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Design and development of a multi-crop power weeder

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Abstract
This study attempted to investigate the possibility of mechanizing weeding operations by developing a multi-crop power weeder that can be used in crops with a row spacing wider than 30 cm at S. D. Agricultural University, Sardarkrushinagar. For different crop spacings, three blade shapes (L-shape, C-shape, and J-shape blade) were designed for weeding. RNAM test codes were used to test the developed weeder on pearl millet (*Pennisetum glaucum* L.) and castor (*Ricinus communis* L.). L, C, and J shape blades achieved weeding efficiency of 80.98, 70.77, and 77.87 percent and 86.30, 71.56, and 78.75 percent for pearl millet and castor crops, respectively. It was found that pearl millet crop was damaged by L, C, and J-shaped blades at a rate of 4.27 percent, 9.99 percent, and 8.37 percent, respectively. During weeding operations with all three blades, no plant damage was observed. Among pearl millet and castor crop, the L-shape blade recorded the highest field efficiency (81.02 and 86.30%) followed by the C-shape blade (76.66 and 77.28%) and J-shape blade (78.73 and 81.61%). The fuel consumption of the weeder ranged from 0.60 to 0.81 l/h. In pearl millet and castor crops, the cost of operation was found to be 105.2 ₹ per hour and 870 and 642 ₹ per hectare, respectively. Compared to manual weeding, the multi crop power weeder saves 83.27 and 86.09 percent in pearl millet and castor crops, respectively.

Keywords: Weeding efficiency, field efficiency, plant damage, cutting blade and cost of weeding

Introduction

Weeding is one of the most important intercultural tillage operations for controlling unwanted plants between rows. Crop yields are reduced by weed growth, which consumes more fertilizer. Weed control is a major problem for farmers. According to Rangasamy *et al.* (1993) [12], unaccompanied weeds reduce yield by 30-60 percent, depending on the crop and the location, and weeding accounts for a third of cultivation costs. In India, weeds reduced crop yield by 31.5% (22.7% during winter and 36.5% during summer and rainy seasons) (Bhan *et al.*, 1999) [1]. In order to arrest weed growth and propagation, farmers generally agree that effective weed control measures are needed. The use of chemical weed control is more prevalent than manual or mechanical methods. Due to its adverse effects on the environment, farmers are becoming more accepting of mechanical methods of weed control. In today's agricultural sector, nonchemical weed control is necessary to ensure food safety. Food safety is a key concern for consumers. They demand high-quality food products. he manufacturing of safe food is considerably aided by these methods. It might be possible to control weeds in a way that satisfies consumer and environmental expectations through the technical development of mechanisms for physical weed control.

Normally, weeding is done manually with the aid of hand tools, but at busy times, labour is scarce. Small farmers in India use bullock drowns, an implement with a poor field capacity, high maintenance costs, and low field efficiency. Therefore, farmers cannot afford it. One effective way of weed elimination is mechanical weeding. Smaller weeding tools, often referred to as portable weeders, are exclusively used to get rid of weeds in places like public parks, gardens, and agricultural areas. Weeders are becoming more commonplace, much like tractors, as labour shortages are a major worry. In promoting weeders, especially in light of the fact that most farmers have small plots of land and can hardly afford more expensive tractors. Therefore, for small farmers, the weeders become a beneficial tool for intercultural operation, particularly for crops that require close spacing, such as paddy, sugarcane, soybeans, and groundnuts. Its primary goal is to reduce workforce requirements because it is difficult to find workers in the current labour market. It also lowers labour costs and working hours associated with agriculture.

Weeds were found to be one of the main causes of low agricultural output. Unwanted plants in human-controlled spaces like farm fields, gardens, lawns, and parks are frequently referred to as "weeds."

While weed management is crucial for agriculture, it is unimportant for the management of all land and water resources. Weeds generate more losses than any other group of agricultural pests that obstruct the production of food and fibre in agriculture. As a result, they need to be under control to prevent crop output losses.

Poor weed management is one of the issues with growing crops and vegetables, and the expense of using a work force and basic tools in a commercial agricultural system is very costly. Currently, weeding in India requires a lot of labour and takes a long time when using basic equipment like a cutlass or hoe. There is no multi-crop weeder that can be used for two or more crops, so the farmers employ different weeders according to the crops they are growing. Therefore, a multi-crop power weeder that can save time and money is needed for India's commercial and intensive farming system.

Material and Methods

Design Consideration

The machine's three primary parts were divided into three groups: the power source, the power transmission system, and the soil cutting tools. This machine was primarily created for small and medium-sized farmers who have limited resources for investment and small area to work with.

Selection of engine

Selection of proper engine was very important while developing the machine. Power requirement for self-propelled weeder were computed by using formula of (Sahay, 2008) [14].

$$\text{Power(hp)} = \frac{\text{Draft(kg)} \times \text{Speed}(\text{ms}^{-1})}{75} \quad (1)$$

Soil resistance of loamy sand soil was 0.60 kgcm^{-2}

$$\text{Power} = \frac{270 \times 2.5 \times 1000}{75 \times 3600} = 2.5 \text{ hp} = 2.5 \times 2$$

$$= 5 \text{ hp(Take factor of safety 2)}$$

Hence, according to the power requirement, commercial 5 hp, (Sabaru EP 16) 2500 rpm, S.I. petrol engine was selected as the source of power.

Diameter of axle shaft

The axle is a rotating member which transmits power from one point to another point.

Assumptions:

Maximum power actually required = 5 hp rpm of the axle = 108

Maximum permissible shear stress = 600 kgcm^{-2}

$$\text{hp} = \frac{2\pi NT}{4500} \quad (2)$$

Where,
hp = Horse power
N = Revolution per minute
T = Torque in kg-cm

$$T = \frac{5 \times 4500}{2 \times 3.14 \times 108} = 3317 \text{ kg} \cdot \text{cm}$$

$$T = \frac{\pi \times F_s \times d^3}{16} \quad (3)$$

Where,
T = torque
F_s = Maximum permissible shear stress
d = Diameter of axle

$$d^3 = \frac{T \times 16}{\pi \times F_s} = 3.043 \text{ cm}$$

In view of availability and work to be performed, the diameter selected for fabrication was 3 cm.

Design of power transmission system

The engine output shaft speed was reduced by the power transmission system from 2500 rpm to 108 rpm on the cage wheel shaft. Two steps of power reduction were designed. Engine power is initially transferred by a V-belt and pulley system from the engine pulley to the intermediate shaft, and then from the intermediate shaft to the driving wheel via a chain sprocket system.

Design of belt drive

“V” type A section belt was selected on the basis of engine safety and as per requirements. Other properties of “A” type belt for Agricultural machinery (Sharma and Mukesh, 2013) [15] are as follows;
Power range: 0.70 - 3.50 KW
Top width of belt (w): 13 mm
Belt thickness (t): 8 mm
Weight: 1.06 N/m

The RPM on engine pulley was measured with the help of digital tachometer 2500 (N_1). For transmitting power from engine pulley (D_1, 5.5 cm) to intermediate shaft pulley, we take velocity ratio as 5. Diameter of driven pulley (D_2) fixed on intermediate shaft was calculated as (Sharma and Mukesh, 2013) [15]

$$VR = \frac{D_2}{D_1} \quad (4)$$

$$D_2 = D_1 \times VR = 27.5 \text{ cm}$$

Therefore, RPM on the intermediate shaft (N_2) is given by

$$N_2 = \frac{N_1}{VR} = 500 \text{ rpm} \quad (5)$$

Belt length (Engine pulley to intermediate shaft)
The length of belt from engine pulley to intermediate shaft pulley

$$L = 2c + \frac{\pi}{2}(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4c} \cong 1.1 \text{ m} \quad (6)$$

Where,
L = Length of belt, m
D_1 = Diameter of drive pulley, m
D_2 = Diameter of driven pulley, m
c = Centre to centre distance between two pulleys, cm (Taken 0.275 m)

Design of chain and sprocket system

Chain was used to give power from intermediate shaft to cage wheel shaft.

Required velocity ratio

Required RPM on the intermediate shaft = 108 rpm

$$VR = \frac{RPM_1}{RPM_2} = \frac{500}{108} = 4.6 \quad (7)$$

Chain pitch:

The standard chain pitch was considered as 12.7 mm. (Sharma and Mukesh, 2013) [15]

The intermediate shaft was fixed with sprocket of 12 teeth (T_1) which was act as derive sprocket and the number of teeth on driving sprocket was calculated by following equation.

$$T_2 = VR \times T_1 = 4.6 \times 12 = 55 \quad (8)$$

Chain length

Chain length is given by

$$L_c = m \times p \quad (9)$$

Where,

m = Number of chain link

p = Chain pitch, mm

$$m = \frac{2c}{p} + \frac{(T_1+T_2)}{2} + \frac{p(T_2-T_1)^2}{4\pi^2 c} = 91.84 \text{ mm} \quad (10)$$

Where,

m = Chain links in pitches

C = Centre to centre distance between sprockets mm, (taken 360 mm)

T_1 = Number of teeth on smaller sprocket

T_2 = Number of teeth on larger sprocket

Chain length

$$L_c = 91.84 \times 12.7 = 1166 \text{ mm}$$

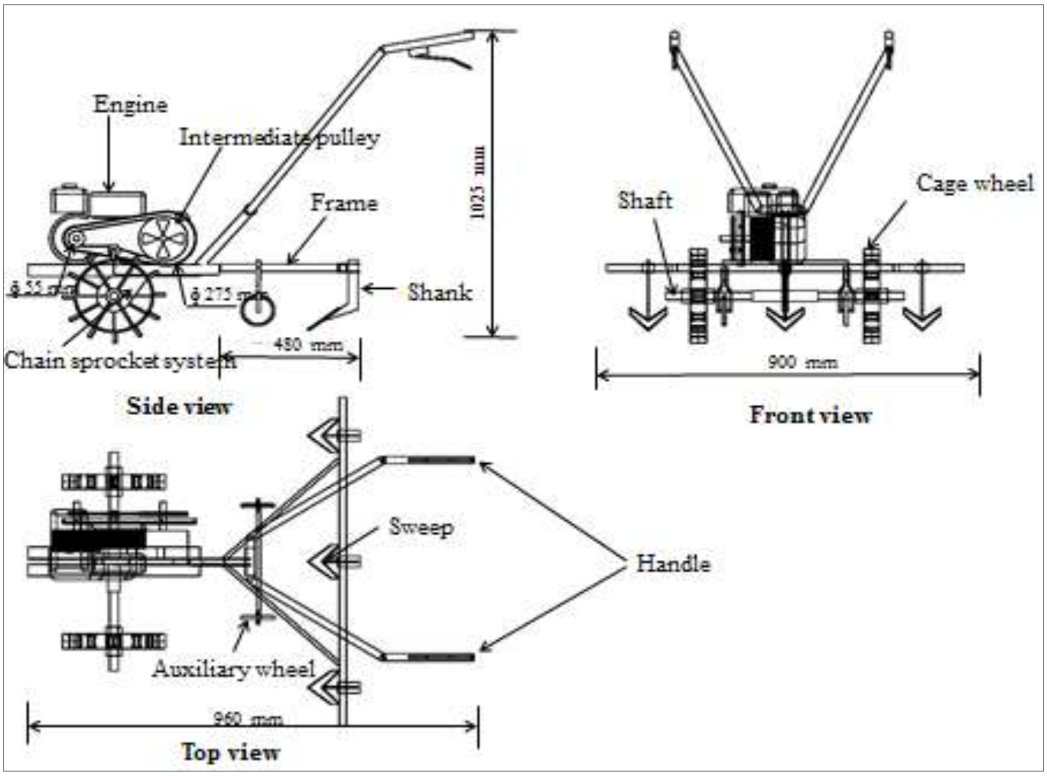


Fig 1: Line diagram of multi crop power weeder

Design of Cutting Tools

Any weeding machine's effectiveness is influenced by the cutting element's (blade shape) design. To fix on the frame of the self-propelled weeder, a sweep type blade was used. According to Biswas and Yadav (2004) [3], sweep blades performed better than straight and curved blades with the lowest draught force per unit operating width and the highest performance index. The multi crop weeder had three (L-shaped, J-shaped, and C-shaped) blades attached.

Design of sweep blade for pearl millet

While designing the sweep blade, following assumptions were taken in to consideration. Depth of the cut (d) = 5 cm (Tajuddin *et al.*, 1991) [21] and Angle of internal friction, ϕ_s =20 degree (Sharma and Mukesh, 2013) [15].

The cutting width of the sweep type tyne can be found by using formula (Sharma and Mukesh 2013) [15].

$$S_c = Z_f + Z_n \quad (11)$$

Where,

S_c = Crop spacing, cm

Z_f = Effective soil failure zone, cm

Z_p = Protection zone, cm

Effective soil failure zone (Z_f) was calculated by equation 11.

Let the crop protection zone (Z_p) be 9 cm.

$$Z_f = S_c - Z_p = 60 - (9\times2) = 42 \text{ cm}$$

Protection zone is multiplied by 2 since protection zone has to be provided on both side of crop.
Width of blade was calculated by following equation.

$$Z_f = W + 2d \tan\phi_s \quad (12)$$

Where,
Z_f= effective soil failure zone, cm
W = cutting width of sweep, cm
d = depth of weeding, cm
ϕ_s= angle of internal friction which ranges between 10^0 to 30^0 depending upon type of soil.
Let $\phi_s = 20^0$
Let d (depth of weeding) be 5 cm

$$42 = W + 2 \times 5 \times \tan 20^{\circ}$$
$$W = 42 - 10 \tan 20^0 = 38.36 \text{ cm}$$

The total calculated width was found 38.36 cm for pearl millet. The spacing between two blades was kept 10 cm for proper working of weeder.
Thus, the cutting width of one sweep (W) = 16 cm
The total working width of implement is 60 cm which included two blades of 16 cm size. The crop protection zone was kept 9 cm with each blade.

Design of sweep blade for castor
Effective soil failure zone (Z_f) was calculated by equation 11.

Let the crop protection zone (Z_p) be 9 cm.

$$Z_f = S_c - Z_p = 90 - (9\times2) = 72 \text{ cm}$$

Protection zone is multiplied by 2 since protection zone has to be provided on both side of crop.
Width of blade was calculated by equation 12.
Let d (depth of weeding) be 5 cm

$$72 = W + 2 \times 5 \times \tan 20^0$$

$$W = 72 - 10 \tan 20^0 = 68.36 \text{ cm}$$

The total calculated width was found 68.36 cm for castor. The spacing between two blades was kept 12 cm for proper working of weeder.

Thus, cutting width of one sweep (W) = 16 cm

The total working width of implement is 90 cm which included three blades of 16 cm size. The crop protection zone was kept 9 cm with each blade.

Design of Wheel
So that the space between wheels can be altered to meet requirements, the wheel arrangement should be as such. In place of pneumatic wheels, cage wheels were used because they offer more stability in sloppy soil and lessen slipping.

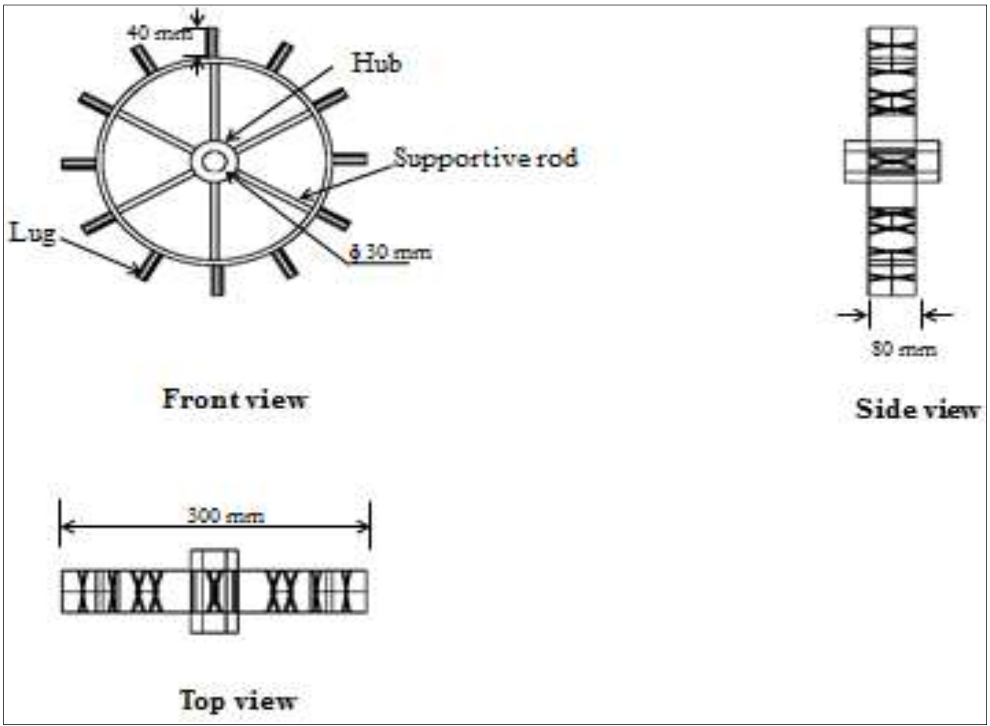


Fig 2: Line diagram of cage wheel

Table 1: Specification of handle

Sr. No.	Parameter	Dimension (mm)
1	Height of handle	1025
2	Length of handle	650
3	Diameter of handle	25
4	Diameter of handle grip	35
5	Shape of handle	Cylindrical
6	Material	MS pipe

Table 2: General specification of multi crop power weeder

S. No.	Particulars		Specification
1.	Type		: Multi crop power weeder
2.	Over all dimensions.		
	A.	Length (mm)	: 1300
	B.	Width (mm)	: 900
	C.	Height (mm)	: 1040
	D.	Weight (kg)	: 70
3.	Dimensions of frame section		: Made of MS angle 40 × 40 × 3 mm GI flat 40 × 5 mm
4.	Engine		: 5 hp petrol engine Subaru EP 16
5.	Fuel tank capacity		: 3.6 liter
6.	Axle		: Made of MS shaft dia. 30 mm
7.	Traction wheel		: 300 mm dia. cage wheel adjustable
8.	Auxiliary wheel		: Made of rubber coated iron 200 mm dia.
9.	Working width (mm)		: 900
10.	Depth of tillage (mm)		: 5 to 8 cm
11.	Number of blades		: 3 sweep of 240 and 160 mm width each

Performance Evaluation
The performance of a multi-crop power weeder prototype was assessed in the field using various combinations of soil-machine parameters in sandy loam soil. According to the randomised complete block design, a field was divided into three equal-sized blocks. Using the field data, the following performance metrics were calculated:

Weeding efficiency
Weeding efficiency, which is represented as a percentage, is the ratio of the weight of weeds eliminated by a power weeder to the weight of weeds remaining after the weeding operation in a unit area. According to Tajuddin (2006) [20], the samples were gathered using the quadrant method by randomly choosing sites inside a square quadrant with a 1-square-meter area.

$$\text{Weeding efficiency}(\%) = \frac{W_1 - W_2}{W_1} \times 100 \qquad (13)$$

Where,
W_1 = Number of weeds before weeding
W_2 = Number of weeds after weeding.

Plant damage
It is the ratio of the number of plants damaged after operation in a unit area to the number of plants present before operation in the same unit area. It is expressed in percentage.

$$PD = \frac{q}{p} \times 100 \qquad (14$$

Where,
PD = Plant damage (%)
p = Total number of plants per unit area before the weeding operation
q = Total number of plants damaged in the same unit area after the weeding operation

Field capacity
According to the overall field time, field capacity is the machine's actual average rate of coverage. It depends on the machine's rated width, the proportion of that width that is actually used, the travel speed, and the amount of field time wasted during the operation. According to Kepner *et al*. (1978) [8], field capacity is often given in hectares per hour.

$$EFC = \frac{A}{T_p + T_i} \qquad (15)$$

Where,
EFC = Effective field capacity (hah^{-1})
A = Actual area covered (ha)
T_p = Productive time (h)
T_i = Non-productive time (h)

Field efficiency
Field efficiency is the ratio of effective field capacity to the theoretical field capacity, expressed as percentage. It includes the effect of time lost in the field and of failure to utilize the full width of the machine.

$$\eta_e = \frac{EFC}{TFC} \times 100 \qquad (16)$$

Where,
η_e = Field efficiency (%)
EFC = Effective field capacity (hah^{-1})
TFC = Theoretical field capacity (hah^{-1})

Draft measurement
The S-type load cell was used to measure the draft. Which could measure the draft up to the range of 1000 kg and least count of load cell was 0.01 kg. As the load cell was fitted horizontally in the line of pull, therefore, it gave the value of draft directly in kgf. Load cell was placed between tractor and power unit and tractor pulled the power unit at a speed of 2.5 kmh^{-1}.

Performance index
Performance of the weeder is assessed through performance index (PI) by using the following relation as suggested by (Srinivas *et al*., 2010) [19].

$$PI = \frac{FC \times (100 - \text{plant damage}) \times WE}{P} \qquad (17)$$

Where,
FC = Field capacity (hah^{-1})
PD = Plant damage (%)
WE = Weeding efficiency (%)
P = Power (HP)

Fig 3: Developed multi crop power weeder

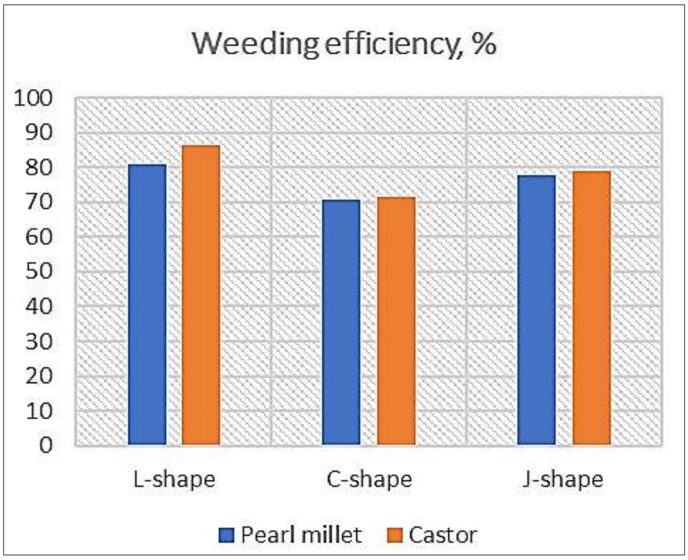
Fig 4: Developed weeder in working condition

Results and Discussion

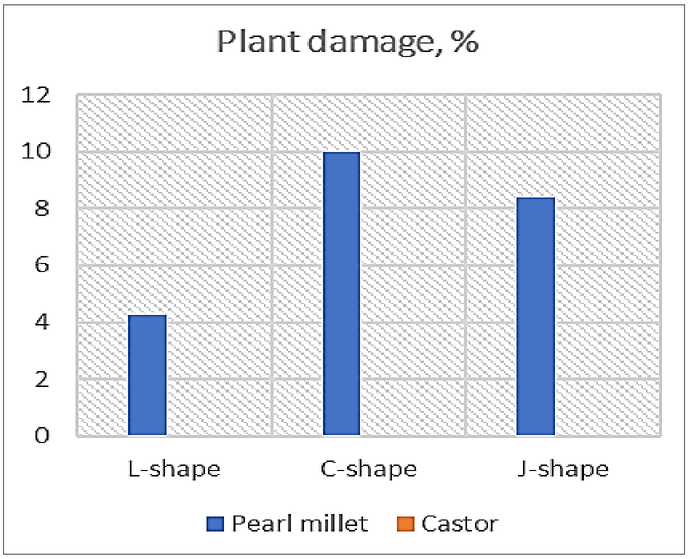
The developed multi-crop power weeder testing was finished in *Kharif* 2018 at the Sardarkrushinagar Dantiwada Agricultural University's Centre for Natural Resource Management. Three different types of blades—L, C, and J shapes—were used to test the weeder. On the basis of weeding effectiveness, plant damage, field capacity, field effectiveness, draught, fuel consumption, and performance index, comparable performance has been evaluated.

Performance of different types of blade in pearl millet

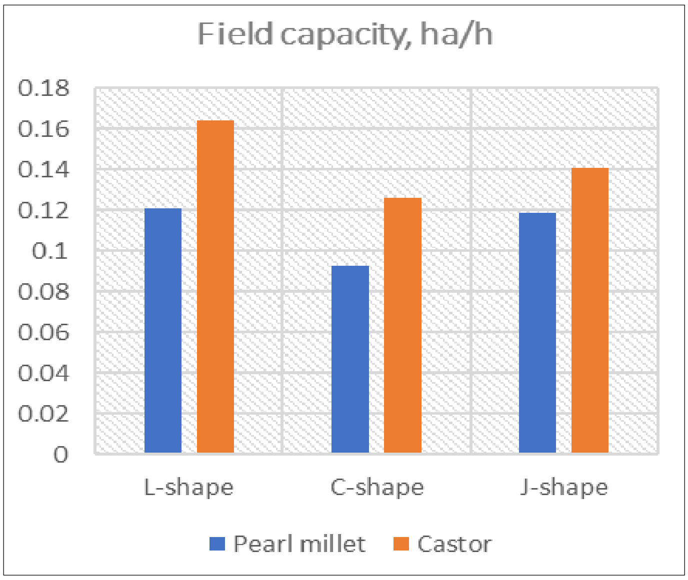
Performance of the weeder with different shape of blade is shown in Fig. 4. Highest weeding efficiency was recorded for L-shape blade (80.98%), and lowest for C-shape blade (70.77%). The highest weeding efficiency of L-shape blade may be due to the higher soil mass handling as well as cutting and burying of weeds in soil. Plant damage was 4.27%, 9.99% and 8.37% for L-shape, C-shape and J-shape weeder, respectively. The minimum plant damage of L-shape blade may be due to stable operation of the weeder because of its higher depth of cut and handling of more soil mass while the maximum plant damage in case of C-shape blade may be due to its lower depth of cut resulting higher blade angle and unstable movement randomly in rows. The highest field capacity of 0.121 hah^{-1} was recorded with L-shape blade which was found at par with filed capacity of J-shaped (0.119 hah^{-1}) as compared to C-shaped (0.093 hah^{-1}) blade. The maximum field efficiency was recorded with the L-shape (81.02%) blade and the lowest field efficiency was observed in C-shape (73.66%) blade. The actual draft required for weeder attachment *i.e.* L, C and J shape blades was 79.21 kgf, 86.88 kgf and 81.17 kgf, respectively. The performance index for developed multi crop power weeder was found to be 187.61, 118.48 and 169.83 for L-shape, C-shape and J-shape blades, respectively.



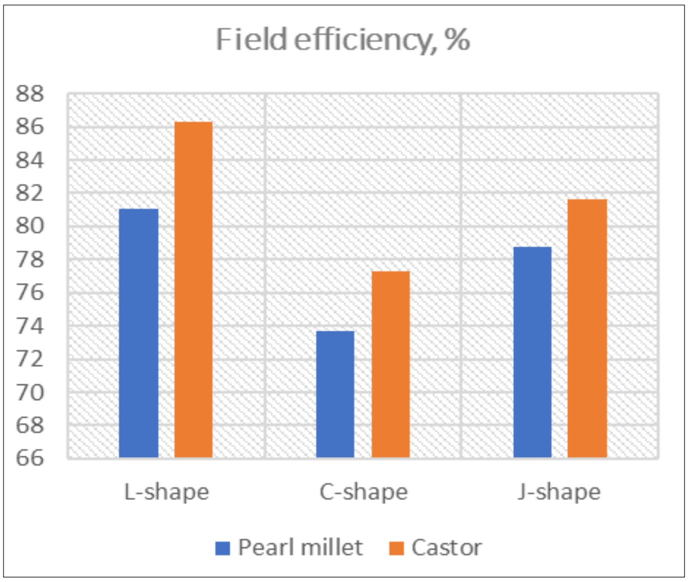
(A) Weeding efficiency, %



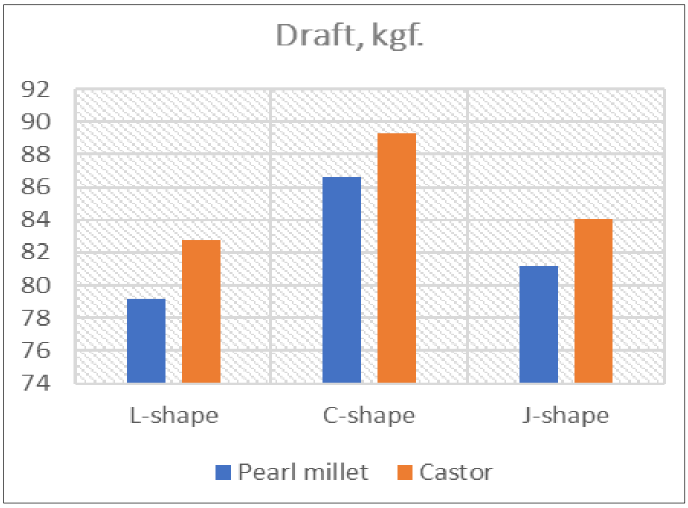
(B) Plant damage, %



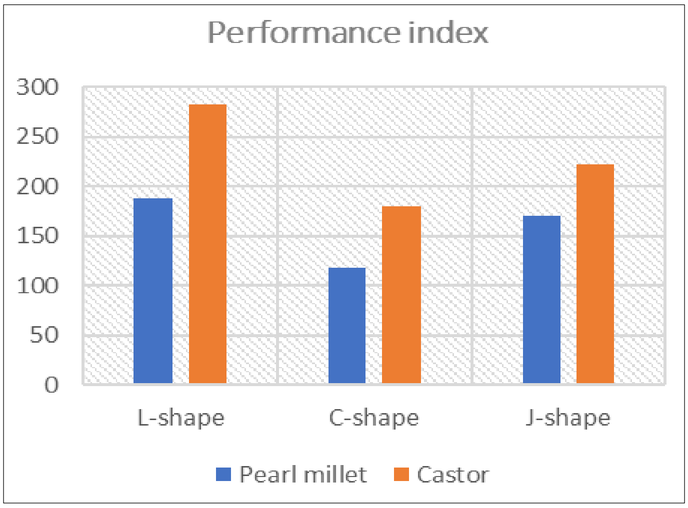
(C) Field capacity, hah^{-1}



(D) Field efficiency, %



(E) Draft, kgf



(F) Performance index

Fig 5 (A to F): Performance of the weeder with different shape of blade

Performance of different types of blades in castor

The maximum weeding efficiency was observed in case of L-shape blade (86.30%) followed by J-shape (78.75%) and the lowest with the C-shape blade (71.56%). No plant damage was observed during weeding operation with all three blades. The maximum field capacity was found to be 0.16 hah^{-1}, 0.12 hah^{-1} and 0.014 hah^{-1} for L-shape, C-shape and J-shape blades, respectively. The field efficiency was obtained maximum in L-shape blade (86.30%) and minimum in C-shape blade (77.28%). The highest performance index (283.07) was achieved in L-shape blade whereas lowest performance index (180.33) was achieved in C-shape blade.

Conclusions

A multi-crop power weeder with a 5 hp engine and a 70 kg weight was created to have the least amount of plant damage while yet having the necessary power for sandy loam soil. The weeder's fuel usage ranged from 0.58 to 0.81 lh-1, which was pretty reasonable. Operating costs for a multi-crop power weeder for pearl millet and castor crop were 105.2 ₹ per hour and 870 and 642 ₹ per hectare, respectively. In comparison to manual weeding, the multi crop power weeder reduces weeding time in castor and pearl millet crops by 94.83 and 95.71 %, respectively. In comparison to hand weeding, the multi crop power weeder reduces costs in the castor and pearl millet crops by 83.27 and 86.09 %, respectively. as compared to manual weeding. The power weeder's overall performance was deemed to be satisfactory, trouble-free, and smooth. Throughout operation, no breakdowns or unintentional incidents were noticed.

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