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

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Existing manual hoes are 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 1.0 km h^{-1}, an operator can 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* weeders was higher than *T*. The field capacities were 0.026, 0.033 and 0.33 ha h^{-1} and energy expenditures were 20.35, 18.82 and 18.78 kJ min^{-1} respectively, for *T*, *S* and *V*; however *V* was best amongst the three.

Keywords: Dynamic force, energy expenditure, field capacity, heart rate, LCP.

WEEDS are major constraints in agricultural production and cause reduction of crop yield up to 30% to 60%. In agricultural operation weeding alone accounts 25% of the total labour requirement (900–1200 man-h ha^{-1}). Mechanical weeding through manual hoe is an effective method of weed control in dryland[1]. Energy requirement of khurpi is least but the work output is lowest, whereas the wheel hoes that are of push–pull type weeders cover maximum area with acceptable physiological demand, work performance and workers' preference[2]. An understanding of force exertions is of immense importance while designing a pushing or pulling task. Existing studies have principally been concerned with static tasks despite the knowledge that most agricultural activities are of dynamic nature and involve overexertion of musculoskeletal system. Accidents also occur due to slipping/tripping[3]. Snook[4] reported that 7% of low back injuries were associated with slipping/tripping accidents. At present, the design of manual weeders is based on static force exertion and most agricultural equipment designers considered static force to improve efficiency and durability. The fact to be considered is that, weeding operation is dynamic and associated with higher risk of injury[5]. In cases where dynamic pushing/pulling activities were 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 develop manually operated dryland weeders.

Manually operated weeders consist of ground wheel, long handle and tool frame. Ground wheel diameter varies from 200 to 600 mm; based on which 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 develop maximum power of 75 W (0.1 hp) which is expressed as

$$\text{Power (hp)} = \frac{\text{Draft (kg)} \times \text{speed (ms}^{-1}\text{)}}{75}. \quad (1)$$

The power and draft force varies with the speed of operation. Weeders can operate at a speed of 0.29 to 0.44 m s^{-1} (refs 6–8).

A laboratory test rig was developed to measure dynamic push-pull strength capabilities of agricultural workers (Figure 1). Twelve healthy male agricultural workers having mean age of 31.75 (±2.45) years 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[9].

Existing designs of agricultural machines limit the manual pushing/pulling force exertions to 30% of maximum static force capability, which is in the range of 39 to 43 N for Indian conditions. However, most agricultural activities involve continuous application of forces higher than 50 N (refs 9, 10). To predict the safe limit of force exertions, five levels of force exertion from 5 to 25 kgf with an increment of 5 kgf at each level and four levels of speed of operation from 0.5 to 2.0 km h^{-1} with an increment of 0.5 km h^{-1} at each level was selected. The physiological responses such as heart rate (HR), volume

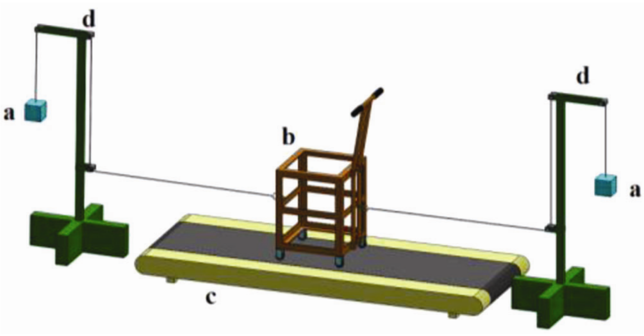

Figure 1. Test rig to measure dynamic push–pull strength capabilities. *a*, Varying load; *b*, four wheeled cart; *c*, treadmill; *d*, supporting stands.

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Table 1. Anthropometric parameters considered for weeder design

Weeder parameters	Anthropometric parameters	Design values
Handle holding height, H (mm)	Acromial height (5th and 95th percentile)	933.6 to 1031.8
Cross handle bar length (mm)	Elbow–elbow breadth (95th percentile)	430
Handle grip (mm)	Middle finger palm and grip diameter (inside) (5th and 95th percentile)	32 to 43
Elbow angle for handle holding (deg.)	Elbow flexon angle (85°–110°)	90°
Angle of weeder operation, ϕ (deg.)	35° to 45°	35°
Handle length (mm)	$H \sin\phi$	1450

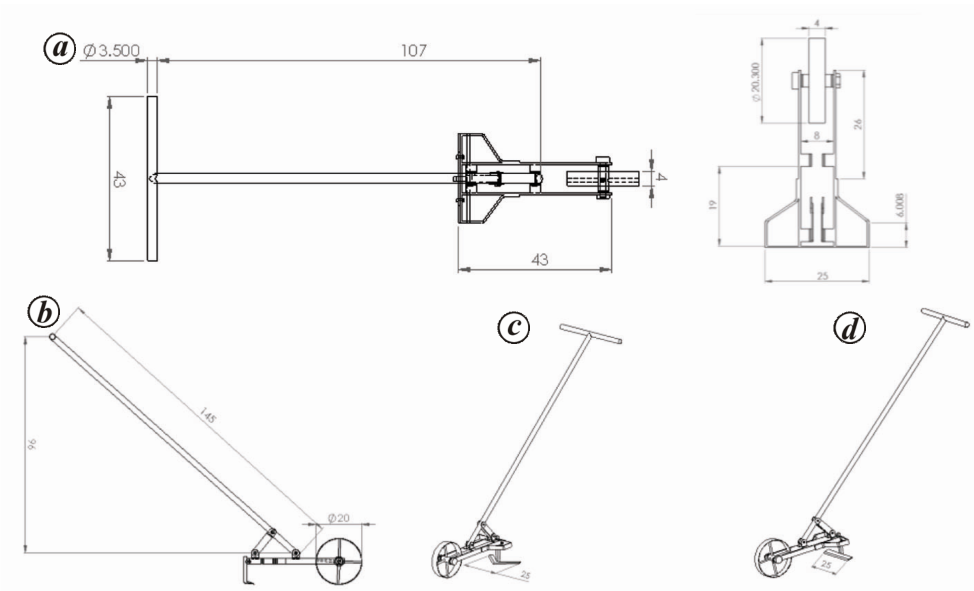

Figure 2. Schematic view of the developed weeders. ***a***, Elevation drawing of main frame and weeding blade holder assembly; ***b***, Plan; ***c***, Apex angle 90°; ***d***, Apex angle 180° (all dimensions are in cm).

of oxygen consumption (VO_2), and amount of energy expenditure (EC) were measured for 30 min 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.

After optimization of force and speed of operation, draft force can be decided. It also helps to later determine the depth and width of operation. The depth and width of cut along with unit draft, influence the draft requirement for weeding. The relation between these parameters is expressed as

$$D = (W \times d_{\mathrm{w}}) \times d_{\mathrm{u}}, \tag{2}$$

where D is the draft (kg), W the width of cut (cm), d_{w} the depth of cut (cm) and d_{u} the unit draft (kg cm^{-2}).

Generally dryland weeders were operated in light to medium soil. For optimum design of weeder, a unit draft and depth of operation was suggested[10] as 0.43 kg cm^{-2} and 20 mm respectively[11]. From eq. (2) width of cut obtained as

$$W = \frac{D}{d_{\mathrm{w}} \times d_{\mathrm{u}}}. \tag{3}$$

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

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

If we consider the speed of operation draft force can be obtained from eq. (1). By considering the average speed (0.36 m s^{-1}) a healthy man can exert maximum draft force of 21 kgf (ref. 10). It cannot be recommended unless proved practically.

The developed test rig simulates the pushing and pulling of weeders in the laboratory. Selected subjects were trained on the test rig. Figure 3 a and b illustrates the performance of pushing/pulling activities. The physiological responses of the subjects during the experiment

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

Load (kg)	Speed (km h^{-1})	HR (beats min^{-1})	VO_2 consumption (l min^{-1})	EC (kJ min^{-1})	Energy grade of work
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
25	0.5	108.9	0.64	12.81	Light
	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
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

Figure 3. Performance on developed test rig. ***a***, Push force; ***b***, pull force.

were measured which include HR, VO_2 consumption and EC. LCP was calculated based on the mean HR response. The recorded data was downloaded to a computer and analysed. The mean values of 6th to 15th min of operation were selected[12]. The safe and comfortable operational limits were drawn based on LCP and EC values obtained during the operation (Tables 2 and 3).

The minimal values were observed at 5 kgf of push/pull exertions and higher values observed at 25 kgf of push force exertion at all speed levels. The subject's physiological responses to operational speed varies significantly; at 0.5 km h^{-1} responses were very low. However most subjects felt it difficult to operate and reported shoulder and lower back pain due to slow speed. At 2.0 km h^{-1} for 20 to 25 kgf and 1.5 km h^{-1} for 20 kgf of push forces, physiological responses were much higher (LCP was >40 beats min^{-1}). Hence, these levels were not recommended. Usually agricultural activities involve high strength applications and operate at average speed of walking. From Tables 2 and 3, it can seen that, at 1.0 km h^{-1} (0.36 ms^{-1}) the subject is able to exert higher strength (maximum LCP of 38.6 beats min^{-1} and EC graded as light work). This was concluded earlier by eq. (1). Hence, 20 to 25 kgf of force application at 1.0 km h^{-1} speed of operation is the best design value[10,13,14] to perform work continuously for 8 h.

Weeders were developed after optimization of speed and force exertion. Equation (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, the width of cut for developed weeders was fixed to 250 mm. The weeders *V*, *S* and *T* were evaluated ergonomically in sandy loam soil (Figure 4 *a* and *b*). Results were tabulated and are presented in Tables 4 and 5.

The performance of *V* and *S* was higher than *T*. The draft force requirements were 17.43, 21.81 and 21.67 kgf, field capacities were 0.026, 0.033 and 0.33 ha h^{-1}, weeding indices were 90.71%, 97.65% and 95.95%, mean HR were 130, 124 and 124 beats min^{-1} and EC were 20.35, 18.82 and 18.78 kJ min^{-1} respectively, for *T*, *S* and *V*. The curvature of handle and angle of operation of the existing weeder makes weeding operation difficult. It leads to lower field capacity and higher energy consumption to

Figure 4. Weeding operation in the cotton field. ***a***, Twin wheel hoe; ***b***, Developed weeder; ***c***, Before and after weeding operation.

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

Load (kg)	Speed (km h^{-1})	ΔHR (beats min^{-1})	LCP (lower/higher than LCP)
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
Pulling force exertions			
5	0.5	16.5	Lower
	1.0	18.7	Lower
	1.5	20.9	Lower
	2.0	25.3	Lower
10	0.5	24.2	Lower
	1.0	26.4	Lower
	1.5	30.8	Lower
	2.0	33	Lower

Table 4. Field performance evaluation of the weeders

	Weeder type		
Parameters	*T*	*S*	*V*
Draft force requirement (kgf)	17.43	21.81	21.67
Mean travel speed (km h^{-1})	1.32	1.32	1.3
Power requirement (hp)	0.085	0.106	0.105
Field capacity (ha h^{-1})	0.026	0.033	0.033
Performance index (%)	2782.16	2992.23	2958.95
Weeding index (%)	90.71	97.65	95.95

Table 5. Ergonomic evaluation of the weeders

Parameters	Weeder type		
	T	*S*	*V*
Mean HR (beats min^{-1})	130	124	124
VO_2 consumption (l min^{-1})	0.97	0.90	0.90
EC (kJ min^{-1})	20.35	18.82	18.78
ODR	6.04	5.42	5.26
BPDS	39.2	36.8	35.2

ODR, Overall discomfort rate; BPDS, Body part discomfort score.

perform the task. Among the developed weeders, *V*-shaped blade weeder performed well as the tip of the blade penetrates easily into the soil and cuts the weeds by sliding along the cutting edges. It offers less frictional resistance between blade and weed stem, and hence, operation is easier and consumes less energy.

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

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ACKNOWLEDGEMENTS. We are grateful to AEC&RI, TNAU Coimbatore for financial and academic support to conduct the study.

Received 26 February 2016; revised accepted 25 May 2017

doi: 10.18520/cs/v113/i08/1601-1605

Weight–length relationship and Fulton's condition factor of the alligator pipefish, *Syngnathoides biaculeatus* (Bloch, 1785) from the Southeast coast of India

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The present study provides information on weight–length relationship (WLR) and Fulton's condition factor (*K*) of the alligator pipefish, *Syngnathoides biaculeatus* (Bloch, 1785) sampled from Palk Bay (PB) and Gulf of Mannar (GoM) regions, southeast coast of India. The pooled estimate for the parameter *b* of the WLR for *S. biaculeatus* ($n = 217$) was determined to be 1.75, indicating the negative allometric growth pattern ($b < 3$). The *K* values ranged from 0.65 to 1.35 (pooled, 0.84) and from 0.68 to 1.27 (pooled, 0.85) for populations of *S. biaculeatus* collected from PB ($n = 120$) and GoM ($n = 97$) respectively. The results may help address the concerns of conservation of *S. biaculeatus* in the wake of habitat loss and/or incidental by-catch.

Keywords: Allometric growth pattern, condition factor, population biology, *Syngnathoides biaculeatus*, weight–length relationship.

THE alligator pipefish or double-ended pipefish, *Syngnathoides biaculeatus* (Bloch, 1785) is listed as 'Data Deficient' in the Red List of Threatened Species by the

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