

22 **1. Introduction**

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

43 **2. Materials and methods**

44 Manually operated weeders consist of ground wheel, long handle and tool frame.
45 Ground wheel diameter varies from 200 to 600 mm; based on the suitability diameter was
46 selected. A provision was made on the tool frame to adjust handle height and working tool

47 depth. The design of manual weeders is based on the draft and power required to operate the
48 tool. A healthy man can able to develop a maximum power of 75 W (0.1 hp) and it is
49 expressed as:

50
$$\text{Power (hp)} = \frac{\text{Draft (kg)} \times \text{Speed (ms}^{-1}\text{)}}{75} \dots\dots\dots (2.1)$$

51 The power and draft force varies with the speed of operation and weeders can operate
52 at a speed from 0.29 to 0.44 ms⁻¹ (Remesen *et al.*, 2006; Yadav and Pund, 2007; Goel *et al.*,
53 2008).

54 **2.1 Data generation on dynamic push-pull strength capabilities**

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

62 **2.2 Pushing-pulling forces and operational speed**

63 Existing designs of agricultural machines limit the manual pushing/pulling force
64 exertions to 30 percent of maximum static force capability, which are in the range of 39 to 43
65 N for Indian conditions. But, most of agricultural activities involve continuous application of
66 forces higher than 50 N (Gite *et al.*, 2009; Agrawal *et al.*, 2010). To predict the safer limit of
67 force exertions, five levels of force exertion from 5 to 25kgf with an increment of 5kgf at
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77 along with unit draft influences the draft requirement for weeding. The relation between these
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$$79 \quad D = (W \times d_w) \times d_u \quad \dots\dots\dots (2.2)$$

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

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86 The V shaped blade and straight blade (S) (apex angle 90° and 180°) weeder were
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89 The schematic views of the developed weeders were shown in Fig.2. Ergonomic and
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91 hoe (T) having width of cut 150 mm.

92 **3. Results and discussion**

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113 From Table.2 & 3, it can be seen that, at 1.0kmh⁻¹ (0.36 ms⁻¹) subject can able to exert higher
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118 **3.2 Design of the weeders**

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

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

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

124 The performance of V and S was higher than the T. The draft force requirement was
125 17.43, 21.81 & 21.67kgf, field capacities was 0.026, 0.033 & 0.33 hah⁻¹, weeding index was
126 90.71, 97.65 & 95.95 %, mean HR was 130, 124 & 124 beats min⁻¹ and EC was 20.35, 18.82
127 & 18.78 kJ min⁻¹ respectively for T, S and V. The curvature of handle and angle of operation
128 of existing weeder makes weeding operation difficult. It leads to lower field capacity and
129 higher energy consumption to perform the task. Among the developed weeders V shaped
130 blade weeder performed well; tip of the blade penetrates easily into the soil and cut the weeds
131 by sliding along the cutting edges. It offers less frictional resistance between blade and weed
132 stem, thus, operation became easier and consumes less energy.

133 **4. Conclusions**

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

138 **Acknowledgement**

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

141

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175

176 **Tables:**

177 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, φ (degrees ⁰)	35 to 45 ⁰	35
6	Handle length (mm)	H sin φ	1450

178 Table.2 HR, VO₂ 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					
5	0.5	92.4	0.46	9.24	Light
	1.0	97.9	0.53	10.50	Light
	1.5	101.2	0.56	11.13	Light
	2.0	105.6	0.61	12.18	Light
10	0.5	99.0	0.53	10.50	Light
	1.0	102.3	0.57	11.34	Light
	1.5	110.0	0.65	13.02	Light
	2.0	114.4	0.70	14.07	Light
15	0.5	102.3	0.57	11.34	Light
	1.0	108.9	0.64	12.81	Light
	1.5	113.3	0.69	13.86	Light
	2.0	116.6	0.72	14.49	Light
20	0.5	105.6	0.60	11.97	Light
	1.0	111.1	0.66	13.23	Light
	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

25	1.0	113.3	0.69	13.86	Light
	1.5	123.2	0.81	16.17	Moderately heavy
	2.0	129.8	0.87	17.43	Moderately heavy

b. Pulling force exertions

5	0.5	96.8	0.51	10.29	Light
	1.0	99	0.54	10.71	Light
	1.5	100.1	0.55	10.92	Light
	2.0	104.5	0.60	11.97	Light
10	0.5	104.5	0.60	11.97	Light
	1.0	106.7	0.62	12.39	Light
	1.5	111.1	0.67	13.44	Light
	2.0	112.2	0.68	13.65	Light

179 Table.3 LCP (Δ HR) of subjects for force exertion

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

180 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

181 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

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

183

184 **Figure legends:**

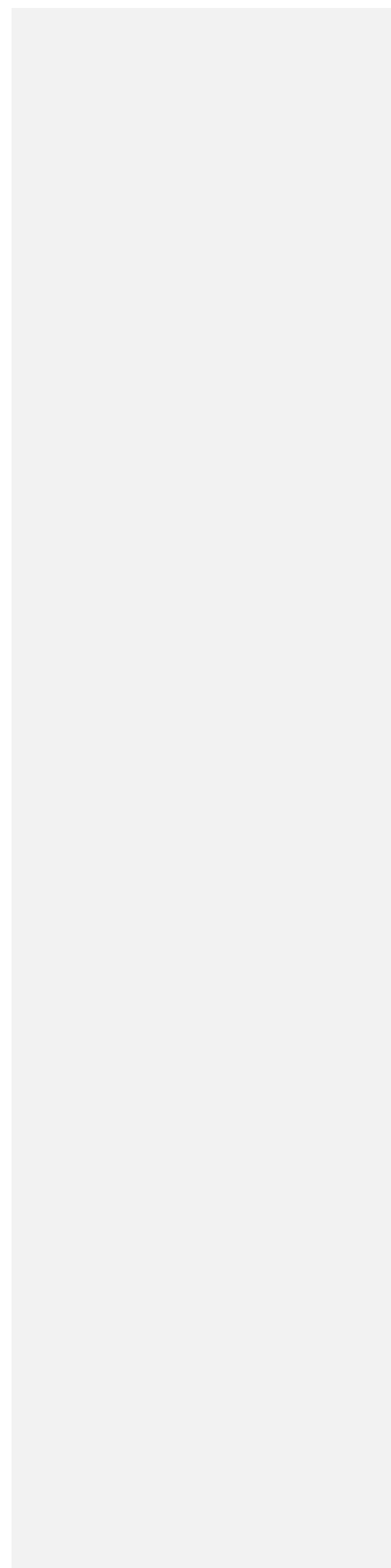
185 Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

186 Fig.2 Schematic view of the developed weeders

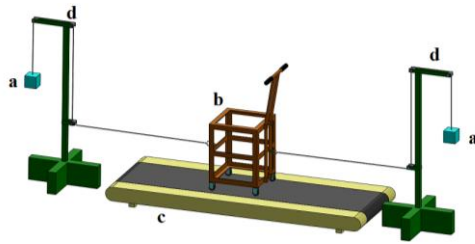
187 Fig.3 Performance on developed test rig

188 Fig.4 Weeding operation in the cotton field

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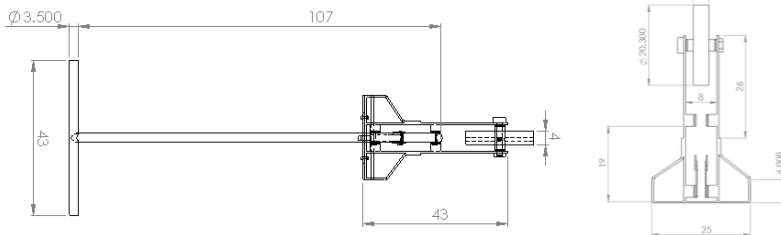
190 **Figures:**



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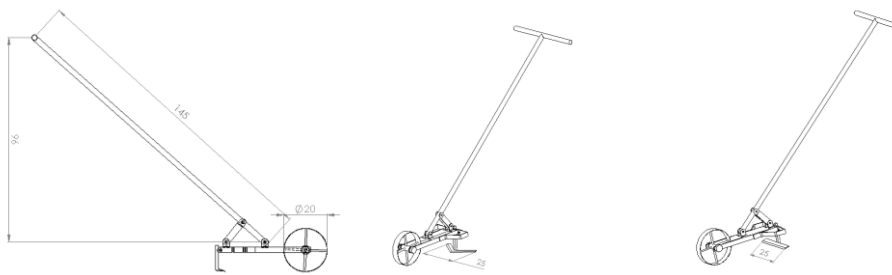
192 **Fig.1 Test rig to measure dynamic Push-Pull strength capabilities**

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



194

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



196

197 b. Plan

198 c. Apex angle 90°

199 d. Apex angle 180°

(All dimensions are in cm)

Fig.2 Schematic view of the developed weeders



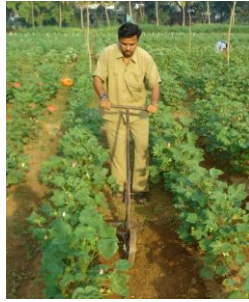
200 a. Push force



201 b. Pull force

202

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

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220 **Abstract**

221 Existing manual hoes are of dynamic push - pull weeders but their designs are based
222 on static force exertions. A test rig was developed to optimize the speed and force exertions.
223 At 1.0kmh⁻¹, operator can able to exert 20 to 25 kgf. Based on optimized results V shaped
224 blade (V) and straight blade (S) weeders were developed and evaluated along with the
225 existing twin wheel hoe (T). Performance of the V and S was higher than the T. The field
226 capacities was 0.026, 0.033 & 0.033hah⁻¹ and energy expenditure was 20.35, 18.82 &
227 18.78kJmin⁻¹ respectively for T, S and V, however V was best amongst.

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

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327 **3.2 Design of the weeders**

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

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

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

333 The performance of V and S was higher than the T. The draft force requirement was
334 17.43, 21.81 & 21.67kgf, field capacities was 0.026, 0.033 & 0.33 hah⁻¹, weeding index was
335 90.71, 97.65 & 95.95 %, mean HR was 130, 124 & 124 beats min⁻¹ and EC was 20.35, 18.82
336 & 18.78 kJ min⁻¹ respectively for T, S and V. The curvature of handle and angle of operation
337 of existing weeder makes weeding operation difficult. It leads to lower field capacity and
338 higher energy consumption to perform the task. Among the developed weeders V shaped
339 blade weeder performed well; tip of the blade penetrates easily into the soil and cut the weeds
340 by sliding along the cutting edges. It offers less frictional resistance between blade and weed
341 stem, thus, operation became easier and consumes less energy.

342 **4. Conclusions**

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

347 **Acknowledgement**

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

350

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385 **Tables:**

386 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, φ (degrees ⁰)	35 to 45 ⁰	35
6	Handle length (mm)	H sin φ	1450

387 Table.2 HR, VO₂ 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					
5	0.5	92.4	0.46	9.24	Light
	1.0	97.9	0.53	10.50	Light
	1.5	101.2	0.56	11.13	Light
	2.0	105.6	0.61	12.18	Light
10	0.5	99.0	0.53	10.50	Light
	1.0	102.3	0.57	11.34	Light
	1.5	110.0	0.65	13.02	Light
	2.0	114.4	0.70	14.07	Light
15	0.5	102.3	0.57	11.34	Light
	1.0	108.9	0.64	12.81	Light
	1.5	113.3	0.69	13.86	Light
	2.0	116.6	0.72	14.49	Light
20	0.5	105.6	0.60	11.97	Light
	1.0	111.1	0.66	13.23	Light
	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

25	1.0	113.3	0.69	13.86	Light
	1.5	123.2	0.81	16.17	Moderately heavy
	2.0	129.8	0.87	17.43	Moderately heavy

b. Pulling force exertions

5	0.5	96.8	0.51	10.29	Light
	1.0	99	0.54	10.71	Light
	1.5	100.1	0.55	10.92	Light
	2.0	104.5	0.60	11.97	Light
10	0.5	104.5	0.60	11.97	Light
	1.0	106.7	0.62	12.39	Light
	1.5	111.1	0.67	13.44	Light
	2.0	112.2	0.68	13.65	Light

388 Table.3 LCP (Δ HR) of subjects for force exertion

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

389 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

390 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

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

392

393 **Figure legends:**

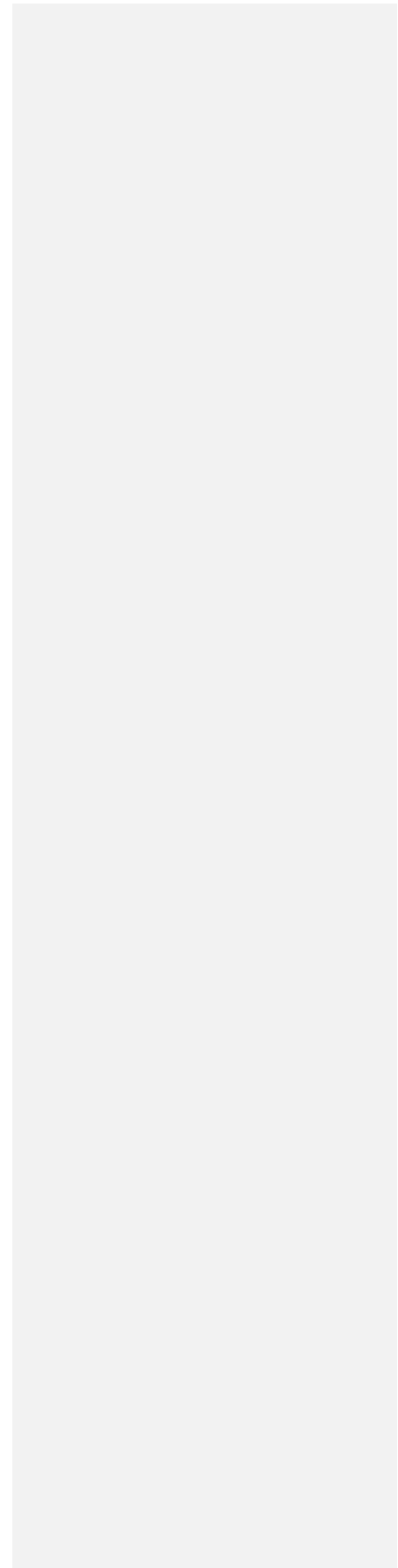
394 Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

395 Fig.2 Schematic view of the developed weeders

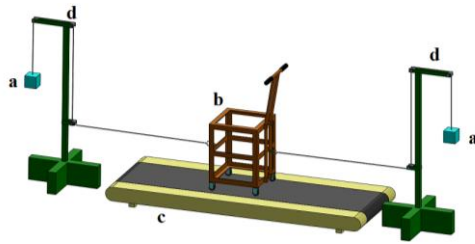
396 Fig.3 Performance on developed test rig

397 Fig.4 Weeding operation in the cotton field

398



399 **Figures:**



400

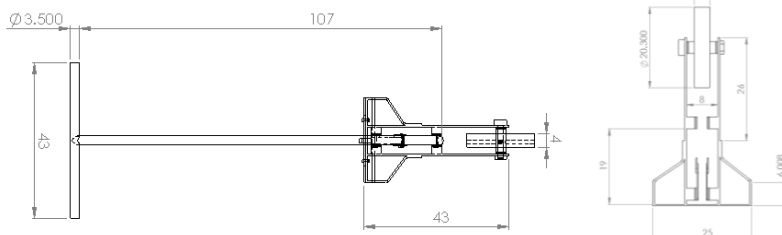
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Fig.1 Test rig to measure dynamic Push-Pull strength capabilities

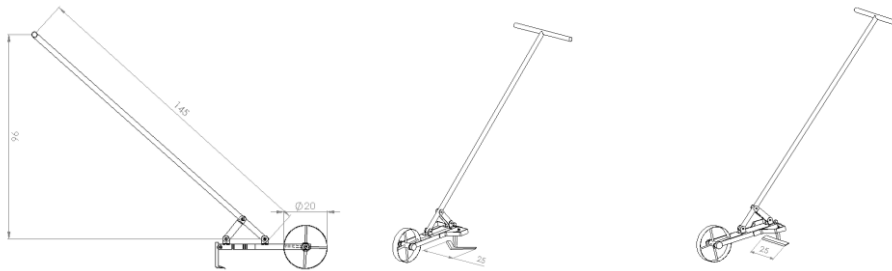
a = varying load; b = four wheeled cart; c = treadmill; d = supporting stands



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



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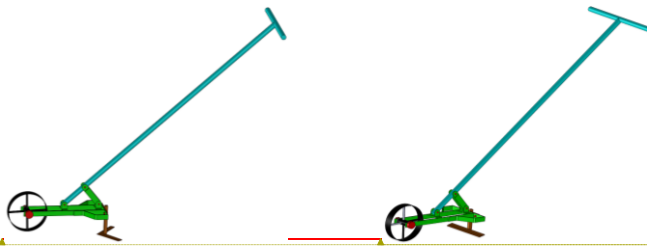
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b. Plan

c. Apex angle 90°

d. Apex angle 180°

(All dimensions are in cm)



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a. Apex angle 90°

b. Apex angle 180°

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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421 **List of changes made against the reviewer comments:**

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

423 All the corrections carried out in the manuscript were incorporated

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

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

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

429 The entire script is rewritten in past tense

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

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