Development and Physiological Cost Evaluation of a Modified Blade System for Power Weeder in Dry Land Cultivation

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Abstract: ***The introduction or development of mechanical weeders was a cost-effective and safe approach for weed-management in dry land cultivation. In this study, the existing power weeder was evaluated in the farm to assess their performance. Entangling of the weeds in the blade unit was commonly noticed for the power weeder causing reduced weeding efficiency and increased labour requirement. Hence modification is done by changing the rotary blades as helical blades to improve the penetration in the soil and there by removing the weeds effectively. The cardiac cost involved in the operation of the modified power weeder was found out and the mean working heart rate of the subject was 102 beats min^{-1}. The corresponding value of energy expenditure was 14.35 kJ min$^{-1.}$ The human energy expenditure was reduced to the tune of 36% after modification. The predicted oxygen consumption rate was 0.8497 l min^{-1} that is 41% of their aerobic capacity (VO_2 max) which was above the acceptable limit of 35% of VO_2 max. Mean overall discomfort rating on a 10 point visual analogue discomfort scale (0- no discomfort, 10- extreme discomfort) was 5.0 and scaled as "moderate discomfort" before modification where as ODR was 4.0 and scaled as "more than light discomfort" during operation of modified power weeder. The weeding index was found to be 85%. If only one worker is engaged for the weeding operation with this equipment, 5 min rest could be provided after 30 minutes of working. Based on the mean energy expenditure, the operation was graded as "Moderately Heavy".***

Keywords: power weeder; heart rate; energy expenditure; aerobic capacity; weeding index; discomfort

1. Introduction

Management of weeds is an important component of crop production technique as removal of weeds is expensive and hard to achieve at later stages. Weeds take away nutrients and harbour destructive insects, thus cause reduction in yield. It has been observed that of the total labour involved in agricultural work during the cultivating season, as much as 15%, is spent in cutting weeds from irrigated or dry lands (Vyavahare and Kallurkar, 2012). Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and water intake capacity. Mechanical weeders are performing activities such as weeding and hoeing simultaneously and thus reduces the time, cost and drudgery involved in manual weeding.

Ergonomics is often referred to an external triangle between efficiency, comfort and health. However, not enough attention has been given to ergonomics in farming operations and in the design of agricultural equipment. The application of ergonomics can help in increasing the efficiency and thereby productivity of the workers without jeopardizing their health and safety. The performance of any machine especially manually operated ones could be considerably improved if ergonomic aspects are given due consideration (Gite, 1993). Evaluation of energy expenditure of the power weeders are important from the safety point of view because whenever the physical capacity of a person is exceeded, it is bound to cause considerable fatigue and large reduction in the alertness of the person making the operation unsafe. Thus, investigations on ergonomical evaluation of power weeders can provide a rational basis for recommendation of methods and improvement in equipment design for more output and safety.

2. Materials and Methods

2.1. Subjects

Three healthy male operators based on age and medical fitness were selected for the study. The strength or power is expected to be maximum in the age group of 25 to 35 years (Grandjean, 1982; Gite and Singh, 1997). Hence three subjects were chosen from the age group of 25 to 35 years. The physiological characteristics of selected subjects are given in Table 1.

Table 1: Physiological characteristics of participants

Sl. No:	*Variable*	*Subjects*		
		1	*II*	*III*
1	Age, years	29	26	33
2	Body weight, kg	65	52	70
3	Height, m	1.65	1.63	1.83
4	Resting heart rate, beats min^{-1}	60.00	69.00	69.00
5	ECG	Normal	Normal	Normal
6	Blood pressure, mm of Hg	120/80	120/80	120/80

2.2. Establishing relationship between Oxygen uptake and Heart Rate

On a separate day and before performing activities, the relationship between heart rate and oxygen uptake for each subject was determined. Both heart rate and oxygen uptake have to be measured simultaneously in the laboratory at a number of different submaximal workloads (Maritz et al., 1961). Since the relationship between the two variables is linear during a typical submaximal workload, a subject's heart rate measured in the field can be converted into an estimate of oxygen uptake by referring to the laboratory data. The selected three subjects were calibrated in the laboratory by measuring oxygen consumption and heart rate simultaneously while running on the treadmill to arrive at the relationship between heart rate and oxygen consumption. The oxygen consumption was measured using Benedict-Roth spirometer and the heart beat rate was recorded using Polar heart rate monitor.

2.3. Modifications of power weeder

Power weeder is a manually operated implement powered by 5.5 Hp petrol engine (**Fig.1**) and designed to work in 93 cm spacing in dry lands. It works by the rotary motion of blades and the weeds were cut and soil was ploughed ensuring better soil aeration and water intake capacity. The blade unit (working part) of the power weeder was modified into helical blades for avoiding entangling of the weeds in the blade unit to improve the penetration in the soil and there by removing the weeds effectively (**Fig.2**).

2.4. Field layout experiments

The experiment was conducted in the farm of Farming Systems Research Station, Sadanandapuram, Kottarakkara, Kollam District, Kerala, India. The power weeder was put in proper test condition before conducting the tests. All the three subjects were equally trained in the operation of the power weeder. They were asked to report at the work site at 7.30 am and have a rest for 30 minutes before starting the trial. All the subjects used similar type of clothing. The subjects were given information about the experimental requirements so as to enlist their full cooperation.

Figure 1: Photographic view of power weeder

Figure 2: Photographic view of modified power weeder

The heart rate was measured and recorded using polar heart rate monitor for the entire work period. Each trial started with taking five minutes data for physiological responses of the subjects while resting on a stool under shade. They were then asked to operate the power weeder (already started by another person) for duration of 15 minutes and same procedure was repeated to replicate the trials for all the selected subjects.

2.5. Data analysis

The recorded heart rate values from the computerized heart rate monitor were transferred to the computer and the values of heart rate at resting level and from 6th to 15th minute of operation were taken for calculating the physiological responses of the subjects. The stabilized values of heart rate for each subject from 6th to 15th minute of operation were used to calculate the mean value for power weeder. From the mean values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects were predicted from the calibration curves of the subjects. The energy costs of the operations were computed by multiplying the value of oxygen consumption (mean of the values of three subjects) by the calorific value of oxygen as 20.88 kJ lit^{-1} (Nag et al., 1980). The energy cost of the subjects thus obtained was graded as per the tentative classification of strains in different types of jobs given in ICMR report as shown in Table 2 (Sen, 1969 and Sam, 2014).

Table 2: Tentative classification of strains (ICMR) in different types of jobs

Grading	*Physiological response*		
	Heart rate (beats min^{-1})	*Oxygen uptake, lit min^{-1}*	*Energy expenditure, kcal min^{-1}*
Very light	<75	< 0.35	<1.75
Light	75-100	0.35 - 0.70	1.75-3.5
Moderately heavy	100-125	0.70 - 1.05	3.5-5.25
Heavy	125-150	1.05 - 1.40	5.25-7.00
Very heavy	150-175	1.40- 1.75	7.00-8.75
Extremely heavy	>175	> 1.75	>8.75

2.6. Assessment of postural discomfort

Assessment of postural discomfort included overall discomfort rating (ODR) and body part discomfort score (BPDS). The subjects were asked to report at the work site at 8.00 AM and have a rest for 30 minutes before starting the trial. After 30 minutes of resting, the subject was asked to operate the power weeder for duration of two hours. Sufficient rest period was given for each subject between the two trials on the same day with the same subject.

2.6.1. Overall discomfort rating (ODR)

For the assessment of ODR**,** a 10 - point psychophysical rating scale (0 – no discomfort, 10 - extreme discomfort) was used which is an adoption of Corlett and Bishop (1976) technique. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly (**Fig.3**). A movable pointer was provided on the scale to indicate the rating.

Figure 3: Visual analogue discomfort scale for assessment of overall body discomfort

At the ends of each trial subjects were asked to indicate their overall discomfort rating on the scale. The overall discomfort ratings given by each of the three subjects were added and averaged to get the mean rating.

2.6.2 Body part discomfort score (BPDS)

To measure localized discomfort, Corlett and Bishop (1976) technique was used. In this technique the subject's body is divided into 27 regions as shown in Fig.4. A body mapping similar to that of Fig.4 was made 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 and the second worst and so on until all parts have been mentioned. The subject was asked to fix the pin on the body part in the order of one pin for maximum pain, two pins for next maximum pain and so on. The body part discomfort score of each subject was the rating multiplied by the number of body parts corresponding to each category. The total body part score for a subject was the sum of all individual scores of the body parts assigned by the subject. The body discomfort score of all the subjects was added and averaged to get a mean score.

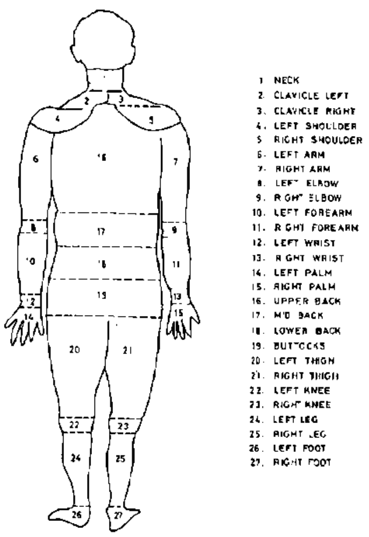

Figure 4: Regions for evaluating body part discomfort score

Weeding index was calculated by using the following formula (Anon 1985).

$e = [(W_1 – W_2)/W_1] \times 100$ ………….. (1)

Where,

e = weeding Index, per cent
W_1 = number of weeds/m^2 before weeding
W_2 = number of weeds/m^2 after weeding

Higher the value (e) means the weeder is more efficient to remove the weeds.

3. Results and Discussion

3.1 Calibration process

By using the data on heart rate and oxygen consumption rate, calibration chart was prepared with heart rate as the abscissa and the oxygen uptake as the ordinate for the selected three subjects.

It is observed that the relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects. This linear relationship defers from one individual to another due to physiological differences of individuals (Kroemer *et al.*, 2000). The relationship between the two parameters oxygen consumption (Y) and heart rate (X) was expressed by the following linear equations.

For subject I, $Y=0.0152 X - 0.8824 (R^2 = 0.9628)$ -- (1)
For subject II, $Y =0.0199 X - 1.2505 (R^2 = 0.9849)$ -- (2)
For subject III, $Y =0.0156 X - 0.7415 (R^2 = 0.9575)$ -- (3)

Where,

Y = Oxygen consumption, l min^{-1}
X = Heart rate, beats min^{-1}

It is observed that R^2 value (coefficient of determination) was very high for all the subjects who indicated that a good fit was arrived between oxygen consumption and heart rate.

3.2 Energy cost of operation

The average working heart rate of the operator was 128 beats min^{-1} and the corresponding energy expenditure was 22.44 kJ min^{-1} for the power weeder. However, the mean working heart rate of the operator was reduced to 102 beats min^{-1} and the corresponding energy expenditure was 14.35 kJ min^{-1} after modification. The human energy expenditure was reduced to the tune of 36% after modification. The weeding index was found to be 85%. Based on the mean energy expenditure, the operation was graded as “Moderately Heavy”.

3.3. Acceptable Workload (AWL)

To ascertain whether the operations selected for the trails were within the acceptable workload (AWL), the oxygen uptake in terms of VO_2 max (%) was computed. Saha et al. (1979)reported that 35% of maximum oxygen uptake (also called maximum aerobic capacity or VO_2 max) can be taken as the acceptable work load (AWL) for Indian workers which is endorsed by Nag et al, 1980 and Nag and Chatterjee, 1981. The oxygen uptake corresponding to the computed maximum heart rate in the calibration chart gives the maximum aerobic capacity (VO_2 max).

Each subject's maximum heart rate was estimated by the following relationship (Bridger, 1995).

Maximum heart rate (beats min^{-1}) = 200 - 0.65× Age in years

The mean oxygen uptake in terms of maximum aerobic capacity was calculated and it was 41% and the value was above the acceptable limit of 35% of VO_2 max indicating that the modified power paddy weeder is could not be operated continuously for 8 hours without frequent rest-pauses.

3.4. Overall discomfort rating (ODR)

Mean overall discomfort rating on a 10 point visual analogue discomfort scale (0- no discomfort, 10- extreme discomfort) was 4.0 and scaled as " More than Light discomfort" during weeding while it was 5.0 and scaled as "Moderate Discomfort" before modification.

3.5. Body part discomfort score (BPDS)

The majority of discomfort was experienced in the left shoulder, right shoulder, left wrist, right wrist, left arm and right arm region for all the subjects during weeding and the body part discomfort score of subjects during weeding with modified power weeder was 21.55.

3.6. Limit of continuous performance (LCP)

The work pulse (Δ HR) was 31 beats min^{-1} and it was within the limit of continuous performance of 40 beats min^{-1}.

3.7. Work rest cycle

For every strenuous work in any field requires adequate rest to have an optimum work out put. Better performance results can be expected from both the operator and the worker only when proper attention is given for the work rest schedule for different operations.

The actual rest time taken for each subject was found from the heart rate response curves of respective operations. The rest time was measured from the cease of the operation till the heart rate of the subject reaches resting level. The rest time taken was averaged to arrive at the mean value for power weeder.

The rest pause to the subject was calculated using the following formula as given by Pheasant (1991):

$$R = \frac{T\ (E-A)}{E-B}$$

Where.

R = Resting time (min)
T = Total working time/day (min)
E = Energy expenditure during working task (kcal/min)
A = Average level of energy expenditure considered acceptable (kcal/min)
B = Energy expenditure during rest (kcal/min)

Average level of energy expenditure considered acceptable was 4 kcal min^{-1} (Murrel, 1965).

Rest pause was calculated using the above formula as all the subjects operated continuously for the 30 min period and it was found that 5 min rest could be provided to operator who was engaged in operating the equipment. The rest period calculated was also in agreement to the recovery heart rate of operator. If two operators are engaged with a machine in shift, it could be operated for day-long work.

4. Conclusions

The blade system of existing power weeder was modified into helical blades for avoiding entangling of the weeds in the blade unit and was ergonomically evaluated at Farming Systems Research Station, Sadanandapuram, Kottarakkara, Kerala for weeding in dry land cultivation. The physiological cost was found out and the mean working heart rate of operator was 102 beats min^{-1}. The operation was graded as "Moderately Heavy". The work pulse of the modified power weeder is within the limit of continuous performance of 40 beats min^{-1}. The oxygen uptake in terms of VO_2 max was above the acceptable limit of 35% of VO_2 max indicating that the power weeder was could not be operated continuously for 8 hours without frequent rest-pauses. It is suggested that two operators may be engaged in shift for a day long work with power weeder. The weeding index was found to be 85%. Mean overall discomfort rating on a 10 point visual analogue discomfort scale (0- no discomfort, 10- extreme discomfort) was 4.0 and scaled as "More than Light discomfort". Shoulder and arm wrist regions are concerned areas of discomfort for operating power weeder. The human energy expenditure was reduced to the tune of 36% after modification.

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