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Design and Development of Rotary Weeder cum Fertilizer Drill

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ABSTRACT

To increase the energy use efficiency and reduce production cost in small landholding agriculture, it is quite necessary to have suitable combination implements which farmers can use and also allow them to use for custom hiring. Intercultivation and fertilizer application are two important operations involved in crop production. Rotary weeder cum fertilizer drill was designed with an objective of timely weeding and effective fertilizer application by considering soil and crop parameters. It performs both weeding and fertilizer application at a time in a single operation. It was fabricated for wider spaced crops like cotton, pigeon pea and castor. After the completion of fabrication, the machine was thoroughly evaluated and calibrated under laboratory conditions. The machine was evaluated in caster crop at different weeding stages to estimate the performance of the machine. From the field tests field capacity, field efficiency, fuel consumption and weeding efficiency obtained were 0.196 ha/h, 86% and 1.35 l h^{-1} 91.23% respectively. It was found that the developed machine requires a very less amount of manual energy on comparing with existing mechanical weeding and manual fertilizer application combinations.

Key words : *Rotary weeder, Fertilizer drill, Calibration, Plant damage, Weeding efficiency*

Introduction

In Indian agriculture, there are many constraints like climate change, insects, weeds, pests, diseases, droughts and market fluctuations which affect both productivity and profitability of farmers. Among them, weeds are the major reason for decrease in yield per unit area, deterioration in quality and declined market price of the produce. Hence weeding is one of the most important operations in Agriculture which affects both productivity and profitability of many crops, if not controlled properly. In addition to it, site-specific application of fertilizers is the need of the hour which helps to reduce nutrient loss, fertilizer rates and weed intensity. Timely fertilizer application and weeding help in proper vegetative crop development.

Weeding and fertilizer application are major labor-dependent operations in crop production. Weeding accounts for 25 % of total labor require-

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ment (900–1200man h ha^{-1}) during a crop cycle (Yadav and Pund, 2007) but there is a continuous shifting of rural workforce towards industrial fields due to better economic opportunities and also use of draught animals power in agriculture has been decreasing continuously. As a result, the wages of Agricultural labor and draught animal are increasing rapidly. These trends emphasize adopting more mechanization and automation in different areas of agriculture.

Existing methods of weeding are manual weeding and mechanical weeding. Similarly, existing methods of fertilizer application are manual broadcasting and top dressing. In broadcasting and top-dressing operations, farmer applies fertilizer on surface of the soil and in non-plant areas also, which is leading to cause a huge weed density in the crop field. Combining the existed mechanical weeders or new weeding designs with the fertilizer application systems or fertilizer drills helps in the reduction of the machine's production cost. The combination of two operations will also help in the reduction of manual and fuel energies. Weeding and fertilizer application are done 2 to 3 times in crop production depending on the type of crop, growth of crop and weed intensity.

The combined operation of weeding and fertilizer application saves many inputs like fuel energy, human energy in crop production. With the same amount of energy, one can complete weeding and fertilizer application operations without compromising work efficiency. It also helps in timely weeding and efficient fertilizer application. Considering all these factors in view, a mini tractor-operated rotary weeder cum fertilizer drill has been developed at Junagadh Agricultural University. The main objective of this paper was to explain how a rotary weeder cum fertilizer drill was designed, developed and optimized.

Materials and Methods

Rotary weeder cum fertilizer drill was designed and developed to perform simultaneous intercultivation and drilling of fertilizer near the root zone. It is suitable for wide-spaced crops like castor, cotton and pigeon pea. It was designed to match the power of mini tractors ranging from 15 to 20 hp, as they are less in weight when compared to 30 to 50 hp tractors, creates less soil compaction in field and avoids heavy traffic on the soil.

'Rotary weeder cum fertilizer drill' was designed and developed at Department of Farm Machinery and Power Engineering, Junagadh Agricultural University. Frame unit, weeding system, and fertilizer application system are three main components of the machine. It is operated by the Power Take-Off (P.T.O) using three-point linkage.

Power requirement of prime mower

Soil resistance, width and operational speed are major parameters that affect the power requirement of prime mower. For draft calculations, maximum specific soil resistance of crop site (medium black soil) was measured as 0.75 kg cm^{-2} by using cone penetrometer. Maximum speed of weeding and fertilizing operation of 3 km h^{-1} was fixed for experimental purposes. The width of the machine was considered as 1.2 m according to the crop physiologies of cotton, pigeon pea and castor. Maximum depth of weeding was considered as 6 cm. Based on above considerations; the draft of the machine is estimated as 5292 N.

Considering PTO power transmission efficiency as 80%, corresponding power required was calculated as eqn. 1. (Sahay, 2010):

Total power requirement (kW), = (Draft, N X Speed, m s^{-1}) / (Efficiency, %) **(1)**

= (5292 X 3 X 1000) / (3600 X (80/100)) = 7.14 kW

Therefore, a minitractor of 8.95 kW power rating was selected as prime mower for the machine.

Development of mounting frame and hitching system

The mainframe holds all other components of the implement. The mainframe was made of a mild steel flat having a thickness of 5 mm and a width of 55 mm. The rectangular frame is made with dimensions of 1050 × 455 mm by welding the mild steel

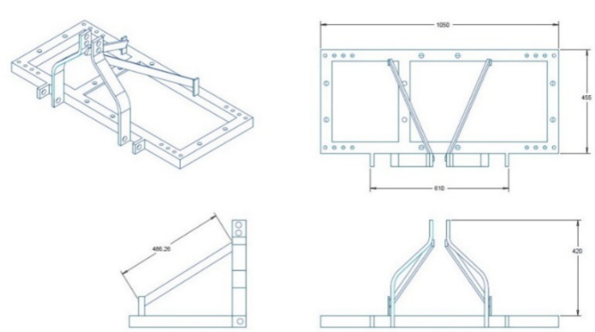

Fig. 1. Mainframe with three-point linkage (all dimensions are in mm)

flats in the shape of a square pipe of 55 × 55 mm.

A three-point hitch system was fabricated and fitted to the frame for hitching as shown in Fig. 1. The upper and lower links on the mast were made from 12 mm thickness, 48 mm width mild steel flats, bent and linked to correlate it with hitch point standards.

In this rotary weeder cum fertilizer drill, two skids were provided at the sides of the frame, on the foreside to adjust the depth of operation. By this provision, depth of operation could be adjusted from 2 to 8 cm. It was made by welding a 500 mm length M.S square bar of 20×20 mm dimension with a bent strip made of 150 mm length M.S flat of 5 mm thickness and 50 mm width.

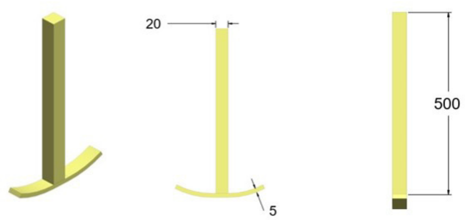

Fig. 2. Depth adjustment unit (all dimensions are in mm)

Development of weeding unit

Rotary weeder cum fertilizer drill should be designed in such a way that it performs both intercultivation and fertilizer application in a single pass without losing the efficiency of both operations. A negative draft was considered for rotary weeder because it creates forward thrust during fieldwork.

Design of Rotor shaft

Rotor shaft speed for weeding operation was selected as 130 rpm from preliminary studies conducted. For its design, maximum tangential force which can be endurewas considered. Maximum tangential force occurs on the rotor shaftwas calculated by using the following equation (Sharma and Mukesh, 2013)

$$K_s = \frac{C_p}{1} \times \frac{P_t}{1} \times \frac{\eta_t}{1} \times \frac{\eta_r}{1} \times \frac{75}{\mu} \quad .. (2)$$

Where,

K_s = Maximum tangential force, kg

P_t = Tractor power, hp

ˆ $_t$= Transmission efficiency of tractor (0.9)

ˆr = Coefficient of reservation of engine power (0.7 - 0.8)

μ = Minimum tangential speed of blades, m s^{-1}

C_p = Overload factor (2 for rocky soils and 1.5 for non-rocky soils)

Tangential peripheral speed (μ) can be calculated using the following eqn. 3.

$$\mu = \frac{2\pi NR}{60 \times 1000} \quad .. (3)$$

Where,

N = rpm of the rotor shaft, rpm

R = Radius of the rotor shaft, mm

Substituting values of rpm of rotor shaft (130) and its radius (140 mm) in eqn. (3) then tangential peripheral speed was obtained as 1.906 m/s. By putting the tangential speed value in eqn. (2) maximum tangential force acting on blades is obtained as follows. Using the tangential peripheral speed and other parameters, maximum tangential force was determined as 637.46 kg.

$$T_d = K_S \times R \quad .. (4)$$

Where,

R = Radius of rotor shaft, mm

Using the eqn. (4) the peak momentum or torque (T) on the rotor shaft was calculated as d as 892.44 kg cm.

The diameter of rotor shaft was determined by using the following equation (Khurmi and Gupta, 2011).

$$T = \left(\frac{\pi}{16}\right) \text{ x } \tau \text{ x } d^3 \quad .. (5)$$

Where,

T = Torque, N-m

τ = Torsional shear stress, N/mm^2

P = P.T.O Power, kW (8.952 kW)

d = Diameter of shaft, mm

Now putting the value of T in eqn. (5) and using = 55 MPa = 55 N/mm^2 for mild steel.

The diameter of shaft comes out as,

d^3 = = 7268.9

d = 19.7 mm

Based on the factor of safety and availability purposes a mild steel shaft of 32 mm diameter and 1060 mm length was used in the fabrication.

Design of Cutting Blades

Cutting blades are most important components of a weeder, from previous reviews concluded that L-type blades work more effectively in weeding at varied conditions. The design of blades depends upon the P.T.O power and soil type. Power coming from P.T.O is distributed between the blades. The number of flanges was calculated by the eqn. (6).

$i = b/b_i$ .. (6)

Where,

b = Working width of the rotary blade assembly (800 mm)

b_i = Distance between the two flanges on the rotor shaft (Assumed 260 mm)

Therefore, total number of flanges obtained:

i = 800 / 260 = 3.07 3

Four blades were considered on each of the flanges (Z_e= 4). Therefore, total number of the blades obtained was:

N_b = i x Ze .. (7)

N_b = 3 X 4 = 12

Blades were fitted alternatively, two on the left side and the other two on the right side of the flange for increased stability and reduced vibration purposes by using a nut and bolts shown in Fig. 3. The rotary blade unit consists of two parts, they were flange and blade as shown in Fig. 4. In the machine rotor shaft assembly, 25% of the blades were jointly acting on the soil during operation.

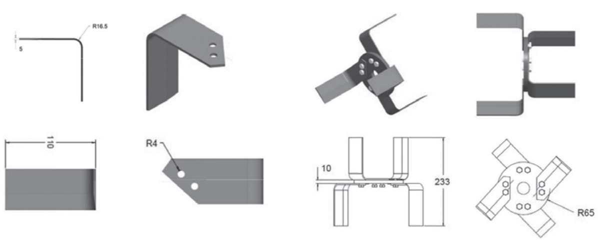

Fig. 3. Blade and flange blade assembly (all dimensions are in mm)

Table 1. Specifications of blades

Sr. No.	Particulars	Specification
1.	Shape of blade	L Shape
2.	Blade width, mm	50
3.	Overall vertical length, mm	100
4.	Overall horizontal length, mm	110
5.	Blade thickness, mm	5

Development of suitable power transmission system

It is designed with many parts which transfer rotary motion from tractor P.T.O to the rotary blade assembly. Those are the Input shaft, Bevel pinion gears, Main shaft, Bearings, Rotor shaft, Chain and sprockets.

Input shaft was fitted on the mainframe by using

Fig. 4. Developed rotor blade shaft assembly

two pedestal bearings. It takes power from tractor P.T.O through the universal shafts and further it transfers power to the bevel pinion gear set up. The diameter of the input shaft was determined by using eqn. (5).

Power coming from tractor P.T.O (Khurmi and Gupta 2005) written as ,

(8)

Where,

N = Speed of P.T.O, rev/min (540)

Putting N value in eqn. (9)

By substituting the T value in eqn. (5) the diameter of the input shaft is calculated as 24.5 mm. Based on availability and factor of safety purpose a mild steel shaft of 32 mm diameter and 450 mm length was used in the fabrication.

Primary and secondary speed reduction

Power was transmitted to the main shaft from the input shaft through a bevel gear mechanism. Bevel pinion set up used as primary speed reduction. To transmit power from the main shaft to the rotor shaft, sprockets and chains were fitted at the right end of the shafts. Chain and sprockets used as secondary speed reduction.

Bevel pinion gear set up

Bevel gears were welded on the input shaft and main shaft which were perpendicular to each other .The main shaft was fitted on the mainframe by using two pedestal bearings. It was provided for transmitting the power from bevel gear to chain and sprocket which were connected to the rotor shaft. To transmit the power from the main shaft to the rotor shaft, chains and sprockets were fitted at the right end of the shafts. Based on design calculations according to equations (5) & (9) main shaft was designed of a mild steel shaft of 32 mm diameter and 550 mm length was used in the fabrication. To provide mechanical support and free movement for input and main shafts of 32 mm diameter size four readymade pedestal block bearings of standard dimensions were used in fabrication.

Chain and sprocket

Chain and sprockets were used in transmission of rotating movement from the main shaft to the rotary blade shaft. The number of teeth on the sprocket and diameter of the sprocket were selected on basis of the rpm of the rotary blade shaft. The chain with dimensions like pitch, roller diameter and tensile strength was 19.05 mm, 12 mm, and 3190 kg respectively used in the fabrication.

The selection of teeth on sprockets and length of chain was carried out by using the standard formula (Khurmi and Gupta, 2011).

$N_1T_1 = N_2T_2$ **(9)**

Where,

N_1 = rpm of main shaft (270)

N_2 = rpm of rotor shaft (130)

T1 = No. of teeth on main shaft's sprocket (12)

T2 = No. of teeth on rotor shaft's sprocket (25)

$N_1T_1 = N_2T_2$

$270 \times 12 = 130 \times T_2$

$T_2 = 24.9$ 25

To get the required rpm of rotor shaft speed, standard sprockets of 12 and 25 teeth made of high carbon steel were used in fabrication of the machine. The available center to center distance between two sprockets was measured as 296 mm. A chain with 50 links of the pitch of 19.05 mm was used in fabrication. The total length of the chain was calculated as 952.5 mm.

Holding arms

To support the rotor shaft assembly two holding arms were fitted below the mainframe by using a nut bolt system. The holding arms are made of mild steel square pipe prepared using 50 × 50 × 5 mm M.S. Angle. The height of the holding arm was 220 mm below the frame. The lower end of the arm was welded with a bush bearing which was used to hold the rotor shaft assembly. The holding arms developed are shown in Fig. 7.

Protective covers

Rotary blade shaft assembly covered with the protective covers at the top and rear portions with a 'rectangular' shape supported sheet metal structures which were fabricated and fitted to the frame. Protecting covers helpin reducing dust concentrations in the surrounding atmosphere during operation. Protective covers fabricated from a galvanized iron sheet of 2 mm thickness. The top cover sheet consisted of 750 mm × 400 mm dimensions and the rear cover sheet consisted of 750 mm × 220 mm dimensions. Developed protective covers are shown in Fig. 7.

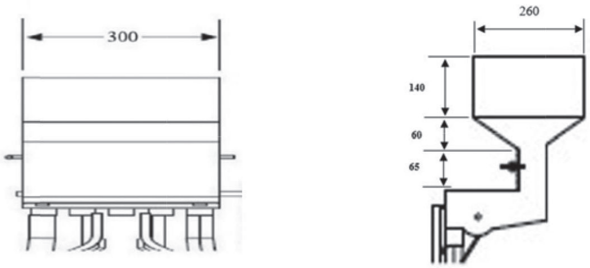

Fig. 5. Cross-sectional view of fertilizer hopper (all dimensions are in mm)

Furrow openers

Reversible shovel-type furrow openers were used in the fabrication which place the fertilizer at the desired depth. A reversible shovel made of high carbon steel with 5 mm thickness was used in fabrication. Nut bolt provisions were made to adjust the position of the tines along with the mainframe according to crop row spacing and vegetative growth. The furrow openers used in study are shown in Fig. 7.

Covering unit

A covering unit was adopted to cover the fertilizer with soil after delivery in the field. It also drags the weeds and disturbs them after their removal. It consists of two spring-loaded arms, two rigid arms and a fertilizer covering pipe of length equal to the total width of the implement. The covering unit used in study are shown in Fig. 7.

Development of fertilizer application unit

The developed hopper must be suitable for different types of fertilizers. It will be designed based on the physical properties of different fertilizers. The bulk density of different fertilizers ranging from 720 kg m^{-3} to 1100 kg m^{-3} were considered for the design of the fertilizer box. (Fulton, 2016). Hopper and metering mechanisms should be designed to deliver different rates of fertilizer during various vegetative stages of crop.

Design of Fertilizer hopper

The capacity of the hopper should be such that it does not cause high additional weight on machineand gives a minimum number of refilling per hectare area. Depending on these factors, a hopper of 12 kg capacity was designed for urea in granular form which is used in crop production. Hopper capacity was calculated based on the quantity of the material to be filled in the box at a given bulk density. Volume of the hopper is calculated as given below.

Let, V = volume of box, m^3

ñ = Bulk density of material for urea, kg/m^3 = 730 kg/m^3

Q = Hopper capacity, kg = 12 kg

Then **(10)**

= = 0.0164 m^3 = 16400000 mm^3

Selection of fertilizer metering mechanism

Metering unit was designed to convey the required quantity of fertilizer to the crop through tubes. To suit the metering unit for different fertilizer rates a vertical rotor with cells on its periphery (Edge cell rotor) was chosen from preliminary studies. Based on availability a plastic fertilizer metering rotor with 95 mm diameter, 12 mm width and with 10 grooves on its periphery was selected. This metering mechanism was fitted in a fertilizer box as shown in Fig. 6. Drive force for the mechanism was provided from the drive wheel through chain and sprocket.

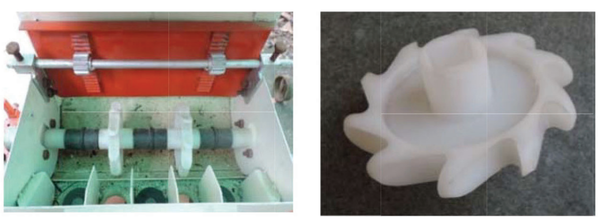

Fig. 6. Detailed view of fertilizer metering mechanism

Development of rotary weeder cum fertilizer applicator

Developed components viz., mounting frame, hitching system, power transmission system, cutting blades, reversible shovels, fertilizer hopper and drive wheel are assembled as shown in Fig. 7. The machine's overall measurements were 1050 x 1460 x 1240 mm in length, width, and height. The implement's coverage breadth was designed for 1.0 to 1.2 m row crops.

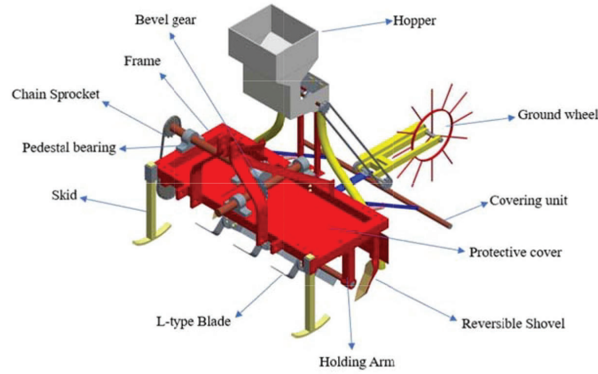

Fig. 7. Isometric view of rotary weeder cum fertilizer drill

Frame unit consists of mainframe and depth adjustment unit. The weeding system consists of a power transmission system, Holding arms, Protective covers and Furrow openers. Fertilizer application system includes fertilizer hopper, metering mechanism, fertilizer delivery tubes and furrow openers. From the design point of view the rotor shaft, cutting blades, fertilizer hopper and metering mechanism were the important components of the machine.

Calibration of machine was conductedin laboratory and field conditions to examine fertilizer delivery rates. During laboratory calibration drive wheel was jacked up, fertilizer delivery rates obtained at different hopper openings and at different speeds of drive wheel when the machine was stationary (IS: 6316, 1993). The fertilizer rates found were adjustable from 25 kg to 175 kg per hectare by varying hopper opening of the developed machine. During field conditions, fertilizer delivery pipes were removed off the boot of the furrow opener and polythene sacks were kept under them to collect the

Fig. 8 Developed rotary weeder cum fertilizer drill

fertilizer when machine was in working condition.

Field testing of the developed unit

The performance of the machine was evaluated in the castor field, at Instructional Farm, department of SWE, Junagadh Agricultural University. Three levels of forward speeds (2.0, 2.5 and 3.0 km h^{-1}) were selected as 3 different treatments in experimentation. Experiments were conducted in 460.8 m^2area by dividing it into 3 treatment plots, each treatment was replicated 6 times. Weeding efficiency, plant damage, field capacity, fuel efficiency and fuel consumption were measured as performance parameters. Cost of operation was compared for both the combinations i.e., (1) manual weeding and manual fertilizer application and (2) mechanical weeding and manual fertilizer application.

Results and Discussion

Effect of forward speed on fertilizer delivery rate

The recommended fertilizer rate for castor crop (40 kg ha^{-1}) was noticed at 40 % door opening of hopper during stationary calibration. It was observed that during field calibration required fertilizer rate (40 kg ha^{-1}) was recorded at 25 % door opening of hopper. During field calibration, more fertilizer rates were observed compared to laboratory working at the same hopper openings. Because of continuous vibrations from the rotary shaft and blade assembly, there was a more dropping of fertilizer from hopper to metering mechanism and then to crop through delivery tubes. Variation in fertilizer delivered at field condition and laboratory condition was ranged from 40.66 % to 44.51. By increasing the speed of operation from 2.0 km h^{-1} to 3.0 km h^{-1} fertilizer delivery rate decreased in both cases.

Fig. 9. Performance evaluation of rotary weeder cum fertilizer drill in castor field

Effect of forward speed on plant damage (%)

During field evaluation, the observed plant damage at 2.0 km h^{-1}, 2.5 km h^{-1} and 3.0 km h^{-1} were 4.30, 4.79 and 7.60 % respectively. Results obtained for plant damage in weeding operation were statistically highly significant because plant damage increased with an increase in forward speed from 2.0 km h^{-1} to 3.0 km h^{-1} for different experiments.

Effect of forward speed on weeding efficiency (%)

During field testing the average weeding efficiency observed at 2.0 km h^{-1}, 2.5 km h^{-1} and 3.0 km h^{-1} speeds was 91.23, 90.72 and 73.38 % respectively. (Rathod *et al.*, 2010. obtained similar results). The results obtained for weeding efficiency were statistically highly significant because weeding efficiency decreased by increasing the forward speed from 2.0 km h^{-1} to 3.0 km h^{-1} speed. The weeding efficiency obtained for the first two speeds was almost the same, but for the 3.0-3.2 km/h speed of operation it was decreased to great extent.

Effect of forward speed on field Efficiency (%)

The average field efficiency observed at 2.0 km h^{-1}, 2.5 km h^{-1} and 3.0 km h^{-1} speeds were 86, 82.79 and 81.79% respectively. Field efficiency was decreased by increasing forward speed from 2.0 km h^{-1} to 3.0 km h^{-1} speed (Rathod *et al.*, 2010. obtained the similar results).

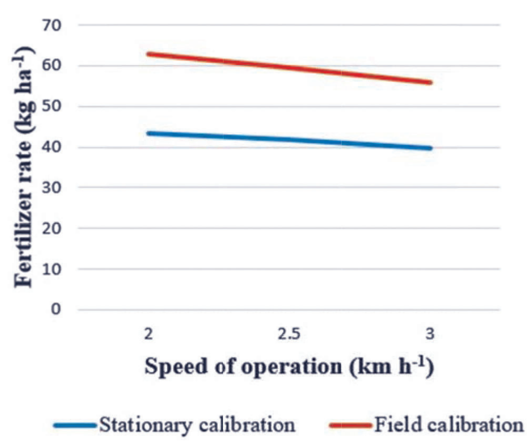

Fig. 10. Effect of forward speed on fertilizer delivery rate

Table 2. Specifications of developed rotary weeder cum fertilizer drill

S.No.	Particulars	Details
1	Tractor HP required	15-20 HP
2	Overall dimension (L×B×H), mm	1050 mm × 1460 mm × 1240 mm
3	Total weight, kg	126.5
4	Rotary weeder	
	i. Width of operation, mm	1000
	ii. Type of blade	L-Shape
	iii. Depth of cut, mm	40-60
5	Fertilizer drill	
	i. Hopper dimensions, mm	300×260×340
	ii. Metering mechanism	Edge cell rotor
	iii. Seed hopper capacity, kg	12
	iv. No. of rows	2
	v. Width of operation, mm	200
	vi. Row spacing, mm	Chain and sprocket
	vii. Type of furrow opener	Reversible shovel type

Comparison of cost of operation with developed rotary weeder cum fertilizer drill over manual practices

Cost of operation was compared for the following combinations (1) manual weeding and manual fertilizer application and (2) mechanical weeding and manual fertilizer application.

It was recorded that manual weeding operation required 80 man-hours per hectare castor field. Manual fertilizer application operation required 8 man-hours per hectare field. It was also noted that the power weeder required 10 man-hours to complete weeding in a hectare castor field. Manual weeding and manual fertilizer application operations require 88 man-hours per hectare castor field.

Mechanical weeding and manual fertilizer application requires 88 man-hours per hectare castor field. The developed machine completed weeding and fertilization by using 5.1 man-hours. The cost of operations noted for Combination-1 and Combination-2 were 4400 Rs ha^{-1}. and 2150 Rs ha^{-1} respectively. The cost of operation with the developed machine was found to be 1500 Rs ha^{-1}.

Conclusion

A mini tractor-operated rotary weeder cum fertilizer drill was designed and developed to complete intercultivation and fertilizer application in a single pass of machine for saving manual and petroleum energies. The developed machine was found to be rigid and had the flexibility to work in various soil conditions. It was suggested that going for field calibration to fix a fertilizer rate is a better option than a stationary calibration because there is a variation of 42.6 % between field and stationery calibrations. Developed machine reducing manual working time compared to manual weeding and manual fertilizer application and mechanical weeding and manual fertilizer application combinations by 94.2% and 71.66 % respectively. It reduced the cost of operations in combination-1 and combination-2 by 65.9% and 30.2% respectively.

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