Ergonomic evaluation of paddy seeder and rotary weeder with women operators

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Abstract:

Women in rural India, play a major role in shaping the country’s economy, through their active participation in agriculture. One of the major constraints, in taking the technologies to farmwomen, is lack of suitable tools / equipment, for women workers. To overcome this, constraint efforts are needed, to develop equipment and technologies, suitable for women, for reducing the drudgery and increasing their productivity. Here the seeding and weeding operations, performed by the females in rice cultivation, were studied ergonomically with selected equipment. Use of rice farming machineries, reduces the energy expenditure of women labourers, to the tune of 39 to 55% compared to manual operations. Oxygen uptake in terms of VO$_2$ max, were higher than that of the AWL limits of 35%, indicating that the selected operations, could not be operated continuously for 8 hours, without frequent rest-pauses. In general, the overall discomfort rating, was lower for machine operation, than manual operation. The body part discomfort score, was maximum in sowing manually, whereas it was minimum in weeding with rotary weeder. Modifications in paddy drum seeder and rotary weeder by adjusting the length of handle and handle grip, to suit the women were carried out, and evaluated for effective use of women labourers, in rice cultivation.

Practitioner Summary

The physiological response of women labourers, while performing the rice farming operations such as sowing the seeds in lines by hand, sowing with paddy drum seeder, weeding by hand and weeding with rotary weeder at different time intervals i.e., before 9 am and after 11 am in a day were investigated. Nine subjects, conforming to the statistical requirements of anthropometric dimensions were selected for the study. The energy cost was observed to be 22.81 kJ min$^{-1}$ for hand sowing in lines, whereas for sowing with paddy drum seeder, it was 16.46 kJ min$^{-1}$. Sowing after 11 am resulted in 10% more energy expenditure than sowing before 9 am. The maximum energy cost was observed to be 21.58 kJ min$^{-1}$ in hand weeding, whereas with the rotary weeder it was 13.96 kJ min$^{-1}$. All the operations were generally graded as "Moderately Heavy". Modifications in paddy drum seeder and rotary weeder were carried out by finding the optimum length for handle from the geometry adopted by the women operator. The energy cost with paddy drum seeder was reduced to 15.47 kJ min$^{-1}$ after modification. The oxygen uptake in terms of VO$_2$ max was 60.97% for paddy drum seeder while it was only 55.71 % for modified paddy drum seeder. The energy cost of modified rotary weeder was reduced to 12.10 kJ min$^{-1}$, the decrease was 13%. The overall discomfort scores scaled as “moderate discomfort” for sowing with paddy drum seeder before modification while it was scaled as “light discomfort” during operation of modified paddy drum seeder. The overall discomfort scores rated by subject was 5.5 and scaled as “moderate discomfort” for weeding with rotary weeder before modification whereas the rating was 4.3 and scaled as “light discomfort” during operation of modified rotary weeder.

Keywords: paddy drum seeder, rotary weeder, energy cost, oxygen uptake in terms of VO$_2$ max, discomfort scores

1. Introduction

In India female agricultural workers constitute 50.2% of the total agricultural work force. Most technologies developed for small-scale farmers are geared to men with no concern for their appropriateness for women, who possess different physiques and energy capabilities in comparison to men. The performance of any machine especially manually operated ones could be considerably improved if ergonomic aspects are given due consideration (Gite, 1993). Human energy measurements are important because whenever the physical capacity of a person is exceeded, it is bound to cause considerable fatigue and reduction in the efficiency of
operation. Thus, investigations on ergonomic evaluation of farm equipment can provide a rational basis for recommendation of methods and improvement in equipment design for more output and safety. In India, most of the operations in rice cultivation are being done by the female labourers such as sowing the seeds, transplanting, weeding, harvesting, threshing and winnowing. Though many of the tasks performed by males are getting mechanized, the women continue to toil in labour intensive jobs, which induces them discomfort and fatigue. There is an urgent need to design and develop farm tools specifically for female operators in order to improve overall ease of use, safety, and effective integration of women in rice farming system. Here the seeding and weeding operations performed by the females in rice cultivation were studied ergonomically with selected tools/implements and analysed and improved the same for effective use of women labourers in rice cultivation and enhancing their opportunities for remunerative employment and income using women friendly equipments.

2. Materials and Methods

2.1 Subjects

An anthropometric survey was conducted to select the subjects for the study. Anthropometric data from 120 women labourers engaged in rice cultivation were collected who were chosen randomly among women agricultural labourers engaged in rice cultivation in Kerala, India. Nine subjects were selected having anthropometric dimensions conforming to statistical requirements from the anthropometric data base of the study region.

2.2 Activities

The subjects were required to do the rice farming operations namely, sowing the seeds in lines by hand (activity 1), sowing with paddy drum seeder (activity 2), weeding by hand (activity 3) and weeding with rotary weeder (activity 4). The trials were conducted two times a day, at different time intervals i.e., before 9 am and after 11 am in order to find out the changes in energy expended and heart rate due to environmental condition. Paddy drum seeder is a manually pulling implement developed by IRRI, Philippines, for line sowing of pre-germinated paddy. Tamil Nadu Agricultural University, Coimbatore, India has further simplified and improved by incorporating certain modifications in the design. This manually pulled implement covers 8 rows of 20 cm row to row spacing at a time. Rotary weeder is a manually operated implement and designed to work in between the rows of 20 cm spacing in wet lands. It works by the push pull action and the weeds were uprooted and buried in the field itself.

2.3 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. 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 nine subjects were calibrated in the laboratory by measuring oxygen consumption and heart rate simultaneously while pedalling a standard bicycle ergometer 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 computerized heart rate monitor (Polar make). For determination of the subject's maximum oxygen uptake, the workload was increased gradually until she reached complete exhaustion. The maximum oxygen uptake is the highest oxygen uptake attainable in the subject where a further increase in workload will not result in an increase in oxygen uptake (Rodahl, 1989). The same procedure was repeated for all the subjects.

2.4 Data collection

All the nine subjects were equally trained in the operation of the paddy drum seeder and rotary weeder before the actual experiment. The drum seeder was put in proper test condition before conducting the tests, i.e. in full working order with the drum filled to 2/3rd of its capacity. 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. The subject was allowed to operate the seeder in the field at a speed of 0.70 km h⁻¹ (Vidhu, 2001). The heart rate was measured and recorded using computerized heart rate monitor for the entire work period. The trials with rotary weeder were performed after three weeks of planting. Each trial started with taking five
minutes data for physiological responses of the subjects while resting on a stool under shade. Each trial was carried out for 15 minutes of duration and same procedure was repeated to replicate the trials for all the selected subjects. All the trials were conducted two times a day, at different time intervals i.e., before 9 am and after 11 am in order to find out the changes in energy expended and heart rate due to environmental condition. The physiological response of the subjects while sowing in lines by hand and weeding by hand was also assessed to compare the energy expenditure in manual and mechanized operation.

2.5 Data analysis
The recorded heart rate values from the heart rate monitor at resting level and from 6th to 15th minute of operation were taken for calculating the physiological responses of the subjects. The heart beat rate increases rapidly in the beginning of an exercise and reaches a steady state by the end of sixth minute. From the mean values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate \( (\text{VO}_2) \) 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 nine subjects) by the calorific value of oxygen as 20.88 kJ lit\(^{-1}\) (Nag et al., 1980). The energy costs for all selected operations were graded as per the tentative classification of strains in different types of jobs given in ICMR report as shown in Table 1. (Sen, 1969 and Vidhu, 2001).

Table 1. Tentative classification of strains (ICMR) in different types of jobs.

<table>
<thead>
<tr>
<th>Grading</th>
<th>Physiological response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heart rate</td>
</tr>
<tr>
<td></td>
<td>beats min(^{-1})</td>
</tr>
<tr>
<td>Very light</td>
<td>&lt;75</td>
</tr>
<tr>
<td>Light</td>
<td>75-100</td>
</tr>
<tr>
<td>Moderately heavy</td>
<td>100-125</td>
</tr>
<tr>
<td>Heavy</td>
<td>125-150</td>
</tr>
<tr>
<td>Very heavy</td>
<td>150-175</td>
</tr>
<tr>
<td>Extremely heavy</td>
<td>&gt;175</td>
</tr>
</tbody>
</table>

The results were statistically analyzed using an analysis of variance technique (ANOVA) by following completely randomised design (CRD) to assess the effect of mode of operation and time of operation on energy cost for sowing and weeding operations.

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 do the operations for a duration of two hours. Sufficient rest period was given for each subject between the two trials on the same day with the same subject. The same procedure was repeated three times for all the selected subjects.

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 (Figure 1). A movable pointer was provided on the scale to indicate the rating. 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 nine 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 Figure 2. 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 number of different groups of body parts which are identified from extreme discomfort to no discomfort represented the number of intensity levels of pain experienced. Each separately reported group can be seen as being separated by a recognizable difference in the level of discomfort. 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.

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 nine subjects (Figure 3).

3.2 Energy cost in sowing operation

Figure 1. Visual analogue discomfort scale for assessment of overall body discomfort.

Figure 2. Regions for evaluating body part discomfort score.

Figure 3. Calibration chart of subjects.
The results showed that mode of operation and time of operation significantly influenced the energy cost as presented in Table 2. There was significant difference in energy costs in hand sowing in lines and sowing with paddy drum seeder, the increase being 39%. While sowing in lines, the women labourers takes a tedious bending posture. In the distorted posture, the muscles have to contract unnecessarily for holding the body erect. Such postures may also affect the pulmonary ventilation rate and increase the respiration frequencies to expel out the extra carbon dioxide produced in the tissues by increased metabolic rate. It is further noticed that the average energy expenditure before 9 am was 18.69 kJ min\(^{-1}\) while after 11 am it was increased to 20.57 kJ min\(^{-1}\). The variation may be attributed to the effect of environment on the subject since the heart rate integrates the total stress on the body and responds more quickly to changes in work demand and indicates more readily the quick changes in body function due to changes in work environment. Based on the mean energy cost of nine subjects, the operation was graded as "moderately heavy" for sowing operations.

### 3.3 Energy cost in weeding operation

The results of the study show that there was significant difference in physiological cost between the rotary weeder operation and weeding by hand. Energy cost was recorded significantly higher in weeding by hand than rotary weeder operation. The maximum energy cost observed to be 21.58 kJ min\(^{-1}\) in hand weeding, whereas with the rotary weeder this value was 13.96 kJ min\(^{-1}\) (Table 3). In hand weeding the subjects were bending over work surfaces for targets which are too low. It may be suggested that pain rather than capacity may often be the limiting factor in such task situations. Since the rotary weeder is provided with a long handle, the subjects can comfortably do the weeding in a standing posture. The energy expenditure after 11 am was increased by 14 % in compared to energy expenditure before 9 am. Weeding operations are graded as "moderately heavy".

**Table 2. Energy cost as influenced by mode of operation and time of operation during sowing.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Energy cost, (kJ min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode of operation</strong></td>
<td></td>
</tr>
<tr>
<td>Sowing with Paddy drum seeder</td>
<td>16.46</td>
</tr>
<tr>
<td>Sowing in lines by hand</td>
<td>22.81</td>
</tr>
<tr>
<td>F (32,1)</td>
<td>90.27**</td>
</tr>
<tr>
<td>CD ( P=0.05)</td>
<td>1.36</td>
</tr>
<tr>
<td><strong>Time of operation</strong></td>
<td></td>
</tr>
<tr>
<td>Before 9 am</td>
<td>18.69</td>
</tr>
<tr>
<td>After 11 am</td>
<td>20.57</td>
</tr>
<tr>
<td>F (32,1)</td>
<td>7.88**</td>
</tr>
<tr>
<td>CD ( P=0.05)</td>
<td>1.36</td>
</tr>
</tbody>
</table>

** Significant at 1 % level of probability, F, variance ratio; CD, critical difference; P, probability

**Table 3. Energy cost as influenced by mode of operation and time of operation during weeding.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Energy cost, (kJ min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode of operation</strong></td>
<td></td>
</tr>
<tr>
<td>Weeding with rotary weeder</td>
<td>13.96</td>
</tr>
<tr>
<td>Hand Weeding</td>
<td>21.58</td>
</tr>
<tr>
<td>F (32,1)</td>
<td>208.93**</td>
</tr>
<tr>
<td>CD ( P=0.05)</td>
<td>1.08</td>
</tr>
<tr>
<td><strong>Time of operation</strong></td>
<td></td>
</tr>
<tr>
<td>Before 9 am</td>
<td>16.63</td>
</tr>
<tr>
<td>After 11 am</td>
<td>18.92</td>
</tr>
</tbody>
</table>
3.4 Acceptable workload (AWL)

Work load can be expressed as percentage of the individual’s maximal aerobic power i.e. how much of the individual’s maximal aerobic power has to be taxed in order to accomplish the work in question. 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.

To ascertain whether the operations selected for the trails were within the acceptable workload (AWL), the oxygen uptake in terms of VO$_2$ max (%) for each treatment was computed.

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

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

The maximum aerobic capacity of the selected nine subjects varied from 1.21 to 1.51 min$^{-1}$. Individual differences in the value of the maximum VO$_2$ max is due to the differences in the ability to supply oxygen to the muscles and also due to genetic factors.

The mean oxygen uptake in terms of maximum aerobic capacity was calculated for all the subjects for each operation. For sowing with paddy drum seeder, the oxygen uptake in terms of VO$_2$ max was 60.97 % while it was 83.05 % for manual sowing. Similarly oxygen uptake in terms of VO$_2$ max was 48.68% for weeding with rotary weeder, where as it was 77.72% for manual weeding. All the values were higher than that of the AWL limits of 35 per cent indicating that the above operations could not be operated continuously for 8 hours without frequent rest-pauses.

3.5 Overall discomfort rating (ODR)

The overall discomfort rating was 6.6 for sowing with paddy drum seeder and scaled as "moderate discomfort" where as it was 8.9 in sowing manually and scaled as "more than moderate discomfort". Similarly ODR was 5.5 and scaled as "moderate discomfort" for weeding with rotary weeder while it was 8.6 in weeding manually and scaled as "more than moderate discomfort", In general the ODR values were lower for machine operation than manual operation.

3.6 Body part discomfort score (BPDS)

The majority of discomfort was experienced in the mid back, lower back, buttocks, left thigh, right thigh, left leg and right leg region for all the subjects during manual operation. However the majority of discomfort was experienced in left shoulder, right shoulder, left fore arm, right fore arm, left leg and right leg for all the subjects during machine operation. Results showed that the intensity of pain experienced by the subjects was more in manual operation compared to machine operation. The BPDS value was maximum in sowing manually, where as it was minimum in weeding with rotary weeder.

3.7 Modification of paddy drum seeder

From the rating of perceived exertion of the subjects it is observed that due to gripping of the hollow pipes provided for the handle, scales are formed in the inner side of the palm besides irritation of the skin. To eliminate the above mentioned problem, in the paddy drum seeder, a soft material was incorporated around the handle to improve the gripping comfort of the operator. The length of the handle was also checked by considering the 5th percentile value of shoulder height and shoulder grip length of the population under the present study region. During the operation of paddy drum seeder, the shoulder is extended and forearm and upper arm are straight, i.e. elbow angle is 180°. The 5th percentile value of shoulder height and shoulder grip length is 116.0 and 57.0 cm, respectively. The optimum length for handle can be found out from the geometry adopted by the operator, which was 113.5 cm considering shoulder extension of 60° ((Dewangan et al. 2010). Therefore, the existing handle length of the paddy drum seeder was modified as 114 cm (Figure 4).
There was significant difference in energy cost with drum seeder before and after modification, the decrease being 6%. The result confirmed that the modified equipment enhanced the comfort and reduces the fatigue of the women labourer. The oxygen uptake in terms of VO$_2$ max was reduced to 55.71% for modified paddy drum seeder. The overall discomfort scores rated by subject was reduced to 4.5 and scaled as "light discomfort" for modified paddy drum seeder.

3.8 Modification of rotary weeder

The handle of the weeder should be designed such that during operation the operator stands erect as far as possible to reduce musculoskeletal discomfort (Dewangan et al, 2008). Grandjean, 1988 suggested that the elbow flexion angle should be in the range of 85 –110° for maximum work efficiency. An angle in the range of 50–60° has been suggested between ground and handle (Pradhan, et al., 1987; Philip, 2000). Taking the elbow flexion value of 100°, inclination of weeder handle with the horizontal as 55° and 5th and 95th percentile values of elbow height from the present study as 89.49 and 104.53 cm, respectively, and elbow grip length for 5th and 95th percentile population as 30.95 and 36.05 cm, respectively, the optimum length of the handle can be found out from the geometry adopted by the operator (Dewangan et al, 2008). The optimum length of the handle for the population under the present study ranges 102.73–120.00 cm. Hence the existing handle of the rotary weeder was modified as telescopic handle as shown in Figure 5. The subjects have also expressed that due to gripping of the handle, scales are formed in the inner side of the palm. To avoid the scale formation, rubber grips were provided for the handle of the weeder.

The energy cost of rotary weeder after modification was reduced to 12.10 kJ min$^{-1}$, the decrease being 13%. The energy expenditure of modified rotary weeder was graded as "Light" while it was "Moderately Heavy" before modification. The overall discomfort rating was 4.3 and scaled as "light discomfort" during operation of modified rotary weeder. Similarly oxygen uptake in terms of VO$_2$ max was reduced from 48.68% to 43.61% for modified rotary weeder.

4. Conclusions
There was significant difference in energy costs in machine and manual operation. The energy cost was observed to be 22.81 kJ min⁻¹ for hand sowing in lines, whereas for sowing with paddy drum seeder, this value was observed to be 16.46 kJ min⁻¹. It is further noticed that the average energy expenditure before 9 am was 18.69 kJ min⁻¹ while after 11 am it was increased to 20.57 kJ min⁻¹. The maximum energy cost observed to be 21.58 kJ min⁻¹ in hand weeding, whereas with the rotary weeder this value was 13.96 kJ min⁻¹. Based on the analysis of the data, modifications in paddy drum seeder and rotary weeder was carried out and evaluated. There was significant difference in energy cost with paddy drum seeder before and after modification, the decrease being 6%. The energy cost of rotary weeder was reduced to 12.10 kJ min⁻¹, the decrease being 13%. The energy expenditure of modified rotary weeder was graded as "Light" whereas it was "Moderately Heavy" before modification. The overall discomfort scores scaled as "moderate discomfort" for sowing with paddy drum seeder before modification while it was scaled as "light discomfort" during operation of modified paddy drum seeder. The overall discomfort scores rated by subject was 5.5 and scaled as "moderate discomfort" for weeding with rotary weeder before modification whereas the rating was 4.3 and scaled as "light discomfort" during operation of modified rotary weeder.

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References