



## Design and development of four wheel weeder for wide-row crops

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### ABSTRACT

Single/twin wheel weeders have been developed for manual weeding in about 20 cm row spaced crops. These weeders are unable to provide uniform depth of cut and lateral stability. Presently marginal and small farmers in the country are inclined to grow cash crops. Manual weeders are not available for vegetables planted at row spacing of 30 to 50 cm. Keeping these facts in view, a weeder, employing two innovative techniques such as application of 'Four-wheels' and 'Swinging handle' was developed for wide row spaced crops. The slicing/cutting the weeds with best possible depth control were the main considerations for its design. Anthropometric data of men and women workers were taken into considerations for design of components of the weeder. Weight of equipment was kept below 10 kg as per the ergonomic requirement by adopting alternate fabrication material. Soil bin study on push force revealed the significant effect of compaction levels and handle angles on the performance of operator in terms of high force. The minimum field capacity of the weeder was 0.0206 ha/h with more than 95% weeding efficiency. The push force requirement per cm cutting width was lowest (6.34N) as compared to other mechanical weeders. The ergo-mech approach of design enabled operators to complete the weeding work timely with reduced drudgery and increased productivity as compared to conventional practice.

**Key words:** Gender-friendly equipment, Manual-operated, Push-pull, Swinging handle, Vegetable crops, Weeder

Weed control is one of the most important aspects in the present agriculture. The control methods for weeds are mechanical, chemical, biological and cultural (Biswas 1984). Mechanical weeding is preferred as compared to chemical weeding because weedicides are generally expensive, hazardous and selective. Moreover, mechanical weeding keeps the soil surface loose which results in better aeration and moisture conservation. Combating one of the major problems (weed control) in crop production, different types of weeder have been developed for weeding in wet and dry upland flat beds (Pandey *et al.* 1997). The tools fitted in these weeders are either directly to the handle or in support of wheels. The weeding tool attached with wheel is generally used for interculture in between rows of crops and wheel assists in guiding the implement and in maintaining the proper depth. These weeders are unable to provide the uniform depth of cut and lateral stability. The lateral instability affects human being in form of static loading which results in less utilization of their limited power. As it is known that static load is the effect of gravity while dynamic load varies with the work rate.

The size of available hand operated weeders is 110-

200 mm and these are suitable for the crops grown at spacing of up to 225 mm. The wide row crops are planted at spacing of more than 300 mm and ranged from 300 to 750 mm. Amongst wide row crops, vegetables are mostly planted at spacing of 300 mm and above. Presently, no hand operated weeders are available for weeding in wide row crops.

Weed management is one of the tedious operations in vegetable production. Because of labour costs, time and tedium, manual weeding is unfavorable. But, two recent trends in agriculture have encouraged the development of alternative weed control mechanisms to chemical application: Firstly, several weed species have shown resistance to glyphosate. The second trend is the adoption of organic farming. Vegetables are important constituents of Indian agriculture and nutritional security. India is the second largest producer of fruits and vegetables in the world. Total area under vegetable crops is 8.49 million ha and production is 146.55 million tonnes (ICAR-IASRI 2012). Compared to area (2.84 million ha), production (16.5 million tonnes) and productivity (5.8 tonnes/ha) in 1950-1951, there had been phenomenal increase in area (2.99 folds), production (8.88 folds) and productivity (2.98 folds) of vegetables in the country.

Keeping in view of the above, a suitable hand operated weeder for weeding in such wide-row crops is attempted. The design is based on ergo-mech (ergonomics and

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mechanical) approach as ergonomics is a science which mainly focuses on human-machine-interaction and mechanical applies the principles of engineering, physics, and materials science for the design, analysis, manufacturing, and maintenance of mechanical systems. Bellinger (1969) rightly reported that equipment designed with proper application of human factors principles can result in increased efficiency and productivity, decreased effort, increased reliability, improved safety, improved flexibility, increased comfort and better operator and consumer acceptance. Singh *et al.* (2012) found in their study that ergonomically designed equipment reduced physiological (47 and 32% over the traditional method & dehusking with hand and shelling with hand operated octagonal maize sheller, respectively) and economic costs (35.4%) over others. In this paper, design consideration, development, fabrication and test results of developed weeder are presented.

#### MATERIALS AND METHODS

Three main physical techniques can be used for controlling the weeds, viz. (1) burying weeds, (2) cutting weeds and (3) uprooting weeds. Limitations of the present weeders are following: (a) Single/twin wheel weeders are unable to provide the uniform depth of cut due to inefficient depth control mechanism and lateral stability. Varying depth of cut affects the worker's efficiency in terms of varying force with awkward posture during operation while the lateral instability affect inefficient utilization of limited power of human being due to its static loading (effect of gravity). (b) The dynamic load varied with work-rate of a worker during operation which also affects the performance of weeder. This may be due to a fixed handle position as workers are dynamic in field operation.

The following design criteria are adopted to develop a weeder for wide-row crops to overcome the above limitations, (1) Weeds can be killed easily when they are at early stages of growth. (2) Physical techniques of weeding i.e., cutting weeds are considered, for this, the slicing action is opted for cutting the weeds to damage their nodes in its initial stage. (3) Ergonomic criteria are considered for design of suitable weeder for wide-row crops sown/ planted on flat bed. (4) Four wheel concept is introduced for hand operated farm equipment to overcome the depth of cut and lateral instability of equipment. (5) Push-pull mode is opted for its operation in the field. This will enable worker for breathing in between the forces. (6) Swinging type handle is also first time attempted to overcome the dynamicity of workers while operating the weeder in push-pull mode. (7) Maximum walking speed for weeding operation with the equipment is 1.5 km/h for effective weeding. (8) The cutting width of weeder was kept 250 mm so that it can be operated successfully in the vegetable crops planted at row spacing of 300 mm and above like, pea, lobia, okra, chilly, capsicum, cauliflower, cabbage, french bean etc. However, it can also be operated in other wide row planted/sown crops. (9) The weight of the weeder should be about 30% of workers

body weight (Grandjean, 1988). A 30% of 5<sup>th</sup> percentile body weight of Indian farm women is 33.5 kg (Gite *et al.*, 2009). Thus, the weight of equipment should be below 10 kg. (10) Sustainable power of human beings, was considered based on literature given below,

- (i) According to Campbell (1990) the power of useful work done by human being is  $HP = 0.35 - 0.092 \log t$   
Where,  $t$  = time in minutes  
So, the power development by the operator would be 0.10-0.13 hp say 0.11 hp or 80W for 3-4 h continuous work.
- (ii) Wilkle (1960) reported that the steady-state power output must be limited to maximum absorption of oxygen under optimal condition, i.e. 298 to 373W. For long-term work, lasting all day power output for ordinary healthy individuals can produce less than 70-80% as much power, i.e. 59 to 112W.
- (iii) Generally, power developed by worker (men) is taken 0.1 hp (75W) (Michael and Ojha, 1987) and 0.8 of men power for women workers, i.e. 60W.
- (iv) Average level of energy expenditure acceptable for day long work was considered on the basis of 40% of aerobic capacity as suggested by Nag and Chatterjee (1981), which comes to 0.64 l/min for women workers (Singh *et al.* 2008). Taking energy equivalent of 20.93 kJ/l of oxygen and 20% efficiency of human being, the power available for day long work would be 45W.

From above, it is clear that work consuming more than 45W may require rest pause to the worker for operation of the equipment. (11) Maximum depth of cut was kept 20 mm for slicing the weeds to utilize human beings power more efficiently.

The 'Four-wheel weeder' consisted rectangular tool bar frame, shanks, weeding blades, handle and wheels. The design of these components is discussed below:

V-shape sweep preferred as the tool geometry of the cutting blades is based on soil-tool-plant interactions (Bernacki *et al.* 1989). The maximum push force with both hands by a man and woman worker in standing posture is 498 and 302N, respectively (Gite *et al.* 2009) but for better muscular efficiency, the dynamic effort of a repetitive nature should not exceed 30% of the maximum push force (Grandjean 1988).

Relationship between mechanics of weeding action and soil resistance could be expressed as below,

$$F \cos \phi_p = w d_w R_s$$

where,  $F$  = sustainable push force (i.e. 30% of 498N and 302N = 149N and 91N),  $\phi_p$  = Angle of operation for weeder by a worker (comfortable operational angle 30-45<sup>o</sup>, Gite and Yadav 1985),  $w$  = Weeding width (mm),  $d_w$  = Weeding depth (mm) (15-20 mm for this weeder),  $R_s$  = Specific soil resistance (value of 0.02 N/mm<sup>2</sup> for heavy soil up to 150 mm depth, Bernacki *et al.* 1985)

After calculation, weeding width comes in range of 351-430 mm and 263-322 mm at operation angle 45 and 30<sup>o</sup> by male worker for weeding depth of 15 and 20 mm,

respectively. Similarly with female worker, corresponding values for weeding width are 215-263 mm and 161-197 mm. To make it gender-friendly, width was selected to 250 mm with a push-pull mode of operation.

Cutting blades were arranged in triangular shape at 45° from line of action to enable weeder for weeding in slicing action. The size of each cutting blade was made of mild steel flat having 175 mm length × 45 mm width × 4 mm thick. A 20 mm cutting edge was provided along length of cutting blade.

A rectangular tool bar frame consisted of a tool bar and spacer. Following assumptions are considered for designing of a tool bar, (i) The tool frame/bar is subjected to torsion and bending moment due to push-pull mode of operation and wheel support. (ii) Maximum push force with both hands is 498 N (Gite *et al.* 2009). Half of the force, i.e. 249 N is considered for a tool bar. (iii) Ultimate tensile stress of mild steel is 320 N/mm<sup>2</sup> (Bhandari 1994). (iv) Ultimate tensile stress of aluminium is 160 N/mm<sup>2</sup> (Bhandari 1994). (v) Draftability (specific soil resistance) for heavy soil up to 150 mm depth is 0.02 N/mm<sup>2</sup> (Bernacki *et al.* 1985). (vi) A numerical value between 1 and 4 is desirable for Factor of safety (Krutz *et al.* 1984). Since maximum depth of weeding operation is only 20 mm under friable moisture condition so uncertainties (risk) will be of moderate level. So factor of safety is kept 2. (vii) Tool bar is considered a simple supported beam due to its support on two wheels.

Number of shank	= 1
Maximum depth of operation	= 20 mm
Width of blade	= 175 mm
Mounting of blade to shank	= angled (45°)
Ground clearance of tool bar and shank	= 125 mm
Length of tool bar	= 600 mm
Weeding cross-section area by blade mounted on shank (mm <sup>2</sup> )	= (length of blade (mm) × cos 45°) × maximum depth of operation (mm) = (175 × cos 45°) × 20 = 2474.87 mm <sup>2</sup>
Draft required for shank	= Weeding cross-section area (mm <sup>2</sup> ) × Draftability (N/mm <sup>2</sup> ) = 2474.9 × 0.02 = 49.5 N
Design draft for tool bar	= draft × factor safety = 49.5 × 2 = 99 N
Torque on tool bar by each shank	= Draft required by shank (N) × Ground clearance (m) = 99 × 0.125 = 12.38 N-m

In addition to torque on tool bar, bending moment would also be acting on simple supported beam. The maximum bending moment (BM<sub>max</sub>) will be,

$$BM_{max} = \text{total weight/force on the tool bar (w, N)} \times \text{total length of tool bar (l, m)}$$

$$= (99+249) \times 0.6 = 208.8 \text{ N-m}$$

Equivalent torque (T<sub>e</sub>) to torsion and bending moment was calculated using following formula,

$$T_e = \sqrt{M^2 + T^2}, \text{ N-m} = \sqrt{(208.8)^2 + (12.4)^2} = \sqrt{43597.4 + 153.3} = 209.2 \text{ N-m}$$

The maximum shear stress developed on the tool bar frame was obtained using following formula,

$$f_s / R = T / J$$

where,  $f_s$  = Shear stress at any section  
R = distance of the section from neutral axis = d/2  
T = Equivalent torque, N-mm  
J = Polar moment of inertia

Design stress = Ultimate stress/ Factor of Safety = 320 N/m<sup>2</sup>/2 = 160 N/m<sup>2</sup>

$$160/(b/2) = 209170/(5b^4/96)$$

$$320/b = 209170 \times 96/5b^4 = b^3 = 385510 \times 96/360 =$$

$$b = 39.74 \text{ mm}$$

The ratio of width and thickness in rectangular section is taken 1:5, means b=5t. Therefore, thickness of mild steel rectangular section will be 8 mm.

Hence, design section of a mild steel tool bar is 600 × 40 × 8 mm. The material for tool bar is taken aluminium flat having width of 50 mm and thickness of 10 mm. Further the rectangular tool bar frame is supported at three places with mild steel hollow square spacer (30 × 3 mm) of 135 mm length.

Maximum force at the tip of the slicing blade should not exceed than multiplication of maximum force and pull/push angle, means the range will be 213-261N and 352-431N at operation angle 45 and 30° by men and women workers, respectively.

For design purpose, maximum value will be taken which is 431N and a factor of safety of 2,

$$\text{Hence, bending load} = 431 \times 2 = 862 \text{ N (Krutz } et al. 1984).$$

Maximum bending moment for a cantilever length of 125 mm would be 107 750 N-mm.

The sectional modulus of the shank is computed from the classical flexure formula given as,

$$\sigma = MC_1/I$$

where, C<sub>1</sub> = distance from neutral axis to point at which stress is determined, mm = t/2, I = moment of inertia of the rectangular section, mm<sup>4</sup> = bt<sup>3</sup>/12. The sectional modulus (Z = I/C<sub>1</sub>) is computed as:

$$Z = M/\sigma = 107750/498 = 216.4 \text{ mm}^3$$

For rectangular section, ratio between base width (b) and thickness (t) = 1:5 (b=5t)

$$216.4 \times 0.125b = (b \times b^3/1500)$$

$$b = 34.4 \text{ mm, so } t = 7 \text{ mm}$$

Hence, design section of a mild steel shank is 40 × 8 mm.

For maximum efficiency, it is suggested that the elbow flexion angle (b) should be in the range of 85-110 degrees (Grandjean 1988). Several studies have suggested a value of 50-60° for the angle between the weeder blades and handle (q) (Sengupta *et al.* 1987 as cited by Rogan 1992). Taking these into consideration and knowing the elbow height (x) and knuckle to elbow height (y) from the

Table 1 Anthropometric data on identified parameters for handle design

Parameters	Values (5 <sup>th</sup> -95 <sup>th</sup> Percentile)	
Elbow height (x)	Men: 915-1172 mm	Women: 831-1077 mm
Metacarpal-III height	Men: 599-805 mm	Women: 547-745 mm
Metacarpal-III (knuckle) to elbow height (y)	Men: 316-367 mm	Women: 284-332 mm
Elbow flexion angle (b)	85-110	
Angle between the weeder blades and handle (q)	50-60	
Optimum length of the handle (Z)	Men <sub>85&amp;50°</sub> : 1230.5-1571.8 mm	Women <sub>85&amp;50°</sub> : 1117-1444.8 mm
	Men <sub>110&amp;60°</sub> : 931.8-1208.4 mm	Women <sub>110&amp;60°</sub> : 847.4-1112.5 mm
Handle height	Men <sub>85&amp;50°</sub> : 920 mm-1190 mm	Women <sub>85&amp;50°</sub> : 850-1090 mm
	Men <sub>110&amp;60°</sub> : 810-1050 mm	Women <sub>110&amp;60°</sub> : 720-940 mm
Handle height= 0.7-0.8 of Acromial height (x) (Gite and Yadav 1989).	Men: 1234-1538 mm	Women: 1159-1387 mm
0.7 of X	Men: 863.8-1076.6 mm	Women: 811.3-970.9 mm
0.8 of X	Men: 987.2-1230.4 mm	Women: 927.2-1109.6 mm

anthropometric data, the optimum length of the handle Z could be easily found from the geometry of the body posture adopted by the operator. The handle length can be given by

$$Z = \frac{X + Y \cos \beta}{\sin \theta}$$

Putting the values obtained from the anthropometric survey of the sample population in to this expression and taking the values for values for elbow flexion angle and blade angle in the ranges of 85-100 and 55<sup>0</sup>, respectively, inclined handle length (Z) of the weeder is obtained and given in Table 1.

From above considerations, it is clear that optimum handle length and handle height varied from 847 to 1572 mm and 720 to 1230 mm, respectively. An optimum handle length was observed to 1220 mm for both men and women workers. This gave the picture in isometric situations for both workers (men and women) while weeding operations in field are dynamic which varied the angle for pulling (34-42<sup>0</sup>) and pushing (38-45.5<sup>0</sup>) by the workers (Table 2). To counter these variations, an idea of swinging handle was introduced as innovation for adjustment of handle height.

To provide T-type handle, the maximum width of handle should be 95<sup>th</sup> Percentile of Bideloid Breadth of men worker, i.e. 504 mm. Therefore, length of T-type handle was kept 515 mm to enable both men and women workers in easy gripping. The diameter of T-type handle was kept 26 mm based on middle finger palm grip diameter as suggested by Singh, 2012 for frequent stroke.

Table 2 Variation of handle angle during weeding operation with 1220 mm handle

Subjects	Handle angle during operation	
	Push	Pull
95 <sup>th</sup> percentile	34-35	38-39
Average	35.4-38	44.1-45.5
5 <sup>th</sup> percentile	40-42	38-41

The lateral stability of the four wheels was considered and observed that the four-wheel weeder will only overturn when one or two wheels are raised to topple. The operational speed of the manual weeder is very low (about 1.5 km/h) which will not be a factor for topple. The mounting of wheel is on centre line of tool bar width and independent. Thus, its centre of gravity will be in centre of tool bar frame. Commercial HDPE wheels were opted for the weeder which has 300 mm diameter and 50 mm thickness. The diameter of wheel was decided based on ground clearance.

Based on the above design, the four wheel weeder was developed. The ground clearance of 125 mm was kept based on initial weeds height which was observed as maximum of 150 mm. In vegetable crops, generally weeding is needed up to one month and after that crops survive. Keeping in view, the wheel of 300 mm diameter was selected. All the wheels are mounted separately so that easy turning can be made on one of the wheels.

The length of frame for the weeder was kept in such a way that space for hand breadth across thumb, i.e. 110 mm (95<sup>th</sup> percentile of men workers) could be provided to easy mounting/dismounting of shank. Thus, length of frame was kept 600 mm. Three mild steel square hollow spacers (30 mm × 3 mm thick) of 135 mm length were used to make a rectangular frame. This provided wheel-base of 250 mm.

The weeding blade was designed for slicing the weed at shallow depth, i.e. 10-20 mm. For which, weeding blade was mounted on shoe of a rectangular shank which is attached at 45<sup>0</sup> from line of action and cutting edge horizontal to the ground. Two separate such weeding blades were provided to make a pointed tip at centre. This way, it enables to reduce the shearing force, means less force per cm cutting width as compared to straight cutting. The separate weeding blade would also be helpful to overcome the debris impact and smooth operation of blades independently. The size of each weeding blade was 175 × 40 × 4 mm and its rake angle was 15<sup>0</sup>. The size of shank was 210 × 40 × 8 mm. The depth adjustment was provided by adjusting the shank height.

Handle was mounted on the 2<sup>nd</sup> square spacer which is at 240 mm distance from front wheel mounting. Based on field assessment, a T-type handle was preferred over U-type handle for this four wheel weeder. A T-type handle enables worker to transmit force along handle, means more conversion of horizontal component of applied force. While in U-type it is vice-versa. The handle was fabricated using two mild steel pipes (1220 mm) parallel to each other with help of 100 mm spacer. This pipe was further mounted in T-shape with another pipe (26 mm diameter × 530 mm length) over it. The technical specifications of developed four wheel weeder are given in Table 3.

A laboratory study on push force measurement was conducted in soil bin at two compaction levels (bulk density (d.b): 1.26 g/cc and 1.334 g/cc) and four handle angles (34, 37, 40 and 43°) in Division of Agricultural Engineering, ICAR-IARI, New Delhi. A fixture was fabricated to mount the four wheel weeder on track trolley of soil bin. Another fixture was fabricated to mount S-type HMM-Hytech make 50 kg tension-compression load cell in between handle of four wheel weeder. During lab study, push force, speed, depth of cut, width of cut, bulk density, cone index and soil moisture content were measured as per standard methods. Push force data obtained during two compaction level was analysed statistically to see the effect of angle on force and also on compaction levels. A graph was plotted for both compaction levels in Fig 2. Complete randomised design (CRD) was applied for statistical analysis, for this, Statistical Analysis Software (SAS) was used. Significance level was checked by Tukey Grouping method.

After soil bin study, the prototype was tested for weeding in Maize, Spinach, Cabbage and Okra in the field

Table 3 Technical specifications of Four-wheel weeder

Particulars	Detail
Overall dimensions, (l × w × h), mm	1480 × 270 × 300
Weight, kg	9.5
Size of wheel (diameter × width), mm	300 × 50
Wheel base, mm	260
Ground clearance, mm	125
Size of each tool bar, (l × w × h), mm	600 × 50 × 10
Number of tool bar	2
Spacer for rectangular tool bar frame, (l × w × t), mm	Square, 135 × 30 × 3
Size of rectangular tool bar frame (l × w × h), mm	600 × 155 × 50
Handle dimension (l × w), mm	1220 × 135
Size of T- type grip of handle, (dia × l), mm	25 × 500
Mounting of T-type handle on top of frame	Swinging
Number of shanks	2
Size of shank (l × w × t), mm	210 × 40 × 8
Rake angle	15°
Shoe clearance from ground, mm	10
Number of weeding blades	2
Size of weeding blade, (l × w × t), mm	175 × 45 × 4
Length of sharpening in weeding blade, mm	20

condition and Capsicum in Polyhouse (Fig 1). During field testing, bulk density, cone index, walking speed, depth of cut, width of cut, number of weed/m<sup>2</sup> before and after weeding, time to cover the test field and operator feedbacks were recorded and data were analysed using standard procedures. Force was also measured during its operation in field using S-type load cell. Data are given in Table 4.

Table 4 Performance of Final prototype of Four-wheel weeder

Particulars	Detail					
	Maize	Vegetable			Polyhouse Capsicum	Fallow field
		Spinach	Cabbage	Okra		
Row to row spacing, mm	60	50	50	50	60	
Average soil moisture, % d.b.	8.5	11.61	11.61	13.54	10.25	6.7
Average bulk density, g/cc (d.b)	1.558	1.632	1.632	1.571	1.502	1.75
Cone index (3.14 cm <sup>2</sup> area cone, 25-75 mm depth), MPa	0.41-1.01	0.453-1.12	0.453-1.12	0.39- 0.968	0.38-0.951	
Weed count variation /m <sup>2</sup>	95-177	100-227	100-227	50-97	50-91	200-500
Weeds length, mm	25-65	25-75	25-75	100-150	25-75	50-75
Weed type	<i>Santhi, Motha, Doob grass etc.</i>					
Average width of weeding, mm	245					
Average depth of weeding, mm	12-15					
Soil type	Sandy clay					
Average walking speed, km/h	1.4	1.45	1.05	1.28	1.18	1.07
Effective weeding area, ha/h	0.0303	0.0314	0.0206	0.0304	0.0231	0.025
Weeding efficiency*, %	100	98.5	98.7	95.18	95.18	98.1
Weeder efficiency**, %	88.34	88.45	80.16	96.8	79.93	95.42
Push force at handle angle of 35°, N						155.4

\* Weeding efficiency is the ratio of number of weeds destroyed per unit area to number of weeds present before operation per unit area and multiplied with 100. \*\* Weeder efficiency is the ratio of total number of weeds destroyed per unit row area to the total number of weeds in the row including plant canopy and multiplied with 100.



Fig 1 A view of operation of four-wheel weeder in field.

Table 5 Manual weeding with *khurpa* (hand hoe) in okra

Particulars	Okra
Weight of wooden handle <i>khurpa</i> , g	300
Row to row spacing, mm	50
Average soil moisture, % (db)	19.11
Average bulk density, g/cc (db)	1.551
Cone index, MPa, (3.14 cm <sup>2</sup> area cone, 25-75 mm depth)	0.39-0.968
Weed count /m <sup>2</sup>	50-97
Variations in weeds height, mm	100-150
Weed type	<i>Motha, Doob grass etc.</i>
Average width of weeding by <i>khurpa</i> , mm	110
Average depth of weeding, mm	10-20
Soil type	Sandy clay
Posture	Squatting and Sitting
Effective weeding area, m <sup>2</sup> /h	24.3
Weeding efficiency, %	99.8

For comparison purpose, weeding in Okra field was conducted with hand-hoe (*Khurpa*) by worker in sitting/squatting posture (Table 5).

RESULTS AND DISCUSSION

The selection of material for fabrication was essential to make desirable weight of four wheel weeder, i.e. about 10 kg. The reduction in weight of wheel was obtained to 80% by adopting commercial available HDPE wheel in place of fabricated mild steel wheel. Similarly, tool bar of the rectangular frame of the weeder was fabricated with aluminium flat which enabled reduction of 45% in its weight. Thus, total weight of developed weeder was achieved below 10 kg (Table 3). All the fabricated components of the equipment are fastened with nut-bolts which enable easy dismantling, replacement and transport.

Effect of handle angle on push force

The push force at different handle angle was measured

for test run of 6 m at speed of 0.45km/h at two compaction levels in soil bin. The average force (+ SD) at handle angle of 34, 37, 40 and 43<sup>0</sup> at 1<sup>st</sup> compaction level (Cone index range at 25-75 mm: 0.14 to 0.437 M Pa/cm<sup>2</sup>) was 50.35 + 9.54, 56.27 + 13.55, 57.64 + 12.50 and 58.43 + 11.93 N, respectively whereas corresponding value of force at 2<sup>nd</sup> compaction level (Cone index range at 25-75 mm: 0.33 to 0.441 M Pa/cm<sup>2</sup>) was 89.00 + 18.89, 106.30 + 16.83, 112.70 + 21.36 and 134.59 + 27.39N. The relationship between handle angle and push force was plotted for both compaction levels in Fig 2. There was found to be significant at 5% significance level in force measured between 1<sup>st</sup> and 2<sup>nd</sup> compaction levels. However there was no significant difference of handle angle on push force at 1<sup>st</sup> compaction level was observed at 5% level of significance. At 2<sup>nd</sup> compaction level, significant difference was observed for handle angles of 34 and 37<sup>0</sup>, 34 and 40<sup>0</sup>, 34 and 43<sup>0</sup>, 37 and 43<sup>0</sup> and 40 and 43<sup>0</sup> but no significant difference was observed for handle angles of 37 and 40<sup>0</sup> (P<0.05). This analysis clearly indicates the effect of compaction levels and handle angles on the performance of operator. It is observed during field experiment with the weeder that compaction level is less during 1<sup>st</sup> weeding when weeds are tender and it increases subsequently with increase in days after sowing/planting under optimal soil condition. This equipment works at maximum depth of 20 mm so effect of compaction level to operator is moderate. In push-pull mode of operation, the variation of handle angle by the operator was in the range of 34 to 42<sup>0</sup> during push mode while it was 38 to 46<sup>0</sup> during pull mode (Table 2). This could not be obtained by providing height adjustment in a handle at fixed position. Therefore, a swinging handle was provided for push-pull operation. This may reduce the effect of handle angles on operators. Thus, handle positions fit as per the requirement of operator based on their rhythmic work.

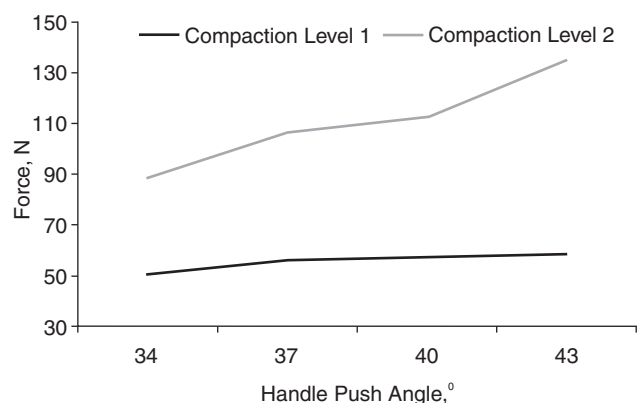


Fig 2 Relationship between handle push angle and force at two compaction levels.

Performance evaluation

Field evaluation of developed four-wheel weeder was conducted in maize crop during *khari*f season, and spinach,

cabbage and okra in *rabi* season. In polyhouse, weeder was tested for capsicum and weeding was also conducted in fallow land. The field test of the equipment was conducted in number of fields for assessing its adoptability as well as performance of the equipment under different soil moisture contents (6.7-13.54%), bulk densities (1.5-1.75 g/cc), cone index range (0.38-1.12 MPa/ cm<sup>2</sup>) and weed count (50-500 weed/m<sup>2</sup>) for depth of 12-15 mm (Table 4). Field capacity of developed weeder in maize crop, spinach, cabbage, okra, capsicum and fallow field was 0.0303, 0.0314, 0.0206, 0.0304, 0.0231 and 0.025 ha/h, respectively. Corresponding walking speed was 1.4, 1.45, 1.05, 1.28, 1.18 and 1.07 km/h. The variation in area covered and speed was due to uneven field, crop growth, planted geometry and weed intensity. In uneven case, weeder was operated twice at same place for complete weeding. Crop growth affected area coverage particularly in polyhouse (120 days of crop) to avoid any damage to the crops. Crop planting geometry was also attributed towards less area coverage as sowing was done manually. In the entire studied crops except polyhouse crop and fallow land, weeder was operated twice in the same row for complete weeding. In fallow land, weeding intensity attributed to less area coverage. At high weed intensity (about 400 or more), weeding operation was paused for cleaning the weed which was clogged. During different experiments on weeding with developed weeder in sandy clay soil, it was observed that the soil moisture content should not be less than 8% on dry basis and also it should not be more than 14% on dry basis for effective operation of weeder.

Practically and theoretically, weeder was having capability for weeding/ slicing all the weeds which comes under the cutting blade due to its slicing action. But in all the experiments, the weeding efficiency varied from 95-100% which was mainly due to depressions at some places. The efficiency of four-wheel weeder was obtained based on ratio of actual and theoretical area coverage which varied 79-96%. The variation was mainly due to above-mentioned factors and turning losses.

Manual weeding was also performed by a farm woman in okra field and area covered was 24.3 m<sup>2</sup>/h with close to 100% weeding efficiency (Table 5). During manual weeding with *khurpa*, weeding is done inside the plant canopy also alongwith its removal from the field simultaneously. Thus, it is justified to assess the productivity of worker by doubling the area covered with *khurpa*, i.e. 50 m<sup>2</sup>/h. In spite of this approximation for traditional (manual) method, the productivity of worker was more than 4 to 6 times with this weeder. Therefore, this weeder enabled farmers in completing the weeding operation timely with reduced drudgery and increased productivity.

The push force requirement in operating this weeder in fallow land was 155.4 N (Table 4). The push force per cm weeding width with this weeder is 6.34 N which is lowest to triangular shaped rotary peg weeder, sweep type wheel hoe and wheel finger weeder (Behra and Swain 2005), and straight flat blade, serrated blade, tine, sweep and double

plough type weeders (Tewari *et al.* 1993). This analysis suggests the advantage of ergo-mech approach for design of the weeder for human beings.

A weeder was designed and developed for wide-row crops using swinging handle, four-wheel concept and slicing action. Soil bin study on push force revealed the significant effect of compaction levels and handle angles on the performance of operator in terms of high force. The area covered by the developed four-wheel weeder was 0.0303 m<sup>2</sup>/h, 0.0314 m<sup>2</sup>/h, 0.0206 m<sup>2</sup>/h, 0.0304 m<sup>2</sup>/h, 0.0231 m<sup>2</sup>/h and 0.025 m<sup>2</sup>/h for maize, spinach, cabbage, okra, capsicum in polyhouse and fallow land, respectively. The row spacing in maize and capsicum was 60 cm while it was 50 cm in spinach, cabbage and okra. The weeding efficiency varied from 95 to 100% in these crops. The push force requirement per cm cutting width was lowest among cited other mechanical weeders. The ergo-mech approach of design enabled operators to complete the weeding work timely with reduced drudgery and increased productivity as compared to conventional practice.

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