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PHYSIOLOGICAL COST AND SUBJECTIVE ASSESSMENT OF RICE TRANSPLANTERS FOR WOMEN OPERATORS

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ABSTRACT

Several models of rice transplanters are available in the market to ease the transplanting work. However, the safety and efficiency aspects of these transplanters with respect to women workers has not been studied. Therefore, the present study was aimed to ergonomically evaluate the commercially available three models of rice transplanters *viz*., Redlands 8 row riding type transplanter, Mahindra 4 row walking type transplanter and Manual 2 row transplanter. A significant variation in heart rate and energy expenditure in the operation of different models of transplanters was observed. Heart rate was lowest in Redlands 8 row riding type transplanter (110.5 beats min^{-1}) and maximum in traditional method of transplanting (148.5 beats min^{-1}). The average heart rate before 9 am was 119.9 beats min^{-1} whereas after 11 am it increased to 142.8 beats min^{-1}. Overall discomfort score varied from 3.0 to 8.4 and were scaled as " light discomfort" to "more than moderate discomfort" for selected operations. The body part discomfort score was maximum (46.8) in transplanting manually and minimum in transplanting with Redlands 8 row riding type transplanter (20.15). The work rest cycle was 30 min work followed by 2 min rest for Redlands 8 row riding type rice transplanter, 9 min rest for Mahindra walking type, 12 min rest for manual transplanter and 14 min rest for traditional method. Based on these results it was found that 8 row riding type transplanter was more suitable and ergonomically comfortable for the women operators.

Keywords: Energy expenditure, ergonomics, heart rate, rice transplanters, women workers

INTRODUCTION

Rice is grown in more than one hundred countries with a total harvested area of about 158 million hectares, producing more than 700 million tons grain annually (Ricepedia, *http://ricepedia.org/rice-as-a-crop/rice-productivity*). Nearly 640 million tons of rice are grown in Asia, representing 90% of global production. The highest productivity is 6710 kg ha^{-1} in China, followed by Vietnam (5573 kg ha^{-1}), Indonesia (5152 kg ha^{-1}), Bangladesh (4375 kg ha^{-1}), etc. (NFSM, 2016). In India rice is grown in 43.86 million ha, and the productivity is about 2665 kg ha^{-1} (NFSM, 2016). Rice is the most important food crop grown in Kerala state which occupies 7.46% of the total cropped area of the State (Kerala State Planning Board, 2016). The lush green paddy field is one of the most captivating features of Kerala's landscape. In Kerala the area under cultivation is steadily shrinking despite the concerted efforts by the Government and other agencies to boost it. From 8.82 lakh ha in 1974-75, the paddy area in the state has come down to 1.96 lakh ha in 2015-16 (Kerala State Planning Board, 2016). The production has also concomitantly declined from 13.76 lakh million tons in 1972-73 (peak of production) to 5.49 lakh million tons in 2015-16. Moreover, the productivity of the crop is very low in the State (2790 kg ha^{-1}), though it is higher than the national average (Kerala State Planning Board, 2016). The decline in rice cultivation is attributed mainly to the high labour cost, shortage of labour and lack of appropriate farming machines. However, considerable reduction in labour requirement can be achieved through selective mechanization with appropriate farm machinery systems. In Kerala (India), women farmers form a significant work force and play a vital role in rice cultivation. In almost all rice growing areas, the women are assigned the work of sowing, transplantation, weeding and crop harvest. However, such heavy works have affected the health of farm women and often farm women complain body pain due to manual weeding, backache due to seedling transplantation, physical strain due to seed bed preparation and hardness in hand and feet due to working in wet field.

Rice is generally sown either by direct seeding or by seedling transplantation depending upon the availability of water. Reports indicate 10-12% increase in rice production by seedling transplantation as compared to direct seed sowing (Ojha and Kwatra, 2014). During rice seedling transplantation, the women workers adopt bent postures in muddy field for a long time in sweltering weather. The continuously bending posture put more stress on knees and repetitive hand movements for planting seedlings conditions cause risky discomforts. The developed risk factors lead to musculoskeletel disorders (MSD's). To offset these persistent problems, mechanical transplantation is a viable economic option.

Agricultural equipment and implements are usually designed to match the physical requirements and capacities of men. However, woman may have greater difficulties in operating such machines, including the risk of injuries to them. If women have right tools for field works, their work efficiency and health would be better; thereby improving their social status and economic empowerment. Now-a-days special attention is given to the needs of women while designing the equipment to ensure their safety while using equipment. To ease the seedling transplantation, various types of rice transplanters are available in the market. Ergonomic evaluation of farm machinery will provide data for improvement in equipment design to suit the labour force as well as yielding higher output and better safety. At present different models of rice transplanters are available in the market, but the safety and efficiency aspects of these transplanters with respect to women worker force is not available. Hence the present study was aimed to evaluate the transplanting operations ergonomically with available equipment for effective output of women labourers available for rice cultivation.

MATERIALS AND METHODS

Selection of transplanters

In this study, three different models of rice transplanters selected were: i) Redlands 8 - row self-propelled riding type rice transplanter, ii) Mahindra 4 row walking type transplanter and iii) Manual 2 row transplanter (Fig. 1a). Redlands 8 - row transplanter consisted of 5.5 HP powered single cylinder

Fig. 1: Different types of planters used in present study: a) Redlands 8 - row riding type, b) Mahindra 4 row walking type, and c) Manual 2 row transplanter

vertical diesel engine which consumes 0.5 L diesel h^{-1}. This transplanter is provided with a 4-gear steering gear box like power steering. Hydraulic lifting function helps to climb ridges and work in muddy fields. It has a split crank swing arm planting mechanism with interchangeable planting arms. To avoid sinking in soft field, a plastic (PP) hollow float board is provided. Mahindra 4 row walking type transplanter transplants seedlings in four rows in a single pass with row to row distance of 30 cm and plant to plant spacing of 12 to 21 cm. The rice transplanter has a 5 HP motor, rubber-lugged wheels, and easily accessible controls to make planting rice an effortless process for farmers. The single-cylinder air-cooled engine enables faster operation, while automatic float adjustment mechanism facilitates to slide over the puddle surface and ensures uniform depth in planting (Fig. 1b). The tray is used to carry the mat nursery and direct the plants to planting arm. The side-wise movement of tray is by a scroll shaft mechanism, which converts rotary motion from engine into linear motion of a rod connected to the seedling tray. It has provision to reverse the direction of movement of tray when it reaches the extreme position at one end. Planting fingers (cranking type) are moved by a 4-bar linkage mechanism which provide designed locus to the tip of planting finger.

Manual 2 row transplanter is a walking backward type manually operated hand transplanter. This model plant seedlings in two rows with a spacing of 250 mm (Fig. 1c). The design fully complies with the growth of seedlings characteristics. Seedlings are raised by conventional method. The seedling height ranges from 18-30 cm and roots are preferably 6 cm. It is simple device in structure but convenient, durable and easy to operate and maintenance. The machine consists of a seedling plate assembly, seedling claw fork, wooden float, chain and sprocket drive mechanism and handle.

Selection of subjects

Anthropometric data from 100 women labourers engaged in rice cultivation was collected to choose the subjects for the study. Thirty five different body dimensions useful for the design or design-modification of rice transplanters selected for the study were recorded by using the following standard anthropometric procedure. Ten subjects meeting the requirements to statistical analysis of anthropometric data were selected for the study so that the selected subjects truly represent anthropometric dimensions such as age, body mass, BMI and body fat. From the measures of height and weight, the body mass index (BMI) was calculated and from skin-fold thickness different body composition parameters were computed (Jackson *et al.*, 1980). The formulae used for the same are as follows:

$$\text{Body mass index} = \text{weight (kg)}, \text{Height}^2 \text{ (m)}$$

$$\text{Body density (g cc}^{-1}) = 1.0994921 - 0.0009929 \text{ (sum of triceps, supra-illium and thigh skin folds)} + 0.0000023 \text{ (sum of the same three skin folds)}^2 - 0.00013929 \text{ (age in years)}$$

$$\text{Fat (\%)} = \left[\frac{4.95}{\text{Body density}} - 4.95\right] \times 100$$

$$\text{Total body fat (kg)} = \frac{\text{Weight (kg) x fat (\%)}}{100}$$

Calibration of subjects

Ten selected subjects were calibrated in a well-lighted, clean and well-ventilated laboratory. For calibration, bi-cycle ergometer and Benedict-Roth spirometer were used simultaneously. All the subjects were properly trained for one month with respect to the use of instruments separately and in combination, prior to the start of experiment. The instrument operation was demonstrated to the subjects to familiarize them with the fair use of instruments. The electrodes contained in the chest belt transmitter of polar pacer heart rate monitor were wetted with water and fastened on the chest of each subject. The subjects were allowed to take complete rest for 30 min before the commencement of test. The Benedict-Roth spirometer (SIGMA-786 BMR) was set up for calibration. The spirometer bell was filled with oxygen and the subject was fitted with the mouthpiece and nose clip. The subject inhaled the atmospheric air through mouthpiece at the initial stage. Heart rate was monitored on display unit. After normalization of breathing rate, the saddle valve was opened to inhale pure medical oxygen from the spirometer. The subjects pedaled a standard bi-cycle ergometer at predetermined speed and with varying breaking loads. The test started with a submaximal load, which serves as a warming-up activity. A mechanism was also provided for applying resistance to the pedals which increases the intensity of the exercise. Then the workload of subjects was increased gradually by increasing the resistance to the pedals using tension knob until the subjects were exhausted. The subjects inhaled oxygen through inspirating valve that was connected to the spirometer filled with oxygen and released CO_2 through expiratory valve coupled to CO_2 absorber. The kymograph starts recording the oxygen consumption pattern of the subject on the chart continuously. Simultaneously the heart rate was recorded in heart rate monitor fitted with the subject. The heart rate and oxygen consumption values were used to prepare a calibration chart for each ten subjects.

Ergonomic evaluation

Transplanters require well prepared mat nursery for conducting the trials. The trials were conducted at Nediyapadam Ela at Sooranad North panchayat in Kollam district in Kerala (India) from September to December, 2016. Mat nursery was prepared with the 'Uma' variety of paddy in farmer's field. Seedlings raised in mats obtain a height of 15-18 cm in 15 days, which is ideal for mechanical transplanting. The 15-day-old seedlings were used for conducting the trials. Seed bed mat was cut into required width and length of the tray of transplanter and loaded in seedling tray. All the ten subjects were equally trained in the operation of transplanters. The experiment was conducted before 9 am and repeated after 11 am to find out the differences in energy expenditure due to heat stress. Each trial was conducted for 30 min duration with all selected subjects. The heart rate of subjects was measured and recorded while using for three selected rice transplanters *viz*., Redlands 8 - row self-propelled riding type rice transplanter, Mahindra 4 row walking type transplanter and Manual 2 row transplanter and the traditional transplanting method. The oxygen consumption (VO_2) corresponding to the values of heart rate were predicted from the calibration chart. The energy expenditure was worked out for selected rice transplanters and traditional method for all the subjects based on the mean heart rate and predicted oxygen consumption (Sam *et al*., 2019).

Acceptable workload

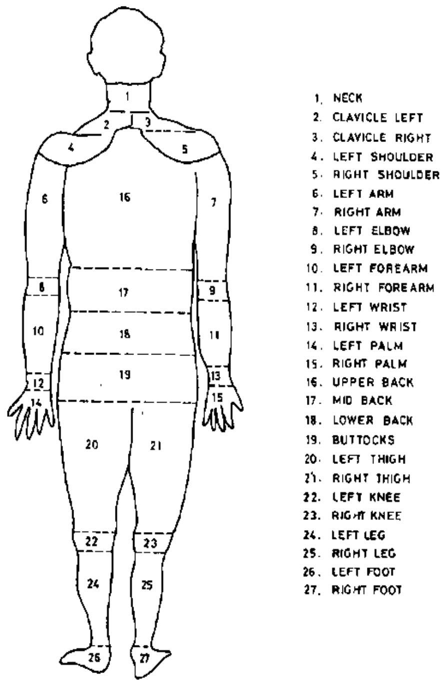
The work load is expressed as a percentage of the individual's maximal aerobic power to accomplish the work in question. Ideally, the individual maximal oxygen (O_2) uptake has to be determined and workload assessed individually. The acceptable workload (AWL) for Indian workers was the work consuming 35% VO_2 max (Saha *et al*., 1979). To ascertain whether the selected operations are within AWL, it is necessary to compute VO_2 max for each subject. Because of the risk that is involved in testing a person on a maximal energy task, various sub maximal tests have been advocated. Maximum oxygen consumption (VO_2 max) was estimated using the data on the heart rate-oxygen consumption relationship. Each subject's maximum heart rate was estimated by the following relationship (Bridger, 1995).

$$\text{Maximum heart rate (beats min}^{-1}) = 200 - 0.65 \times \text{Age in years}$$

The intersection of computed maximum heart rate of the subjects with plotted calibration chart line and the line of fit to O_2-uptake define the maximum aerobic capacity (VO_2 max) of the individual.

Subjective rating scales

Subjective self-reported estimates of effort expenditure were quantified by using rating of perceived exertion. The discomfort ratings such as overall discomfort rating (ODR), body part discomfort score (BPDS), overall safety rating (OSR) and overall ease of operation rating (OER) were assessed for each selected transplanter. The scale for ODR was 1-10 scale (Corlett and Bishop, 1976) with 0 = no discomfort, 3 = light discomfort, 5 = moderate discomfort, 7 = more than moderate discomfort, 9 = very uncomfortable, and 10 = extreme discomfort. For OSR the scale devised by Mohankumar *et al.* (2013) was used wherein 0 = completely secure and no fear, 2 = secure and meagre fear, 4 = moderately secure and less fear, 6 = slightly secure and moderate fear, 8 = insecure and more fear, and 10 = totally insecure and extreme fear. In case of OER the scale of Mohankumar *et al.* (2013) was used, wherein 0 = very easy, 2 = easy, 4 = light difficulty, 6 = difficult to operate, 8 = very difficult, and 10 = extremely difficult. To measure localized discomfort, a body map technique (Corlett and Bishop, 1976) in which body is divided into 27 regions as shown below was adopted.



Regions for evaluating body part discomfort score

Work rest cycle

During every strenuous work in field, adequate rest is required to have optimum work output. Better performance results can be expected from the operator only when proper attention is given to the work - rest schedule for different operations. The actual rest time taken for each subject in all the selected equipment was found from the heart rate response of respective operations. The rest time was measured from the cease of operation till the heart rate of subject reached resting level. The rest time taken was averaged to arrive at the mean value for each selected operation. The rest pause for each operation conducted in present study with selected rice transplanter was calculated theoretically using the Pheasant (1991) equation:

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

Where R = resting time (min); T = total working time day^{-1} (min); E = energy expenditure during working task (kcal min^{-1}); A = average energy expenditure considered acceptable (kcal min^{-1}); B = energy expenditure during rest (kcal min^{-1}).

The ceiling for energy expenditure standard taken for the calculation was 4 kcal min^{-1} (Murrel, 1965). Rest pause was calculated using the above formula as all the subjects operated continuously for 30 min period for the selected rice transplanter.

Statistical analysis was carried out to assess the effects of three selected rice transplanters, different time intervals and their interaction effect on subjects' heart rate and energy expenditure. The data collected were analyzed statistically as 2 x 3 factorial experiments. IBM SPSS 24.0 statistical software was used to analyze the data. Analysis of variance was performed using general linear model (GLM) procedure from IBM SPSS 24.0 software. Multivariate test with POST-HOC (BUTKEY) analysis was used (Sam *et al.*, 2019) to compare the significant differences among mean of the treatments at 5% level of probability and relationship between subgroups of sampled data.

RESULTS AND DISCUSSION

Anthropometric detail of selected subjects

The age of the selected subjects varied from 32 to 40 years. Reports reveal that the maximum percentage of work could be expected from 20 to 40 years (Ardle *et al.*, 2001). The body mass index score of the selected subjects was within the normal range and varied from 20.0 to 25.75 kg m^{-2}. The normal range of BMI for female subjects was 18.5 to 25.0 kg m^{-2}. As per the BMI score, the selected subjects had good health status (Table 1).

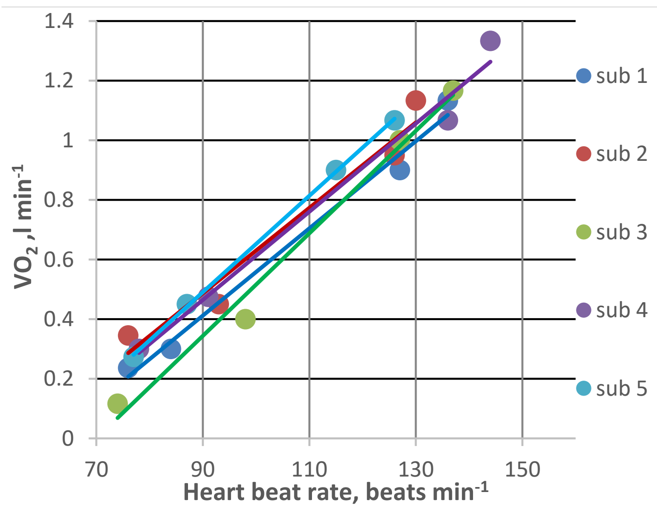
Calibration chart

A calibration chart was prepared with heart rate as ordinate and oxygen uptake as abscissa for the selected 10 subjects (Fig. 2a, b). The relation between heart rate and oxygen consumption of subjects was linear, which is in agreement with Kroemer and Grandjean (2000). This linear relationship generally varies from one individual to another due to physiological differences of individuals (Kroemer *et al.*, 2000). The normal range of BMI for female subjects is 18.5 to 25 kg m^{-2}. As per BMI score, the selected subjects had good health status and their BMI was within normal range (Table 1).

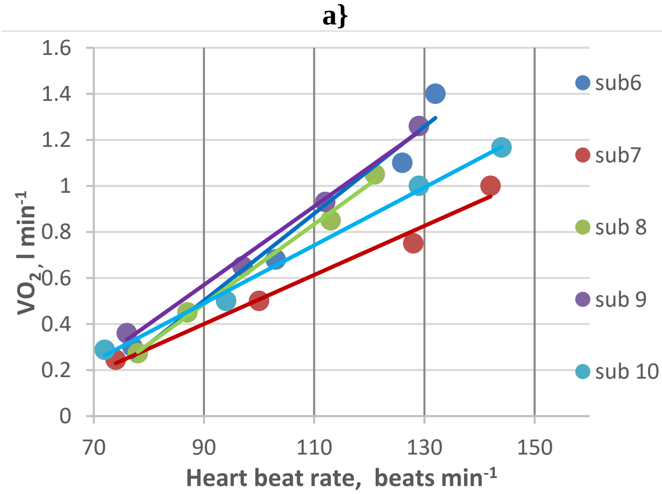
Table 1: Anthropometric details of the subjects selected for the study

Subjects	Age (years)	BMI (kg m^{-2})	Total body fat (kg)	Body mass (kg)
1	32	25.23	0.14	64.86
2	40	24.81	0.14	60.86
3	33	23.83	0.13	57.87
4	40	20.00	0.17	44.83
5	37	20.55	0.11	49.89
6	40	25.75	0.18	67.82
7	40	22.83	0.12	56.88
8	40	22.52	0.11	49.89
9	38	24.15	0.14	65.86
10	32	25.27	0.15	62.85

BMI: It is a subject's weight in kg divided by height^2 in m



a}



b)

Fig. 2: Relationship between oxygen uptake and heart rate a) 1-5 subjects, & b) 6-10 subjects

Energy expenditure of selected rice transplanters

The average heart rate and energy expenditure of selected transplanters is given in Table 2. The results revealed that the selected transplanters significantly influenced the heart rate and energy expenditure. There was significant difference in heart rate and energy expenditure in the operation of different models of transplanters and traditional method of transplanting. Minimum heart rate was observed in Redlands 8 row riding type transplanter and maximum in traditional method of transplanting; the increase being 34%. The energy expenditure was also maximum in traditional method of transplanting. Manual transplanting is tedious, tiresome and labour consuming, because a person has to stand in puddle field and bend for hours for putting seedling into the soil by hand (Ojha and Kwatra, 2012). The increase in energy cost while operating Mahindra 4 row walking type transplanter was 13% in comparison to Redlands 8 row riding type transplanter. As Redlands 8 row riding type transplanter was provided with a seating attachment, the operator can comfortably sit and ride the transplanter without much drudgery. But in walking type Mahindra 4 row transplanter, the subjects have to walk

Table 2: Mean heart rate and energy expenditure of selected transplanters

Selected transplanting operations	Average heart rate (beats min^{-1})	Energy expenditure (kJ min^{-1})
Redlands 8 row riding type transplanter	110.53[a]	17.36[a]
Mahindra 4 row walking type transplanter	124.98[b]	21.79[b]
Manual 2 row transplanter	141.38[c]	26.39[c]
Manual transplanting	148.52[d]	28.49[d]

In columns, the mean values followed by the same letter do not differ significantly at P = 0.05 as per Post hoc tests)

during the entire exercise. It was observed that operating the Redlands 8 row riding type transplanter saved human energy requirement to the tune of 12%. The heart rate observed in manual 2 row transplanter was141.38 beats min^{-1}. This value nearly conformed to the results of other investigations where value was 139.38 beats min^{-1} (Vivek *et al.*, 2014). In present study, in manual 2 row transplanter, the energy expenditure increased by 28% as compared to the Redlands 8 row riding type transplanter and 13% as compared to Mahindra 4 row walking type transplanter.

The time of operation was significantly influenced by the heart rate and energy expenditure. The average heart rate before 9 am was 119.90 beats min^{-1} which increased to 142.81 beats min^{-1} after 11 am. The energy expenditure was significantly higher in operating the transplanters after 11 am than before 9 am operation. Human energy expenditure increased upto 35% after 11 am than before 9 am operation. An increase with time was observed in energy expenditure due to high environmental stress (high temperature and solar radiation) among the operators.

Acceptable work load

The data on acceptable work load limit revealed that only Redlands 8 row riding type transplanter was within the recommended AWL (Table 3). It means that all the transplanters, except Redlands 8 row riding type transplanter, could not be operated continuously for 8 h without rest pauses (Sam, 2015).

Table 3: Oxygen uptake in terms of VO_2 max in transplanting operation

Selected transplanting operations	Mean VO_2 (L min^{-1})	Oxygen uptake in terms of VO_2max (%)	AWL (35% of VO_2max)
Redlands 8 row riding type transplanter	0.57	35.98	AWL
Mahindra 4 row walking type transplanter	0.80	50.50	> AWL
Manual 2 row transplanter	1.15	72.60	> AWL
Manual transplanting	1.24	78.28	> AWL

Subjective rating scales

The overall discomfort rating varied from 3.0 to 7.9 and scaled as “light discomfort" to "more than moderate discomfort” (Table 4). In general, the ODR values were lower for transplanting with 8 row riding type transplanter. The lower values of ODR were in agreement with earlier results that the use of seat in Redlands 8 row riding type transplanter reduced the discomfort due to bending posture. In many situations, the work may be well within the physiological limits, but body discomfort may restrict the duration of work depending upon the static load component involved in it.

Table 4: Overall discomfort rating of subjects during selected operations

Selected transplanting operations	ODR (mean value)	Level of discomfort
Redlands 8 row riding type transplanter	3.0	Light discomfort
Mahindra 4 row walking type transplanter	5.2	Moderate discomfort
Manual 2 row transplanter	7.2	More than moderate discomfort
Manual transplanting	7.9	More than moderate discomfort

Table 5: Overall safety rating of selected operations

Selected transplantor	OSR (mean value)	Scale	OER (mean value)	Scale
Redlands 8 row riding type	2.9	> Secure & meager fear	2.7	> easy
Mahindra 4 row walking type	3.0	> Secure & meager fear	3.2	> easy
Manual 2 row transplanter	3.5	> Secure & meager fear	4.8	> less difficulty
Manual transplanting	1.4	> Completely secure & no fear	1.0	> very easy

The body part discomfort score was maximum (46.8) in transplanting manually, and minimum in transplanting with Redlands 8 row riding type transplanter (20.15). This showed the seating attachment eliminates the drudgery due to walking behind the transplanter. In traditional method of transplanting, the major portion of energy expended is consumed in bending and walking in puddle field. In case of Mahindra 4 row walking type transplanter, the subjects had to walk in muddy field during the entire operation period. The workers had to spend more energy for taking out their legs out of the puddle field at each and every step. However, in Redlands transplanter, an operator's seat is provided comfortably sit and ride the transplanter. In case of Redlands transplanter, the self-starter of transplanter made the operation very easy and synthetic fibre float also helped in easy movement in field when compared to Mahindra 4 row walking type transplanter. It was observed that the three models of transplanters were comparatively safe in operation. The safety score was minimum for manual transplanting and maximum for operating with Manual 2 row transplanter (Table 5). The result showed that Manual 2 row transplanter was difficult to operate as compared to other transplanters with a score of 4.8. In case of Redlands 8 row riding type transplanter and Mahindra 4 row walking type transplanter model, the rating on ease was comparatively less with scores of 2.7 and 3.2 respectively.

Work rest cycle

The calculated rest pause was compared with the actual time taken by the subjects in field to reach the heart rate to resting level. It was observed that the average actual rest time taken by the subjects for the selected rice transplanters and traditional method were in close agreement with the computed value of rest time. The rest pause for achieving functional effectiveness during transplanting the paddy by Redlands 8 row riding type rice transplanter, was 2 min, followed by 30 min of work. The rest pause for Mahindra 4 row walking type transplanter was 9 min followed by 30 min work. The rest pause for Manual 2 row transplanter was 12 min followed by 30 min work. More resting time was needed for conventional transplanting with a resting time of 14 min followed by 30 min work.

Conclusions: The study revealed that minimum energy was expended in Redlands 8 row riding type transplanter (17.36 kJ min^{-1}) and maximum energy expenditure in conventional method of transplanting (28.49 kJ min^{-1}). Human energy expenditure increased upto 35% after 11 am than before 9 am operation. The overall discomfort rate was maximum for traditional method of rice transplanting (7.9) and minimum for 8 row riding type transplanter (3.0). The rest pause, for achieving functional effectiveness during transplanting the paddy by Redlands 8 row riding type rice transplanter, was only 2 min after 30 min operation. Based on ergonomic evaluation, the Redlands 8 row riding type transplanter was adjudged as the best rice transplanter for agricultural women workers.

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