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Battery assisted single wheel weeder for medicinal plants

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ABSTRACT: One of the most difficult but essential tasks in an agricultural unit operation in aromatic and medicinal crops is weed management. Delays in weed control and negligence affect the yield. In order to reduce the excessive use of weedicides, mechanical weeding is recommended instead of chemical or biological methods which keep soil surface dry and provide better aeration and moisture conservation. The modernisation of mechanical weeding has not yet been well developed in particular for small and marginal farmers. To that end, a battery-operated weeder has been developed and tested to assess its performance. The developed weeder consisted a BLDC hub motor, motor speed controller, Lithium iron phosphate battery, flat cutting blade and weed collecting tool as well as a drive wheel. The average field capacity, field efficiency and weeding efficiency of the weeder were found as 0.033 ha/h, 78.5% and 89.5% respectively. The weeder is gender friendly and therefore has scope of adoption by small and marginal hill farmers for timely weeding operations with reduced drudgery and reduced cost of operation compared to other weeding methods.

Key words: Aromatic and medicinal crops, BLDC hub motor, flat cutting blade, gender friendly, mechatronics, small farm

In field crops where row-to-row and plant-to-plant spacing is minimal, weed populations tend to be lower. However, in aromatic plants, where the spacing between rows and plants is greater, the weed population becomes denser. Weeds cause significant losses, especially during the early stages of crop growth, making early control and elimination essential. Due to the rising cost of labour, time constraints, and the tedious nature of manual weeding, this method is becoming increasingly unfavourable. Manual weeding not only demands a large number of man-hours but also involves considerable drudgery and discomfort.

Popular weed control methods include mechanical, chemical, biological, and cultural approaches (Biswas, 1984). Mechanical weeders are particularly effective, as they control weeds while also benefiting the crop by breaking the surface crust, improving soil aeration, enhancing soil microflora, retaining moisture, and facilitating rainwater infiltration. A variety of mechanical weeders are already in use in Indian agriculture, with weights typically ranging between 50-500 kg (Gavali and Kulkarni, 2014). However, for small and marginal farmers, a lightweight mechanical weeder powered by stored energy, such as a battery, offers an eco-friendly

alternative that can save human energy and reduce drudgery during weeding operations.

Given this context, the present study aims to develop an eco-friendly mechatronic weeder specifically designed for aromatic and medicinal plants. The design follows an ergo-mech (ergonomic and mechanical) approach, which is intended to increase efficiency, productivity, reliability, safety, comfort, and consumer acceptance (Bellinger, 1969). This innovative tool could appeal to farmers who are considering or already shifting their cropping patterns from conventional crops to more profitable cash crops.

MATERIALS AND METHODS

The process of developing battery assisted single-wheel weeder is described briefly under following sub-sections

Power Source and Power Requirement for the Weeder: As reported by Singh *et al.* (2019) average energy and power requirement in operation of various manual operated farm equipment varied from 50 to 70W while energy expenditure was 15–22 kJ. This clearly indicated the strain that people put on themselves when using manually operated farm

equipment. If an auxiliary power source is shared with main load, the energy consumption can be decreased. For calculating the power requirement of the weeder following considerations were taken.

1. The developed unit has to work with soil and soil resistance has a substantial consequence upon the power requisite of weeder. specific soil resistance for light and medium soil up to 150 mm depth was considered as 0.034 N/mm² (Bernacki *et al.*, 1985).
2. The depth of operation is considered in the range of 10 to 15 mm because it is well established that 15 to 20 mm is the maximum depth of emergence of weeds (Agarwal and Singh, 1968).
3. On the basis of relationship between mechanics of weeding action and soil resistance, Singh *et al.* (2016) reported that for a push pull mode of operation corresponding values of weeding width are 161 to 263 mm for a working depth of 10 to 20 mm hence the width of coverage of cutting blades is considered in the range of 200 to 300 mm.
4. The auxiliary power source should be mobile and synchronized with human power source, particularly at speed of operation, i.e. 2-2.5 km/h (0.5 to 0.7 m/s), (Singh, 2005). Hence the speed of operation of the weeder is considered as 0.5 m/s to 1.0 m/s.

The power requirement of the weeder was calculated using equation.

$$P = \frac{SR \times d \times w \times v}{75} \quad \dots(1)$$

Where,

P = Power required, hp; SR = Soil resistance, N.mm⁻²; d = Depth of cut, mm

w = Effective width of cut, mm; v = Speed of operation, ms⁻¹

Hence, Power requirement is estimated as 0.45 hp (~300 W). The weight of the weeder should be about 30% of worker's body weight (Grandjean, 1988). A 30% of 5th percentile body weight of Indian farm

women is 33.5 kg (Gite *et al.*, 2009). Thus, the equipment should be light weight, mobile and synchronized with a human power source, specifically at a speed range of 2-2.5 km/h (Singh *et al.*, 2005). Further, commercially accessible components should be considered for developing the machine so that components can be easily repaired, keeping this in view a BLDC motor was considered as an auxiliary power source. The advantages of the BLDC motor, are its availability in the power range of 100 to 500W with a gear reduction unit as well as a speed control mechanism through a microcontroller (Singh *et al.*, 2021). The second big advantage is that BLDC motors can be controlled, using feedback mechanisms to deliver precisely the desired torque and rotation speed (Kim, 2017). One kind of BLDC motor is a gearless wheel hub motor which incorporates BLDC motor into the hub of a wheel and drives the wheel directly. Hub motors have their greatest torque as the rotor first begins to turn so, we do not require a transmission system. Eliminating mechanical transmission, including chain and sprocket, gears, driveshaft and axle provides a significant reduction in weight and manufacturing cost saving in the development of the machine. Therefore, a BLDC hub motor of 250W was selected for the unit to be developed. It gives peak power up to 500 W at continuous current 7.3 A and load current 15.7A. The maximum torque developed by the motor was 60 N-m torque at rpm of 404. The speed of the motor is controlled by the Throttle Position Sensor (TPS) unit which supplies corresponding throttle position voltage to DC motor speed controller unit operating at 350W output power, 36 V, 23 A. The DC supply through battery was opted due to its mobile use. One 12V, 14Ah lithium-ion battery was used to get required output voltage. Lithium iron phosphate batteries have 2000 times the theoretical service life that of charging and discharging. After 3900 cycles of use, the battery capacity of lead acid may be reduced to 66% while Lithium iron phosphate batteries can still have 84% battery capacity after 5000 cycles of use (Su, 2021). Therefore, the lithium iron phosphate battery has longer cycle life in contrast. There is no hazardous or noxious substance inside the battery and it is environmental friendly. The specific volume of a

LiFePO₄ battery is 65% of lead-acid batteries and the weight is 1/3 of that of a lead-acid battery, which also makes the battery more portable.

Machine development: The components of weeder was developed keeping the fact into consideration that it should be easy in handling during weeding operation as well as light in weight, hence the single wheel concept was used and size of frame was kept in such a way that it occupies all the mechatronic system including power wheel, battery and weeding tool.

Weeding tool: The interaction between soil and machines takes place at the blades and thus to reduce power requirement and improve life of the machine it is important to have proper geometry of the blade. A blade designed to cut the weeds easily when they are in the early stages of growth. Also, not only cutting the weeds but uprooting them and collecting them simultaneously were also considered. The width of the cutting blade was calculated based on the following formula (Yadav and Pund, 2007).

$$\text{Push/pull force (kgf) developed by motor} = \frac{\text{HP} \times 75}{\text{speed (m/s)}} \dots (2)$$

Size of cutting blade can be calculated as suggested by Sharma and Mukesh (2008).

$$W \times D \times U = F \dots (3)$$

Where, W = width of cut (mm); D = depth of operation (mm); U= unit draft (N/mm²); F= push/pull force (N)

The width of weeding tool should be 50 mm less than the track width of machine to avoid any damage to the standing rows of plants while operation. So, a weeding blade of 250 mm was fabricated. In order to have easy penetration and minimum tillage of soil, the blade was inclined with the angle of attack (ϕ) of approximately 15° as it is ideal to lift and separate the weeds from the soil as per Yadav and Pund (2007). For this a blade headpiece connecting rod of 250mm length was fabricated. Punia (2015) mentioned that for a given cross-section, section

modulus of a circular rod is almost equal to the rectangular flat it means that bending stress will be also being almost equal for the rod and rectangular flat. Studies on the strength of material tell that a hollow section imparts more strength in comparison with a solid section so it will be beneficial to choose a hollow rod or hollow rectangular bar. A rod of 30 mm diameter has been used for blade headpiece connecting rod.

Handle rod: Length of handle rod was calculated based on average standing elbow height of female operator's because normally weeding is done by female farm workers. It has been suggested that the average standing elbow height of women workers is 1000 mm. (Gite and Yadav, 1989).

Distance of wheel centre from operators standing elbow height (900 to 1050 mm) in operating condition = 1150 mm

Therefore, angle of inclination (θ_h) with horizontal,

$$\begin{aligned} \tan(\theta_h) &= \frac{\text{operators standing elbow height}}{\text{distance of wheel center}} \dots (4) \\ &= \frac{80}{115} \\ &= 0.696 \\ &= 34.82 \text{ say } 35 \end{aligned}$$

$$\text{Now, } \sin(\theta_h) = \frac{\text{operators standing elbow height}}{\text{length of handle}} = \frac{80}{l_h}$$

length of handle rod (l_h) = 1394.9 mm say 1400 mm

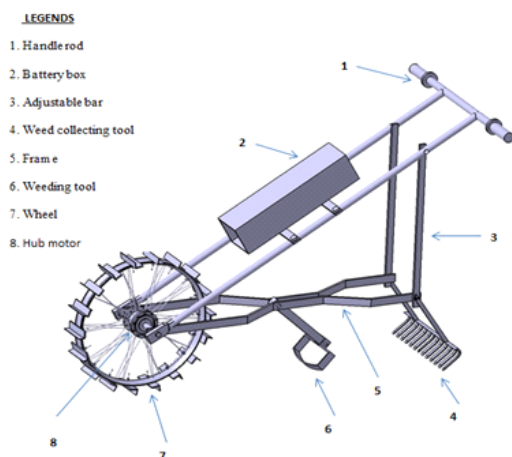
An optimum handle rod length is observed to 1400 mm for both men and women workers. A light weight hollow pipe of 27.5 mm outer diameter made of mild steel was selected for handle of weeder. Design of T-type handle was adopted as reported by Singh *et al.* (2016). The handle has a provision to adjust the height of handle to suit the operator irrespective of the operator's height. The essence of the long handle is to enable an upright posture while on weeding operation. A throttle lever is provided on right side of the handle to control the motor speed. The different component of machine is given in Table 1

Table 1: Technical specification of battery assisted single wheel weeder

| S No. | Particulars | Specification |
|-------|--|---------------------|
| 1. | Weight, kg | 25 |
| 2. | Size of wheel, mm | 419 |
| 3. | Size of frame ((l×w×t)), mm | 950×30×5 |
| 4. | Handle type and size (dia and width) | T type (25 and 550) |
| 5. | Length of handle rod, mm | 1400 |
| 6. | Handle mounting | Adjustable |
| 7. | Number of weeding blade | 1 |
| 8. | Size of weeding blade (l×w×t), mm | 400×30×2 |
| 9. | Length of sharpening edge in blade, mm | 10 |
| 10. | Mounting of weeding blade | Rear of power wheel |
| 11. | Effective cutting width, mm | 200 |
| 12. | Weeding depth, mm | 10 to 30 |
| 13. | Number of weed collector | 1 |
| 14. | Size of weed collector, mm | 350 |
| 15. | Auxiliary power source | LiFePO ₄ |
| 16. | Power transmission system | BLDC hub motor |

and Fig 1.

A field test was conducted to evaluate the performance of the developed weeder in the field of aloe Vera, mint and lemongrass crops having a row-to-row spacing of 45,40,60 cm respectively in MRDC Pantnagar. Two plots having two different weed populations i.e., high and medium weed intensity were taken. Each plot was divided into three sub sections for different implements viz., grubber weeder, wheel hand hoe and mechatronic weeder used for testing and comparison. The soil moisture

**Fig. 1: Isometric view of battery assisted single wheel weeder**

contents, bulk density, speed of operation, time of operation, weed count were measured as per standard techniques. All the data were tabulated and calculated to determine weeding efficiency, field efficiency, man-h/ha, field capacity and weeding cost per hectare by using standard formulas. Performance data are given in Table 2.

RESULTS AND DISCUSSION

The gearless wheel hub motor of 250W/36V can generate a peak power of up to 500W at continuous current and load current capacity of 7.3 and 15.7A respectively. The maximum torque developed by the motor was 60N-m at rpm of 404 at no load. The controller has output power 350W at an operating voltage of 36/48V dual mode operating with current 23A, which provides pulses of current to the motor windings that control the speed and torque of the motor was well synchronised with the selected motor. The moisture content (dry basis) of the soil was measured at the time of the weeding operation. The samples were collected from the field at random locations. Soil moisture was observed at 10.42% to 13.69% and the average value of moisture content was found at 11.55%. The soil bulk density was measured by the core cutter method. The soil bulk density of the test field varied from 1.50 to 1.59 g/cc and the average value was found 1.541g/cc. The average weeding efficiency of grubber weeder, single wheel hand hoe with sweep blade and mechatronic weeder was found 94.43%, 91.3%, and 90.15 % respectively for aloe Vera crops 92.5%, 88.1%, 89.14 % for mint crops and 94.35%, 84.55%, 89.25% for lemongrass crop. The test results show that for the same field condition weeding efficiency varies with weed density as well as plant-to-plant spacing. Singh *et al.* (2019) reported weeding efficiency in the range of 76.22% to 95.37 % in maize, moong bean, pearl millet, pigeon pea and soybean crop with a four-wheel electric power unit having a sweep blade. Senthil Kumar *et al.* (2014) also found the weeding efficiency with manual hand hoe and power weeder (60, 45, and 30cm width) in pulse crops 82.5%, 73.45%, 64.15% and 43.13% respectively. Better weeding efficiency with a mechatronic weeder was obtained due to an

improved weeding tool. This was also attributed towards very little or negligible plant damage during the weeding operation. The average field capacity, ha/day, for the above implements was recorded as 0.018, 0.053 and 0.25 for the aloe Vera crop and 0.019, 0.052 and 0.272 for the mint crop, 0.023, 0.042 and 0.265 for lemongrass crop respectively.

Results revealed that the field capacity of a mechatronic weeder is higher than single wheel weeder and Grubber weeder. Singh *et al.* (2019) reported field capacity of four-wheel electric power units 0.33, 0.45, 0.40 and 0.42 ha/h in maize, mong bean, pearl millet and pigeon pea at speeds of 2.72, 2.8, 2.55 and 2.57 km respectively. The field efficiency was obtained as 86.62%, 85.48%, 74.95% respectively for the aloe vera crop, 85.79%, 87.47%, 81.54% for the mint crop and 82.11%, 80.9%, 79.16% for lemongrass crop. Field efficiency with a four-wheel weeder with a sweep blade was 78% to 83.26% as reported by Singh *et al.* (2019). Senthil kumar *et al.* (2014) also reported field efficiency up to 64%-71.5%. Better field efficiency with a mechatronic weeder was obtained due to better handling and control by the operator and that was due to its light weight. Earlier Kumar *et al.* (2018) reported plant damage with the power weeder 11% followed by 1.17% with star weeder and 2.2% with hand wheel hoe. Traditional grubber weeder had the highest labour requirements 420, 400, and 398 man-h/ha for aloe Vera, mint, and lemongrass crops respectively. Man^h/ha requirement

for single wheel weeder with sweep blade was 150, 145, and 218 respectively for aloe vera, menthe, and lemongrass crops. Man-h/ha requirement for mechatronic weeder was the least, 32, 29, and 30 for aloe vera, mentha, and lemongrass crops respectively. Almost 80% to 90% less labour requirement has been reported in the case of using mechatronic weeder as compared to other traditional weeders.

This means substantial savings in labour requirement per hectare of crops. Hence dependence upon an uncertain supply of labour could be minimized by the use of a developed mechatronic weeder. The cost of wedding per hectare was determined from the network rate and the corresponding wage rates/the cost of operation per h. The average wedding cost by the mechatronic weeder was the minimum, Rs. 1255.73, 1162.78, and 1190.21 per ha for aloe vera crop, mentha and lemongrass crop respectively, followed by cost of operation of single wheel weeder, which was Rs.6242.26, 6482.50, 9755.47 per ha for aloe vera crop, mentha and lemongrass crop respectively. The cost of weeding with grubber weeder was Rs. 18430.78, 17538.28, 14814.84 per ha for aloe vera crop, mentha and lemongrass crop respectively. The minimum operating cost/ha was found 1255.73 with the mechatronic weeder, which was the lowest as compared to single wheel hand hoe and grubber weeder. This indicates an economical weeding operation with a mechatronic weeder. As the developed mechatronic weeder has

Table 2: Performance data of battery assisted weeder

| Particular | Values for weeding tools | | |
|--------------------------------|--------------------------|---------|------------|
| | Aloe vera | Mint | Lemongrass |
| Location | MRDC Pantnagar | | |
| Soil type | Sandy clay loam | | |
| Average row to row spacing, cm | 45 | 40 | 60 |
| Weed intensity/ | 100-120 | 80-90 | 90-10 |
| Soil moisture content, % (d.b) | 11.49 | 10.57 | 12.48 |
| Bulk density, g/c (d.b) | 1.59 | 1.53 | 1.50 |
| Total operational time, min | 25 | 22 | 25 |
| Walking speed, km/h | 1.5 | 2.3 | 2.5 |
| Field efficiency, % | 74.95 | 81.54 | 79.16 |
| Field capacity, ha/h | 0.0315 | 0.034 | 0.0332 |
| Weeding efficiency, % | 90.15 | 89.54 | 89.25 |
| Labour requirement, man-h/ha | 32 | 29 | 30 |
| Cost of operation Rs./ha | 1255.74 | 1162.80 | 1190.21 |

provision to collect the weeds simultaneously with the weeding operation hence extra labour charge for picking the weeds between the rows of plants is not required which lowers the overall cost. Whereas other two weeding operations also include Rs.100/ labour extra for picking the weeds between rows of plants. Idle running (without load) of the developed prototype consumed about 2 to 4 A while during actual weeding operation the average current required was 6 to 8 A which means the developed prototype can be run for 60 to 90 minutes with selected 12Ah LiFeP Battery. With an extra set of batteries, the weeder can be used for day-long work.

CONCLUSION

From the study, it can be concluded that the developed mechatronic weeder could be used for weeding in aromatic and medicinal crops as well as other wide-row crops. The average field capacity with this machine is 0.033 ha/h at walking speeds of 2 to 2.5 km/h with 89.64% weeding efficiency. The labour requirement is 30.28 man-h/ha and the average cost of weeding is 1202.90rs/ha which is 80 to 90% less as compared to another traditional weeder. The machine is easy to operation for both men and women workers. Small and marginal hill farmers can adopt this weeder for the economical and timely operation of weeding in small fields.

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