Dynamic push-pull strength data generation for agricultural workers to develop manual dryland weeders

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Abstract

Existing manual hoes are of dynamic push - pull weeders but their designs are based on static force exertions. A test rig was developed to optimize the speed and force exertions. At 1.0kmh^{-1}, operator can able to exert 20 to 25 kgf. Based on optimized results V shaped blade (V) and straight blade (S) weeders were developed and evaluated along with the existing twin wheel hoe (T). Performance of the V and S was higher than the T. The field capacities was 0.026, 0.033 & 00.33hah^{-1} and energy expenditure was 20.35, 18.82 & 18.78kJmin^{-1} respectively for T, S and V, however V was best amongst.

Key words: *dynamic force, energy expenditure, field capacity, heart rate, LCP.*

1. Introduction

Weeds are major constraints in agricultural production and causes reduction of crop yield upto 30 to 60 percent. In agricultural operation weeding alone accounts 25 % of the total labour requirement (900–1200 man-hha^{-1}). Mechanical weeding through manual hoe is an effective method of weed control in dryland (Gite and Yadav, 1990). Energy requirement of khurpi is least but the work output is lowest, where as the wheel hoes are of push - pull type weeders cover maximum area with acceptable physiological demand, work performance and workers preference (Nag and Dutt, 1979). Idea on force exertions is of immense importance while designing a pushing or pulling task. Existing studies have been principally concerned with static tasks despite the knowledge that most of agricultural activities are in dynamic nature and involves overexertion of musculoskeletal system and accidents due to slipping/tripping (Chaffin, 1987). Snook (1978) reported that 7 percent of low back injuries are associated with slipping/tripping accidents. At present, the design of manual weeders is based on the static force exertions and most of agricultural equipment designers considred static force to improve efficiency and durability. The fact should be considered that weeding operation is dynamic and associated with higher risk of injury (Allread *et al.*, 2000). Where dynamic pushing/pulling activities have been studied, little effort was made to measure oxygen intake, heart rate, energy consumption and suggestion of the work load according to speed of operation. Hence, an investigation was carried out to develop a dynamic push-pull strength data of agricultural workers to improve the design and to develop manually operated dryland weeders.

2. Materials and methods

Manually operated weeders consist of ground wheel, long handle and tool frame. Ground wheel diameter varies from 200 to 600 mm; based on the suitability diameter was selected. A provision was made on the tool frame to adjust handle height and working tool depth. The design of manual weeders is based on the draft and power required to operate the tool. A healthy man can able to develop a maximum power of 75 W (0.1 hp) and it is expressed as:

$$\text{Power (hp)} = \frac{\text{Draft (kg)} \times \text{Speed (ms}^{-1}\text{)}}{75} \qquad \text{…………..} \ (2.1)$$

The power and draft force varies with the speed of operation and weeders can operate at a speed from 0.29 to 0.44 ms^{-1} (Remesen *et al.,* 2006; Yadav and Pund, 2007; Goel *et al.,* 2008).

2.1 Data generation on dynamic push-pull strength capabilities

A laboratory test rig was developed to measure dynamic push-pull strength capabilities of the agricultural workers (Fig.1). Twelve healthy male agricultural workers having mean age of 31.75 (± 2.45) years were participated in the study. To measure push-pull force, a specially designed four wheeled cart was assembled on VIASYS LE 200 CE computerized treadmill with a support of stands. The dimensions of cart for handle width, handle height and handle grip were considered according to anthropometric dimensions of Indian agricultural workers (Gite *et al.,* 2009).

2.2 Pushing-pulling forces and operational speed

Existing designs of agricultural machines limit the manual pushing/pulling force exertions to 30 percent of maximum static force capability, which are in the range of 39 to 43 N for Indian conditions. But, most of agricultural activities involve continuous application of forces higher than 50 N (Gite *et al.,* 2009; Agrawal *et al.,* 2010). To predict the safer limit of force exertions, five levels of force exertion from 5 to 25kgf with an increment of 5kgf at each level and four levels of speed of operation from 0.5 to 2.0kmh^{-1} with an increment of 0.5kmh^{-1} at each level was selected. The physiological responses such as, heart rate (HR), volume of oxygen consumption (VO_2), amount of energy expenditure (EC) are measured for 30 minute duration using a computerized ambulatory metabolic measurement system ($K4b^2$)

and HR monitor. The Limit of Continuous Performance (LCP) for individual subjects at each combination level was calculated.

2.3 Design of the weeder

After optimization of force and speed of operation, draft force can be decided. It will help to determine the depth and width of operation in later part. The depth and width of cut along with unit draft influences the draft requirement for weeding. The relation between these parameters is expressed as:

$$D = (W \times d_w) \times d_u \qquad \ldots\ldots\ldots\ldots.. (2.2)$$

Where, D = Draft (kg); W = Width of cut (cm); d_w = Depth of cut (cm); d_u = Unit draft ($kgcm^{-2}$).

Generally the dryland weeders were operated in light to medium soil. For optimum design of weeder Sharma and Mukesh (2007) suggested a unit draft and depth of operation as 0.43 $kgcm^{-2}$ and 20 mm respectively (Bernacki *et al.*, 1972). From equation 2.2 width of cut obtained as:

$$W = \frac{D}{(d_w \times d_u)} \qquad \ldots\ldots\ldots\ldots\ldots (2.3)$$

The V shaped blade and straight blade (S) (apex angle 90^0 and 180^0) weeder were developed after optimizing the width of cut. Anthropometric dimensions of participants were measured and considered in the design (Table.1)

The schematic views of the developed weeders were shown in Fig.2. Ergonomic and field evaluation was conducted for developed weeders along with one existing twin wheel hoe (T) having width of cut 150 mm.

3. Results and discussion

If we consider the speed of operation draft force can be obtained from equation 2.1. By considering average speed ($0.36ms^{-1}$) a healthy man can able to exert maximum draft force of 21kgf (Sharma and Mukesh, 2007). It cannot be recommended until unless proved practically.

3.1 Measurement of dynamic push-pull strength capabilities

Developed test rig simulates the pushing and pulling of weeders in laboratory. Selected subjects were trained on the test rig. The Fig.3.a & 3.b illustrates the performance of pushing/pulling activities. The physiological responses of the subjects during experiment were measured; it includes HR, VO_2 consumption and EC. LCP was calculated based on the mean HR response. The recorded data was downloaded to computer and analysed. The mean values of 6^{th} to 15^{th} minutes of operation were selected (Davis and Harris, 1964). The safer and comfortable operational limits were drawn based on the LCP and EC values obtained during operation (Table.2 & 3).

The minimal values were observed at 5 kgf of push/pull exertions and higher values at 25kgf of push force exertion at all speed levels. Subject's physiological responses to operational speed varies significantly; at 0.5kmh^{-1} responses were very low, however most of the subjects felt difficult to operate and reported a shoulder and lower back pain due to slow speed. At 2.0kmh^{-1} for 20 to 25kgf and 1.5kmh^{-1} for 20kgf of push forces, physiological responses were much higher (LCP was > 40 beats min^{-1}), hence, these levels were not recommended. Usually agricultural activities involve higher strength applications and operated at average speed of walking. From Table.2 & 3, it can seen that, at 1.0kmh^{-1} (0.36 ms^{-1}) subject can able to exert higher strength (maximum LCP was 38.6 beats min^{-1} and EC graded as light work). This was also concluded earlier by equation 2.1. Hence, 20 to 25kgf of force application at 1.0kmh^{-1} speed of operation will be the best design value (Sharma and Mukesh, 2007; Goel et al., 2010; Firouzi and Alizadeh, 2012) to perform work continuously for 8 hours.

3.2 Design of the weeders

Weeders were developed after optimization of speed and force exertion. Equation 2.3 was used to calculate width of cut at draft force 21 kgf, thus:

$$W = \frac{21 \times 100}{20 \times 0.43} = 244.18 \text{ mm} \cong 250 \text{ mm}$$

Therefore, width of cut for developed weeders was fixed to 250 mm. The weeders V, S and T were evaluated ergonomically in sandy loam soil (Fig.4.a & 4.b). Results were tabulated and were presented in Table.4 and 5.

The performance of V and S was higher than the T. The draft force requirement was 17.43, 21.81 & 21.67kgf, field capacities was 0.026, 0.033 & 0.33 hah^{-1}, weeding index was 90.71, 97.65 & 95.95 %, mean HR was 130, 124 & 124 beats min^{-1} and EC was 20.35, 18.82 & 18.78 kJ min^{-1} respectively for T, S and V. The curvature of handle and angle of operation of existing weeder makes weeding operation difficult. It leads to lower field capacity and higher energy consumption to perform the task. Among the developed weeders V shaped blade weeder performed well; tip of the blade penetrates easily into the soil and cut the weeds by sliding along the cutting edges. It offers lees frictional resistance between blade and weed stem, thus, operation became easier and consumes less energy.

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The generated data gives a new design limit to manually operated tools. The developed weeders perform better than existing weeder in terms of field capacity, operational comfortness and physiological responses. Design criterion drawn in this research will satisfy the requirement.

Acknowledgement

Authors are very grateful to the AEC&RI, TNAU Coimbatore for their financial and academic support to conduct the study.

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Tables:

Table.1 Anthropometric parameters considered for weeder design

S.N.	Weeder parameters	Anthropometric parameters	Design Values
1	Handle holding height, H (mm)	Acromial height (5^{th} and 95^{th} percentile)	933.6 to 1031.8
2	Cross handle bar length (mm)	Elbow-Elbow breadth (95^{th} percentile)	430
3	Handle grip (mm)	Middle finger palm and Grip diameter (inside) (5^{th} and 95^{th} percentile)	32 to 43
4	Elbow angle for handle holding(degrees^0)	Elbow flexon angle (85 to 110^0)	90^0
5	Angle of weeder operation, ɷ (degrees^0)	35 to 45^0	35
6	Handle length (mm)	H sinɷ	1450

Table.2 HR, VO_2 and energy consumption of subjects for force exertion

Load (kg)	Speed (kmh^{-1})	HR (beats min^{-1})	VO_2 consumption ($l\ min^{-1}$)	EC ($kJmin^{-1}$)	Energy grade of work
a. Pushing force exertions					
	0.5	92.4	0.46	9.24	Light
	1.0	97.9	0.53	10.50	Light
5	1.5	101.2	0.56	11.13	Light
	2.0	105.6	0.61	12.18	Light
	0.5	99.0	0.53	10.50	Light
	1.0	102.3	0.57	11.34	Light
10	1.5	110.0	0.65	13.02	Light
	2.0	114.4	0.70	14.07	Light
	0.5	102.3	0.57	11.34	Light
	1.0	108.9	0.64	12.81	Light
15	1.5	113.3	0.69	13.86	Light
	2.0	116.6	0.72	14.49	Light
	0.5	105.6	0.60	11.97	Light
	1.0	111.1	0.66	13.23	Light
20	1.5	115.5	0.71	14.28	Light
	2.0	123.2	0.80	15.96	Moderately heavy
	0.5	108.9	0.64	12.81	Light

	1.0	113.3	0.69	13.86	Light
25	1.5	123.2	0.81	16.17	Moderately heavy
	2.0	129.8	0.87	17.43	Moderately heavy
b. Pulling force exertions					
	0.5	96.8	0.51	10.29	Light
	1.0	99	0.54	10.71	Light
5	1.5	100.1	0.55	10.92	Light
	2.0	104.5	0.60	11.97	Light
	0.5	104.5	0.60	11.97	Light
	1.0	106.7	0.62	12.39	Light
10	1.5	111.1	0.67	13.44	Light
	2.0	112.2	0.68	13.65	Light

Table.3 LCP (ΔHR) of subjects for force exertion

Load (kg)	**Speed (kmh^{-1})**	**ΔHR (beats min^{-1})**	**LCP (lower/higher than LCP)**
a. Pushing force exertions			
	0.5	14.3	lower
	1.0	19.8	lower
5	1.5	22	lower
	2.0	26.4	lower
	0.5	18.7	lower
	1.0	22	lower
10	1.5	29.7	lower
	2.0	34.1	lower
	0.5	22	lower
	1.0	28.6	lower
15	1.5	31.9	lower
	2.0	35.2	lower
	0.5	29.7	lower
	1.0	35.2	lower
20	1.5	38.5	lower
	2.0	46.2	higher
	0.5	35.2	lower
	1.0	38.6	lower
25	1.5	47.3	higher
	2.0	53.9	higher
b. Pulling force exertions			
	0.5	16.5	lower
	1.0	18.7	lower
5	1.5	20.9	lower

	2.0	25.3	lower
	0.5	24.2	lower
	1.0	26.4	lower
10	1.5	30.8	lower
	2.0	33	lower

Table.4 Field performance evaluation of the weeders

S.N.	Parameters	Weeder type		
		T	S	V
1	Draft force requirement, kgf	17.43	21.81	21.67
2	Mean travel speed, kmh^{-1}	1.32	1.32	1.3
3	Power requirement, hp	0.085	0.106	0.105
4	Field Capacity, hah^{-1}	0.026	0.033	0.033
5	Performance index, %	2782.16	2992.23	2958.95
6	Weeding index, %	90.71	97.65	95.95

Table.5 Ergonomic evaluation of the weeders

S.N.	Parameters	Weeder type		
		T	S	V
1	Mean HR, beats min^{-1}	130	124	124
2	VO_2 consumption, l min^{-1}	0.97	0.90	0.90
3	EC, kJ min^{-1}	20.35	18.82	18.78
4	ODR	6.04	5.42	5.26
5	BPDS	39.2	36.8	35.2

(ODR = Overall Discomfort Rate; BPDS = Body Part Discomfort Score)

Figure legends:

Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

Fig.2 Schematic view of the developed weeders

Fig.3 Performance on developed test rig

Fig.4 Weeding operation in the cotton field

Figures:

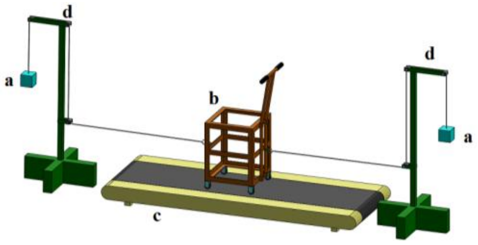
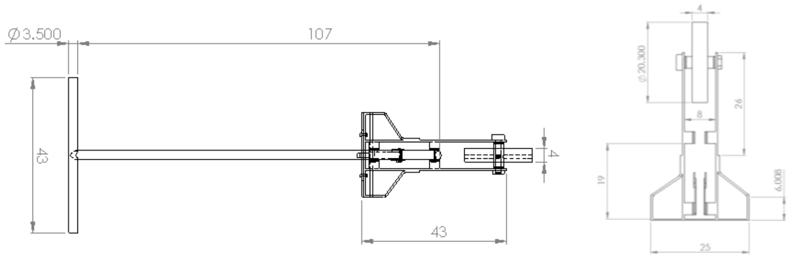
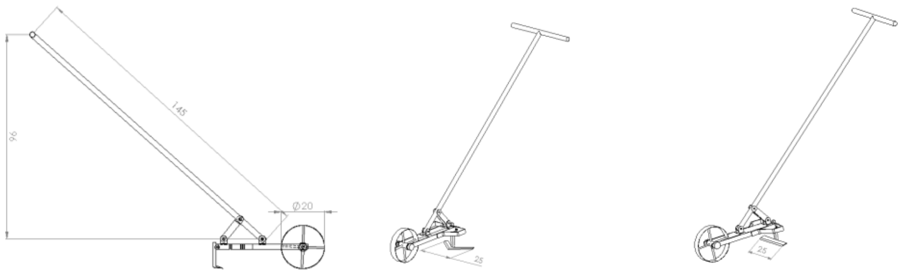


Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

a = varying load; b = four wheeled cart; c = treadmill; d = supporting stands



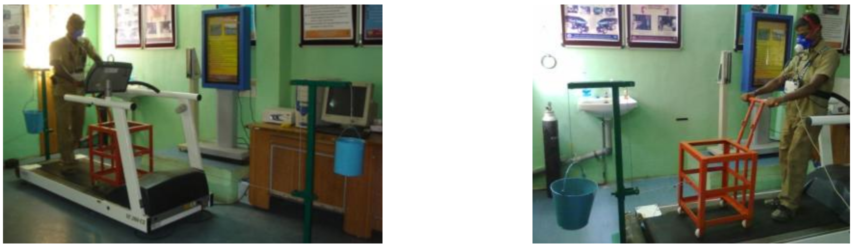
a. Elevation drawing of main frame and weeding blade holder assembly



b. Plan c. Apex angle 90^0 d. Apex angle 180^0

(All dimensions are in cm)

Fig.2 Schematic view of the developed weeders



a. Push force b. Pull force

Fig.3 Performance on developed test rig

a. Twin wheel hoe b. Developed weeder

c. Before and after weeding operation

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The generated data gives a new design limit to manually operated tools. The developed weeders perform better than existing weeder in terms of field capacity, operational comfortness and physiological responses. Design criterion drawn in this research will satisfy the requirement.

Acknowledgement

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Tables:

Table.1 Anthropometric parameters considered for weeder design

S.N.	Weeder parameters	Anthropometric parameters	Design Values
1	Handle holding height, H (mm)	Acromial height (5^{th} and 95^{th} percentile)	933.6 to 1031.8
2	Cross handle bar length (mm)	Elbow-Elbow breadth (95^{th} percentile)	430
3	Handle grip (mm)	Middle finger palm and Grip diameter (inside) (5^{th} and 95^{th} percentile)	32 to 43
4	Elbow angle for handle holding(degrees^0)	Elbow flexon angle (85 to 110^0)	90^0
5	Angle of weeder operation, θ (degrees^0)	35 to 45^0	35
6	Handle length (mm)	H sinθ	1450

Table.2 HR, VO_2 and energy consumption of subjects for force exertion

Load (kg)	Speed (kmh^{-1})	HR (beats min^{-1})	VO_2 consumption (l min^{-1})	EC (kJmin^{-1})	Energy grade of work
a. Pushing force exertions					
	0.5	92.4	0.46	9.24	Light
	1.0	97.9	0.53	10.50	Light
5	1.5	101.2	0.56	11.13	Light
	2.0	105.6	0.61	12.18	Light
	0.5	99.0	0.53	10.50	Light
	1.0	102.3	0.57	11.34	Light
10	1.5	110.0	0.65	13.02	Light
	2.0	114.4	0.70	14.07	Light
	0.5	102.3	0.57	11.34	Light
	1.0	108.9	0.64	12.81	Light
15	1.5	113.3	0.69	13.86	Light
	2.0	116.6	0.72	14.49	Light
	0.5	105.6	0.60	11.97	Light
	1.0	111.1	0.66	13.23	Light
20	1.5	115.5	0.71	14.28	Light
	2.0	123.2	0.80	15.96	Moderately heavy
	0.5	108.9	0.64	12.81	Light

	1.0	113.3	0.69	13.86	Light
25	1.5	123.2	0.81	16.17	Moderately heavy
	2.0	129.8	0.87	17.43	Moderately heavy
b. Pulling force exertions					
	0.5	96.8	0.51	10.29	Light
	1.0	99	0.54	10.71	Light
5	1.5	100.1	0.55	10.92	Light
	2.0	104.5	0.60	11.97	Light
	0.5	104.5	0.60	11.97	Light
	1.0	106.7	0.62	12.39	Light
10	1.5	111.1	0.67	13.44	Light
	2.0	112.2	0.68	13.65	Light

Table.3 LCP (ΔHR) of subjects for force exertion

Load (kg)	**Speed** (kmh^{-1})	**ΔHR** (beats min^{-1})	**LCP** (lower/higher than LCP)
a. Pushing force exertions			
	0.5	14.3	lower
	1.0	19.8	lower
5	1.5	22	lower
	2.0	26.4	lower
	0.5	18.7	lower
	1.0	22	lower
10	1.5	29.7	lower
	2.0	34.1	lower
	0.5	22	lower
	1.0	28.6	lower
15	1.5	31.9	lower
	2.0	35.2	lower
	0.5	29.7	lower
	1.0	35.2	lower
20	1.5	38.5	lower
	2.0	46.2	higher
	0.5	35.2	lower
	1.0	38.6	lower
25	1.5	47.3	higher
	2.0	53.9	higher
b. Pulling force exertions			
	0.5	16.5	lower
	1.0	18.7	lower
5	1.5	20.9	lower

	2.0	25.3	lower
	0.5	24.2	lower
	1.0	26.4	lower
10	1.5	30.8	lower
	2.0	33	lower

Table.4 Field performance evaluation of the weeders

S.N.	Parameters	Weeder type		
		T	S	V
1	Draft force requirement, kgf	17.43	21.81	21.67
2	Mean travel speed, kmh^{-1}	1.32	1.32	1.3
3	Power requirement, hp	0.085	0.106	0.105
4	Field Capacity, hah^{-1}	0.026	0.033	0.033
5	Performance index, %	2782.16	2992.23	2958.95
6	Weeding index, %	90.71	97.65	95.95

Table.5 Ergonomic evaluation of the weeders

S.N.	Parameters	Weeder type		
		T	S	V
1	Mean HR, beats min^{-1}	130	124	124
2	VO_2 consumption, l min^{-1}	0.97	0.90	0.90
3	EC, kJ min^{-1}	20.35	18.82	18.78
4	ODR	6.04	5.42	5.26
5	BPDS	39.2	36.8	35.2

(ODR = Overall Discomfort Rate; BPDS = Body Part Discomfort Score)

Figure legends:

Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

Fig.2 Schematic view of the developed weeders

Fig.3 Performance on developed test rig

Fig.4 Weeding operation in the cotton field

Figures:

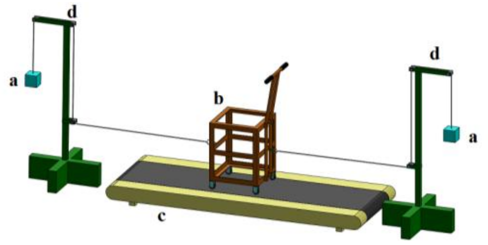
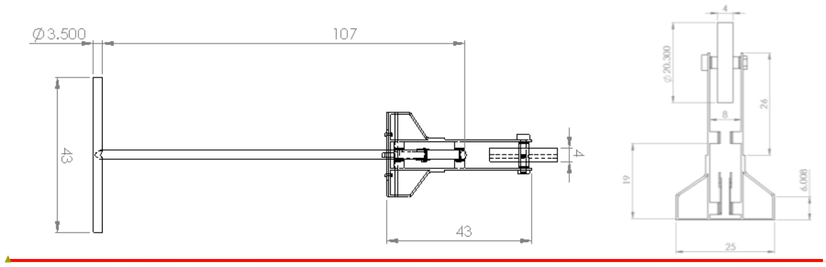
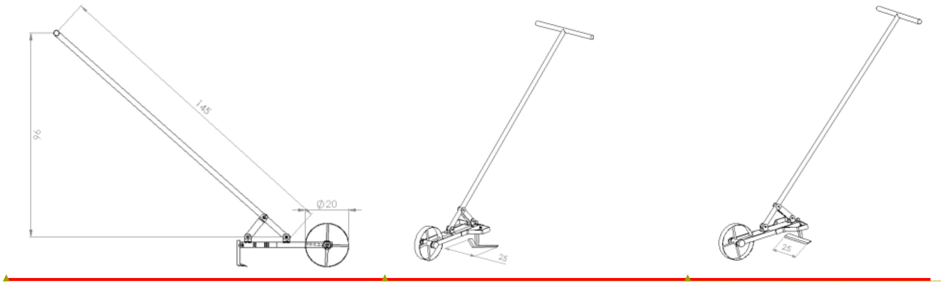


Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

a = varying load; b = four wheeled cart; c = treadmill; d = supporting stands

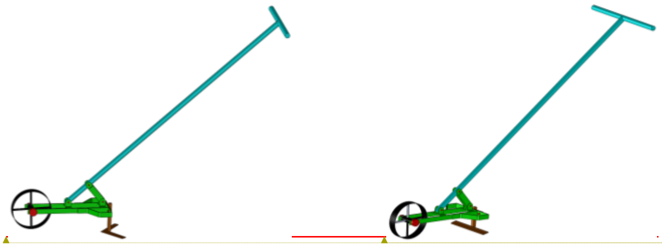


a. Elevation drawing of main frame and weeding blade holder assembly



b. Plan c. Apex angle 90^0 d. Apex angle 180^0

(All dimensions are in cm)



~~a. Apex angle 90^0 b. Apex angle 180^0~~

Fig.2 Schematic view of the developed weeders

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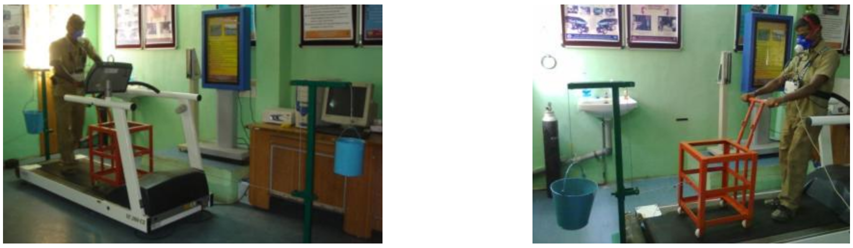

a. Push force b. Pull force

Fig.3 Performance on developed test rig

a. Twin wheel hoe b. Developed weeder

c. Before and after weeding operation

Fig.4 Weeding operation in the cotton field

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List of changes made against the reviewer comments:

1. **The corrections carried out in the manuscript may be incorporated**

   All the corrections carried out in the manuscript were incorporated

2. **The engineering drawing of the developed weeder with all major essential dimensions may be provided**

   The engineering drawing of the developed weeders with all major essential dimensions are provided in the manuscript

3. **The entire script may be rewritten in past tense**

   The entire script is rewritten in past tense

4. **A photograph of a field with weed before operation and the same location after removal of weed using the developed weeder may be provided to compare the performance of the weeder visually, if available**

   Photographs of field with weed before operation and the same location after removal of weed using the developed weeder are incorporated in the manuscript