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Effect of hand arm vibration on operator during power weeder operation in paddy field

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Abstract
India is the sixth biggest economy in the world where most of the people depend on the agricultural sector for their employment. The major crop in India is rice in which weeds are one of the foremost problems for reduction of yield. Among the weed control methods, the most efficient, less time consuming and eco-friendly method is mechanical weeding. It is done generally by power operated weeders. The power weeder is fitted with a motor which gives drives to the L type blade and weed is removed by the impact action of blade and soil. Because of all these actions, the farmers are subjected to very intense vibration which may cause different types of vibration disorders. So, to investigate this a study was conducted by selecting twenty numbers of subjects. To investigate the vibration transmitted to the subjects, an accelerometer was attached to the handle and the data was collected and analyzed. It was found that the overall weighted hand-arm vibration acceleration was found to be 6 m/s^2 whereas average daily vibration exposure was 5.2 m/s^2 which are greater than the exposure limiting value. This indicates that there is a chance of neurological injuries, vascular injuries and musculoskeletal injuries in hand. The vibrotactile sensitivity was found on the higher side which may results in white finger disease among the operator.

Keywords: weeder, vibration, vibration disorders, accelerometer, exposure limiting value, vibrotactile sensitivity, white finger disease

Introduction

India is the sixth biggest economy in the world where most of the people depend on the agricultural sector for their employment. The agriculture sector contributes 48.9 percent of workforce in employment (ILO, 2016) [1]. It is estimated that India's population will reach to 1.7 billion and food demand will cross 400 million tonnes (Rao *et al*.). Rice is one of the most widely cultivated crops in India and is the second largest producer accounting to 20 percent of the world of world production. In rice farming weeds is one of the foremost problems for the decrease in yield. Weeds consume crop plants nutrients and in the lack of an effective control measure, eliminate 30 to 40 percent of applied nutrients resulting in a substantial decrease in yield (Dryden and Krishnamurthy, 1977) [3]. Weeds decline the crop yields from 15 to 50 percent influenced by the species, density and weeding period (Mirza *et al*., 2009) [4]. So, appropriateness weeding operation is required for the rice crop to control the weeds and to upturn the production. Among the weed control methods, the most efficient, less time consuming and eco-friendly is mechanical weeding. By mechanical weeding, the weeds are uprooted thereby retaining loose soil surface, ensuring better soil aeration and increasing the capacity of water consumption of the soil (Goel *et al*., 2008). Power operated mechanical weeder generally consists of an engine, power transmission unit and blades. The to and fro motion of the piston caused by the combustion inside the engine provides rotational motion of the blades. The rotating blades have to strike on the ground for proper weed removal and burying them in the soil. All these actions generate vibration which is transmitted to the machine handle and then to the operator's hand. The long-term exposure of vibration may cause different types of disorders and a combination of these is called Hand Arm Vibration Syndrome (HAVS) (Griffin, 2001) [6]. Factors affecting HAVS include occupational safety, health condition, ergonomics factors, work rest cycle and vibration exposure (Armstrong *et al*., 1987) [7]. Many studies were conducted regarding the hand transmitted diseases in different countries. Among 21000 workers, 154 workers were found to have symptoms of HAVS due to exposure of hand-arm vibration environment in a shipbuilding industry in South Korea (Yoo *et al*., 2005) [8]. In India, a study was conducted to access the effect of hand-transmitted vibration during tillage work and found that in 13 percent of tractor operator working eight hours per day, the latency period for white finger disease due to vibration was 13 years (Dewangan *et al*., 2013) [9]. In 2012, cross-sectional study in the influence of hand-transmitted vibration on operators' health depicted that the exposure of segmental vibration resulted in vascular and neurological syndromes, reduction in operators' working efficiency and affecting the social life (Deshmukh and Patil, 2012) [10]. No vibration related study has done on the effect of hand-held power-operated weeder work in the agricultural industry on the hand function due to hand-transmitted vibration. Several diagnosis techniques have been used to investigate HAVS, but none of them clearly established to investigate the cause of the vibrating tool (Azmir et. al., 2015) [11].

In view of the present discussion, a study was undertaken at Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India to quantify the hand-arm vibration transmitted to the operator's hand during weeding operation with power weeder. The collected data were also analyzed so that its consequences can be predicted as per limit set by the International Standard Organisation (ISO 5349:2001).

Materials and Method

Selection of Power Weeder

The power weeder available in College of Agricultural Engineering and Technology, OUAT, Bhubaneswar was selected for the study (Fig.1). It consists of 1.75 hp engine, L type blade, gearbox, mainframe, rotary wheel, float, handles, and controls. The engine and all accessories are mounted on the main frame fabricated out of mild steel pipe. Engine axis is fitted to the final drive mechanism through centrifugal clutch with frictionless roller bearing with packed seal. A throttle is provided to control the speed of the engine on right side handle. The axle is driven by a propeller shaft encased in a casing. Speed reduction of 40:1 was achieved by a worm gearbox. The detailed specification of the weeder is given in Table 1. Fig 2 shows L type blade which is attached in the power weeder for performance evaluation.

Fig 1: Power Weeder

Fig 2: L type blade

Table 1 Specification of Garuda paddy power weeder engine

Sl. No	Item	Specifications
1	Weight, kg	17.00
2	Vertical height, mm	850
3	Width, mm	720
4	**Prime mover**	
	Type of engine	Two-stroke single cylinder forced air cooled petrol engine.
	Displacement	43 cc (Bore 40 mm, Stroke 34 mm)
	Power	1.75 hp
	Rated speed	6500 rpm
	Torque	2.35 Nm @ 4000 rpm
	Carburetor	Diaphragm type
	Starting	Recoil start
	Dry weight	3.8 kg
5	**Drive**	
	Clutch	Centrifugal expanding shoe type
	Gear reduction	Worm type reduction of 40:1
6	**Skid**	
	Skid dimensions (L×B×H)	1000×150×50 mm
	Runners below skid	2 Nos. wooden / nylon runners
7	**Weeding rotor**	
	Blade Shape	L blade
	No of blades/rotor	4
	Row spacing	Adjustable 220, 240, 260 and 300 mm
	The width of the weeding rotor	150, 140 and 130 mm variable by changing the blade

Selection of Subjects

Twenty number of subjects were selected for the weeder testing in the age group 18-30 years as the highest strength level was obtained between this age group. All the subjects were physically fit and well-practiced with the weeding operation by power weeder. Before conducting the experiments, the anthropometric data were measured and tabulated in Table 2. The physiological parameters of the operator were also measured before and after the experiment of both L type blade and Hatched type blade.

Table 2: Physiological parameters of the selected subjects (n=20)

Sl. No	Dimensions	Range	Mean	Standard Deviation	5th Percentile	95th percentile
1	Weight, kg	34.0-77.0	51.8	7.0	40.4	63.3
2	Stature, mm	1412-1850	1635	69	1521	1749
3	Vertical reach, mm	1751-2390	2097	92	1945	2249
4	Vertical grip reach, mm	1632-2285	1989	93	1836	2143
5	Eye height, mm	1303-1730	1517	65	1410	1625
6	Acromial height, mm	1137-1540	1361	61	1260	1462
7	Elbow height, mm	850-1170	1032	49	951	1112
8	Olecranon height, mm	832-1130	1004	48	926	1083
9	Iliocristale height, mm	774-1063	937	48	857	1016
10	Iliospinale height, mm	730-1021	875	49	795	956

11	Trochanteric height, mm	565-925	808	59	710	905
12	Metacarpal –iii height, mm	575-815	691	39	626	756
13	Knee height, mm	380-580	485	34	429	542
14	Arm reach from the wall, mm	702-1030	844	47	767	921
15	Thumb tip reach, mm	561-890	749	60	650	848
16	Grip diameter (inside), mm	35-61	47	5	39	55
17	Grip diameter (outside), mm	61-115	86	9	71	101
18	Forearm hand length, mm	390-552	462	29	415	510
19	Elbow grip length, mm	290-498	368	34	313	424
20	Hand length, mm	126-226	180	12	160	200
21	Palm length, mm	75-140	104	9	90	118
22	Hand breadth across thumb, mm	72-135	97	10	80	115
23	Hand breadth across metacarpal III, mm	60-105	76	9	61	62

Field Testing

The field available in the Central Farm OUAT was selected for testing of the weeder. The field was divided into two parts each one for each type of blade. It was done after 25-30 days of operation. The operation of the weeder was done in two alternate rows interleaving one row in between. After this weeder was operated in a left out row and the alternate row interleaving already weeded row in between them. Fig.3 shows the field which was selected for the testing of power weeder.

Fig 3: Experimental field

Physiological parameters

The physiological parameters of the operators were measured after completion of the test or during operation with each blade. The detailed procedure for measuring the parameters are described below.

Heart rate

Herat rate is one of the most important parameter in physiological study. During weeding operation heart rate was measured by a computerized heart rate monitor. The collected data was then transferred to computer and the 6th and the 15th minute operation were taken for calculation of physiological response.

Volumetric Oxygen Consumption

The volumetric oxygen consumption was measured by a portable K4B2 instrument available in College of Agricultural Engineering and technology, OUAT. It was measured during weeding operations. As the usage of the portable unit in the wetland condition was found to be difficult, the measured continuously recorded heat rate was adopted for the indirect assessment.

Fig 4: Heart rate and VO_2 measurement

Energy expenditure rate

The energy cost of the operation was calculated by multiplying the value of oxygen consumption rate by the calorific value of oxygen 20.88 kJ lit^{-1} (Nag *et al*., 1980).

Body parts discomfort ratio

The localized discomfort in the body was measured by the technique that the body was divided into 27 regions (Corlett and Bishop, 1976). The subjects were asked to mention all the 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 pains 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 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. The regions for evaluating the body part discomfort score was given in Fig. 5

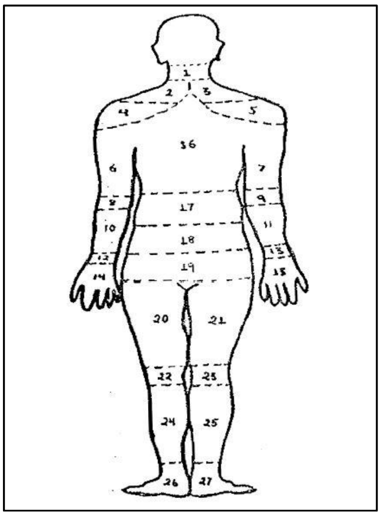

Fig 5: Regions for Evaluating Body Discomfort Score

1	Neck	15	Right palm
2	Clavicle left	16	Upper back
3	Clavicle right	17	Mid back
4	Left shoulder	18	Lower back
5	Right shoulder	19	Buttocks
6	Left arm	20	Lift thigh
7	Right arm	21	Right thigh
8	Left elbow	22	Left knee
9	Right elbow	23	Right knee
10	Left forearm	24	Left leg
11	Right forearm	25	Right leg
12	Left wrist	26	Left foot
13	Right wrist	27	Right foot
14	Left palm		

Experimental Setup for vibration measurement

Fig 3 shows the schematic representation of the experimental setup for hand-arm vibration measurement in power weeder. The measurements were done as stated in the ISO 5349-1:2001 standard. The experimental setup consists of the tri-axial accelerometer to access the vibration generated from the power weeder, data logger to collect the data from the accelerometer and transfer it to the computer, a battery unit for power supply and a computer for collecting and storing of data. The accelerometer was installed near to the grip of the handle. The vibration data were collected at a rate of 500 Hz in the time domain. for each subject three replications were done. The vibration is measured in x-axis, y-axis, and z-axis. The sign convention of the axes for hand-arm vibration is shown in the Fig.7. The position of the tri-axial sensor in the handlebar of the power weeder was shown in Fig. 6.

Fig 6: Position of triaxial sensor in the handlebar

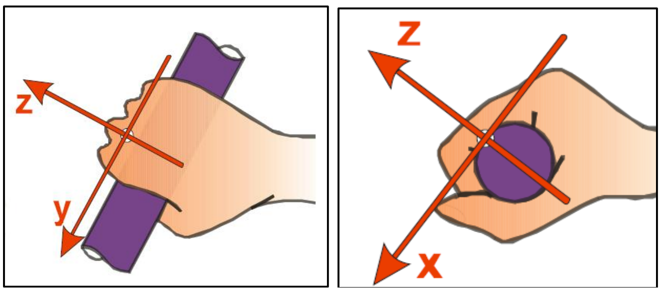

Fig 7: Sign Convention for Hand Arm Vibration Measurement

Analysis of vibration data

The vibration data collected in weeding operation at full throttle and half throttle condition was analyzed as stated in ISO 5349-2:2001. The vibration data were collected in the time domain. In the software, it was first converted to the frequency domain. The frequency domain converted data is again converted to 1/3rd Octave band frequency data. and finally, it was analyzed for the 1/3rd-octave band. Then weight was applied as per ISO 5349-1:2001 to the data in the frequency range 8-1000 Hz. The weightages were applied to take care of the risk of damage to hand from different frequencies range. Because of the this, the weighted acceleration decreases when the frequency increases. For hand-arm vibration analysis, only one weighing data is used for all the three axes of vibration i.e. X, Y and Z axis. After applying weightage, the overall acceleration was calculated by using the formula given below.

$$a_{hv}=\sqrt{a_{hwx}^2+a_{hwy}^2+a_{hwz}^2}$$

Where, a_{hv} = overall weightage vibration acceleration

a_{hwx} = weighted vibration acceleration for x-axis

a_{hwy} = weighted vibration acceleration for y-axis

a_{hwz} = weighted vibration acceleration for z-axis

Statistical analysis of overall weighted vibration data

For each operator, the test was repeated for three times. Hence for twenty operators, sixty numbers of data were collected. To check the variability of data for each operator and within the operator, ANOVA analysis was done for 5 percent level of significance. The calculated F value was compared with the critical value and P-value was calculated for investigating the variability among test data. The ANOVA analysis was done considering the null hypothesis as there is no significant difference between the data and the alternate hypothesis as there is a significant difference between the data.

Daily vibration exposure

The risk from hand-arm vibration affect the people in many industries. The risk increases, when the workers are exposed to higher magnitude vibration with a longer period of time. So, to investigate the vibration hazard and risks, Directive 2002/44/EC gives Daily Vibration Exposure A(8). It is the quantity of hand-arm vibration a worker exposed on daily basis with a reference to eight hours of working per day. It depends on both the magnitude and duration of exposure to vibration. The daily vibration exposure A(8) can be calculated from the vibration magnitude and duration by using the formula given below.

$$A(8)=a_{he}\sqrt{\frac{T}{T_0}}$$

Where, a_{hv} = overall vibration magnitude, m/s^2

T = actual duration of exposure, h

T_0 = reference duration of exposure i.e. 8 h

The Directive also set Exposure Action Value (EAV) and Exposure Limiting Value (ELV). EAV is the value of daily vibration exposure above which action should be taken to minimize the exposure whereas the ELV is the magnitude above which the workers should not be exposed. As per the directive, the EAV is 2.5 m/s^2 A(8) and ELV is 5 m/s^2 A(8). The weeder vibration was also converted A(8) values and its severity to the operator was analyzed.

Rotor speed measurement

For measurement of rotor speed, a non-contact type tachometer was used. A sticker was fixed to the rotor shaft. By focusing the tachometer laser light on the sticker the speed of the rotor was measured. By keeping the throttle of the weeder in three different positions i.e. high, medium and low, three different rotor speed was measured. Fig 6 shows the rotor speed measurement by the non-contact type tachometer.

Vibrotactile sensitivity by scoring results of blanching

The subjects are instructed to operate the weeder continuously 15 min in the field for both types of rotary blades. The questions asked to the operator about the blanching, tingling or numbness sensation immediately after the operation. The extent of blanching was assessed by a numerical scoring system in which total score out of 66 for all 10 digits was obtained (Griffin, 1986) [6]. The scoring parts are shown in Fig. 7.

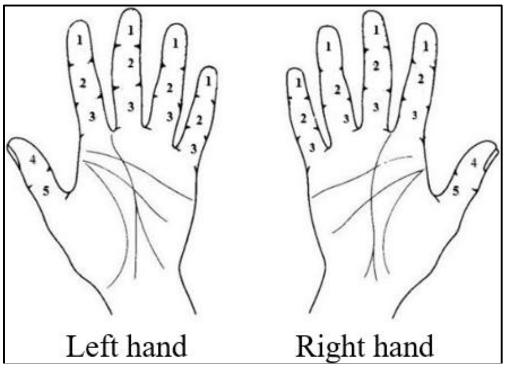

Fig 7: Method of scoring reports of blanching

Result and Discussions

Physiological Parameters of Workers

The field performance parameters of the speed of operation, theoretical field capacity, effective field capacity field efficiency, the average time of operation, fuel consumption, Heart Rate work, Oxygen consumption work, Relative Cost Work Load, and Energy Expenditure Rate was calculated and shown in Table 3.

Table 3: Physiological parameters of worker

Parameters	Range	Mean	Standard deviation
HR work, beats/min			
After 5 min	131-138	133	2.91
After 10 min	132-142	136	4.06
After 15 min	141-156	149	5.68
Mean HR work	135-145	139	4.22
VO_2 work, l/min			
After 5 min	0.99-1.12	1.05	0.05
After 10 min	1.04-1.15	1.07	0.48
After 15 min	1.28-1.33	1.28	0.03
Mean VO_2	1.11-1.18	1.13	0.19
RCWL, % of VO_2 max	50.4-60.8	55.9	3.92
Energy expenditure rate, kJ/min	22.8-24.7	23.78	0.71

Field Performance Parameters of Power Weeder

For performance evaluation of the weeder, it was tested for measurement of field efficiency, weeding efficiency and plant damage. For each performance parameter, five replications were done. The range, mean value and standard deviation were given in Table. 4.

Table 4: Field Performance Parameters of the weeder

Sl. No	Parameters	Range	Mean	S.D
1	Field Efficiency, %	73.2-75.8	74.23	1.35
2	Weeding Efficiency, %	80.6-85.5	83.65	2.49
3	Plant Damage, %	3.24-4.83	3.82	0.68

The less field efficiency of the weeder was due to time loss such as higher turning time, operator's inability to balance it for a long duration and adjustment time of the weeder. The power weeder can tilt the soil to the desired depth. Hence it can work very efficiently. But due to its rotating parts, it can damage the plants when it comes closer to the rows. Because of this limitation, the weeding efficiency was found to be 83.6 percent. The plant damage was 3.82 percent. The high level of plant damage is due to the higher speed of rotation of blades and higher width of cut which when brought nearer to the plant, caused injury to it by cutting either stem or root.

Overall Weighted Vibration

Table 5 shows the overall weighted vibration and daily exposure value A(8). This is the overall weighted vibration over three axes i.e. x, y, and z-axis. The overall weighted vibration value ranges between 6.13 m/s^2 to 5.89 m/s^2 with an average value of 6 m/s^2. The Daily vibration exposure A(8) is calculated assuming that the workers are working in the field for 6 hours per day. Its value ranges between 5.31 m/s^2 to 5.10 m/s^2 with an average value of 5.2 m/s^2. In all the cases the daily vibration exposure A(8) was found to be more than the ELV i.e. 5 m/s^2. Hence there is a chance of neurological injuries, vascular injuries and musculoskeletal injuries in hand.

Table 5: Overall weighted vibration and daily vibration exposure A(8) in Weeder operation

Subjects	Overall Weighted Vibration, m/s^2			Daily Vibration Exposure A(8), m/s^2		
	Replications			Replications		
	1	2	3	1	2	3
1	5.96	6.01	6.04	5.16	5.21	5.23
2	5.98	5.99	5.99	5.18	5.18	5.19
3	5.99	5.96	6.01	5.18	5.16	5.20
4	6.03	5.99	5.96	5.22	5.18	5.16
5	5.98	5.95	6.03	5.18	5.15	5.22
6	5.92	5.95	5.89	5.13	5.15	5.10
7	5.92	6.04	6.07	5.13	5.23	5.26
8	6.01	6.02	5.99	5.20	5.21	5.19
9	5.92	6.01	5.99	5.13	5.21	5.19
10	5.99	6.13	5.99	5.18	5.31	5.19
11	6.04	6.08	6.01	5.23	5.27	5.20
12	5.98	6.05	5.99	5.18	5.24	5.19
13	6.02	6.06	5.99	5.21	5.25	5.19
14	6.03	6.01	6.03	5.22	5.21	5.22
15	5.99	6.02	5.92	5.18	5.21	5.13
16	5.99	6.01	6.03	5.19	5.20	5.22
17	5.97	6.01	5.96	5.17	5.20	5.16
18	5.98	6.04	5.96	5.18	5.23	5.16
19	6.08	6.00	6.04	5.27	5.19	5.23
20	5.97	6.03	5.99	5.17	5.22	5.19

Statistical analysis of daily exposure vibration A(8)

Table 5 shows the statistical analysis result of the daily vibration exposure data. The F calculated value is less than the F critical value. Hence the null hypothesis as stated in the previous section is true and there was no significant difference among the measured data i.e. all the data were at par.

Table 6: Statistical analysis of daily exposure vibration

Source of Variation	SS[1]	df[2]	MS[3]	$F_{calculated}$	$F_{critical}$
Between Replication	0.007659	2	0.003829	2.814688	3.158843
Within Subjects	0.077549	57	0.001361		
Total	0.085208	59			
[1]Sum of square [2]Degree of Freedom [3]Mean sum of square					

Effect of weeder rotor speed on vibration

The effect of rotor speed of vibration was studied by taking three rotor speed i.e. 150 rpm, 180 rpm, and 210 rpm. In each speed, the hand-arm vibration transferred to the handle from engine and impact action of the rotor blade on the ground was measured. The vibration data then converted to daily vibration exposure considering the subjects working on the field for a duration of 6 hours. Fig.8 shows the effect of rotor speed on vibration. From the figure, it is clearly seen that with an increase in rotor speed from 150 to 210 rpm the daily vibration exposure increases from 5.8 m/s^2 to 6.2 m/s^2.

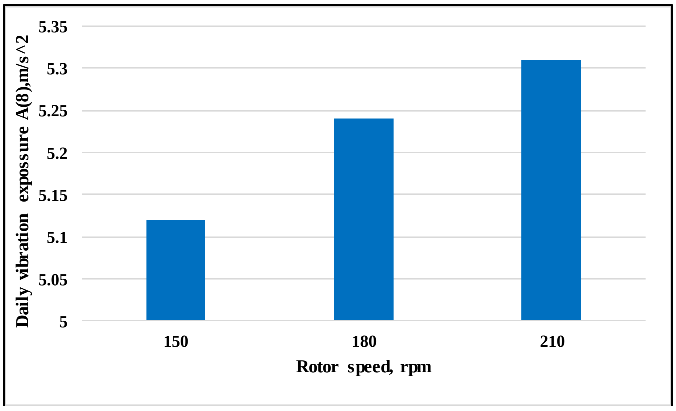

Fig 8: Effect of rotor speed on daily vibration exposure A(8)

Effect of vibration on vibrotactile sensitivity by blanching scoring

Table 7: Blanching scores by the operator for L type blade

	Left hand					Right hand				
Digit	Thumb	1	2	3	4	Thumb	1	2	3	4
Possible score	4+5	1+2+3	1+2+3	1+2+3	1+2+3	4+5	1+2+3	1+2+3	1+2+3	1+2+3
Actual score	0	6	6	3	1	0	6	6	3	1
Total score	16/33					16/33				

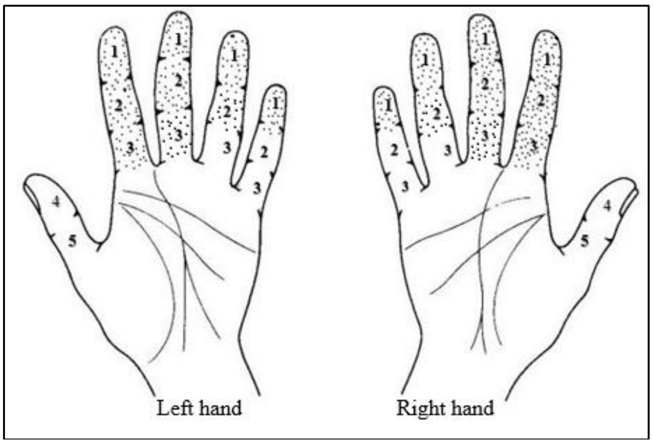

Fig 9: Blanching scores for L type blade

From the Table 3.1, it was observed that had an effect on vibrotactile sensitivity by blanching scoring method. It was also observed from Fig. 9 that the power weeder is more sensitive. There is the possibility of getting the vibration-induced white finger on both the hands. The blanching scores on both the hands indicate chances of having numbness in these fingers. This may be due to less blood circulation.

Conclusion

The performance evaluation of Power Operated Lowland Paddy Weeder was evaluated in the Central Farm of Orissa University of Agriculture during Kharif 2017. It was evaluated with twenty male workers with the age group of 18-35. The mean value of age, height, and weight observed to be 26.6 years, 159.4 cm and 59 kg respectively. The weight of the Power Weeder was 17 kg without fuel. From the testing of the weeder, the following conclusions were drawn.

1. The mean value of physiological parameters was working Heart rate, Oxygen Consumption Rate, Relative Cost of Work Load and Energy Expenditure Rate observed to be 139 beats/min, 1.13 l/min, 55.9 percent and 23.78 kJ/min respectively.
2. The mean value of field efficiency, weeding efficiency, and plant damage was found to 73.23 83.65 and 3.83 percent, respectively.
3. The average overall weighted vibration among all three axes was found to be 6 m/s^2 whereas the average daily vibration exposure was 5.2 m/s^2.
4. On statistical analysis, it was found that all the samples collected were at par which means there is no significant difference among the samples collected as $F_{calculated}$ was 2.81 which is less than $F_{critical}$ value i.e. 3.15.
5. With the increase in speed of operation from 150 rpm to 210 rpm the daily vibration exposure A(8) was found to be increased from 5.12 to 5.31 m/s^2.
6. The vibrotactile sensitivity of the weeder is more which may cause vibration-induced white finger.

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