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Battery assisted four-wheel weeder for reducing drudgery of farmers

MUKESH K SINGH[1], S P SINGH[2], M K SINGH[3] and UTPAL EKKA[4]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

Mechanical methods of weeding are preferred over other methods of weed control because of their added advantages of simple construction, low cost and environmental friendly. Mechatronics concept was incorporated in development of a battery-assisted four-wheel weeder for weeding operation in wide row (more than 30 cm) crops. The developed machine consisted of brushed DC motor, DMSC, battery, power transmission system, drive-wheels, front wheels, frame and swinging handle. A brushed DC motor of 250W powered by 24V-14Ah battery with sweep type weeding tool performed satisfactorily in the field for weeding operation up to 147N draft.The operators are to only guide the weeder up to 147N draft while they need to apply their muscle power beyond 147N to prevent slippage.The average field capacity with this machine was 0.0554 ha/h at walking speed of 2.52 km/h with 97.5% weeding efficiency. The machine is gender-friendly with simple in design and technology and has potential to be adopted by small and hill farmers with reduced drudgery. The concept of transforming manual operated to battery assisted weeder was found satisfactory for wide row crops.

Key words: D C motor, Drudgery reduction, Gender-friendly, Mechatronics, Small farm, Tractive force, Wide-row crops

The manually operated weeder needs use of muscle power for its push-pull operation. Based on feedback received from users of this manually operated weeder, it was noticed that today's farmers want to use such equipment which has less force requirement. Out of available sources of power for farm, Renewable Energy sources can be utilized in many ways like charging batteries to run the prime mover. Research and development on utilization of solar power is going on in solar power/assisted sprayer and evaporatively cooled vending cart (Samuel *et al.* 2016, Sinha *et al.* 2018). Variety of manually operated mechanical weeders have been developed in the country for weeding operation in 150 to 250 mm wide row crops (Gavali and Kulkarni 2014 and Singh *et al.* 2016). To overcome the limitations of manual operated weeders, engine and electrical power sources are being used for the operation to increase output. Amongst engine operated, power tiller is being used by the farmers for ploughing, transport and stationary purposes. Use of power tiller for sowing and weeding has some limitations and the limitations intend to increase drudgery to operator due to exposure to high level of vibrations that might cause dynamic disorders, damaging different parts of the body, digestion disorders and vascular diseases (Heidary *et al.* 2014). Some experiments have been done globally to use electrical power which is found an appropriate source because of nonexistence of uncomplimentary materials such sulfur, nitrogen, polycyclic aromatics and air pollution (Lee *et al.* 2004). The latest technologies are now days commercially available which can be tried in agriculture for developing such weeder that can be operated with stored energy (battery) and also serve as eco-friendly power source in field. Amongst latest technologies, mechatronics application has potential for use in weeder as smart tool. Thus, an attempt was made to utilize the electrical power through battery for developing a four-wheel weeder that will share major workload of operator for providing ease in operation.

[1]Scientist (muky12345@gmail.com), Department of FMP, CTAE, MPUAT, Udaipur; [2,3]Principal Scientist (singhsp65@gmail.com,mksinghars@gmail.com), ICAR-IARI; [4]Scientist (uekka818@gmail.com), Division of Agricultural Engineering, ICAR-IISR, Lucknow.

MATERIALS AND METHODS

Development process of battery assisted four-wheel weeder is described in following sections (At ICAR-IARI, New Delhi, 2016-17)

The step-wise development process

Process of developing manually guided battery assisted four-wheel weeder is described briefly under following four sub-sections;

Power source: Based on earlier studies, it was observed that 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 load exerted by human being while operating manual operated farm equipment. The energy expenditure can be reduced if major load is shared with auxiliary power source. Keeping this in view, following considerations were taken to design and develop this machine,

(i) The auxiliary power source should be mobile and synchronized with human power source, particularly speed of operation, i.e. 2-2.5 km/h (0.5 to 0.7 m/s), Singh *et al.* (2005).
(ii) The auxiliary power source should be of light weight, high torque and rugged in its management.
(iii) Stability of the developed unit should be trouble-free in its operation.
(iv) The developed unit should be capable to utilized for more than one farm operation and also for day-long work.
(v) The commercially available components should be considered for developing the unit so that components can easily be replaced or repaired.

Mechatronics application: Mechatronics enhances combination among mechanical and electrical system. The advantage of DC motor, now days, are its availability in power range of 100 to 500W with gear reduction unit. This provides high torque with better efficiency, less operating and maintenance cost over fossil fuels, and light in weight. Therefore, a DC motor was considered viable option for unit to be developed as per design consideration. The details of different components of unit to be developed are discussed below:

The size of DC motor was decided based on following design criteria,

(i) The commercial available wheel of size (406.4 mm diameter and 44.5 mm width) was taken for the traction wheel of unit to be developed.
(ii) The desired acceleration time was taken 2s to get operational speed of 0.5-0 m/s.
(iii) The maximum design draft force was 200 N.
(iv) Coefficient of rolling resistance was taken 0.15 (Chauhan 2015).
(v) Mechanical friction losses (Mfl) between motor and a drive wheel axle is taken to 11%, i.e.1.11.

The developed unit has to work with soil, thus determination of tractive force is necessary to know the required size of motor. Tractive force (T_f) is expressed as sum of rolling resistance (R_r), draft force (f_d) and acceleration force (f_a) as per standard formula. After determining the tractive force (228.7 N), the required drive wheel torque was calculated considering mechanical frictional losses (M_{fl}) using formula.

The required maximum drive wheel torque was calculated 51.0 N-m. This torque should be less than the maximum tractive torque (41.42 N-m) that can be transmitted through the drive wheels to avoid slippage which was calculated by following equation;

$$T_{MT} = Ww \times \mu \times r \qquad 1$$

where;Ww, weight (normal load) on drive wheels; μ = friction coefficient between the wheel and the ground (0.8), Kepner *et al.* (2005)

Based on calculation, a 24V brushed DC motor of 250W was selected which geared motor with gear reduction ratio of 9.77. The maximum torque developed by the motor was 11.5 N-m torque at rpm of 315. The DC supply through battery was opted due to its mobile use. Two 12V, 14Ah lead acid battery was connected in series to get required output voltage and run-time for day-long work in the field. A main power switch was provided in between battery and DC motor speed controller (DMSC) to completely switch off the power supply. A safety switch with key lock was also provided to ON-OFF the DMSC temporarily during field operation.

The speed of the motor is controlled by the Throttle Position Sensor (TPS) unit which supplies corresponding throttle position voltage to DMSC unit. The DMSC provides necessary biasing to the TPS and the TPS outputs voltages according to the throttle's angle. This output is fed to the DMSC which powered the motor. A digital watt meter was developed using ATmega328/P microcontroller, ACS712 hall current sensor (20A) with 100 mV/A output sensitivity and Voltage sensor (0-25 V) with resolution of 0.00489V. Further micro-controller was programmed in 'C' language to display power consumption during weeding operation and battery charging levels.

Design of power transmission system for machine was needed to get the required drive wheel torque for weeding operation. As per design calculation, the required torque was obtained by reducing the speed at drive wheel shaft. The developed transmission system has provided reduction of 5.1:1 at drive wheel shaft.

Machine development: The components of machine was developed using following design considerations;

(i) The developed machine should be stable with mechatronic system for which a four-wheel concept was used (Singh *et al.* 2016).
(ii) Machine should be ease in maneuverability during operation.
(iii) Size of frame was kept in such a way that it occupies mechatronic system.
(iv) Swinging handle was adopted for mounting the handle in machine due to its ease for the workers in its operation.
(v) Rear wheels should be larger than the front wheels for obtaining better traction.

The machine is to be operated by workers in pushing mode of operation (walk behind type). This mode will enable the workers for ease in operation and crop damage prevention during weeding operation. The frame provides support for the DC motor, batteries, transmission system, drive wheels and front wheels, weeding tools and handle frame. Two aluminum flats (each 700×50× 10mm) was used to fabricate frame for the machine. Spacer of 130mm was provided normal to the face of its width at both ends by nut and bolts. Nut and bolts arrangements were made to mount mechatronic system and handle on the frame.

Four-wheel concept was utilised for supporting frame due to stability purpose. The minimum wheel size was selected based on required ground clearance of 100mm. Size of rear wheels were kept larger than front wheel for getting more traction as well as inclined angle for ease in penetration of weeding tool. A pneumatic tyre was selected for better traction with rear wheels. Size of drive and front-wheel was 406 mm ×45 mm and 254 mm × 43 mm, respectively that provided 9.4° slope towards front wheel. The front wheels are independently mounted for ease in manoeuvrability during its operation with wheel base of 470 mm. Design of a T-type handle was adopted as reported by Singh *et al.* (2016). The mounting of handle was at 230 mm from ground which was 170 mm from rear side.

Weeding tool: Following considerations were taken to design weeding tool for continuous operation in pushing mode,

- The width of weeding tool should be 50 mm less than the track width of machine to avoid any damage to the crops while operation.
- Mounting of weeding tool should be in front side towards front wheel to meet the line of action of push force exerted by the operator and resultant of directional and lateral component of useful soil forces acting upon the tool.
- The position of weeding tool was adopted as per Singh *et al.* (2016) but mounting was made from spacer of front wheel with curved shank to get optimum angle for penetration at fixed position. Provision was made to vary the depth of cut by providing mast at center of spacer so that weeding can be done continuously.

Fig 1 Isometric view of battery-assisted four-wheel weeder.

As per design considerations, sweep and round type weeding tool of size 250 mm was fabricated. The different component of machine is given in Table 1 and Fig 1.

Solar power utilization: Solar energy can be utilized for charging the battery (electric energy storing device). Energy storage systems are technologies that convert electricity into another form of stored energy and then convert the energy back to electricity at another time. The technology is considered key to enhancing grid reliability as well as grid resiliency in the face of adverse conditions. On an average the energy required to run the developed weeder is 156W (24V and 6.5amp). Considered following points in order to choose a Solar panel or create a Solar charging system;

For 2 h continuous use of developed weeder the battery capacity requirement will be

Battery size in Ah x Battery Voltage = Power available in watt h
$= 5.5 \times 2 \times 24 = 264$ watt h

However it is never possible to take all the power from a battery as once the voltage drops below equipment's requirements it will no longer be able to power it. The selected 14AH battery of 24V will however provide run time of 75 min with lead-acid battery.

Performance of machine: The developed machine was tested in laboratory for assessing the DC motor specifications with developed energy meter. Assessment of DMSC output

Table 1 Technical specifications of battery assisted four-wheel weeder

Particular	Specification
Weight, kg	30.0
Mounting distance from drive wheel shaft, mm	265
Rated RPM at motor shaft	354
Power transmission unit	
Stage of speed reduction	Two (1st stage through chain-sprocket and 2nd through spur gear)
Speed reduction ratio from motor to drive wheel shaft	5.1
Wheel base, mm	470
Size of frame (l × w), mm	700 × 150
Handle type and size (diameter and width), mm	T (25.4 and 140)
Length of handle, mm	990
Handle mounting	Swinging
Mast height for mounting weeding tool, mm	139 with slot of 150
Shape of shank	Curved
Sweep angle, 0	60
Cutting width, mm	250
Maximum weeding depth, mm	75
Maximum and minimum turning radius, mm	950, 760

voltage characteristics corresponding to throttle position voltage was also measured using digital multi meter for determining the speed response of the controller system. Further assessment was made to know the relation between motor torque and maximum tractive torque at different coefficient of traction and draft force. A calibration table was prepared based on theoretical estimate about run-time of battery at different load (current). After laboratory testing of auxiliary power to the four-wheel weeder, the developed battery-assisted four-wheel weeder was tested for assessing sweep type and round type weeding tools.

Finally the developed prototype was tested in different fields at ICAR-IARI, New Delhi farm for cauliflower, moongbean, urd bean, maize and pigeonpea during year 2016 to 2018. Performance data are given in Table 2. The machine was also tested in open grassy field at IARI farm and in orchards at farmers' field as interculture operation. Performance data are given in Table 3. The soil moisture contents, bulk density, speed of operation, power consumption, time of operation, weed count, draft force, etc. were measured as per standard techniques.

RESULTS AND DISCUSSION

Torque and traction characteristics: A brushed DC motor of 250W has capability to take minimum current of 1.86A at no load, whereas the consumption of current goes up to 13.12A with efficiency of about 80% at rated load. The DMSC output voltage characteristics corresponding to throttle position voltage showed the linear characteristics with voltage from 0 to 24V - as per manufacturer's catalogue. The selected brushed DC motor has characteristics to withheld the maximum required torque, i.e. 51 N-m.

Traction force received from selected drive wheel for development of prototype was assessed based on 26 kg weight on both drive wheel, cross-section area of drive wheel (85.8 cm^2) at 0.15 kg/cm^2 soil cohesion force and 30^0 angle of internal friction. Traction force obtained from drive wheel was 261.76N which is nearly sufficient to required drive wheel torque. The relationship between draft and required drive wheel torque indicated linear trend with increase in draft. Similarly the maximum tractive torque increases with increase in coefficient of traction. As per the design considerations, the required maximum drive wheel torque was 51 N-m at 196 N draft. The available maximum tractive torque with developed prototype was found to be 41.42 N-m at 0.8 tractive coefficients. The draft force at 41.42 N-m torques was found to 147 N. This indicates need of human muscle power to avoid further slippage.

Fabrication of prototype: A prototype of four-wheel battery-assisted machine was developed for weeding operation as per design criteria. The prototype consist of drive-wheels, front wheels, frame, swinging handle, battery, brush DC motor and power transmission system. Making a versatile prototype, the mounting of weeding tool was kept at front wheel spacer. Swinging type handle was adopted due to its ergonomic advantage of fitting of handle height as per operator's need. A sweep and round type weeding tools was developed as per design. During assessment of both weeding tools, sweep type was found to have lower

Table 2 Performance data of battery-assisted four-wheel weeder in crops

Particular	Values for weeding tools				
	Cauli-flower	Urd bean	Moong bean	Maize	Pigeonpea
Soil type	Sandy loam				
Weeding width, mm	250				
Power consumption in idle condition, W	40-60				
Soil moisture content, % d.b	14.37	15.73	15.17	15.73	11.37
Bulk density, g/cc (d.b)	1.51	1.38	1.37	1.38	1.33
Total operation time, min	30	90	100	100	45
Row spacing, mm	600	600	600	600	600
Walking speed, km/h	2.2	2.4	2.5	2.5	3.0
Theoretical area covered, ha/h	0.055	0.06	0.0625	0.0625	0.075
Area covered, ha/h	0.0506	0.054	0.0562	0.0525	0.638
Field efficiency,%	92.0	90.0	89.0	84.0	0.85
Weed count/m^2	20-30	20-35	19-37	35-75	72-103
Weed height, mm	40-65	40-70	40-60	40-74	37-95
Weeding efficiency, %	98	98.5	97.7	97.0	96.3
Power consumption range, W	160-200	120-168	120-175	130-190	120-150
Draft force, N	196-245	135-189	135-189	140-205	108-135

Table 3 Performance data of battery-assisted four-wheel weeder in open field

Particular	Values for weeding tools	
	Open grassy field	Orchards
Soil type	Sandy loam	Silt-clay loam
Soil moisture content, % d.b	12.9	11.0
Bulk density, g/cc (d.b)	1.33	1.65
Total operation time, min	90	120
Speed of operation, km/h	2.98	2.88
Depth of operation, mm	40-60	40-60
Area covered, ha/h	0.0541	0.0662
Theoretical area covered, ha/h	0.075	0.072
Field efficiency,%	72.13	91.94
Weed count/m^2	150-225	35-75
Weed height, mm	40-70	50-120
Weeding efficiency, %	97.3	98.6
Power consumption range, W	100-120	144-312
Draft force, N	90.0-108.0	134-290

draft as well as power requirement in comparison to round type. The weeding efficiency was also much higher (98%) to round type. This was due to side skipping of weeds from round type weeding tool as compared to sweep type.

Performance evaluation: The developed prototype of battery-assisted four-wheel weeder was tested in wide row crops namely cauliflower, urd bean, moong bean, maize and pigeonpea at IARI field. Total operation time for these crops was 6 h (Table 2). Average walking speed in these crops was 2.2 to 3.0 km/h. The variation of walking speed was due to soil texture, field conditions and different operators. The area covered per h was 0.0506, 0.054, 0.562, 0.0525 and 0.0638 ha in cauliflower, urd bean, moong bean, maize and pigeonpea, respectively. The variations in area covered were also reflected in field efficiency (84-92%) which was due to operator, field condition and moisture content. Weeding efficiency varied from 96.3–98.5%. The variations in weeding efficiency were due to undulating surface condition only. Maximum draft force was 196-245N in cauliflower field followed by maize, urd bean, moong bean, and pigeonpea. The higher draft force in cauliflower field was due to more soil compaction (1.51 g/cc d.b). Similarly the power requirement was found higher in cauliflower followed by maize, moong bean, urd bean and pigeonpea. The trend is in agreement to earlier studies (Kepner *et al.* 2005). Based on the data, average area covered with this prototype was 0.0554 ha/h at walking speed of 2.52 km/h with 97.5% weeding efficiency. The average draft force and power requirement was 168N and 153W, respectively. The area covered with this prototype was 2.68 times more than hand operated four-wheel weeder (Singh *et al.* 2016). The main reason of higher output with this machine over manual operated was due to higher walking speed due to less workload on operator. In a study, they also found optimum speed of 1.5 km/h (0.47 m/s) for manual operated sweep type weeder (Kankal *et al.* 2014).

An experiment was also conducted in open grassy field at IARI field and at farmers' orchard (Table 3). Total operation time was 3.5h. The area covered in open grassy field was 0.0541 ha/h at walking speed of 2.98 km/h with field efficiency of 72.13% and 97.3% weeding efficiency. Low field efficiency in grassy field was only due to overlapping. The area covered in farmers' orchard was 0.0662 ha/h at walking speed of 2.88 km/h with field efficiency of 91.94% and 98.6% weeding efficiency. The degeneration of weed after weeding with this machine and traditional was at par. Average power requirement and draft force was 110W and 99N, respectively. In open grassy field, whereas corresponding values were 228W and 212N in farmers' orchard. Low draft force and power requirement in grassy field was due to less bulk density (1.33 g/cc).

Battery running time: It is observed that battery run-time decreased from 420 min to 36.18 min with increase in current requirement from 2 to 22A. At this load, the watt requirement varied from 48 to 528W. The idle running of the developed prototype consumed about 2-3A while in weeding operation the average current required was 6-7A. This will allow the developed prototype to run for 2h at stretch with 14Ah battery.

Solar charging: Considering 50% panel efficiency, a 200 watt solar panel will charge 24V 14AH (two 12V 14 AH) batteries in less than 3 h. Simultaneously, a 100w solar panel will charge the 12V battery in about 3h. Thus a separate set of battery will enable operators to work for day long work.

The battery-assisted four wheel weeder with sweep type weeding tool worked well in field for weeding operation up to 147N draft. At this draft, the operators have to guide the weeder only when they need to apply their muscle power at increasing draft to avoid further slippage. The average field capacity with this machine was 0.0554 ha/h at walking speed of 2.52 km/h with 97.5% weeding efficiency. The machine is gender-friendly with simple in design and technology and has potential to be adopted by small and hill farmers with reduced drudgery. The concept of transforming manual operated to battery assisted weeder was found satisfactory for wide row crops.The developed machine is eco-friendly as battery can be charged with solar panel.

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