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Dynamic strength based dryland weeders – ergonomic and performance evaluation

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ABSTRACT

Human labour is a single costliest input in farming operations. Most of agricultural equipment designers regarded the operator as only another part of man-machine system and neglected their comfortness. Manually operated weeders are of push/pull type weeders, operated by application of force in dynamic motion. But, the existing dryland weeders designed based on static force exertion, even though they are in dynamic nature and require higher amount of force application than static ones. Hence, weeders of straight blade (apex angle 180^0) and V blade (apex angle 90^0) were developed for dryland conditions based on the dynamic strength optimized under laboratory conditions. The ergonomical and field performance evaluation was conducted for developed weeders along with one existing twin wheel hoe. The developed weeders showed an increased field performance in terms of field capacity, weeding efficiency and performance index with minimum physiological responses over twin wheel hoe. There was an increase in weeding efficiency, field capacity and performance index by 5, 21 and 7 percent and 4, 21 and 6 percent for straight and V blade weeders, respectively over twin wheel hoe. Further, the physiological responses such as heart rate, oxygen consumption, energy expenditure, acceptable work load (AWL), limit of continuous performance (LCP), overall discomfort rating (ODR) and body part discomfort score (BPDS) were reduced by 5, 7, 8, 8, 9, 11 and 6 percent for straight blade and 5, 7, 8, 9, 10, 13 and 10 percent for V blade respectively over twin wheel hoe.

INTRODUCTION

Human labour is a single costliest input in farming operations contributing to major part of the total cost of cultivation. Most designers of agricultural equipment regarded the operator as only another part of man-machine system, but none of them seem to concentrate on their comfortness. Hence, there is an urgent need to critically analyse agricultural tools/equipment for their ergonomical design in order to improve man-machine system efficiency without sacrificing the performance. The application of ergonomic principles are more relevant in the present-day situation in terms of providing proper design of hand tools and farm equipment. This will help to develop an appropriate design, labour effective and simpler operational tools. These, designs not only minimize the drudgery of labours, it also increases the productivity and effectiveness at minimized physiological expenditure levels. For ergonomical evaluation of the task, a cardinal principle and oxygen consumption rate of a person can be considered (Rodahl 1989, Kroemer and Grandjean 1997). In addition, perceived responses of the operator also play a major role in ergonomical designs. Weeding with traditional tools like *khurpi* and spade has to be performed in bending/squatting posture and it leads to 30-50 % more energy consumption than sitting or standing posture. These tools requires less energy consumption, but involves repetitive movement of body parts which may lead to musculoskeletal disorders, that outweighs its other advantages (Tewari *et al.* 1993). Whereas the wheel hoes, cover maximum area with the acceptable physiological demand, work performance and workers preference (Nag and Dutta 1979).

Manually operated weeders are of push/pull type, operated by application of force in dynamic motion. Most of the existing weeders designs are based on static force exertions, despite the knowledge that they are in dynamic nature and requires higher strength force compared to static force. However, the dynamic force exertions are lower than the static force exertions and involve higher risk of injuries and health complaints; thus, parameters optimized for static conditions may not be accurate for dynamic conditions (Snook 1978, Lee *et al.* 1991, Resnick and Chaffin 1995, Allread *et al.* 2000). Hence, a dryland weeder based on dynamic strength of agricultural workers has been developed and their performance was evaluated ergonomically in field conditions.

MATERIALS AND METHODS

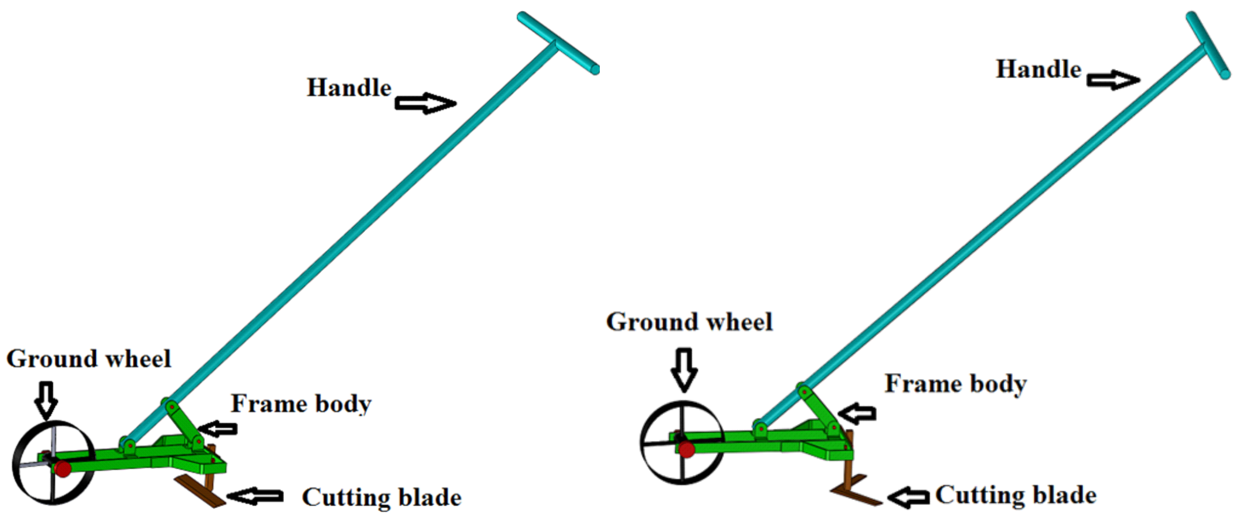
The dynamic push strength of agricultural workers to design the dryland weeders has been optimized to 20 to 25 kgf, at operating speed within 1.0 to 1.5 km/h (Sharma and Mukesh 2010, Chethan and Krishnan 2017). Two types of dryland weeder V and straight blade (S) (apex angle 90^0 and 180^0) having width of cut of 250 mm has developed and their field performance was evaluated ergonomically in comparison with one existing twin wheel hoe having the width of cut of 150 mm **(Figure 1).** The field evaluation of the weeders was conducted at cotton crop research fields, TNAU, Coimbatore (11°00’51.0"N, 76°55’43.4 "E; 11°00’30.4"N, 76°56’24.3"E). Later, based on the performance of the operators during weeding operation, the ergonomic parameters were drawn.

Selection of the subjects

Selection of the subjects plays a vital role in ergonomic evaluation. The subjects should be mentally and physically fit enough to undergo the trials. There should not be any major illness and handicaps and also they should be a true representative of the user population. The maximum strength or power can be expected from the age group of 25 to 35 years (Gite and Singh 1997, Zend *et al.* 2004). Hence, 5 male workers among the population in the mentioned age group were selected considering their expertise in weeding operation for investigation. The subjects were calibrated on the treadmill at different operating load to access their medical fitness under laboratory conditions **(Photo 1)**.

Ergonomical and field performance evaluation of the weeders

Ergonomic evaluation was carried out in terms of heart rate (HR), oxygen consumption rate (VO_2), energy consumption rate (EC), acceptable work load (AWL), limit of continuous performance (LCP), overall discomfort rating (ODR) and body part discomfort score (BPDS) to access the suitability of weeder to the operator. HR and VO_2 are the prominent parameters to access the human energy required to perform the task and there is a close interaction between circulatory and metabolic processes. Thus, by using a computerized ambulatory metabolic measurement system (K4b2) and HR monitors, the physiological responses of the operator can be easily predicted. The recorded values were transferred to the computer through RS232 interface. The



a. Straight blade hoe

b. V blade hoe

Figure 1. Schematic diagram of the developed weeders

Photo 1. Laboratory calibration of the subject

physiological responses increases rapidly at the beginning of an exercise and reaches a steady state by the end of sixth minute. The stabilized values of heart rate for each subject from 6th to 15th minute of operation were used to calculate the mean values. Based upon the obtained mean values the Energy consumed, AWL and LCP were calculated. Whereas, the ODR and BPDS are the subjects self reported estimates of effort expenditure, quantified using ratings of perceived exertion. For this, a 10 - point psychophysical rating scale (0 - no discomfort, 10 - extreme discomfort) was used. For BPDS rating scale technique, the subject's body is divided into 27 regions (**Figure 2**).

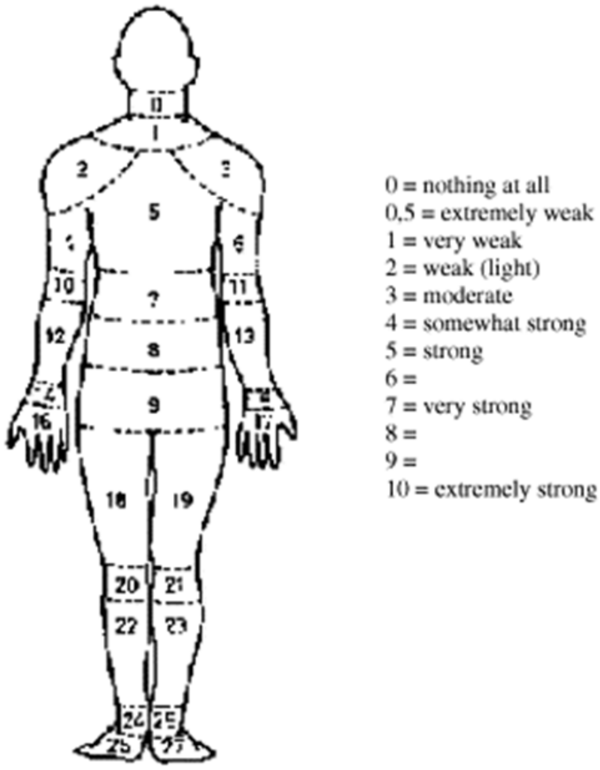


Figure 2. BPDS rating map (Nordic body map)

A body mapping similar to that of body mapping was made with thermocol to have a real and meaningful rating of the perceived exertion of the subject. The subject was asked to mention all body parts with discomfort, starting with the worst, the second worst and so on until all parts have been mentioned and the subjects were asked to give the markings according to the discomfort (Corlett and Bishop 1976, Lusted *et al.* 1994).

The field evaluation of the weeders was conducted to investigate the performance, suitability and comfortability of the weeders to the operator. The evaluation was done for developed weeders in comparison with the existing twin wheel hoe. Weeding efficiency, plant damage, draft force required to operate the weeder, power requirement, filed capacity and performance index are the operational parameters, which are criterion to decide the weeder performance and their suitability. The comparative parameters were also drawn for the selected weeders.

RESULTS AND DISCUSION

Selection of subjects

Five male subjects of group 25 to 35 were selected for ergonomical investigation from the agricultural labour community; medical fitness test was carried out prior to the experiment and details are furnished in **Table 1**. The maximum aerobic capacity of the selected subjects was varied from 1.40 to1.84 l/min (lpm). The varied individual differences in maximum aerobic capacity (VO_2max) was observed due to the differences in the ability to supply oxygen to the muscles and also due to genetic factors (Bridger 1995), whereas, Noakes (1988) suggested that failure of muscle power might be the reason for variation of the VO_2 max among the subjects.

Ergonomical and field performance evaluation of the weeders

Table 1. Details of the subjects participated in the study

Subject	Age (year)	Maximum HR, bpm	Maximum aerobic capacity (VO_2 max), lpm	Stature (mm)	Weight (kg)
S_1	34	186	1.61	165	63
S_2	30	190	1.74	163	74
S_3	36	184	1.55	175	68
S_4	36	184	1.41	168	67
S_5	27	193	1.84	156	56
Mean	32.6	187.4	1.63	165.4	65.6
SD	3.97	3.97	0.17	6.95	6.65

(bpm = beats per minute; lpm = litres per minute)

a. Weeding by developed weeder   b. Weeding by Twin wheel hoe

Photo 2. Weeding operations by different weeders

The ergonomical and field performance evaluation was carried out for all selected weeders (**Photo 2**). The results obtained were depicted in **Table 2 and 3**. During weeding operation the weeders were operated at an average speed of 1.3 km/h. It was noticed that, the developed weeders showed an increased performance in terms of field capacity, weeding efficiency and performance index with minimum physiological responses over twin wheel hoe. The heart rate values of the subjects during operation for developed weeders were comparatively in lower range than the twin wheel hoe (**Figure 3**); the mean heart rate values obtained were 127 beats/ min (bpm) for straight blade weeder, 126 bpm for V blade weeder and 133 bpm for twin wheel hoe and corresponding oxygen consumption rate values were 0.92, 0.92 and 0.99 lpm, respectively. The weeding task performed by all the weeders was graded as "*moderately heavy*". The AWL and LCP for weeding operation was varied from 56.20 to 61.80 and 44.47 to 49.27, respectively (**Table 2 and Figure 4**); whereas for twin wheel hoe it was highest.

In general, the work pulse values for weeders showed that, they could not be operated for longer duration without adequate rest since the work pulse values were more than the limit of continuous performance (LCP) of 40 bpm. Whereas, the perceived exertions *i.e.* ODR and BPDS for selected weeders was considered as "more than moderate discomfort" and the values were 6.22 and 39.88, 5.51 and 37.54 and 5.41 and 35.90 for twin wheel hoe, straight blade and V blade weeders, respectively. In weeding with twin wheel hoe, the maximum levels of pain experienced were in 4 categories. The majority of discomfort experienced by the subjects was at right shoulder, left shoulder, clavicle left, clavicle right, left arm, right arm, left elbow, right elbow, left forearm, right forearm, left wrist, right wrist, left palm and right palm. But, this was reduced in case of developed weeders; the maximum pain experienced was in only 3 categories with majority discomfort at right shoulder, left shoulder, clavicle left, clavicle right, left arm, right arm, left wrist and right wrist. This clearly shows that, the developed weeders reduced an operational discomfort (**Figure 4**). Further, the physiological responses of the subjects for developed weeder were much lower and field performance was superior compared to twin wheel hoe. From **Table 3**, it is clearly seen that, there is a considerable increase in performance index (3052.0

Table 2. Physiological responses of the subjects for weeding operation

Parameter	Twin wheel hoe	Developed weeders	
		Straight blade	V blade
Mean heart rate, bpm	133	127	126
Oxygen consumption, lpm	0.99	0.92	0.92
Energy expenditure, kJ/min	20.81	19.18	19.18
AWL, % VO_2 max	61.8	56.8	56.2
LCP, bpm	49.27	44.78	44.47
ODR	6.22	5.51	5.41
BPDS	39.98	37.50	35.90

Table 3. Field performance results of the selected weeders

Parameter	Twin wheel hoe	Developed weeders	
		Straight blade	V blade
Weeding efficiency (%)	92.5	97.8	96.3
Draft force (kg force)	17.75	22.24	22.13
Power requirement (hp)	0.087	0.108	0.107
Field Capacity (ha-h^{-1})	0.027	0.034	0.034
Performance index (%)	2838	3052	3018

Table 4. Percentage of increase in field performance of the developed weeders over twin wheel hoe

Parameter	Developed weeders	
	Straight blade	V blade
Weeding efficiency	5	4
Draft force	20	20
Power requirement	19	19
Field Capacity	21	21
Performance index	7	6

Table 5. Percentage of reduction in physiological responses of the subjects for developed weeders over twin wheel hoe

Parameter	Developed weeders	
	Straight blade weeder	V blade weeder
Mean heart rate	5	5
Oxygen consumption	7	7
Energy expenditure	8	8
AWL	8	9
LCP	9	10
ODR	11	13
BPDS	6	10

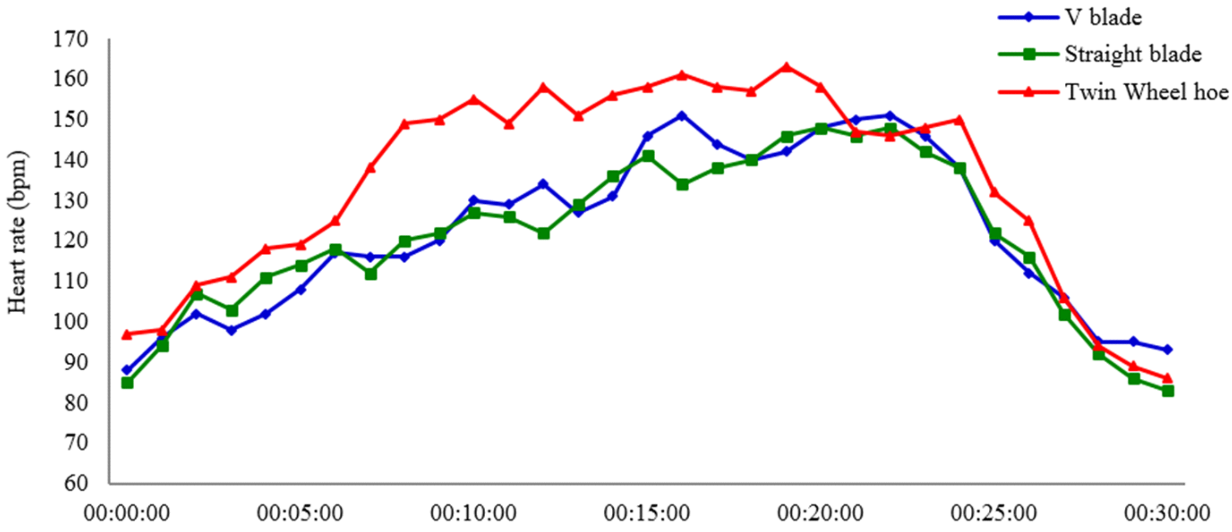


Figure 3. Heart rate responses of the subject for weeding by different weeders

and 3018%) and field capacity (0.034 ha/h each) for straight and V blade weeder over the twin wheel hoe. The energy consumption rate was reduced to19.18 kJ/min (Straight and V blade weeder) from 20.81 kJ/ min (twin wheel hoe). Due to the apex angle of 180^0, the weeding efficiency was higher for straight blade weeder; thus, the amount of power required to operate was quite high. Whereas, in V blade weeder, due to the apex angle of 90^0, the blade penetrated easily in to the soil, weed roots slides along the edges of the cutting blade and offered less frictional forces. Thus, the power requirement was quite lower in V blade weeder compared to other weeders. However, the plant damage of 1% was observed in all weeders during weeding operation.

The percentage of increase in field performance and reduction in perceived exertions of the developed weeders over twin wheel hoe are furnished in the **Table 4 and 5**. The draft force and the power requirement to operate the developed weeders increased due to larger width of cut (250 mm) over the twin wheel hoe; however, they showed an

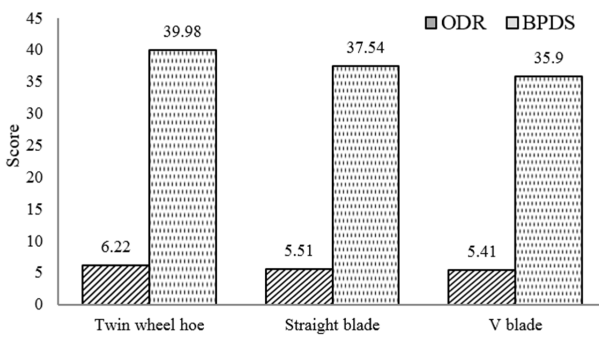


Figure 4. Perceived responses of the subjects for weeding operation

increased field performance with optimum physiological work load over the twin wheel hoe. Weeding by developed weeders enhanced the performance by increasing the weeding efficiency, field capacity and performance index to 5, 21 and 7 percent and 4, 21 and 6 percent for straight and V blade weeders, respectively. But the draft force requirement was increased to 20 percent over twin wheel hoe. Even though the draft force requirement increased there was no compromise in operator comfortness and seen a reduction of 5, 7, 8, 8, 9, 11 and 6 percent for straight blade and 5, 7, 8, 9, 10, 13 and 10 percent for V blade in heart rate, oxygen consumption, energy expenditure, AWL, LCP, ODR and BPDS respectively over twin wheel hoe.

The overall performance of the developed weeders was superior over twin wheel hoe, because of the operational comfort. The weeding operation from the selected twin wheel hoe was so tough for the subjects selected for the experiments. It was because of the anthropometric parameters considered for the twin wheel hoe was not according to the Tamil Nadu agricultural workers; thus created the operational discomfort during the weeding operation. The design parameters of twin wheel hoe such as the curvature of the cross handle bar, handle holding height and elbow angle during the weeding operation were not suited to the subjects, due to which subjects felt discomfort to operate it. Whereas, such problems were rectified in the developed weeders, due to which a good operational comfort and improved physiological responses were obtained even though the operational draft was higher than the twin wheel hoe, which is clearly seen in **Table 2 and 3**. It was obvious that, the developed weeders, *viz*. straight blade and V blade, not only increased the field capacity and performance index but also reduced the physiological work load on operator compared to existing twin wheel hoe.

The design criterion based on dynamic strength capabilities can improve the operational capacity of the operator with optimal physiological work load to perform weeding operation. The developed weeders performed better than the existing twin wheel hoe with minimal physiological responses. However, the performance of the developed V blade weeder was superior over the others due to the blade design.

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