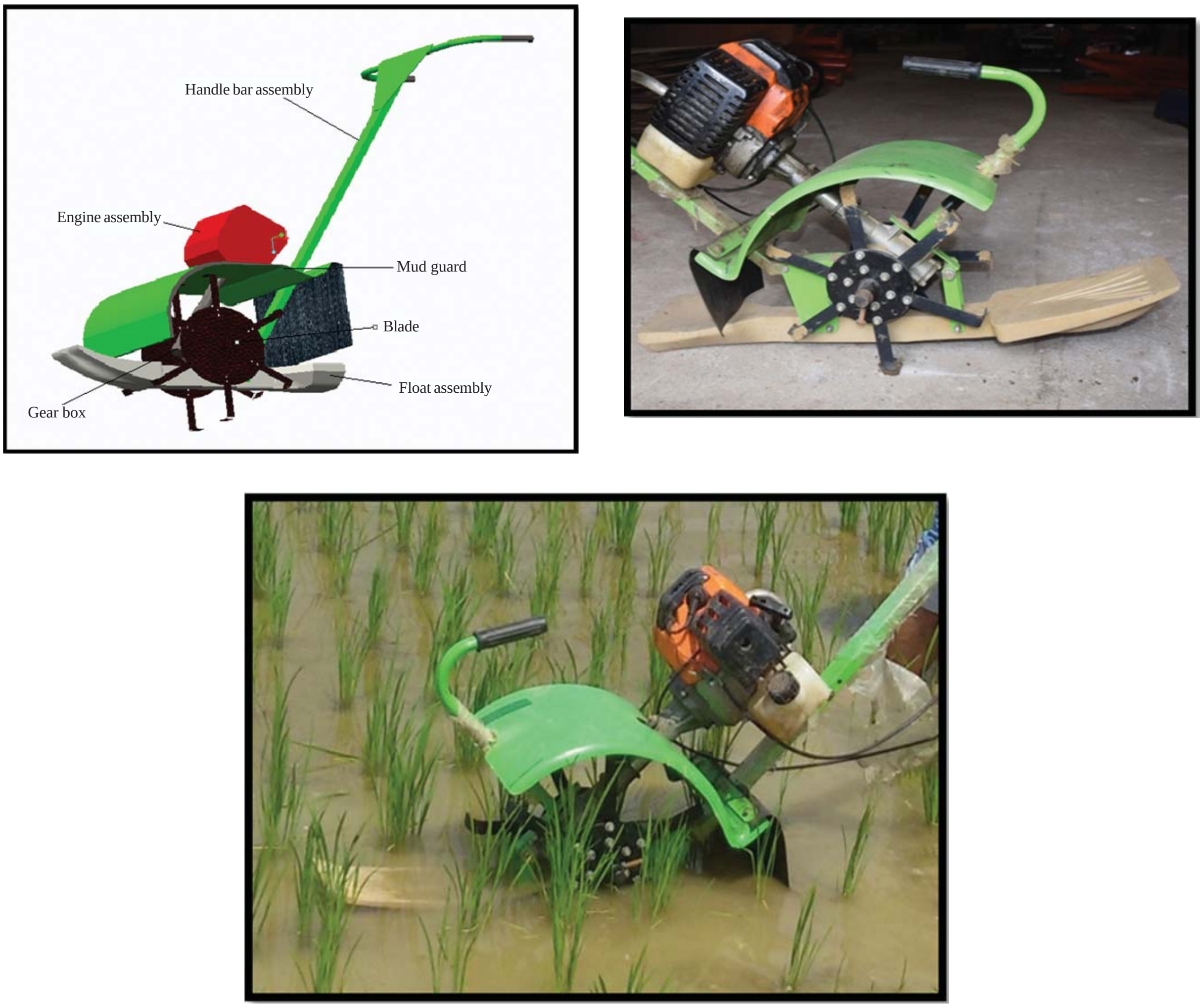

Fig.4: Isometric view of developed power weeder for rice

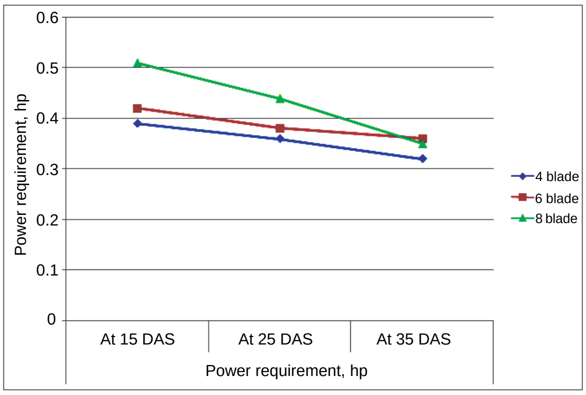

Fig. 5: Power requirement of power weeder with different blades

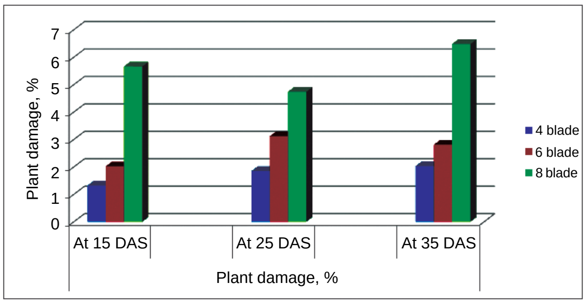

Fig.6: Plant damage per cent of power weeder with different blades

In order take into account fluctuating load during the operation, diameter of the rotor shaft was selected higher than the calculated value as 16 mm.

Design of cutting blades

Different parameters used in the study and have been in consideration to give safe strength and bending values for manufactured blades during weeding operation. The calculation and assumptions are based on standard handbook of machine design were followed (Shigley *et a*l., 2004). Assumption was made as follows; Number of blades in one working set = 4; Length of blade = 11.3 cm; Width of blade = 4 cm. To calculate the design strength of blade; revolution per minute of rotor shaft (N) = 176 r.p.m; radius of engine output rotor (R) = 16 cm.

The soil force acting on the blade (Ke) was calculated by the following equation:

$$K_e = \frac{Ks \text{ x } C_p}{i \text{ x } Z_e \text{ x } n_e}$$

Where,

K_s = Maximum tangential force, kg,

C_p = Coefficient of tangential force as 0.8,

i = Number of flanges is 2,

Z_e = Number of blades on each side of the flanges is 4 and

n_e = Number of blades which act jointly on the soil by total number of blades.

By solving eqn. 3, the soil force acting on the blade (K_e) was determined as 55.1 kg.

The dimensions of the blades are given in Fig. 1.

The values of be, he, S_s, S and S1 were equal to 0.2 cm, 2.0 cm, 4.0 cm, 8.0 cm and 1.0 cm respectively.

Considering the shape of the blades, the bending stress (ó$_{zg}$), shear stress (ô$_{skt}$), and equivalent stress (ó$_{zt}$) can be calculated by the following equations (Bernacki *et al*., 1972):

$$\sigma_{zg} = \frac{6 \text{ x } K_e \text{ x } S}{b_e \text{ x } h_e^2}$$

$$\tau_{skt} = \frac{3 \text{ x } K_e \text{ x } S_1}{\left(\frac{h_e^1}{b_e} - 0.63\right) \text{ x } b_e^3}$$

$$\sigma_{zt} = \sqrt{\sigma_{zg}^2 + 4\tau_{skt}^2}$$

Where,

σ_{zg} = bending stress, MPa,

τ_{skt} = shear stress, MPa, and

σ_{zt} = equivalent stress, MPa.

The bending stress, shear stress and equivalent stress were determined as 324.20 MPa, 216.25 MPa and 540.52 MPa, respectively.

Determining the blade width (W)

It was assumed that most of the tilled soil mass is in the first half of the blade working depth and maximum working depth should be assumed 6 cm for power weeder so that the minimum blade width (W) can be determined.

$$W = \frac{H_h}{\sin\beta}$$

and

$\beta = 90^0 + \gamma - \alpha$

Where,

H_h = half of maximum working depth, m

α = angle of blade rotation from the horizontal, degree

β = angle of inclination of the blade from horizontal, degree

γ = cutting angle, 23.8^0

Inclination angle (β) was calculated, angle α was determined as:

$$\alpha = \sin^{-1}\left(\frac{H - H_h + R}{R}\right)$$

where,

H= maximum working depth

R= radius of rotor

The cutting angle γ was determined as 23.8°. By substituting above calculated values of angles γ and α in Eq. 3.19, inclination angle β was calculated as:

$\beta = 90^0 + \gamma - \alpha = 90^0 + 23.8^0 - 54.34^0 = 59.46^0$

According to Eq. 3.18, the calculated minimum blade width W was 3.48cm.

Maximum force required to cut the soil for each blade (P);

P = pA = 6.49 kg/each blade

Where;

p = Maximum specific resistance of soil = 0.50 kg/cm^2

A = Area to be disturbed,

A= a × length of soil slice; and

a = edge length of the blade, 2.2 cm.

l = length of blade, 11.3 cm

If we have maximum four blades but only one can cut and disturb the soil, and 3 sets in the power rotor, so the maximum force required to cut the soil by the weeder.

P_{max} = 6.49 x 3 = 19.47 kg

Cutting force per unit length of blade

$$P_a = \frac{P_{max}}{1} = 1.72\ kg\,cm^{-1}$$

Taking this as beam (cantilever) with uniformly distributed load, both maximum bending load and moment of inertia can be calculates as below:

$$\text{Maximum bending load} = \frac{P_a\ x\ l^2}{2} = 109.81\ \text{kgcm}$$

$$\text{Moment of inertia (I)} = \frac{1}{12}\ x\ b_e\ x\ S_8^3 = 1.066\ \text{cm}^4$$

Where;

S_s is width of blade edge, 2 cm; and

b_e is maximum thickness of blade edge, 0.2 cm.

To check for bending ;

$$\text{Deflection for cantilever beam} = \frac{P_{max}\ x\ l^3}{3\ EI}$$

Where;

E = 2.1 × 106 kg /cm^2 for mild steel.

The value will be 4.18 x 10^{-3} . It is almost negligible and for safe design deflection should be < a/1200 (4.18 × 10^{-3} < 5 × 10^{-3}), so, it is safe.

Description of machine components

Based on design values of different components, an engine operated rice weeder was fabricated in the workshop of Faculty of Agricultural Engineering, IGKV, Raipur. The technical specifications of the engine are shown in Table 3.3.

Table 3 : Technical specifications of the machine

S.No.	Specification	Value
1	Number of cylinder	1
2	Engine maximum power at 6000 rpm	2 hp
3	Weeding width	140 mm to 250 mm
4	No. of Blades	4,6,8 as per field condition
5	Rotor speed	176 rpm
6	Weeding depth	3 - 8 cm
7	Power transmission	Light weight aluminium gear box
8	Fuel tank capacity	1.1 Lts
9	Fuel	Petrol mixed with lub.oil(1lts of petrol with 40 ml of oil)
10	Material of blade	Mild steel-L type blade
11	Overall dimension (LxWxH)	1345.8 x 573 x 1020 mm
12	Total weight	14.5 kg

Transmission

A light weight aluminium gear box connected vertical with the engine. The power from the single central vertical rotor was transmitted to the rotor by means of worm and worm gear arrangement. The rotary wheels were rotated by the power transmission system of the engine

Floating mechanism

The floating mechanism is important part of the machine, as it helps the machine to float in muddy conditions without sinking. The floats reduce the ground reaction due to buoyancy effect. In the present study adjustable float made of plastic control the depth of shearing as required in different ground conditions.

Rotary blades

In this study, three units of rotary cutting blades were used for weeding operation. Each unit consist of four “L” shaped blades connected in orthogonally opposite direction on a rotary flange which is attached to the rotatory shaft by means of sleeved hub and nut – bolt system. The rotary cutting blades were made of MS flat 25×5 mm size, length of 11.3 cm. The MS flat are bending from one end to form “L” shape to satisfy the cutting length of 4 cm and fixed to rotary flange of 120 mm diameter by using nut and bolt of dia 10 mm.

Handle

Handles are made of 20 mm MS rectangular frame of length 40 mm and width 18 mm with plastic grip fitted at the ends. The overall length of handle 1090 mm with two bends from point of attachment and have a height of 1020 mm from ground level. The length of handle cross bar is 570 mm and diameter of handle grip is 25 mm with a length of 105 mm

Mud flap

To avoid throwing of mud and stones towards operator and as a safety, a mud flap is provided covering the upper and rear side of the blades of the rotary cutting units. Upper side is made up of plastic sheet of length 490 mm and width 262 mm and the rear side is covered by rubber sheet of length 270 mm and width 190 mm.

Weeding efficiency

It is the ratio between the numbers of weeds removed by power weeder to the number of weeds present in a unit area and is expressed as a percentage. The samplings were done by quadrant method, by randomly selection of spots by a square quadrant of 1 square meter (Tajuddin, 2006).

$$\text{Weeding efficiency (\%)} = \frac{W_1 - W_2}{W_1}$$

Where,

W_1 = Number of weeds counted per unit area before weeding operation

W_2 = Number of weeds counted in same unit area after weeding operation

Field capacity

Field capacity (ha/h) was computed by recording the area weeded during each trial run in a given time interval. With the help of stopwatch, time was recorded for respective trial run along with area covered.

Plant damaged

It is the ratio of the number of plants damaged after operation in a row to the number of plants present in that row before operation. It is expressed in percentage.

$$\text{plant damage (\%)} = \left(1-\frac{q}{p}\right)\times 100$$

Where,

p = Number of plants in a 10 m row length of field before weeding.

q = Number of plants in a 10 m row length of field after weeding

Fuel consumption

The fuel tank was filled to full capacity before the testing at levelled surface. After completion of test operation, amount of fuel required to top fill again is the fuel consumption for the test duration.

RESULTS AND DISCUSSION

Operation speed

The speed of operation was found as 0.69 m/sec by using 4 blades in power weeder followed by 0.61 m/sec on using of 6 blades.

Power requirement

The power requirement at 15 DAS with 22 cm of width is maximum found in 8 blades as 0.51 hp followed by 0.42 hp in 6 blade and then 0.39 hp in 4 blades.

The testing was carried out to assess the technical and economic performance of the developed power weeder. It was tested on the basis of field capacity, field efficiency, weeding efficiency, performance index, energy consumption and cost of operation. Thus, the following conclusions could be drawn.The performance of paddy weeder was found excellently on wet condition, the working width of the developed machine should be adjustable between 140 to 250 mm, forward speed 2.48 km/h and depth of operation ranged from 3- 4.2 cm, with fuel consumption of 0.55 l/h. The effective field capacity was 0.054 ha/h. The weeding efficiency as 82.92per cent, the operating cost of the rotary paddy weeder was Rs.980/ha compared to Rs. 2300/ha for manual weeding. The saving in cost of weeding was 60 per cent and saving in time was 65per cent compared to manual weeding.

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