ASSESSMENT OF ERGONOMIC PARAMETERS OF RICE TRANSPLANTERS FOR WOMEN OPERATORS

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"ASSESSMENT OF ERGONOMIC PARAMETERS OF RICE TRANSPLANTERS FOR WOMEN OPERATORS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"ASSESSMENT OF ERGONOMIC PARAMETERS OF RICE TRANSPLANTERS FOR WOMEN OPERATORS"** is a record of research work done independently by **Ms. Gorla Gayathri** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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EXTERNAL EXAMINER

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Gorla Gayathri

Dedicated

To

My parents

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SYMBOLS AND ABBREVIATIONS

AICRP	:	All India Co-coordinated Research Project
Acers/ h	:	Acers per hour
AM	:	Ante Meridian
ARS	:	Agricultural Research Station
AWL	:	Acceptable Work Load
beats min^{-1}	:	Beats per minute
BMI	:	Body Mass Index
BMR	:	Basal Metabolic Rate
BPDS	:	Body Part Discomfort Score
CATIA	:	Computer Aided Three-Dimensional Interactive Application
cm	:	Centimeter
CV	:	Coefficient of Variation
dB	:	Decibel
DHM	:	Digital Human Manikin
ECG	:	Electro Cardio Graph
ESA	:	Ergonomic Safety in Agriculture
ESR	:	Erythrocyte Sedimentation Rate
et al.	:	and others
Fig.	:	Figure
FSRS	:	Farming Systems Research Station
g	:	Grams
g/cc		Gram per cubic centimeter
h	:	Hour
Hills/m^2	:	Hills per meter square
HR	:	Heart Rate
Hz	:	Hertz

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=		equal to
°C	:	Degree Celsius
°K	:	Degree Kelvin
µg	:	Micrograms
ICA	:	Integrated Composite Anthropometer
ICMR	:	Indian Council of Medical Research
IS	:	Indian Standards
ISO	:	International Organization for Standardization
kcal day^{-1}	:	Kilo Calories per day
kg	:	Kilogram
kg m^{-2}	:	Kilogram per meter square
kg m^{-3}		Kilogram per cubic meter
kJ min^{-1}	:	Kilo Joule per minute
Km/h	:	Kilo meter per hour
kW	:	Kilo Watts
l min^{-1}	:	Liter per minute
l/h	:	Liters per hour
LCP	:	Limit of Continuous Performance
m ha		Million hectare
m mol l^{-1}		Mill molar per liter
m t		Million tonnes
m/s		Meter per second
mg dl^{-1}	:	Milligrams per deciliter
mg dl^{-1}	:	Milligrams per deciliter
min	:	Minute
mm	:	Millimeter
mm h^{-1}	:	Millimeter per hour
mm of Hg	:	Millimeter of mercury

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mm s^{-1}	:	Millimeter per second
mm s^{-2}	:	Millimeter per second square
MSD	:	Musculoskeletal Disorders
MSQ	:	Musculoskeletal Questionnaire
NASA	:	National Association of Student Anthropologies
NIOSH	:	National Institute for Occupational Health and Safety
ODR	:	Overall Discomfort Rating
OER	:	Overall Ease of Operation Rating
OSHA	:	Occupational Safety and Health Administration
OSR	:	Overall Safety Rating
Rh	:	Rhesus
RH	:	Relative Humidity
RMS	:	Root Mean Square
rpm	:	Revolutions Per Minute
RULA	:	Rapid Upper Limb Analysis
s	:	Second
SD	:	Standard Deviation
SEM	:	Standard Error of Mean
Sl. No	:	Serial number
SPSS	:	Statistical Package for the Social Sciences
t ha^{-1}	:	Tonnes per hectare
v	:	Volts
VO_2 Max	:	Maximum volume of oxygen consumed
WMSD	:	Work related Musculoskeletal Disorders

Introduction

CHAPTER I

INTRODUCTION

Rice (*Oryza Sativa)* is one of the principal food crops of the world and is grown between latitudes 45°N and 40°S. Rice is cultivated in 113 countries and it is the staple food of more than 50 per cent population of the world. About 92 per cent rice area exists in Asia. India, with highest area (43.95 m ha) under the crop, is the second largest producer (106.55 m t) of rice in the world after China but ranks 35th with respect to its productivity which is only 2.42 t ha^{-1} as compared to 6.58 t ha^{-1} in Japan and world average of 3.91 t ha^{-1} (Agriculture statistics, 2014 and Rice market monitor, 2015).

Kerala is one of the traditional states of rice cultivation and lush green rice fields are one of the most captivating features of Kerala's landscape. The area under rice cultivation increased substantially during the first fifteen years after the state's formation from 0.76 million hectares in 1955–56 to 0.88 million hectares in 1970–71. Rice cultivation in Kerala has witnessed a steady decline since the 1980's. The rice area has shrunken from 0.85 million hectares in 1980's to about 0.19 million hectares in 2014 (Agriculture statistics, 2014). The sharp fall in the area under rice cultivation and its production in the state has had important implications on Kerala's economic, ecological and social development. Today, rice occupies only the third position among Kerala's agricultural crops with respect to area under cultivation which is far behind coconut and rubber.

The rice farming sector in Kerala is experiencing a multitude of problems and consequently the rice lands are getting connected into non-farming use to other cash crops which will alternatively affect our food security in long run. Rice being a labour intensive crop, non-availability of timely labour is the most critical problem faced by many farmers. Another serious problem is higher wage rate. It has become impertinent that profitable and sustainable rice farming methods are to be evolved and alternative strategies to counter the problems of labour shortage that is mechanization options in rice cultivation are to be adopted. Mechanization is considered as a remedy to the growing labour scarcity and uneconomic nature of farming. Mechanization increases land productivity by timely completion of farm operations. It increases labour productivity and reduces drudgery of the humans Mechanization decreases cost of production by reducing the number of man days required for a particular operation and economy of power and other inputs.

Rice is generally sown either by direct seeding or by transplanting depending upon the availability of water. Generally it was found that the production increases by 10 to12 per cent in transplanting when compared with direct sowing (Ojha and Kwatra, 2014).

Presently, transplanting of the rice crop depends completely upon manual labour which is a labour intensive, drudgery prone and back- breaking operations. from nursery to transplanting, the total labour requirement of about 250 to 320 man-hour ha^{-1} which is roughly about 25 per cent that includes a sequence of operations like nursery raising, uprooting of the seedlings, transporting and transplanting the uprooted seedlings in the main fields (Yadav and Pund, 2007). High labour demand during the peak periods adversely affects the timeliness operation, thereby reducing the crop yield.

In many areas, among the rice cultivation operations, transplanting is generally done by women. Not only in rice cultivation but also in agriculture as a whole, women are the backbone of workforce and they work longer than men in fields, but worldwide, their hard work has remained mostly unpaid. There are more than 200 million agricultural workers in India, in which more than 35 per cent are female workers (Mohanty *et al.* 2012). During transplanting, the women workers adopt upright bending posture in the muddy field for a long time in sweltering weather. The continuous bending posture, putting hands support on knees and repetitive movement of hands for planting of seedlings in different and adverse environmental conditions cause great discomfort and develop risk factors. The developed risk factors leads to musculoskeletal disorders (MSD).

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The work related MSD include disorders of the back and neck, nerve entrapment syndromes, musculoskeletal disorders such as tenosynovitis, tendinitis, peritendinitis, epicondylitis and nonspecific muscle and forearm tenderness (NIOSH, 1997). The six prime categories of ergonomic risk factors that may be identified as the cause of musculoskeletal injury or illness within a work environment include repetition, forceful exertion, awkward posture, contact stress, vibration, and temperature extremes. The female work force had WMSD (work related musculoskeletal disorders) problems about two to five times more than male work force (Choobineh *et al.* 2009).

To offset these problems, mechanical transplanting is the solution. Mechanical transplanting of rice has been considered the most promising option, as it saves labour, ensures timely transplanting and attains optimum plant density that ultimately contributes to high productivity.

To ease the transplanting work, research organizations have developed various types of rice transplanters and these are available in the market. These equipment were primarily developed keeping men workers in consideration, despite rice transplanting being performed mostly by women workers in India. The equipment also may not be suitable for farm women as such, because of their ergonomic characteristics are different from men workers (Singh, 2009). The result is that women workers have to carry out the operation without comfortable posture, leading to occupational health problems. The suitability of equipment for farm women can better be judged using ergonomic studies.

Ergonomics is often referred to an external triangle between efficiency, comfort and health. Ergonomic studies cover all aspects that deal with anthropometry, assessment of workload, working environment, safety features, and mechanisms to optimize human–machine environment system. This helps in increasing working efficiency with reduced drudgery by fitting to the capabilities and limits of human operators.

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The systematic efforts to ergonomically evaluate the various farm tools and equipment for different operations under different environmental conditions, are essential. These measurements are also 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 reduction in the attentiveness of the operator, making the operation unsafe. 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.

At present a number of highly developed rice transplanters are available in Indian market. However safety and efficiency aspects of rice transplanters are so far not being studied and there need to be comparatively evaluated. Keeping in view the above facts, the present study on "**Assessment of ergonomic parameters of rice transplanters for women operators**" was undertaken with the following specific objectives.

- To identify and measure the pertinent anthropometric dimensions of women with reference to the dimensions and positions of components of rice transplanters.
- To assess the energy expenditure of women while using selected rice transplanters.
- To assess the postural discomfort in terms of rating scales and musculoskeletal disorders by using standardized Nordic questionnaire while using selected rice transplanters.
- To suggest the optimal range for spatial, visual and control requirements of operator based on evaluation of rice transplanters.

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Review of literature

CHAPTER II

REVIEW OF LITERATURE

A comprehensive review of the research work carried out is briefly reported under the following subtitles.

1. Anthropometry
2. Selection of subjects
3. Calibration of subjects
    i. Basal metabolic rate
    ii. Indirect assessment of oxygen uptake
4. Physiological cost of work
5. Grade of work
6. Acceptable work load
    i. Maximum aerobic capacity
    ii. Limit of continuous performance
7. Subject rating scales
8. Work rest cycle
9. Musculoskeletal disorders
10. RULA analysis
11. Vibration and noise level
12. Spatial, Visual and Control requirements of operator

2.1 ANTHROPOMETRY

Anthropometry is the science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body. It includes the systematic measurement of the physical properties of the human body, primarily dimensional descriptors of body size and shape. The knowledge of body dimensions is essential for designers of equipment and work places. The anthropometric measurements are essential for the correct design of the work areas.

Gupta *et al.* (1983) reported that proper matching of machine requirements with the human capabilities is basically necessary for optimum performance of any man-machine system. Agricultural mechanization has increased considerably over the last few years in India, but little anthropometric data is available for looking into the ergonomic problems of mechanization in a particular region. Data of other countries cannot be used for design of farm machines in India because it can result in either an uneconomical design or a design with less efficiency due to improper matching of the operator and the machine. Thus anthropometric data available for other countries cannot be applied in India.

Vasudha and Gaur (1998) reported that in any engineering design or ergonomics consideration, usage of the average value had got no importance and we should consider either 5^{th} or 95^{th} percentile as demanded by the design. To calculate 5^{th} and 95^{th} percentile values following equations were used.

5^{th} percentile = mean – F x SD

95^{th} percentile = mean + F x SD

Where, SD = standard deviation of mean and F = 1.645

According to Philip *et al.* (2000) the relative high standard deviation, in general, shows the diversity in body dimensions of the subjects. The percentile values were logical in most of the design situations. In their study different body dimensions of the subjects were collected from 137 female workers and data were compared with that of male workers of the region as well as data of female workers from other ethnic groups. The survey suggested that devices and implements designed for these populations should be suitably modified before introducing it to the Indian farm workers.

Victor *et al.* (2002) carried out an anthropometric survey and compared with available data of other regions. Anthropometric measurements were carried out on 5 males from each village randomly chosen from 6 districts of Chhattisgarh region.

The data showed that Indians (Chhattisgarh region) were smaller than western people (Americans, Swedes and Germans). The other body dimensions were also found to be lower than the western people except popliteal height (sitting) and buttock popliteal length in which Indians have the higher value of body dimensions.

Gite and Majumder (2007) collected anthropometric and strength data for agricultural workers. They estimated the mean stature and weight of Indian agricultural workers as 163.3 cm and 54.7 kg for male workers and 151.5 cm and 46.3 kg for female workers. The mean values for strength data in pushing and pulling by both hands in standing posture were 224 N and 218 N for male workers and 143 N and 158 N for female workers, respectively.

Ratn *et al.* (2010) carried out study of healthy Indian adults (n=102, 51 male, 51 female, aged 20 to 40 years) representing 14 states of India. Study identified that age, gender and BMI were best predictors of the muscle strength and these variables accounted for 61 to 75 per cent of variability in muscles strength.

Khogare and Borker (2011) suggested dimensions of manually operated weeders based on anthropometric data of the agricultural workers from five districts in vidharbha region of Maharashtra State and found that anthropometric data of agricultural workers of Maharashtra was significantly different from the other regions of the country. Different body dimension to stature ratio was also calculated and compared with other studies.

Sengupta and Sahoo (2012) carried out study on young male tea garden workers (n=15, aged 18 to 25 years) from Cooch Behar District, West Bengal and found a significant difference in body surface area, BMI, percentage of body fat (per cent fat), blood pressure, physical fitness index, energy expenditure, anaerobic power, mean upper arm circumference, thigh circumference, waist circumference and buttock. No significant difference was observed in calf circumference and waist to hip ratio.

Ismaila *et al.* (2013) measured various body dimensions (sitting elbow height, shoulder height, knee height, popliteal height. buttock popliteal length. stature and body weight) of the students using standard anthropometer and 5th. 50th. and 95th per centiles of the data obtained were computed using a SPSS 16.0 statistical package.

More and Vyavahare (2014) measured 64 anthropometric and grip strength parameters including weight and age of agricultural male workers for Marthwada region of Maharashtra state. Statistical analysis was performed in order to evaluate the distributional characteristics such as minimum, maximum, mean, standard deviation, SEM, coefficient of variance, 5^{th}, 50^{th} and 95^{th} percentile values of the dimensions. They suggested that the data will be helpful to the agricultural tools/equipment manufactures to design the tools/equipment ergonomically for the Maharashtra population.

2.2 SELECTION OF SUBJECTS

Selection of subjects have vital role in ergonomic evaluation. The selected subjects should have ability to perform work without sudden fatigue and should be medically fit to do work. The subjects should not be pregnant, lactating or handicapped. An output of a job always depends on not only the level of skill but also their physical and mental strength. The main factors mainly considered for the selection were age, and medical fitness.

Reinberg *et al.* (1970) reported that the workers between 25 to 30 years old, both men and women reached peak muscle strength. Older workers between 50 and 60 years age could produce only about 75 to 80 per cent of muscular strength compared to their younger days.

Seidal *et al.* (1980) reported that the medical and bio-clinical investigations to assess the medical fitness of selected subjects include Electro Cardio Graph (ECG), blood pressure and bio-clinical analysis.

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Grandjean (1982) presented the relation between the oxygen consumption and age of the workers. He found that the maximum percentage of work could be expected during 20 to 30 years. The percentage loss of maximum performance of different age groups is given in Table 2.1.

Table 2.1 Loss of percentage of work performance with respect to age

Sl. No	Age (years)	Percentage of maximum performance
1	20-30	100
2	40	96
3	50	90
4	60	80
5	65	75

Rodahl (1989) reported that maximum heart rate declines with age.

Haribabu *et al.* (2015) conducted the study with different age group of farmers (20-25, 30-35 and 35-40 years). He concluded that the 30 to 35 years of age groups were observed to be developing maximum working heart rate and oxygen consumption higher than the age groups of 20 to 25 years and 35 to 40 years during weeding operation.

Maximum strength power expected from age group was stated by different researches as in Table 2.2.

Table 2.2 Maximum strength power expected from age group

Sl. No	Source	Age group (years)
1	Grandjean (1982)	20-30
2	Gite and Singh (1997)	25-35
3	Nigg and Herzog (1999)	25-35
4	Ardle *et al.* (2001)	20-40

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2.3 CALIBRATION OF SUBJECTS

2.3.1 Basal Metabolic Rate

Basal metabolic rate is the minimum amount of energy that a body requires when lying in physiological and mental rest. BMR is measured under standardized conditions, conducted with the subject in a postprandial state.

Curteon (1947) reported that basal metabolic rate, heart beat rate and oxygen consumption rate were the pertinent parameters for assessing the human energy required for performing various types of operation.

Passmore (1956) estimated the energy expended by man and reported that basal metabolism of an adult is 1900 kcal. He assessed the metabolism requirement for non - working and 8 hours of bed rest as 1400 kcal and 5000 kcal respectively.

Grandjean (1982) revealed that a resting person had steady expenditure of energy depending on size, weight and sex when a person was lying down with an empty stomach.

Narashingrao (1997) conducted investigation on the ergonomics of man machine system on sprayers and estimated the BMR of three subjects which were ranged from 1507 to 1744 kcal day^{-1}. The range of BMR (kcal day^{-1}) of an adult at rest position (lying down and empty stomach) was stated by different researches as shown in Table 2.3.

Table 2.3 Range of BMR (kcal day^{-1}) of an adult at rest position

Sl. No	Source	BMR of an adult (kcal day^{-1})
1	Robinson (1978)	1300 to 1800
2	Tuttle and Schottelius (1979)	1500 to 1800
3	Kathrivel (1986)	1441 to 1565
4	Saraswathyeswaran *et al.* (1987)	1332
5	Karunanithi (1997)	1450 to 1750

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2.3.2 Indirect assessment of oxygen uptake

Since it is difficult to measure the oxygen consumed by the subjects while performing various types of tasks, the subjects are calibrated in the laboratory.

Naughton *et al.* (1963) followed the principle for the sub-maximal exercise on treadmill. The work rate for each subject was increased stepwise at intervals of 3 min on load (slope) until exhaustion. The speed for walk on treadmill was decided based on the field experiment carried out, where they perform the various farm operations at speed varying from 2.5 to 4.5 km h^{-1} (Singh 2005).

Davies and Harris (1964) reported that in the beginning of an exercise the heart rate increased rapidly and reached a steady state by the end of sixth minute. At the start of the exercise, there was a rapid rice in pulse rate and the maximum pulse rate was achieved within 5 seconds.

Astrand and Rodhal (1977) found that there existed a linear relationship between the oxygen consumption and heart rate and hence those variables could be determined during the required task and an extrapolation could be made to determine the maximal heart rate and oxygen consumption. They stated that one of the most useful ways of assessing the workload was measuring the heart rate, since it could be measured easily.

Brockway (1978) stated that the heart beat rate predicts the energy expenditure. This study correlated the heart beat rate, oxygen consumption by indirect calorimetry and indicated the possibility of extrapolating the energy expenditure from the stabilized heart beat rate.

Verma *et al.* (1979) used the bicycle ergometer to find the energy expenditure at different workloads. Heart rate and ventilation rate were measured accurately using ECG machine for assessing the energy expenditure at different workloads.

Rodahl (1989) stated that a linear relationship existed between heart rate and oxygen consumption rate. This relationship established for a given person can be used to determine the oxygen uptake of the given work, if heart rate during the operation is noted.

Sanders and McCormick (1993) reported that heart rate was best used as a predictor of oxygen consumption when moderate to heavy work was performed. They also stated that heart rate continuously sampled over a work day or task, was useful as a general indicator of physiological stress without reference to oxygen consumption or energy expenditure. And they pointed that for different people the linear relationship between heart rate and oxygen consumption was different. So they suggested calibration of each person to determine the relationship between heart rate and oxygen consumption.

Bridger (1995) stated that it was easy to measure heart rate of a subject but could not estimate energy expenditure. So, both variables had to be measured simultaneously in laboratory at different submaximal loads.

Kroemer *et al.* (2000) stated that measuring the heart rate was one of the most useful ways of assessing the workload as it could be done so easily.

Singh *et al.* (2008) suggested that regression equations can be used for estimating the oxygen consumption rate of farm women at their measured/known heart rate for agricultural activities/operations in the field.

2.4 PHYSIOLOGICAL COST OF WORK

Physiological cost involved in any operation is expressed in terms of cardio respiratory response of the subjects during work and the main parameters measured are heart rate and oxygen consumption rate. Heart rate integrates the total stress on the body and can be used as an index of the physiological cost of work.

Lehmann (1958) stressed upon the need to figure out the reasonable ceiling of energy expenditure over the period of conventional working day. He found that the maximum energy output, a normal man can afford in long run, was about 4800 kcal day^{-1} subtracting his estimate of basal and leisure requirements of about 2300 kcal day^{-1}, leaves a maximum of about 2500 kcal day^{-1} available for the working day. Although he proposed a maximum of about 2000 kcal day^{-1} as a normal load.

McCormick (1976) reported that the posture of workers while performing some tasks is another factor that can influence energy requirements. Transplanting in bending posture required the highest energy than any other posture.

Nag and Dutt (1980) concluded that, the transplanting of rice by hand demanded higher energy as the workers have to immerse their feet in mud (mid-calf to knee depth). Walking in a puddled field itself required 22 per cent more oxygen uptake and the heart rate was higher by 11 beats min^{-1}. As the transplanting operation needs to be done in a puddled field. the workers have to immerse their feet in mud (mid-calf to knee depth) during their activities and it takes about 240 man-hours to plant one hectare area.

Nag *et al.* (1980) suggested that the energy costs of the operations were computed by multiplying the value of oxygen consumption by the calorific value of oxygen as 20.88 kJ l^{-1}.

Baqui and Latin (1982) studies human energy expenditure in rice transplanting using IRRI manual rice transplanter in comparison with traditional hand transplanting by indirect calorimetry. The maximum energy expenditure in machine and hand transplanting were 3.79 and 3.09 kcal min^{-1}, respectively.

Kathirvel *et al.* (1991) observed that energy expenditure of power tiller operation varied from 13.48 to 25.82 kJ min^{-1} during rototilling operation under different operating conditions.

Varghese *et al.* (1994) also suggested formula for predicting energy expenditure of field operations which was as follows

$$\textit{Energy expenditure (kcal min}^{-1}\textit{)} = 0.039 \times \textit{heart rate} - 2.33$$

Karunanithi (1997) observed that while performing different tasks in puddled field, walking alone consumed 72 per cent of total energy expended by subjects.

Tiwari and Gite (1998) measured heart rate and oxygen consumption of the power tiller operations during rototilling operations under actual filed condition. The mean values of human energy expenditure during rototilling operations were 10.02, 12.11 and 13.15 kJ min^{-1} at the forward speed of 1.09, 1.96 and 2.26 km h^{-1} respectively.

Vidhu (2001) conducted experiment on manually operated rice transplanter with trial duration of 30 minutes for physiological measurements of women subjects. The trial period was decided based on the time taken to empty of the total seedlings in rice transplanters at continuous operation.

Anonymous (2002) was carried out study on ergonomical evaluation of paddy transplanter and they observed that the mean heart rate and energy expenditure of the male subjects were 136.03 beats min^{-1} and 24.45 kJ min^{-1}. The corresponding oxygen consumption for this heart rate was 1.171 l min^{-1} and the operation of paddy transplanter was graded as 'heavy'.

Sam (2002) measured the human energy expenditure of work of power tillers for rotary ploughing at forward speed of operation of 1.5 to 5.0 km h^{-1}. For untilled field, the energy expenditure of work varied from 17.13 to 20.09 kJ min^{-1} and 13.95 to 15.43 kJ min^{-1} and for tilled field the values varied from 15.70 to 18.23 kJ min^{-1} and 13.28 to 14.59 kJ min^{-1} respectively for walking type (7.46 kW) and riding type (8.95 kW) power tillers.

Karunanithi and Tajuddin (2003) reported that the energy expenditure of male workers varied from 2.4 to 4.9 kcal min^{-1} whereas that of female workers varied from 2.3 to 3.5 kcal min^{-1}. Male workers consumed 2 to 10 per cent more energy than female workers for performing the same task.

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Mohanty *et al.* (2012) conducted experiment on manually operated rice transplanters with trial duration of 25 minutes with 10 minutes rest before and after the work for each subject and concluded that the physiological cost of work is influenced by the health of the operator, nutrition, basal metabolic rate (BMR) and energy expended while working.

Ojha and kwatra (2014) stated that the mean value of working heart rate was assessed to be maximum 138.32 ± 7.67 beats min^{-1} in manual hand transplanting and 110.12 ± 5.79 beats min^{-1} in eight- row paddy transplanter. The energy expenditure was measured 18.40 ± 0.95 kJ min^{-1} in local transplanting method and reduced to 15.17 ± 1.68 kJ min^{-1} with paddy transplanter.

Tamilselvi and Krishnan (2016) stated that the heart beat rate and operating energy requirement for ergo refined knapsack and rocker arm sprayers were observed as 93 to120 beats min^{-1}, 97 to 120 beats min^{-1}, and 18.86 to 24.31 kJ min^{-1}, 19.27 to 25.54 kJ min^{-1} respectively.

2.5 GRADE OF WORK

To perform the manual activity, muscular movement is necessary which causes stress on the cardio-pulmonary system to meet the demand of extra energy. But assessment of cardio-pulmonary conditions, one can give the degree of physiological stress going to be imposed on our body and how effectively our body will be capable to maintain that condition.

Sen (1969) classified the manual jobs based on the physiological responses of young Indian male and female workers. The classification based on heart rate, oxygen consumption and energy expenditure is furnished in Table 2.4.and 2.5 respectively for male and female Indian workers.

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Table 2.4 Tentative Classification of workload for male subjects

Physiological workload	Physiological response		
	Heart rate (beats min^{-1})	Oxygen uptake, (l 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

Table 2.5 Tentative Classification of workload for female subjects

Physiological workload	Physiological response	
	Heart rate (beats min^{-1})	Energy expenditure,(kcal min^{-1})
Very light	< 90	< 5.0
Light	91- 105	5.1-7.5
Moderately heavy	106- 120	7.6- 10
Heavy	121- 135	10.1- 12.5
Very heavy	136- 150	12.6- 15
Extremely heavy	>150	>15

Nag *et al.* (1980) categorized the occupational work load in performing the agricultural activities. Work intensity of the agricultural operations were classified in terms of "light", "moderate", "heavy" and "extremely heavy" which corresponded up to 25 per cent, 25 to 50 per cent, 50 to 75 per cent and above 75 per cent of the maximal oxygen consumption respectively, obtained from rhythmic bicycle ergometry.

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2.6 ACCEPTABLE WORK LOAD

There are many criteria for defining acceptable workloads like difference in pulse rate between working heart rate and resting heart rate, time for regaining resting heart rate and percentage of maximum aerobic capacity. During physical activity there is increase in heart rate and oxygen consumption depending upon work load, and the maximum values which could be attained in normal healthy individuals were about 190 beats min^{-1} for heat rate and 2 l min^{-1} (i.e. up to VO_2 max). Researchers have worked on different parameters for defining acceptable workloads.

Astrand (1960) stated that acceptable workloads were based on the maximum aerobic capacity, usually measured by sequentially increasing the load on a treadmill or bicycle ergometer.

According to Saha *et al.* (1979), 35 per cent of maximum oxygen uptake (also called maximum aerobic capacity or VO_2 max) can be taken as the acceptable workload (AWL) for Indian workers, which work out to a work consuming 0.7 l min^{-1} of oxygen. The corresponding heart rate at this workload was 110 beats min^{-1}. They also reported that acceptable limit of work for a woman is 110 beats min^{-1} for hot environment.

Grandjean (1982) has suggested that the measurement of stress at work must focus on the individual's psychological state. Psychophysical methods were one of the methods used to determine acceptable workloads.

Gite (1993) reported that generally, a workload, which requires oxygen at a rate of about 35 per cent of VO_2 max, is considered as the accepted workload for Indian workers and the values work out to be 0.70 l min^{-1} and 0.63 l min^{-1} for male and female workers respectively. The corresponding heart rate values for this workload was about 110 beats min^{-1} and 105 beats min^{-1}.

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Chauhan and Saha (2004) determined the acceptable limits of physiological workload of Indian women. They found that the acceptable limits of heart rate were 110 beats min^{-1}, 95 beats min^{-1} and 100 beats min^{-1} respectively for different age groups of 21 to 30, 31 to 40 and 41 to 50 years, and the corresponding values of energy expenditure were 10 kJ min^{-1}, 9.6 kJ $min^{-1}$and 10.5 kJ min^{-1}.

2.6.1 Maximum aerobic capacity (VO_2 max)

Astrand and Rodahl (1970) found that during continuous work lasting for at least 5 to 6 min, oxygen consumption equaled oxygen demand and during the last 2 to 3 min of the activity, pulmonary ventilation, heart rate and other cardiovascular parameters were constant. They also reported the same heart rate at a given sub maximal workload in old and young. However, maximal oxygen uptake, heart rate, stroke volume, pulmonary ventilation and muscle strength decreased significantly with age.

The VO_2 max values were dependent factors like race, age, body built up training etc. for western workers, it ranges from 3.5 to 4.5 l min^{-1} (Astrand and Rodhal 1977). Some types of exercises and corresponding VO_2 max values were presented in Table 2.6.

NIOSH (1981) reported that there is increase in physiological parameters depending upon the workload, during any physical activity, and the maximum values, which could be attained in normal healthy individuals, will be up to VO_2 max. However at this extreme workload, a person can work only for a few seconds. The acceptable workloads for extended periods as 33 per cent of maximal aerobic capacity for an 8 hour shift and 28 per cent for 12 hour shift.

Nag and Chatterjee (1981) conducted study to find aerobic capacity of eight farm women of Eastern region of the country using Harvard step up test and average aerobic capacity was found as 37.8 ml kg^{-1} min^{-1}.

Rodahl (1989) stated that aerobic capacity is higher in men than women.

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Varghese *et al.* (1995) conducted study on aerobic capacity of urban women home makers in Mumbai, using bicycle ergometer and treadmill. They found significantly higher maximal oxygen consumption (VO_2 max) with treadmill as compared to cycle ergometry.

Gite and singh (1997) stated that maximum aerobic capacity also called as maximum oxygen consumption capacity or VO_2 max was conceived as an international reference standard of cardio-respiratory fitness.

Table 2.6 Mean values of maximal O_2 uptake attained in various types of exercise (Astrand and Rodahl 1977).

Sl. No	Type of exercise	VO_2 max (per cent)
1	Running uphill (≥ 3° incline)	100
2	Running horizontal	95 – 100
3	Bicycling upright (60 rpm)	92 - 96
4	Bicycling upright one leg	65 - 70
5	Bicycling (supine)	82 - 85
6	Arm cranking	65 - 75
7	Arm and leg (with 10-20 per cent of loads on arms)	100
8	Step test	97

Aerobic capacity of sedentary female university students of same socio-economic background was also determined by both direct method, using bicycle ergometer, and indirect method, using Queen's College Step Test by Chatterjee *et al.* (2005). They found significant difference in aerobic capacity obtained by both methods and based on their study; they also suggested a regression equation for predicting oxygen uptake.

Maximum aerobic capacities (VO_2 max) of Indian male and female agricultural workers as represented by various authors were presented in Table 2.7.

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Table 2.7 Maximum aerobic capacity of agricultural workers

S.No.	Source	Maximum aerobic capacity (VO_2 max), l min^{-1}
A. Male		
1.	Nag (1981)	2.24
2.	Nag *et al.*(1988)	2.01
3.	Gite *et al.* (1996)	1.95
4.	Vidhu (2001)	1.69 - 1.92
5.	Sam (2002)	1.98 - 2.48
6.	Kumar (2001)	1.69 - 1.92
7.	Balasankari (2003)	1.76 - 2.35
8.	Thiyagarajan (2013)	1.85 - 2.19
9.	Thambidurai (2007)	2.01 - 2.26
10.	Mohankumar (2014)	1.98- 2.34
B. Female		
1.	Nag (1981)	1.80
2.	Bimla *et al.*(2002)	1.76
3.	Singh *et al.* (2001)	1.60 - 1.87
4.	Sirisha (2004)	1.25 - 1.39
5.	Thambidurai (2007)	1.56 – 1.75

Muthamilselvan *et al.* (2006) observed that the heart rate of the subjects increased steadily from the beginning of the operation and stabilized in the range of 121.0 ± 4.56 beat min^{-1} after 6^{th} minute of operation. The average oxygen consumptions were 0.53 and 0.45 lit min^{-1} for machine and conventional picking respectively. Average energy expenditure for operation of the cotton picker was 11.16 kJ min^{-1} and the operation of the machine could be graded as 'moderately heavy'. The average per cent VO_2 max (29.71 per cent) was lesser than that of the Acceptable Work Load (AWL) limits of 35 per cent.

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2.6.2 Limit of continuous performance (LCP)

The extent to which a person may increase his work rate depends in part on how much he can increase his heart rate from resting level to his maximum level, because the increase in heart rate plays a major role in increasing the cardiac output form rest to maximal work (Rodahl, 1989). For this, the average values of the heart rate at rest level and at working condition were used. The maximal output under these conditions is the limit of continuous performance throughout an 8 hours working day.

Karrasch and Muller (1951) made use of their studies to define an acceptable upper limit of workload as the one below which the working pulse does not continue to rise indefinitely and when the work is stopped, returns to the resting level within about 15 minutes. They further observed that this limit seems to ensure that energy was used up at the same rate as it was replaced to maintain steady state of the body. While performing an activity, the energy output was regulated to agree with body abilities to develop energy under sufficient supply of oxygen. When work was stopped, accumulated metabolic byproducts were resynthesized and the metabolic, circulatory and respiratory systems were returned to their normal states (Kroemer *et al.* 1997).

Brundke (1984) calculated the average work pulses of agricultural operators. Based on the data, Limit of Continuous Performance (LCP) for 8 hours day was suggested as 40 work pulse.

Tiwari and Gite (1998) calculated Δ values (Increase over resting values) for heart rate (work pulse), to have a meaningful comparison of physiological response. For this, the average values of the heart rate at rest level and at working condition were used.

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2.7 SUBJECT RATING OF PERCEIVED EXERTION

Subjective self-reported estimates of effort expenditure might be quantified using rating of perceived exertion. As an investigating tool, Rating of Perceived Exertion (RPE) has proved to be useful adjuncts for studies in exercise physiology by researchers (Borg, 1962; Borg, 1970; Corlett and Bishop; 1976 and Legg and Mahanty, 1985).

Kroemer and Grandjean (2000) defined the fatigue symptom as a general sensation of weariness. They reported the subjective and objective symptoms *viz.*, subjective feeling of weariness, faintness and distaste for work, sluggish thinking, reduced alertness, poor and slow perception and unwillingness to work.

Borah *et al.* (2001) reported that out of 30 women, 70 per cent experienced severe pain in the shoulder joints and 68 per cent found low back pain due to long hours of bending for uprooting of seedlings.

2.7.1 Overall discomfort rating

Borg (1962) developed a "category scale" for the rating of perceived excretion (RPE). The scale ranges from 6 to 20 to match heart rates from 60 to 200 beats min^{-1}, with every second number anchored by verbal expressions. In 1970s, Borg developed a 15-point graded category scale to increase the linearity between the ratings and the workload was developed in 1970. Using this scale, ratings of perceived exertion (RPE) values were shown to be approximately one-tenth of heart rate values for healthy, middle aged men performing moderate to heavy exercise. The Borg – RPE scale as shown in Table 2.8.

Corlett and Bishop (1976) developed a technique for the assessment of overall discomfort rating in which a 10 - point psychophysical rating scale (0 - No discomfort, 10 - Extreme discomfort) was used.

Wos *et al.* (1988) have found that self-rating based on Borg's scale can be used to assess vibrational intensity. The pictorial representations, where discomfort 43 is plotted on a human figure, have been used for studies of vibration tolerance and discomfort and also for studies of back pain (Kuornika, 1983).

Table 2.8 Borg- RPE scale (1962)

Category	No. scale
No exertion at all	6-7
Extremely light	8
Very light	9- 10
Light	11
Somewhat hard	12-13
Hard (heavy)	14- 15
Very hard	16-17
Extremely hard	18- 19
Maximal exertion	20

Gite *et al.* (1992), conducted ergonomic evaluation of manual weeders and found that the postural discomfort (overall discomfort rating) varied from 3.0 to 5.1 on 8-point scale (0 – no discomfort, 8 - extreme discomfort) for a 15-min operation of each weeder.

Tiwari and Gite (2000) conducted a study to find the overall discomfort ratings on a 10 point visual analogue discomfort scale for a power tiller operation for 20 minutes. The discomfort ratings were in the range of 1.0 to 3.5 with seating attachment and from 2.0 to 5.0 without seating attachment.

Kumar (2001) used the Borg-RPE 15 point scale and reported that the mean values of overall discomfort rate (ODR) for the operation of drum seeder by the subjects varied from a minimum of 13.5 to a maximum value of 16.7. The discomfort experienced by the subjects is more when the number of rows, furrow opener and ground wheels added to the drum seeder necessitating additional effort from the subject to cope up with the increased load and weight of the drum seeder.

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Vidhu (2001) used the Borg RPE 15 point scale and reported that the overall discomfort was maximum for conoweeder (16.13) followed by seeding with direct paddy seeder (14.70), harvesting with self-propelled paddy harvester (14.60) and transplanting with manually operated paddy transplanter (14.37) using 15 point overall discomfort rating scale.

Sam (2002) used the 10-point scale developed by Corelett and Bishop (1976) and reported that the value of ODR varied from 4.6 to 5.0 and scaled as 'moderate discomfort' for rotary tiller ploughing and during transport with trailer the values varied from 3.2 to 4.0 and scaled as 'more than light discomfort' at the forward speeds of 1.5 and 1.8 km h^{-1}.

Balasankari (2003) used the 10-point scale developed by Corelett and Bishop (1976) and reported that with increase in speed, the ODR values increased at all conditions for both the tractors. The values of ODR ranged from 1.67 during cultivator operation to a maximum of 9.12 during transporting.

Sirisha (2004) reported that the overall discomfort rate was maximum (7.55) for fertilizer broadcaster followed by conoweeder (7.15), seeding with four row paddy seeder (7.07), pulling stalks with cotton stalk puller (6.43), harvesting fruits with fruit harvester (6.37) and stripping with groundnut stripper (6.27) using 10 point overall discomfort rating scale.

Sam (2014) found that mean overall discomfort rating on a 10 point visual analogue discomfort scale (0- no discomfort, 10- extreme discomfort) was 6.6 and scaled as "moderate discomfort" for harvesting with self-propelled harvester whereas the rating was 8 and scaled as "more than moderate discomfort" for manual harvesting. Similarly, the rating was 6.3 and scaled as "moderate discomfort" for threshing with mini thresher while the rating was 8.5 and scaled as "more than moderate discomfort" for manual threshing.

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2.6.2 Body part discomfort score (BPDS)

Corlett and Bishop (1976) used body mapping for assessment of postural discomfort at work. In this method, the perceived discomfort was referred to a part of the body. The subject's body was divided into 27 regions and the subject was asked to indicate the regions which were experiencing discomfort or pain in decreasing order. The subject was also asked to assess total discomfort from the worst on a particular body part, using a five or seven point scale. The scales were graded from "no discomfort" to "maximal discomfort".

Lusted *et al.* (1994) developed a body area chart discomfort checklist. It was used to rate the discomfort under dynamic condition to identify body area experiencing discomfort. Two discomfort checklists were to be filled, one at the start of the test and the second after a long period in the seat. The ratings were then compared to estimate the level of discomfort.

Kroemer and Grandjean (2000) defined the fatigue symptom as a general sensation of weariness. They reported the subjective and objective symptoms *viz.*, subjective feeling of weariness, faintness and distaste for work; sluggish thinking; reduced alertness; poor and slow perception and unwillingness to work.

Sam (2002) reported that, the majority of discomfort was experienced in the left arm, right arm, left leg, right leg and shoulder region for all the subjects for walking type power tiller (7.46 kW) during rototilling whereas the majority of discomfort was concentrated in the lower back, buttocks, left thigh and right thigh region for riding type power tiller (8.95 kW). It was also reported that in the field operation the body part discomfort score of the subjects for riding type power tiller (8.95 kW) was lower than the walking type power tiller (7.46 kW). The level of discomfort increased with forward speed of operation. The intensity of pain experienced by the subject was more in untilled than tilled field.

Balasankari (2003) reported that in tractor operator the BPDS values were minimum during cultivator operation (45.67) at lowest tested speed and maximum 46 during driving empty trailer on bitumen road (138.11). The discomfort was localized in lower back, buttocks and mid back regions of the body.

2.7 WORK REST CYCLE

For every strenuous work in any field requires adequate rest to have an optimum work out put. Proper attention to find the work rest schedule for different operations will reduce better performance results.

Kodak (1986) gave the rest allowance as a function of the work and the length of the uninterrupted work period. He presented the nomogram for the levels of work corresponding to the levels of energy expenditure where 1 to 2.5 kcal min-^{1} was taken as light work, followed by 2.6 to 3.75 kcal min^{-1} moderate, 3.8 to 6 kcal min^{-1} heavy, and 6.1 to 10 kcal min^{-1} very heavy and more than 10 kcal min^{-1} as extremely heavy.

Datta and Tiwari (1988) found that an allowance of about 30 per cent of the total working time would be the most advantageous from ergonomic point of view as well as the work out put view in the operation of manual weeders.

Phesant (1991) computed the following formula for estimating the total amount of rest required for any given work activity depending on its average energy cost.

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

Where,

R = Resting time (min)

T = Total working time day^{-1} (min)

E = Energy expenditure during working task (kcal min^{-1})

A = Average level of 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}.

Mehta *et al.* (1997) measured ride vibrations on a power tiller with a seating attachment under different operating conditions and compared them with the values specified under ISO 2631 (1985) in relation to working efficiency, health and safety of the operator. They found that exposure time for the power tiller should not exceed 2 to 5 h during rototilling.

Yadav and Pund (2007) stated that the rest pause for achieving functional effectiveness during transplanting the paddy by six row transplanter was found to be 14.30 min followed 30 minutes of work.

2.8 MUSCULOSKELETAL DISORDERS

The knowledge of prevalence of musculoskeletal disorders is important information and can provide a potential practical guidance to prevent musculoskeletal disorders.

Gustafsson *et al.* (1994) investigated the presence of musculoskeletal symptoms in Swedish dairy farmers during the preceding 12 months. As compared to women, men reported more back and knee problems. Women reported more symptoms in the neck, upper back and upper extremities than men.

Meyers *et al.* (1995) stated that occupational musculoskeletal disorders (MSD) might affect muscles, tendons, joints, nerves and related soft tissues anywhere in the body. The lower back and upper extremities, including the neck and shoulders, were the most common sites.

Raffi *et al.* (1996) studied workers histories in an agricultural farm and they were given periodical medical checkups. The presence of upper limb disorders was seen in a group of workers. The study confirmed that electromyography and ultrasonography were highly useful tools for identifying cumulative trauma disorders.

NIOSH (1997) concluded that based on the epidemiologic studies reviewed, the evidence is clear that exposure to a combination of the occupational risk factors studied (repetition, force, posture, etc.) increases the risk for CTS (cumulative trauma disorders)

Park *et al.* (2001) investigated the frequency of risk factors related to back pain on a total of 287 male farmers from Iowa. Daily back pain with duration of one week or more was reported by 31 per cent of the farmers. Farmers in the age range 45 to 59 years and those with an additional nonagricultural job had the highest risk for back pain.

Jyotsana *et al.* (2005) stated that during wheat harvesting activity from morning till evening, women usually adapts squatting posture and they continue to work in this posture for long duration without adapting any other posture due to which they reported severe pain in lower back and knees.

Sharan *et al.* (2010) investigated the relationship between self-reported musculoskeletal symptoms and the work style in Indian computer professionals. A questionnaire survey was conducted among 4511 Indian computer professional using a musculoskeletal survey form and the short work style form. The study concluded that the work style was contributed to musculoskeletal symptoms.

Puntumetakul *et al.* (2011) examined the prevalence of MSD in 311 farmers aged between 20 to 75 years by the standardized Nordic questionnaire and found that the top four of the most prevalence of musculoskeletal pain in seven days were lower back pain, knee pain, hip pain and shoulder pain, respectively. The top four of the most prevalence of musculoskeletal pain in twelve months were lower back pain, hip pain, shoulder pain and knee pain, respectively.

Kar *et al.* (2012) conducted study on occupational problems of about 375 women workers in agricultural tasks and evaluated on the basis of Nordic questionnaire method. They stated that the results of the MSD in agricultural workers reveal that the shoulder problem was highly prevalent (97.6per cent) among the rice cultivation workers and followed by the problems in low back (95.2per cent), in thigh (91.6per cent) and in neck (88.4per cent). The results of the other 49 health hazards reveal that digestive disorders (66.8per cent) were also prevalent among the women agricultural workers.

Pal *et al.* (2014) stated that the prevalence of MSD was very high among the workers and the most affected areas were back and upper extremity. Postural analysis indicated that the subjects had to adopt different stressful postures during performing different potato cultivation jobs. A modified Nordic Questionnaire and Body Part Discomfort scale were applied to identify MSD in different body parts. The postural pattern was assessed by direct observation method.

Swangnetr *et al.* (2015) stated that the planting task performance to pose the highest compressive load on lumbar spine, as well as induce the highest risk level of low back injury, primarily due to force and postures. Other tasks with high risk of back injury included harvesting and ploughing. Moreover, risk assessment was rated based on "worst case" scenario, which was represented by the tallest farmer who required additional trunk forward bending during harvesting task performance.

Davidmin *et al.* (2016) investigated the prevalence and characteristics of musculoskeletal pain (MSK) pain in Korean farmers (534 females and 479 males: mean age 57.2 ±7.5 years) using structured questionnaires and stated that the almost all subjects (n=925; 91.3 per cent) complained of pain in more than one body part. The frequency order was low back (63.8 per cent), leg/foot (43.3 per cent), shoulder (42.9 per cent), wrist/hand/finger (26.6 per cent), arm/elbow (25.3 per cent), and neck (21.8 per cent). Low back pain was more frequent in those with over 30 years of farming experience.

2.9 RULA ANALYSIS

RULA method (Rapid Upper Limb Assessment) was developed at the University of Nottingham in 1993 (Institute for Occupational Ergonomics) in order to evaluate workers exposition to risk factors which may cause disorders in the body parts subjected to forceful posture.

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Stanton *et al.* (2004) and Hashim *et al.* (2012) mentioned that RULA assessment was more towards upper side of the body. It was best for sedentary and seated works and there were four levels of actions to indicate the obtained scores.

Shanahan *et al.* (2013) evaluated the efficacy of RULA, REBA and Strain Index (SI) in the assessment of non-fixed work (non-structured, non-routinised and multi task work) through comparison to four occupationally relevant Borg 10 psychophysical scales: lifting effort, grasping effort, wrist discomfort and low back discomfort.

Ansari and Sheikh (2014) conducted study on 15 workers engaged in small scale industry and evaluation of posture was carried out using RULA and REBA. The RULA method determined that the majority of the workers were under high risk levels and required immediate change. The REBA method determined that some of the workers were under lower levels and majority at high risk levels.

Sanjog *et al.* (2012) highlighted a relevance of digital human modeling (DHM)software in identifying 'fit' of product to intended users during product conceptualization stage to avoid preparation of costly, time consuming physical-mockups for ergonomic studies with real human trial and ensure user friendly product with saving in production cost, time and manual labour. This was also proved by Vyavahare and Kallurkar, (2015).

Bhuse and Vyavahare (2014) used the CATIA V5R18 for ergonomical evaluation of knapsack sprayer. Analysis uses modules of CATIA like Human Builder, Human Activity Analysis and Rapid Upper Limb Assessment (RULA) analysis. Improvements in the design of knapsack sprayer were made to make sprayer ergonomically suitable for 5^{th} to 95^{th} percentile population.

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2.10 VIBRATION AND NOISE LEVEL

2.10.1 Vibration

Vibration is typically an oscillating motion of a mechanical system or body. The magnitude of vibration can be described by the displacement (mm) of the motion above some reference point or, alternatively by the rate of change of this displacement (*i.e.*, velocity m s^{-1}) or acceleration (m s^{-2}) with reference to time. However, the human vibrations are measured in terms of acceleration only. Mechanical vibrations have instantaneous and long term effects upon the human body. Kinds of effect depend upon the duration of exposure and the frequency of vibrations.

Singh and Kaul (1972) observed that vibration and noise contributed 5–7 per cent of the total human energy demand for operating a power tiller.

Salokhe (1995) investigated the vibration characteristics of a power tiller (two-wheel tractor) at 1000, 1200, 1400, 1600, 1800, 2000, and 2200 rpm engine speeds in a stationary condition, and at 1000, 1200, 1400, 1600, and 1800 rpm engine speeds during transportation and tillage. Vibration characteristics of the power tiller were found to be quite complex. In general, it was observed that, in any working condition, due to an increase in engine speed of the power tiller, the acceleration of vibration increased. At the same operating speed and test condition, the intensity of the vibration was the highest in the vertical mode and the lowest in the lateral mode.

Dong (1996) concluded that the main cause of vibration was engine and the vibrations in the handle were very strong and seriously affects walking tractor operator's health.

Mehta *et al.* (1997) suggest that there were many factors which influenced human response to vibrations. These factors can be grouped into two categories of variables *viz.* intrinsic variables and extrinsic variables. Intrinsic variables include

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factors such as population type (age, sex, size, and fitness), behavioral attributes (experience, expectation, arousal, motivation, financial involvement) and body posture activities which were directly linked with the operator. Extrinsic variables include factors such as vibration magnitude, vibration frequency, vibration axis, vibration input position, vibration duration, seating restraints and other environmental influences (noise, heat, acceleration, light) which were not directly linked to the operator.

Goglia *et al.* (2003) presented research results of the vibration transmitted from the steering wheel of the small tractor with a 4-wheel drive to the driver's hands. Based on the measurement, the vibration acceleration level transmitted from the steering wheel to the driver's hands will produce finger blanching in 10 per cent of exposed persons in less than 2 years.

Tewari *et al.* (2004) modified a hand tractor to enable operation in a seated position. They observed that vibration intensity in root mean square (RMS) acceleration was a maximum as 45 m s^{-2} without the seat whereas this value was 20 m s^{-2} with the seating arrangement.

Cakmak *et al.* (2011) measured the vibration of different harvesters at both idling and full load conditions. The results indicated that in 10 per cent of the exposed population, traumatic vasospastic disease (TVD) appeared after 0.7 to 7.1 years for the left hand, 1.0 to 4.7 years for the right hand in continuous use of these harvesters, under usual working conditions.

2.11.2 Noise level

The noise produced by engines may cause discomfort, nervousness, tension, irritability and fatigue. Levels from 86 to 115 dB (A) can cause specific effects to the ear such as the damage of the corticells and can involve psychosomatic diseases. Noise also results in increase in the pulse rate & blood pressure and irregularities in heart rhythm. Emerson (1975) proposed the occupational noise exposure standards as given in Table 2.9.

Table 2.9 Noise exposure standards

Duration per day, h	8	6	4	3	2	1.5	1	0.5	0.25
Sound level (dB)	90	92	95	97	100	102	105	110	115

Gupta (1978) inferred from the test reports at Central Farm Machinery Testing and Training Institute, Budni that noise levels in different makes of tractors ranged between 90 to 100 dB which were above the safe limit for 8 hour work exposure.

Bansal *et al.* (1982) surveyed the noise levels of seven makes of tractors and reported that noise levels were between 87 to 98 dB (A). They observed that over all noise level in the tractors was attributed mainly due to combustion. The cooling fan noise level increased with the engine speed and the power generated.

Noise levels generated by 35 wheel tractors were measured at driver ear level by Mastri *et al.* (1985) and he stated that. the decibel levels increased with increasing tractor age and poor tractor maintenance so that it was not possible to assess whether increasing engine power led to higher decibel levels. Preliminary results from another trial with tractors fitted with cabs showed that noise levels were reduced by 3 to 12 dB (A) (noise levels of 76 to 95 dB (A)) when the doors of the cab were closed.

Ragni *et al.* (1999) conducted studies on some of the small cultivators. He found that the level of noise at the workers ear should not involve an appreciable risk for hearing after 10 years of use.

2.12 SPATIAL, VISUAL AND CONTROL REQUIREMENTS OF OPERATOR

Dupuis (1959) examined the strain on the tractor operators during operation of different controls. It was observed that human energy consumption could be reduced by 13 to 29 per cent by making improvement in tractor controls and seat. It

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was concluded that the efficiency and comfort of the operator were improved with a properly designed tractor workplace.

Shao and Zhou (1990) described the design principles of tractor driver seat static comfort from ergonomics point of view. They considered geometric parameters of seat construction from anthropometric data of Chinese population. The geometric parameters were lumbar support, backrest slope angle, seat width, seat length, seat height, seat pan angle, etc. They concluded that the seat position should be vertically and longitudinally adjustable. Seat should allow the operator to change his position from time to time in order to relieve pressures and rotate muscle groups under tension. The position of lumbar support should be vertically adjustable.

The International organization for Standardization (ISO 4253, 1993) and Indian Standard (IS 12343, 1998) lay down range of dimensions for the operator's seat and location of specific control relative to the seat index point (SIP) within the seating accommodation on agricultural tractor with a track width greater than 1150mm (Figure 2.2) and were given in Table 2.10. The SIP as per ISO 5353 (1984) is the interaction on the central vertical plane passing through the seat center line of the theoretical pivot axis between a human torso and thighs. At present, the Bureau of Indian Standard (IS 12343, 1998) has incorporated most of the requirements of the ISO 4253 (1993) standard except seat height. The ISO standard is primarily based on the data of Western/European workers.

Tewari and Prasad (2000) concluded that the seat pan with radius of curvature 750 mm, backrest with radius of curvature 300mm and backrest inclination of 10° were the most suitable values for Indian tractor operators.

Kumar *et al.* (2002) developed a safer design of thresher using anthropometric data of Indian population. They increased the chute cover length and chute length up to 650 mm and 1000 mm respectively. They recommended the 220 mm chute opening height to ensure smooth feeding of crop bundles. Another preventive measure was proposed to reduce injury probability by increasing the slope of feeding chute from 15° to 25°. A hand warning roller was placed at the end of a baffle plate in the mouth of the chute. They suggested a new design platform on the basis of the anthropometric dimension of elbow height of the 95th percentile Indian male population.

Table 2.10 Comparison of recommendations on tractor seating by various researchers with ISO standard

Dimensions	ISO 4253 (1993)	IS 12343 (1998)	Shao and Zhou (1990)	Whyte and Stayner (1984, 1985)	Donati *et al.* (1984)
Seat pan width (mm)	>450	>450	≥400	450-480, 465(optimum)	>450
Seat length (mm) (in front of SIP)	210-310	210-310	240-290	300-330	250-310
Seat pan tilt (°)	3-12	3-12	3-7	-	4.5-10
Seat backrest width (mm)	-	-	-	350-425	-
Seat backrest height (mm) (above SIP)	>260	>260	-	300-330	333
Seat backrest inclination (°)	95-105	95- 105	105-115	102-103	>111
Seat height (mm)	-	<540	380-400	-	-

Hsiao *et al.* (2007) investigated the hundred farm-workers anthropometry and determined the critical anthropometric measures and 3- D feature envelopes of body landmarks for the design of tractor operator enclosures. Knee height (sitting) and other eight parameters were found to affect the cab-enclosure accommodation rating and multiple anthropometric dimensions interactively affected the steering wheel and gear-handle impediment. A principal component analysis has identified 15 representative human body models for digitally assessing tractor cab accommodation. Finally, the vertical clearance (90 cm) for agriculture tractor enclosure in the current SAE International J2194 standard appeared to be too short as compared to the 99th percentile sitting height of male farm workers in this study

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(100.6 cm) and in the 1994 National Health and Nutrition Examination Survey (III) database (99.9 cm) values.

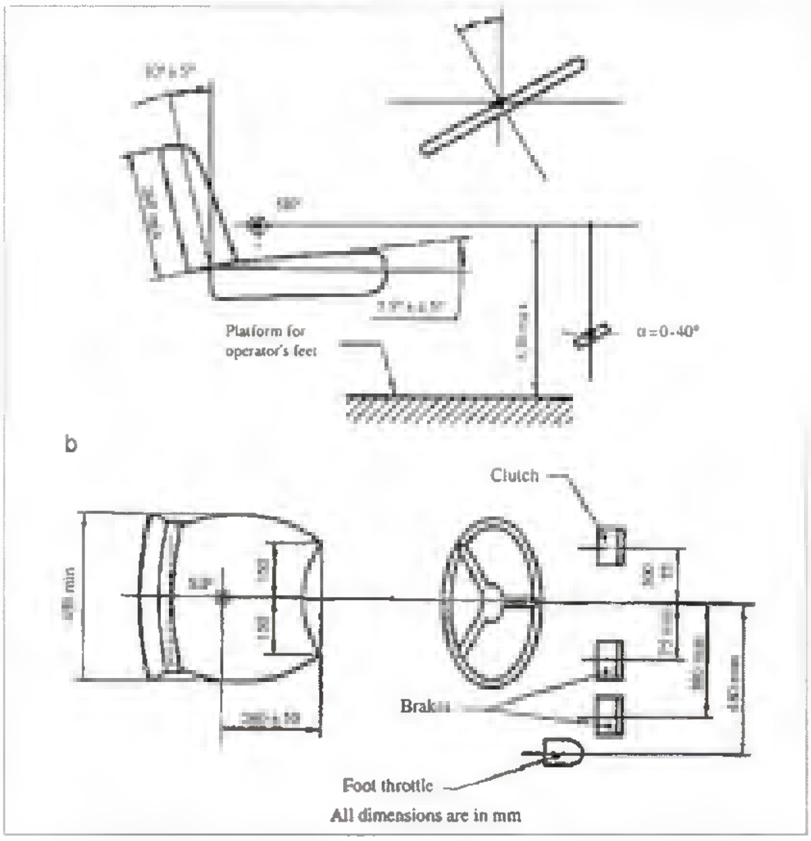

Fig. 2.1 Operator seating accommodation (IS 12343, 1998): (a) Side view and (b) plan view.

Dewangan *et al.* (2010) used the 801 male's anthropometric data to design and design modification of agricultural tools, implements and machines to be operated by male workers in the hilly region of the country. Based on the data they recommended handle length for direct paddy seeder was 122 cm. In LOK sprayer design, they considered 5th percentile values of scapula to waist back length (40.5 cm) for designing of strap length. For effective handle length, 95th percentile values of elbow grip length and shoulder grip length was considered. They suggested the weight of spray material was 13 kg based on the 5th percentile value of the body weight of the operator.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

In this chapter, the complete description and specifications of the selected rice transplanters were explained. The procedure followed for anthropometry and selection of subjects were detailed. The procedure adopted for calibration of selected subjects and the methodology adopted for ergonomic evaluation of the selected rice transplanters was narrated. The methods adopted for assessing the postural discomfort in terms of rating scales and musculoskeletal disorders by standardized Nordic questionnaire were explained. The optimal range for spatial, visual and control requirements of operator were detailed.

3.1 SELECTION OF EQUIPMENT

In the process of mechanization / modernization of Indian agriculture, the improved designs of agricultural machinery in the country were introduced by adopting imported designs from developed countries with some modifications to suit Indian field condition. This had enhanced the use of farm machinery and equipment during last three decades. Though all these machines/ equipment were either operated or controlled by human workers, no little modification was done in design of equipment or work place to suit size, capabilities and limitations of Indian workers. And also most of the agricultural equipment was designed for men with no concern for their appropriateness for women, who possess different physiques and energy capabilities in comparison to men. In this study, three different makes of 8 row transplanters is being widely used for rice transplanting in Kerala were selected. The selected 8 row transplanters for the present study were listed below.

i. Yanmar 8 - row self-propelled riding type rice transplanter
ii. Redlands 8 - row self-propelled riding type rice transplanter
iii. Yanji 8 - row self-propelled riding type rice transplanter

The physiological costs of work of these three transplanters were compared with the traditional transplanting method.

3.1.1 Yanmar 8 row self-propelled riding type rice transplanter

The Yanmar rice transplanter is a self-propelled ride-on machine with a four stroke water cooled diesel engine. It has eight rows with 30 cm row to row and five standard positions (12cm, 15cm, 17cm, 20cm, and 28cm) for hill to hill spacing. One more position 30 x 30 cm (square planting) can be obtained by removing one of the two planting tines provided on each planting arm.

The machine was provided with travelling speed, planting speed and reverse speed. There were eight rotor cases, each consist of two planting arms, two push rods and two planting tines. The machine has a provision to adjust the planting depth according to field conditions, i.e. SOFT/HARD by selecting field condition and uniform depth will be maintain by the hydraulic sensor. It was also provided with unit clutch levers to stop any two rows from planting at the headland or at irregular boundaries. It was having features like high capacity fuel tank, easy turning on the head land, automatic levelling control, driven by petrol engine, auto transplanting depth control, high transmission rate 15 per cent more than HST transmission. Easy operation, speed control was just only pushing or releasing on the pedal. The specification of the selected Yanmar8 row self-propelled riding type rice transplanter (Plate 3.1) was furnished in Table 3.1.

Plate 3.1 Yanmar 8 row self-propelled riding type rice transplanter

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Table 3.1 Specification of the selected Yanmar 8 row self-propelled rice transplanter

Sl. No	Details	Specifications
1	**Key Specifications**	
	Model & Type	Yanmar, 8 rows, riding Type
	Operation efficiency	1.2 acres/h
2	**General Features**	
	Length x width x height (mm)	3350 x 2220 x 1800
	Weight (kg)	810
3	**Engine**	
	Output/RPM (kW (PS) / rpm)	14.7 kW(20 PS)/3200rpm
	Applicable fuel	Petrol
	Fuel tank capacity(l)	20
	Fuel efficiency	2.5 l /acre
4	**Traveling**	
	Steering system	Power Steering
	Wheel adjustment	Hydraulic System
	Wheel type	Puncture free tire/Rubber covered two side lugged tyre
	Shifting System	Hydro-mechanical transmission (HMT)
	No. of shifting positions/no. of Gears	Forward 2 / Reverse 1
5	**Planting**	
	Number of planting rows	8
	Planting system	Rotary type
	Distance between rows (mm)	300
	Hill space/planting distance (mm)	210, 180, 160, 140, 130
	No. of hills/no. of Seedlings	50, 60, 70, 80, 90 (Seedlings/3.3 m^2)

	Planting depth (mm)	2 – 44
	Number of seedlings per hill/adjustment per seedling, cross feed, vertical scraping, mm/rotation	11 (26 times), 12 (24 times), 14 (20 times), 16(18 times), Vertical Scraping: 8 – 17
	Planting speed	0 – 1.60 m/s
6	**Seeding**	
	Seedling type	young seedling, medium seedling
	Seedling height (mm)	80 – 250
	Number of leaves	2.0 – 4.5
	No. of spare boxes for spare seedlings	6

3.1.2 Redlands 8 - row self-propelled riding type rice transplanter

The Redlands rice transplanter is a self-propelled riding type machine with a four stroke air cooled diesel engine. It has eight rows with 23.8 cm row to row and four standard positions (12cm, 14cm, 16cm and 19cm) for hill to hill spacing. The machine is provided with travelling speed and planting speed. The machine has provision for changing number of plants per hill by a manual adjusting screw knob provided at each planting arm. It has also the provision for the planting depth adjustment with the help of a lever provided on the planting mechanism. There were eight crank cases, each consist of one planting arm and one push rod.

The machine has a provision to adjust the planting depth according to field conditions, i.e. SOFT/HARD by selecting field condition and uniform depth will be maintain by the float. The specification of the selected Redlands 8-row self-propelled riding type rice transplanter (Plate 3.2) was furnished in Table 3.2.

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Plate 3.2 Redlands 8 row self-propelled riding type rice transplanter

Table 3.2 Specification of the selected Redlands 8-row self-propelled riding type rice transplanter

Sl. No	Details	Specifications
1.	**Key specifications**	
	Model & type	Redlands, Riding Type
	Operation efficiency	0.36 – 0.6 acres /h
2.	**General features**	
	Length x Width x Height (mm)	2640 x 2150 x 1300
	Weight (kg)	400
3.	**Engine**	
	Type	Single cylinder diesel engine
	Output/RPM (kW (PS) / rpm)	3.4 kW
	Applicable fuel	Diesel
	Fuel efficiency	0.5 l/h
4.	**Traveling** (Steering system)	
	Wheel adjustment	Hydraulic system
5.	**Planting**	
	Number of planting rows	8

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	Distance between rows (mm)	238
	Hill space (mm)	120, 140, 160, 190
	Planting depth (mm)	0 – 50
	Number of seedlings per hill	2 – 8
6.	**Seeding**	
	Seedling type	Seedling mat/ Tray type

3.1.3 Yanji 8 row self-propelled riding type rice transplanter

The Yanji rice transplanter is a self-propelled riding type machine with a single cylinder air cooled diesel engine. It has eight rows with 23.8 cm row to row and four standard positions (10-12cm, 12-14cm, 17-20cm and 20-23cm) for hill to hill spacing. The machine is provided with travelling speed and planting speed.

The machine has provision for changing number of plants per hill according to density and thickness of seedling by a manual adjusting screw knob provided at each planting arm. It has also the provision for the planting depth adjustment with the help of a lever provided on the planting mechanism. There were eight crank cases, each consist of one planting arm and one push rod.

Plate 3.3 Yanji 8-row self-propelled riding type transplanter

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The machine has a provision to adjust the planting depth according to field conditions, i.e. SOFT/HARD by selecting field condition and uniform depth will be maintain by the float. It is a high labour saving machine, eliminates drudgery, increases productivity and gives very high return on investment. The specification of the selected Yanji 8-row self-propelled riding type rice transplanter (Plate 3.3) was furnished in Table 3.3.

Table 3.3 Specification of the selected Yanji 8-row riding type transplanter

Sl. No	Details	Specifications
1.	**Key specifications**	
	Model &Type	8- row rice transplanter, riding type
	Operation efficiency	0.33 to 0.5 acres/h
2.	**General features**	
	Length x Width x Height (mm)	2500 x 2131 x 1300
	Weight (kg)	305
3.	**Engine**	
	Output/RPM (kW (PS) / rpm)	2.94 kW/ 2600
	Applicable fuel	Diesel
4.	**Traveling**(Steering system)	
	Wheel type	Single wheel driven – steel wheel in rice fields or rubber tyre on land
	Travelling speed on road	8.2 km /h
5.	**Planting**	
	Number of planting rows	8
	Planting system	Separate crank shaft & connecting Rod system with seedling pusher

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	Distance between rows (mm)	238
	Hill space (mm)	140-170 (standard), 100-120, 120-140, 170-200,200-230 (optional)
	No. of hills	32-42 hills/m^2
	Planting depth (mm)	0 – 60 (Adjustable)
	Number of seedlings per hill	3 – 8 (Adjustable according to density and thickness of seedlings)
	Planting Speed	0.44 – 0.54 m/s
6.	**Seeding**	
	Seedling type	Seedling mat

3.2 ANTHROPOMETRY

Anthropometry is the science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body. It involves the systematic measurement of the physical properties of the human body, primarily dimensional descriptors of body size and shape. The knowledge of body dimensions is essential for designers of equipment and work places. The anthropometric measurements are essential for the correct design of the work areas. Anthropometric dimensions differ considerably across gender, race, ethnicity and age, taking into account ergonomic and anthropometric principles (Singh *et al.* 2013). The standard proforma developed by AICRP on ESA, Bhopal, India was used for collecting the data (Tewari, 2004).

3.2.1 Subjects

As per recommendation of AICRP on ESA, Bhopal, the anthropometric data were collected from 450 women agricultural workers of 18-60 years age group from three zones of Kerala namely northern, central and southern zones. A sample of 150 women agricultural workers were selected from each zone for the study.

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3.2.2 Body dimensions and Instruments

Seventy nine body dimensions including age and body weight and ten strength measurements, necessary for the design/design modification of agricultural machines from ergonomic considerations were selected. In the standing posture, 49 measurements including 16 vertical dimensions, 9 transverse dimensions, 5 circumferential dimensions, 18 fore limb measurement and weight were recorded. In the sitting posture, 16 measurements including 8 heights and 8 transverse measurements were taken. In sitting/ standing posture 14 measurements included 7 hind limbs, 3 head dimensions and 4 skin fold dimensions. Standard terminologies given in the anthropometric source book (NASA, 1978) have been used. The selected body dimensions and strength measurements were shown in Table 3.4. The instruments used for the anthropometric study were depicted in Table 3.5.

Table 3.4 Anthropometric dimensions selected for the study

Sl.no	Dimensions	Sl.no	Dimensions
1	Age	41	Buttock knee length
2	Weight	42	Buttock popliteal length
3	Stature	43	Abdominal depth sitting
4	Vertical reach	44	Hip breadth sitting
5	Vertical grip reach	45	Elbow-elbow breadth sitting
6	Eye height	46	Knee-knee breadth
7	Acromion height	47	Functional leg length
8	Elbow height	48	Thumb tip reach
9	Olecranon height	49	Shoulder grip length
10	Illiocrystale height	50	Elbow grip length
11	Illiospinal height	51	Hand length
12	Trochanteric height	52	Forearm hand length
13	Metacarpal – III height	53	Hand breadth across thumb
14	Waist back length	54	Hand breadth at metacarpal III
15	Scapula to waist back length	55	Hand thickness at metacarpal – III

16	Wall to acromion distance	56	Frist phalanax digit – III length
17	Arm reach from wall	57	Palm length
18	Biacromial breadth	58	Grip diameter (inside)
19	Bideltoid breadth	59	Grip diameter (outside)
20	Chest breadth	60	Middle finger palm grip diameter
21	Chest depth	61	Grip span
22	Interscye breadth	62	Maximum grip length
23	Waist breadth	63	Index finger diameter
24	Hip breadth	64	Span
25	Wall to lumbo sacral joint distance	65	Span akimbo
26	Abdominal extension to wall	66	Foot length
27	Chest circumference	67	Instep length
28	Waist circumference	68	Foot breadth (ball of the foot)
29	Thigh circumference	69	Heel breadth
30	Calf circumference	70	Medial malleolus height
31	Wrist circumference	71	Lateral malleolus height
32	Vertical grip reach sitting	72	Bimalleolar breadth
33	Sitting height	73	Head length
34	Sitting eye height	74	Head breadth
35	Sitting acromion height	75	Menton to top of the head
36	Elbow rest height	76	Bicep skinfold
37	Thigh clearance height sitting	77	Tricep skinfold
38	Knee height sitting	78	Subscapular skinfold
39	Popliteal height sitting	79	Superailiac skinfold
40	Coronoid fossa to hand length		
Strength measurements			
1	Right hand push strength (sitting)		
2	Right hand pull strength (sitting)		

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3	Maximum right foot strength (sitting)
4	Right hand push strength (standing)
5	Right hand pull strength (standing)
6	Push strength (both hands) standing
7	Pull strength (both hands) standing
8	Hand grip strength (right hand)
9	Hand grip strength (left)
10	Pinch strength (kg)

Table 3.5 Anthropometric instruments used for the study

Sl. No	Instruments Name	Measurement Possible
1	Integrated Composite Anthropometer	Measuring linear dimensions, diameters and clearances. Measuring hand strength parameters- pull and pull in seated and standing posture. Range: 0 to 100kg
2	Weighing balance	Measuring the weight : 0 to125 kg
2	Baseline 300 Pound Digital Hand Dynamometer	Hand grip strength Range: 0 to135 kg
3	Mechanical pinch gauge	Pinch strength
4	Baseline Lift dynamometer	Muscle strength

3.2.2.1 Integrated Composite Anthropometer

Integrated Composite Anthropometer (ICA) (developed by Indian Institute of Technology, Kharagpur) was used by various researchers for measurement of various body dimensions and strength parameters (Tewari *et al.* 2007). It consists of a base platform, backrest, sitting plank, horizontal and vertical supports and a handle support. Other support attachments of this equipment includes a 1m scale 69 with free moving measuring tips for higher accuracy, a 0 to 100 kg spring balance, a 0 to125 kg digital weighing balance, a multi hole finger diameter (13 mm to 24 mm) measuring device, a conical shape device for measuring internal grip diameter, a vernier for recording palm and hand measurements and measuring tapes.

An integrated composite anthropometer adapted to measure multiple body parameters of a large population in a short span of time. This reliable and portable anthropometer can be used for measuring 84 anthropometric dimensions including strength parameters, which having direct or indirect bearing on agricultural implements and machinery design (Gite and Chatterjee, 1999). The components of integrated composite anthropometer were presented in Plates 3.4 to 3.9.

Plate 3.4 Integrated Composite Anthropometer 70

Plate 3.5 Skin fold diameter measuring device

Plate 3.6 Conical device for measuring internal grip diameter

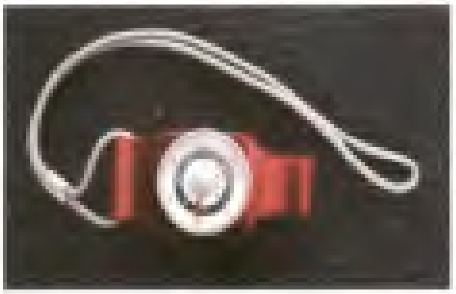

Plate 3.7 Mechanical pinch gauge

Plate 3.8 Baseline 300 pound digital hand dynamometer

Plate 3.9 Baseline lift dynamometer

3.2.3 Experimental procedure

A preliminary survey was conducted among women agricultural laborers engaged in rice cultivation in three zones of Kerala. Anthropometric data from 150 women labourers engaged in rice cultivation were collected whom were chosen randomly among women agricultural labourers engaged in rice cultivation in three zones of Kerala. The subjects were thoroughly screened to ascertain that they were in normal health; and they were not physically handicapped.

All subjects were informed about the objectives, measurement procedures and clothing requirement. For measuring body dimensions in standing posture, the subjects stood on base platform of ICA with their feet closed and their body vertically erected, while heels, buttocks and shoulders touched the same vertical plane. ICA was adjusted for height of the subject. Similarly, in the sitting posture, subjects sat with their body vertically erect, while their shoulders and head touched the same vertical plane. In sitting posture, feet of the subject completely touched the base platform. Subjects were bare footed with light clothes during measurement to minimize errors. During the measurement of body dimensions, care was taken to avoid any excessive compression of underlying tissues.

Data so collected were recorded in a standard proforma supplied by AICRP on ESA, Bhopal. Personal information like, name, address, ethnic group, preferred hand, preferred clothing etc. was also collected as per the standard practice.

3.2.4 Data analysis

Micro Soft Excel software package was used for most of the statistical analysis. The outliers and unreasonable data, which may be result of mistake in recording were identified and eliminated carefully. The values of minimum, maximum, mean, standard deviation (SD), standard error of mean (SEM), coefficient of variation (CV), 5^{th} and 95^{th}percentile of the 76 body dimensions including age and body weight and 10 strength measurements were calculated. The correlation coefficients between different anthropometric dimensions were

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calculated to see what extent these dimensions are correlated with each other. Regression modeling was done for estimation of body dimensions.

3.3 SELECTION OF SUBJECTS

Selection of subjects plays a vital role in conducting the ergonomic studies. The subject should be medically fit to undergo the trials. Also they should be a true representative of the user population in operation of the selected implements. Subjects should not be pregnant, lactating or handicapped. The following main criteria were used for the selection of subjects.

i. Age
ii. Anthropometric dimensions
iii. Medical fitness

3.3.1 Age

The maximum strength/ power can be expected from the age group of 25 to 35 years (Gite *et al.* 1996). The relation between the oxygen consumption and age of the workers was investigated and found that the maximum percentage of work could be expected during 20 to 40 years (Ardle, 2001). Hence the subjects in the age group of 25 to 40 years were chosen considering their experience in the operation of the implements selected for the study.

3.3.2 Anthropometric dimensions

Subjects for the study were selected by conducting an anthropometric survey according to procedure as furnished in the section 3.2. Ten subjects were selected those having anthropometric dimensions conforming to statistical requirements based on the anthropometric survey.

3.3.3 Medical Fitness

Fitness of an individual is a multivariate concept, although a distinction can be drawn between fitness and health (Kroemer *et al.* 1997). Performance of a job depends on the level of skill and motivation of the worker as on physical fitness. The assessment of a worker's fitness for prolonged work is necessary to ensure compatibility between the physical demand of the work and the physiological limitations of the worker. Seidal *et al.* (1980) and Sam (2015) had conducted medical and bio-clinical investigations to assess the medical fitness of subjects. So the selected ten subjects were screened for normal health with the medical tests such as Blood pressure, Electro cardio graph (ECG) and Bio-clinical analysis.

3.4 CALIBRATION OF SUBJECTS

To evaluate the physiological workload using heart rate, the relationship between heart rate and oxygen uptake must be determined for each subject. Both variables have to be measured in the laboratory at a number of submaximal loads. This process is called calibration of subjects. With linear relationship of the heart rate and the oxygen consumption, the later in the field trials can be predicted from the calibration charts (Bridger, 1995).

The direct measurement of oxygen uptake of the subjects while operating the implements is the most accurate method. The disadvantage with this approach is that the measured oxygen uptake only represents the energy expenditure for the time period during which the expired air sample is collected, which may not be representative for this operation in general for the entire work period. Also the equipment used for collection of the expired air may restrict or affect the worker causing the test situation to be a typical and may even hamper the actual work operation besides causing inconvenience to the operator.

The indirect assessment of the workload on the basis of the continuously recorded heart rate reveals on the other hand, a general picture of the activity level during the whole day's work or the specific time periods of work. Moreover by this method it is possible to relate the individual workers reaction to different treatments as judged by the heart rate response (Rodhal, 1989).

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For indirect assessment of oxygen uptake, the heart rate of the subject while pedaling on a bi-cycle ergometer and the corresponding oxygen uptake have to be measured and plotted. The heart beat rate of the subject during exercise in the bi-cycle ergometer was measured using the polar pacer heart rate monitor.

3.4.1 INSTRUMENTS USED FOR CALIBRATION OF SUBJECTS

3.4.1.1 Polar pacer heart rate monitor

The heart beat rate was measured using polar pacer heart rate monitor (Plate 3.10). It is a compact portable instrument to monitor the heart beat rate. This can be used in the field directly where the telemetry system cannot be used. This polar pacer has the three basic components.

i. Chest belt transmitter
ii. Elastic strap
iii. Receiver unit

Plate 3.10 Polar pacer heart rate monitor

i. Chest belt transmitter

It has the two electrodes fixed in the grooved rectangular area on the underside of the belt transmitter, which picks up heart beat rate from the body of 75 the subject and converts to electromagnetic signals. For better sensing the electrodes are wetted with water.

ii. Elastic strap

This is to secure the belt transmitter as high under the pictorial muscles (breasts) as comfortable. The belt transmitter should fit snugly and comfortably and allow normal breathing.

iii. Receiver

This is a unit which receives the signals from the transmitter and displays it on screen and record the data in the memory with the help of battery fixed in it. This receiver unit must be placed within one meter range and it can be fitted in watch strap. This receiver has two buttons below the screen to operate the heart beat rate monitor. This has provision to set up high target zone and low target zone limits. When the subject reaches the limits of heart beat it will indicate through alarm, or visual alarm, so that we can stop exerting the subject beyond this level. Similarly the low heart beat rate target zone will be helpful in certain critical condition. This receiver is also water resistant to 20 m water column.

3.4.1.2 Benedict – Roth recording spirometer

The oxygen consumption of the subjects was measured using Benedict-Roth recording spirometer (Plate 3.11). The apparatus consists of a 6-liter spirometer with a speed strip chart recorder. The spirometer bell is hung by means of a chain and counter weighed over a pulley. The counter weight carries the light perspex ink writing pen. The main base is made of aluminum casting with leveling screws. It houses the kymograph gear box, three stop cocks one to serve as water outlet and the other two for oxygen. The two outlets provided on the left side of the base were connected to the stopcock. One of the outlet houses a rubber outlet valve and other has provision to take a thermometer. The two-way stopcock (breathing valve) is carried by an adjustable arm and fitted with a rubber mouthpiece through 76 corrugated rubber tubing. All air hoses were of 25 mm inner diameter. The speed of the spirometer is adjusted to 20 min/rev with the help of the speed selector.

Plate 3.11 Benedict- Roth Recording Spirometer

3.4.1.3 Bi – Cycle Ergometer

The bi-cycle ergometer (BSA Duatron CX 004) was used for the calibration of the selected subjects. It consisted of a 4.3 kg steel flywheel, mainframe, handlebar post, console, pedal, seat, and seat post, front and rear base. It houses a single window display, which displayed the time, distance covered, speed of operation, calories and pulse rate of the subject during exercise. It also had a programming facility to increase the load on flywheel according to the requirement. The ergometer is run without electricity and the display is ON with two 1.5V lead

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batteries while pedaling. The subjects were trained in the Bi-cycle ergometer until they were sufficiently accustomed to pedal the ergometer at ease.

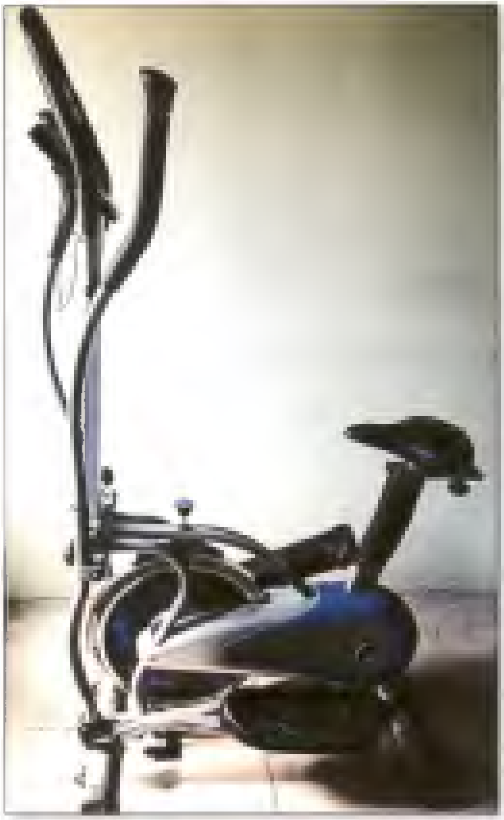

Plate 3.12 Bi-cycle ergometer

3.4.2 CALIBRATION PROCESS

The following are the two calibration processes adopted in the study.

i. Basal metabolic rate
ii. Indirect assessment of oxygen uptake

3.4.2.1 Basal metabolic rate

The energy required to maintain the body in an inactive state is known as basal metabolic rate. This is measured when the subject is in post absorptive state. The BMR was measured by using Benedict - Roth recording spirometer. Benedict - Roth apparatus spirometer bell was filled with oxygen from the storage oxygen 78 cylinder. The subjects were given complete rest for half an hour in a semi reclining position before the commencement of the test. The subject was fitted with a mouthpiece. The nose was clipped with the help of nose clip (Plate 3.13).

The subject initially inhales atmospheric air for some time. After normalization of breathing rate, the saddle valve was turned on to oxygen which was present in the spirometer bell. The kymograph recorded the oxygen consumption on the strip chart. The oxygen consumption is measured by selecting a satisfactory uninterrupted section of exactly six minutes. Same procedure was repeated for all the subjects.

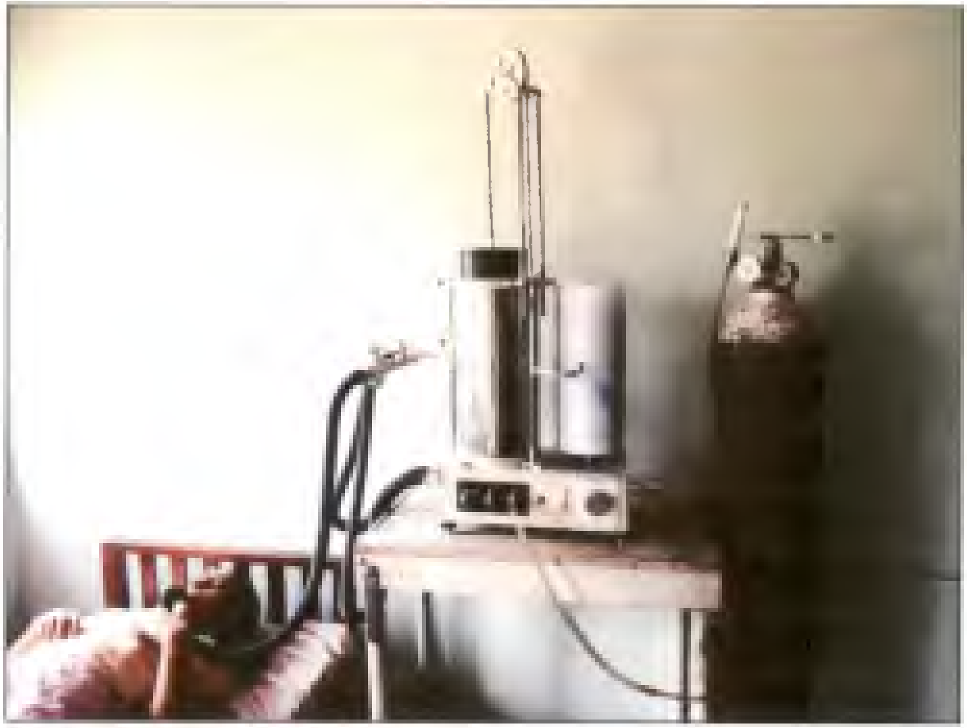

Plate 3.13 Measurement of BMR using Benedict-Roth Recording Spirometer

3.4.2.2 Indirect assessment of oxygen uptake

The instrument handling procedure was practically demonstrated to the subjects to familiarize them with the instruments. Before starting the experiment, all the subjects were properly trained for one month in using the instruments separately and in combination. After thorough training the subjects were calibrated 79 in the laboratory. Before the start of the day's work, the subjects were asked to relax for about half an hour and the blood pressure and heart rate were measured. If these measures were within the normal ranges, the subjects were assigned the task otherwise the work was postponed to another day.

For indirect assessment of oxygen uptake, the Bi-cycle ergometer and the Benedict Roth spirometer were used simultaneously. The subject to be tested was asked to perform the work, which utilize the muscles most closely associated with their occupational work in a Bi-cycle ergometer. Oxygen from the storage oxygen cylinder was filled in Benedict Roth apparatus spirometer. The subject was allowed to take complete rest for half an hour before commencement of the test and allowed initially to inhale atmospheric air for some time. The mouthpiece was fitted to the subject. After normalization of breathing rate, the saddle valve was opened to inhale oxygen from the spirometer. The nose of the subject was closed with the help of nose clip. Then the workload of the subjects was increased gradually by increasing the resistance to the pedals using Tension knob until the subject was exhausted. The subject inhaled oxygen through the inspiriting valve that was connected to the spirometer filled with oxygen and released carbon dioxide through the expiratory valve coupled to carbon dioxide absorber. The kymograph starts recording the oxygen consumption of the subject on the chart continuously (Plate 3.14). Simultaneously the heart beat rate was recorded in the heart rate monitor fitted with the subject. The same procedure was repeated for all the subjects. By using the data on heart rate and oxygen consumption rate, a calibration chart was prepared with heart rate on the ordinate and the oxygen uptake on the abscissa.

Plate 3.14 Indirect assessment of oxygen uptake (calibration process)

3.5 ERGONOMIC EVALUATION OF SELECTED RICE TRANSPLANTERS

Ergonomic evaluation of the selected rice transplanters was conducted for assessing their suitability and performance. It was carried out at the farmer's field (13 acres) (Nediyapadam Ela, Sooranad north, Kollam) as shown in Plate 3.15. The field was well-ploughed and puddled using tractor with cage wheel and properly leveled. A thin layer of water was maintained in the field for conducting the trials with selected transplanters.

Transplanters requires well prepared mat nursery for conducting the trials. Mat nursery was prepared with the Uma variety of paddy in farmer's field. The soil thickness on the sheet was maintained as 2 cm and the soil used was made free of stones and other unwanted materials, which will otherwise disturb the picking of seedlings during planting. The seedlings at an age of 18 days were used for conducting the trials. The seedling mats were cut into the required size of seedling tray of selected rice transplanters and filled in the trays for transplanting. The process of mat nursery preparation was showed in Plate 3.16.

Plate 3.15 Experimental field (Nediyapadam Ela, Sooranad north, Kollam)

A thorough training was given to the subjects to get familiarized with the selected rice transplanters, who have already experienced in mechanical transplanting until they get ease on that. The subject were given information about the experimental requirements so as to enlist their full cooperation. They were asked to report the work site at 6.30 AM in post absorptive stage and have a rest for half an hour before starting the trial. Each trial was conducted two times in a day at different time intervals that were before 9 AM and after 11 AM in order to find out the changes in energy expenditure and heart rate due to environmental conditions. Each trial was conducted for 30 minutes. Three trials were carried out for each subject. The physiological responses of the subjects while manual transplanting (traditional method) was also assessed to compare the energy expenditure in manual and mechanized operation.

Plate 3.16 Steps of mat nursery preparation

During the test, the electrodes contained in the chest belt transmitter of polar pacer heart rate monitor were wetted with water and fastened on the chest of the subject. Each trial started with taking five minutes data for physiological responses of the subjects while resting on a stool under shade. Heart rate during the mechanical transplanting with selected rice transplanters was measured by polar heart rate monitor. The same procedure was repeated for testing of three selected rice transplanters and traditional method for ten female subjects.

The ergonomic evaluation was carried out for the selected rice transplanters with respect to the following parameters

i. Heart rate and oxygen consumption
ii. Energy expenditure of operation
iii. Acceptable work load
iv. Subjective rating scale
v. Work rest cycle

3.5.1 Heart rate and oxygen consumption

Heart beat rate and oxygen consumption rate are the pertinent parameters for assessing the human energy required for performing various types of operations (Curteon, 1947). There was a close interaction between circulatory and metabolic processes. For proper functioning, nutrients and oxygen must be brought to the muscle or other metabolizing organs and metabolic by products removed from it. Therefore, heart rate as a primary indicator of circulatory function and oxygen consumption, representing the metabolic conversion taking place in the body, has a linear and reliable relationship. Heart rate measurement has a major advantage over oxygen consumption as an indicator of metabolic process. Heart rate responds more quickly to changes in work demands and hence indicates more readily quick changes in body function due to changes in work requirement (Kroemer *et al.* 1997).

Because of the advantages of the indirect assessment of oxygen uptake as explained in section 3.4, only the heart rate of the subject during the operation of the selected equipment was measured.

3.5.2 Energy expenditure of operation

The values of heart rate at resting level and after 30th minute of operation were taken for calculating the physiological responses of the subjects (Vidhu 2001). The heart beat rate increases rapidly in the beginning of an exercise and reaches a steady state by the end of sixth minute (Davies *et al.* 1964). The stabilized values of average heart rate for each subject from 6th to 30th minute of operation were used to calculate the mean value for all the selected implements.

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From the values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects for all the selected rice transplanters and traditional method were predicted from the calibration chart of the subjects. The energy expenditure of operation of the selected rice transplanters were computed by multiplying the oxygen consumed by the subject during the trial period with the calorific value of oxygen as 20.88 kJ l^{-1} (Nag *et al.* 1980) for all the subjects.

The energy expenditure of the subjects for the selected rice transplanters thus obtained was graded as per the tentative classification of strains in different types of jobs according to the young Indian female workers given in ICMR report (Sen, 1969).

3.5.2.1 Statistical analysis

Statistical analysis was carried out to study the effects of three selected rice transplanters, different time intervals and their interaction effect on subjects' heart rate and energy expenditure ergonomical parameters. The experiment was laid as Randomized Block Design (RBD) with three replications and the data collected were analyzed statistically. IBM SPSS 24.0 statistical software was used to analyze the data. The data were expressed as Mean. Analysis of variance (ANOVA) was performed using the general linear model (GLM) procedure from IBM SPSS 24.0 software. Multivariate test with POST-HOC (TURKEY) analysis was used to compare the significant differences among mean of the treatments at 0.05 level of probability and relationship between subgroups of sampled data. This test was followed the sub commands (univariate command) such as SSTYPE (3) (type III sum of squares) method and INCLUDE=INTERCEPT to calculate the sum of squares of an effect "F" in the design.

3.5.3 Acceptable work load (AWL)

The work load should be expressed as a 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. Ideally, therefore, the individual maximal oxygen (O_2) uptake should be determined, and the workload should be similarly assessed individually.

3.5.3.1 Maximum aerobic capacity (VO_2 max)

The maximum oxygen consumption is the highest oxygen consumption attained by the subject where a further increase in workload will not result in an increase in oxygen uptake. The maximum aerobic capacity also called as maximum oxygen consumption capacity or VO_2max is conceived as an international reference standard of cardio-respiratory fitness (Gite and Singh, 1997). 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).

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

The intersection of the computed maximum heart rate of the subjects with the plotted calibration chart line and the line of fit to the oxygen consumption defines the maximum aerobic capacity (VO_2 max) of the individual.

During any physical activity, there is increase in physiological parameters depending upon the workload, and the maximum values, which could be attained in normal healthy individuals, will be up to VO_2 max. However at this extreme workload, a person can work only for a few seconds. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO_2 Max (Saha *et al.*, 1979). To ascertain whether the operation of all the selected rice transplanters were within the acceptable workload (AWL), the VO_2 maximum for each treatment was computed and recorded.

3.5.3.2 Limit of continuous performance (LCP)

The extent to which a person may increase his work rate depends in part on how much he can increase his heart rate from resting level to his maximum level, because the increase in heart rate plays a major role in increasing the cardiac output form rest to maximal work (Rodahl, 1989). To have meaningful comparison of physiological response Δ values (increase over resting values) for heart rate (work pulse) was calculated (Tiwari and Gite, 1998). For this, the average values of the heart rate at rest level and at working condition were used.

The values of resting heart rate and heart rate during transplanting were taken for each selected rice transplanters. The values of heart rate (ΔHR) of the ten subjects were averaged to get the mean value for all the selected rice transplanters. The calculated values of work pulse for each operation were compared with the acceptable work pulse values of 40 beats min^{-1}(Brundke, 1984).

3.5.4 Subjective rating scales

Subjective, self-reported estimates of effort expenditure might be quantified using ratings of perceived exertion. Promising results have been obtained with perceived effort scale (Hogan and Fleishman, 1979). A 10-point scale was used for assessing the perceived exertion of the subjects during operation of selected rice transplanters (Borg, 1985). As an investigating tool, ratings of perceived exertion have proved to be useful adjuncts for studies in exercise physiology.

The body part discomfort score and the overall discomfort score were taken as the postural discomfort parameters and the subjective evaluation of discomfort was done by recording the discomfort levels in different body part and overall discomfort experienced by the subject. The ease of operation and safety of operation was measured by using the scales such as overall ease of operation rating (OER) and overall safety rating (OSR) scale.

3.5.4.1 Measurement of overall discomfort rating (ODR)

Prior to conducting the experiments with all the selected implements, the subjects were anchored to a 10-point overall discomfort rating (ODR) scale. For the assessment of overall discomfort rating a 10 - point psychophysical rating scale

(Figure 3.1) (0 - no discomfort, 10 - extreme discomfort) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their overall discomfort rating on the scale. The overall discomfort ratings given by each of the ten subjects was added and averaged to get the mean rating. The same procedure was repeated for all experiments.

3.5.4.2 Measurement of Overall safety rating (OSR)

For the assessment of safety rating, a 10 - point psychophysical rating scale (0 – completely secure and no fear, 10 – totally insecure and extreme fear) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their safety rating on the scale. The overall safety ratings given by each of the ten subjects were added and averaged to get the mean rating.

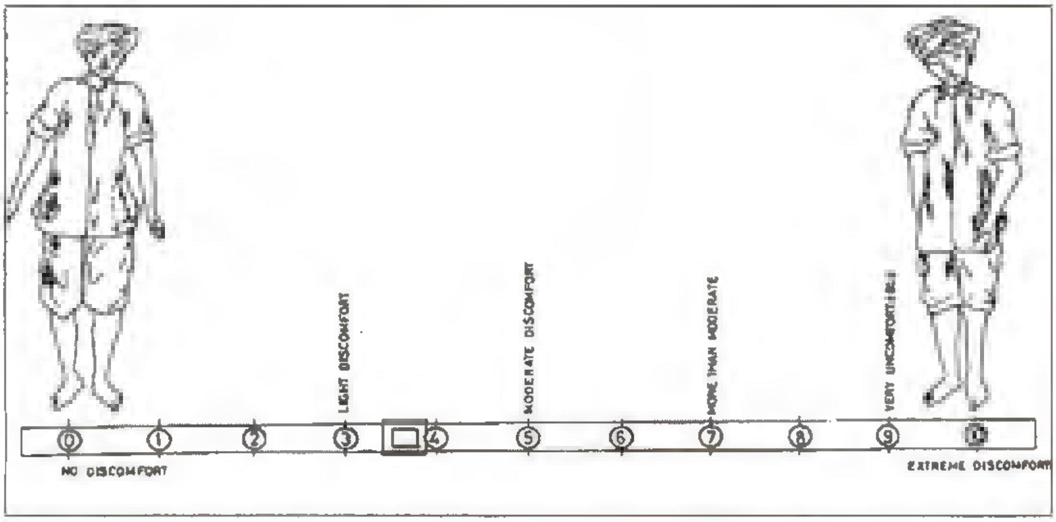

Fig. 3.1 Visual analogue discomfort scale for assessment of discomfort

3.5.4.3 Measurement of Overall Ease of Operation Rating (OER)

For the assessment of ease of operation, a 10 - point psychophysical rating scale (0 – very easy, 10 – extremely difficult) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their ease of operation rating on the scale. The overall ease of operation ratings given by each of the ten subjects were added and averaged to get the mean rating. The scale for ODR, OSR and OER were given in Table 3.6.

Table 3.6 Scale for ODR, OSR, and OER

Levels	ODR	OSR	OER
0-1	No discomfort at all	Completely secure and no fear	Very easy
2		Secure and meagre fear	Easy
3	Light discomfort		
4		Moderately secure and less fear	Less difficulty
5	Moderate discomfort		
6		Slightly secure and moderate fear	Difficult to operate
7	More than moderate		
8		Insecure and more fear	Very difficult
9	Very uncomfortable		
10	Extreme discomfort	Totally insecure and extreme fear	Extremely difficult

3.5.4.4 Measurement of body part discomfort score (BPDS)

To measure localized discomfort, Corlett and Bishop (1976) technique was used. In this method, the body of subject was divided into 27 regions (Figure 3.2). The subject was asked to mention all body parts with discomfort, starting with the most painful, the next painful in descending order till no further areas were referred. The number of different groups of body parts, which were identified, from extreme discomfort to no discomfort represented the number of intensity levels of pain experienced by the operator. The maximum number of intensity levels of pain experienced during the experiment need to be categorized. The rating was assigned 89 to these categories in an arithmetic order as explained below. If the maximum number of intensity levels of pain experienced for the experiment were five categories, first category (body parts experiencing maximum pain) was given a rating of 5 and for second category (body parts experiencing next maximum pain) rating was given as 4 and so on, for the fifth category (body parts experiencing least pain) rating was allotted as one. The number of categories of pain experienced by different subjects might vary.

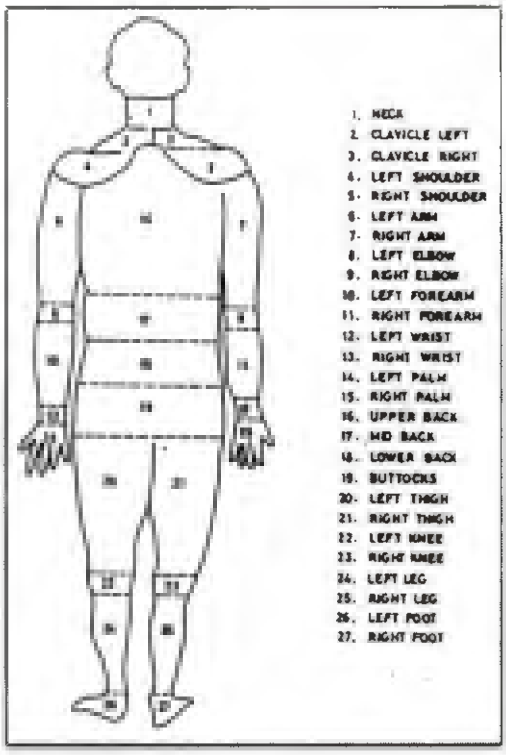

Fig. 3.2 Body regions for evaluating body part discomfort score

For example, if one subject has experienced 4 categories of pain, first category (body parts experiencing maximum) rating was allotted as 5 and for second category (body parts experiencing next maximum pain) rating was allotted as 3.75 and the fourth category (body parts experiencing least pain) was allotted rating of 1.25. 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 part discomfort score of all the subjects was added and averaged to get mean score. The same procedure was repeated for all the experiments. The overall BPDS were taken as the average value of all the subjects.

3.5.5 Work rest cycle

During every strenuous work in field, adequate rest is required to have an optimum work output. Better performance results can be expected from the operator only when proper attention is given for the work rest schedule for different operations.

The actual rest time taken for each subject in all the selected equipment were found from the heart rate response 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 each selected implement. The rest pause for each of the operation conducted in the present study with the selected rice transplanters was calculated theoretically using the Pheasant (1991) equation

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

Where,

R = Resting time (min)

T = Total working time day^{-1} (min)

E = Energy expenditure during working task (kcal min^{-1})

A = Average level of 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}. The rest required for all the selected rice transplanters were computed.

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3.6 MUSCULOSKELETAL DISORDERS

3.6.1 Musculoskeletal disorders survey on women agricultural workers

Musculoskeletal disorders are the leading cause of the occupational ill health. Three main risk factors contribute to musculoskeletal disorders are force, repetition and awkward postures. Any one or combination of these may contribute to the development of MSD. The present investigation carried out the occupational health problems of the women workers engaged in rice transplanting operation. The occupational health problems of the workers have been evaluated by standardized Nordic questionnaire.

3.6.1.1 Musculoskeletal disorders of subjects in traditional transplanting method

The study was conducted on 330 women agricultural workers whom had experience on rice transplanting operations for the past 15 years from different districts of Kerala. Prior to experimental trial, the protocol was explained verbally in local language. The selected women workers were in the age group of 18 to 50 years. The information was collected from these women workers based on Nordic musculoskeletal questionnaire technique. The questionnaire emphasized their individual details, type of work and the occurrence or frequency of pain felt in different parts of their body.

3.6.1.2 Nordic musculoskeletal questionnaire technique

The Nordic (Neuro-Ophthalmology Research Disease Investigator Consortium) Musculoskeletal Questionnaire (MSQ) (Kuorinka, *et al.* 1987) has been widely used to assess the nature and severity of self-rated musculoskeletal symptoms. The questionnaire includes items asking about the experience of musculoskeletal problems in nine body areas (neck, shoulders, elbows, wrists/hands, upper back, lower back, hips/thighs, knees, and ankles/feet) over the

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past week and over the past year as shown in Appendix I. Thus, weekly and annual prevalence's of MSD was derived.

In addition, a second group of questions (Appendix I) in which detailed information about MSD problems relating to three main body areas; neck, shoulders, and lower back was collected. In these sections, the information such as the total length of time during the past 12 months that the symptoms have been experienced, whether work or leisure activities have been reduced because of the problem, the total length of time that normal work has been prevented, and whether a medical practitioner or other healthcare professional had been consulted were collected. Other information obtained in this study included age, height and weight, mental health, and perceptions of the work environment.

3.6.2 Musculoskeletal disorders of subjects in selected rice transplanters

The occupational health problems of the subjects in selected rice transplanters have been evaluated by Nordic questionnaire technique. The questionnaire emphasized their individual details, type of work and the occurrence or frequency of pain felt in different parts of their body. After completing seven days of transplanting with selected each rice transplanter, a series of objective questions were asked to each of the subjects. A five point scale ranging from very light (1) to very severe pain (5) was used to identify the pain in musculoskeletal systems such as neck, shoulders, elbows, wrists/hands, upper back, lower back, hips/thighs, knees, and ankles/feet.

3.6.3 Postural analysis

The postures adopted by the workers in their working place depends upon the type of work, personal characteristics, the tools required to perform the particular work and also the duration and frequency of the work cycle. Postural analysis can be a powerful technique for assessing work activities as the risk of musculoskeletal injury associated with the posture. So, various techniques have been applied for postural analysis to identify the stress of different phases of work. 93

In this study, working postures were analyzed and evaluated by using tools like DHM (Digital Human Manikin) and RULA (Rapid Upper Limb Analysis).

RULA allows, manikin's upper limbs analysis based on parameters such as distance, weight and frequency (Hashim *et al.* 2012). It is used to canvas many aspects of manikin posture based on various variables and user data, such as lifting distance, lowering distance, action duration, object weight and task frequency. It takes care of work specific variables such as external support to the manikin, the balance of the manikin and orientation of arms of the manikin with reference to the body and feet. RULA score depicts acceptability of the task and posture and gives suggestions whether task or posture is acceptable or should be investigated further or should be changed soon or immediately. Hence, the RULA analysis helps to optimize manikin posture resulting in better designed and widely accepted products and workplaces.

Photographs were taken in various postures adopted by the subjects during the operation of selected rice transplanters and traditional method. The existing workplace was modeled with the various postures adopted by the operator using CATIA software. The manikin was modeled using CATIA's (CATIA V5R17) human builder module using various anthropometric dimensions. Using human measurements editor workbench, dimensions of selected subjects were updated. Sitting posture of subjects working in three selected rice transplanters and bending posture adopted in traditional method were observed. RULA analysis was performed for these two commonly adopted postures by operator as shown in Plate 3.18, 3.19, 3.20 and 3.21. At most care was taken to model the posture as operator working in the field.

Plate 3.17 Sitting posture adopted by operator in Redlands 8 row riding type self propelled rice trnaplanter

Plate 3.18 Sitting posture adopted by operator in Yanji 8 Row Self-Propelled Riding Type Rice Transplanter

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Plate 3.19 Sitting posture adopted by operator in Yanmar 8 row riding type self propelled rice trnaplanter

Plate 3.20 Bending posture adopted by subjects during manual transplanting method 96

The RULA analysis examines the risk factors like the number of movements, working posture, static muscle work force and working time without a break to provide a final score ranging from 1 to 7. The final score is accompanied by a colored zone changing from green to red on the basis of the final score. The score report consists of two modes, namely basic modes and advanced or detailed mode (as shown in Plate 3.21).

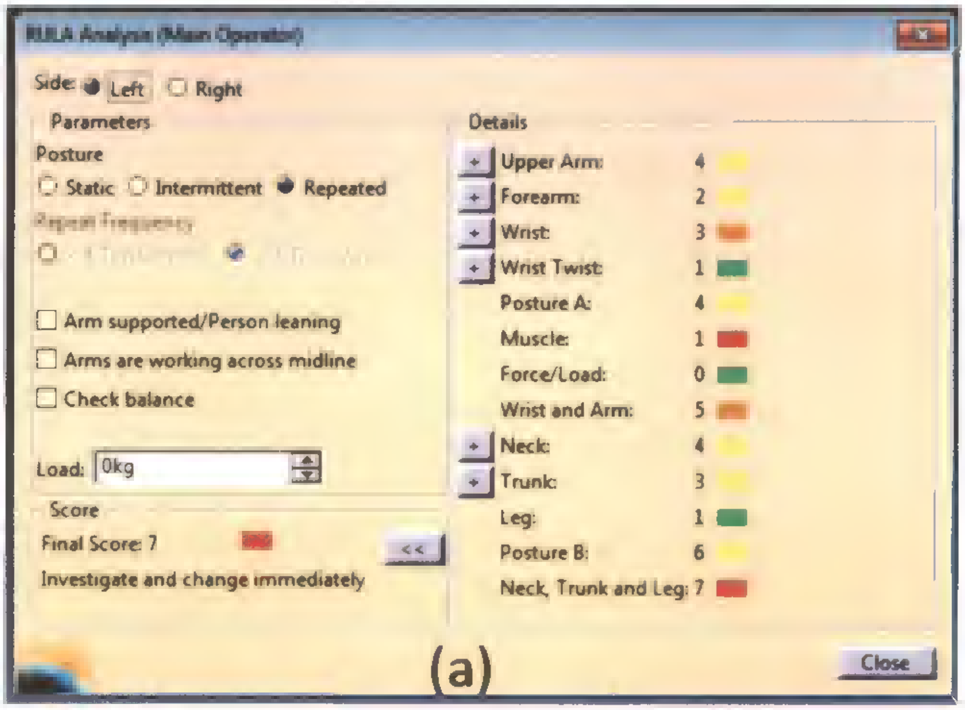

Plate 3.21 RULA score in basic and detailed mode

As seen from Plate 3.21, the RULA score sheet takes into account the scores of posture A (muscle use score, muscle load/ force score for both arm and wrist score) and that of posture B (neck, leg and trunk score). These scores allowed us to see if any of the participants had any physical force being applied on their body parts. Apart from the combined score (final score), the RULA score sheet also can be used for looking at different scores for individual parts. The RULA assessment can be carried out swiftly, so several postures and tasks within one work cycle can be evaluated without any noteworthy time and endeavor. While assessing with RULA, only one side (right or left) is evaluated at a time. After observing the worker, the evaluator can decide if the evaluation is required for both sides. The RULA final score in basic mode of a particular posture represents the level of MSD risk. The RULA decision based on score as outlined below in Table 3.7.

Table 3.7 RULA score decision

Score	Color	Meaning
1 and 2		The posture is acceptable if it is not retained or repeated for longer period
3 and 4		Further investigation is required and changes may also be required.
5 and 6		Investigation and changes are needed soon.
7		Investigation and changes are needed immediately.

3.7 SOUND LEVEL MEASUREMENT

Noise decreases the quality and precision of any work and also noise produced by engines may cause discomfort, nervousness, tension, irritability and fatigue. Levels from 86 to 115 dB can cause specific effects to the ear such as the damage of the corticells and can involve psychosomatic diseases. Noise also results in increase in the pulse rate & blood pressure and irregularities in heart rhythm (OSHA -1910.95).

Sound level was recorded using the sound level meter RS 232 interface (Plate 3.23) at operator's ear level while operator sitting on machine in stationary condition. The sound level meter was put ON in the range prevailing at the operating time of the selected rice transplanter. The sound level was measured at planting and neutral gear in stationary condition. The specification of the sound level meter was furnished in Table 3.8.

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Plate 3.22 Sound level meter RS232 interface

Table 3.8 Specification of sound level meter RS232 interface

Items	specification
Display	18 mm liquid crystal display
Measurement range, dB	35-130, input signal only, three ranges
Frequency, Hz	31.5 - 8000
Microphone	Electric condenser microphone
Range selector, dB	30-80, 50-100, 80-130
Operating temperature	0°C - 50°C
Power supply	006 P DC 9V battery (heavy duty type)
Weight, kg	0.28
Dimension, mm	205 x 80 x 35

3.8 VIBRATION MEASUREMENT IN SELECTED RICE TRANSPLANTERS

Mechanical vibrations have instantaneous and long term effects upon the human body. Kinds of effect depend upon the duration of exposure and the frequency of vibrations. Being subject to vibration of machine for extended periods of time because of constant shaking and pulsating of the body may be a major risk factor for MSD. So, the measurement of vibration of machine is an important aspect to know the effect of vibration on operators comfort.

The vibration of selected rice transplanters was measured by using VB-8201HA vibration meter (Plate 3.24).The specifications of vibration meter was shown in Table 3.9. The vibration of selected rice transplanters was measured on separate day after completion of field tests. Concrete surface was used for testing. The vibration was measured at different parts of a machine at planting gear and neutral gear in stationary condition. The different parts of machine were seat (top and bottom side), steering (left and right side), platform (right, middle and left), float (right, middle and left), and different type of levers. During the test, the accelerometer senses the vibration signals to display of meter. The display meter shows the values in terms peak (maximum and minimum) and root mean square (RMS maximum and minimum). The RMS (maximum and minimum) values was taken for this study.

Plate 3.23 Vibration meter

Table 3.9 Specification of VB-8201HA vibration meter

Item	Specifications
Display	Display 61 mm×34 mm LCD display
Measurement	Velocity, Acceleration, RMS value, Peak value, Data hold, Max.& Min. value
Range	Velocity: 200mm s^{-1} (0.5 to 199.9 mm s^{-1}) Acceleration :200mm s^{-2} (0.5 to 199.9 mm s^{-2})
Frequency range	10 Hz to 1 KHz
Calibration point	Velocity : 50 mm s^{-1} (160 Hz) Acceleration : 50 mm s^{-2} (160 Hz)
Sampling time	Aprox.1 second
Operating temperature	0° C to 50°C
Operating humidity	Less than 80 per cent RH

3.9 SPATIAL, VISUAL AND CONTROL REQUIREMENTS OF THE OPERATOR

In this study, the spatial, visual and control requirements of the operators were observed in the field. After completion of test trials, the questions were asked to the subjects about the spatial, visual and control requirements of the selected rice transplanters. The questions asked were shown in below. The workplace dimensions, controls and operations regard to the operator's size, operator position and the directions in which operator can most easily work were considered for proper workplace layout. These measurements were checked with the selected transplanters. In addition, the optimum spaces in which operator can manipulate the controls, arrangement of controls and displays, visual requirement for maximum operator efficiency, working posture of the operator viz. sitting, standing or squatting were measured for the transplanters. The measured values were compared with the anthropometric dimensions of the subjects to check suitability of the machine for women operators. The anthropometric dimensions considered for this study were described in section 3.2.

3.9.1 Questions about spatial, visual and control requirements

1. **Mounting and alighting**
   a) Is it possible to mount and alight without undue discomfort? Yes/ No
   b) Is there any risk of slipping while mounting / alighting? Yes/ No
2. **Operator's seat**
   a) Is the seat properly located? Yes/ No
   b) Is the sitting posture comfortable? Yes/ No
   c) Are there adequate legroom and knee room? Yes/ No
   d) Do you have to adopt twisted/awkward posture during work?
   e) Are the seat and the backrest comfortable? Yes/ No. If not what are the problems?
   f) Is the seat adjustable? Yes/ No. Is the range of adjustment sufficient? Yes/ No
3. **Visibility**
   a) Do you get good visibility of the ground? Yes/ No. if not mention specific problems.
   b) Do you get good visibility of the transplanting operation? Yes/ No. if not mention specific problems.
   c) Whether the all controls/displays are visible? Yes/ No
4. **Displays**
   a) Whether the displays provided are sufficient? Yes/ No
   b) Whether these are correctly located? Yes/ No
   c) Are these displays clearly understandable? Yes/ No
5. **Working climate**
   i. **Acoustic**
      a) Do you feel any problem due to engine noise / machine noise? Yes/ No
      b) Do you have hearing problem? Yes/ No. if yes, since when?
      c) Do you feel vibration during operation? Yes/ No

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ii. **Thermal**

a) Do you face any problems while working in different timings? If yes mention the same. Morning - Yes/ No. Afternoon - Yes/ No and Evening - Yes/ No

6. **Whether the machine is safe**

a) From operators point of view

b) From by standards point of view. if no give detail

Table 3.10. Operator's controls

Sl. No	Controls	Is the control conveniently located?	Do you face any problem in operation of this control?	Is the force required for its operation is ok?
1	Steering	Yes/ No	Yes/ No	Yes/ No
2	Hydraulic planting lever	Yes/ No	Yes/ No	Yes/ No
3	Main shifting lever	Yes/ No	Yes/ No	Yes/ No
4	Hill space shift lever	Yes/ No	Yes/ No	Yes/ No
5	Differential lock paddle	Yes/ No	Yes/ No	Yes/ No
6	Accelerator lever	Yes/ No	Yes/ No	Yes/ No
7	Parking brake lever	Yes/ No	Yes/ No	Yes/ No
8	Speed control paddle	Yes/ No	Yes/ No	Yes/ No
9	Brake paddle	Yes/ No	Yes/ No	Yes/ No
10	Hydraulic stopper	Yes/ No	Yes/ No	Yes/ No
11	Unit clutch lever	Yes/ No	Yes/ No	Yes/ No
12	Hydraulic sensing adjusting lever	Yes/ No	Yes/ No	Yes/ No
13	Number of seedlings adjustment lever	Yes/ No	Yes/ No	Yes/ No

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter explained the analysis of anthropometric data, calibration process and computed values of oxygen consumption and energy expenditure during the operation of selected rice transplanters. The grading of energy expenditure of operation of the selected rice transplanters were presented. The overall discomfort rating, overall safety rating, overall ease of operation rating and body parts discomfort score were discussed. The work rest cycle for the operation of the selected rice transplanters were arrived. The musculoskeletal disorders of women agricultural workers in rice transplanting were narrated. The optimal spatial, visual and control requirements for the selected rice transplanters were discussed.

4.1 ANALYSIS OF ANTHROPOMETRIC DATA

Anthropometric data of 450 female subjects were collected from three zones of Kerala, and were statistically analyzed. The values of minimum, maximum, mean, SD, SEM, CV, and 5th and 95th percentile of the 76 body dimensions including age and body weight were presented in Table 4.1 and 10 strength measurements were in Table 4.2. Percentiles are important in the study of ergonomics, in that 5th percentile indicates maximum product dimensions when reaches are involved and 95th percentile indicates minimum product dimensions involving clearances.

Mean age of total population was 34.8 ± 10.04 years. Mean stature and body weight were 152.4 ± 6.26 cm and 52.5 ± 10.34 kg respectively. From the table, the wide variations were seen in most of the body dimension of the subjects. For example, stature of the female subjects varied from 136 to 183.3 cm with mean value of 152.4 cm. This wide variation in the body dimension of the subjects was reflected in the high standard deviation of the body dimensions. Also this wide variation is helpful in designing of agricultural devices by taking 5th and 95th percentiles.

Twenty seven body dimensions were observed which have correlation coefficient equal to or greater than 0.7. Table 4.3 shows the correlation coefficients of these twenty seven body dimensions. The highest correlation was found above 0.9 in most of the dimensions. All correlation coefficients, which are greater than 0.058 were significant at 5 per cent level (Dewangan, 2010). It was observed that the stature was significantly correlated with all the 79 dimensions except wall to acromion distance, body circumferences (chest, thigh, calf and wrist), abdominal depth sitting, index finger diameter, bicep, tricep, subscapular and superailiac skin folds. Similarly weight was significantly correlated with all 79 body dimensions except elbow grip length, hand breadth at metacarpal III, grip diameter, maximum grip length, foot breadth, head length, head breadth and menton to top of the head. But the stature was correlated better than weight in all the dimensions.

Based on correlation coefficient, best fit least square simple liner regression equations with pertinent body dimension were developed and it was presented in Table 4.4. Since anthropometric surveys are both costly and time consuming, the practical ergonomist is frequently forced to estimate the data he/she requires (Wang and Chao, 2010). Regression equations were commonly used for estimation purpose. Kroemer *et al.* (1986) state that the "0.7 convention" has been generally used for establishing a minimum acceptable threshold value for the correlation coefficient. In present anthropometric survey, 18 body dimensions can be estimated with simple linear regression equations (Table 4.4). For estimation of 18 body dimensions, 5 body dimensions were required.

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Table 4.1 Analyzed Anthropometric data of female agricultural workers

Sl.no	Dimensions	Unit	Mean	Max	Min	STDV	SEM	CV (%)	Percentile	
									5^{th}	95^{th}
1	Age	Year	34.8	58.0	18.0	10.04	0.47	28.8	20.0	51.4
2	Weight	kg	52.5	84.8	16.8	10.34	0.49	19.7	38.0	72.0
3	Stature	cm	152.4	183.3	136.0	6.26	0.30	4.1	142.0	163.0
4	Vertical reach	cm	194.2	233.6	170.0	8.01	0.38	4.1	181.8	208.6
5	Vertical grip reach	cm	185.6	224.7	163.5	8.16	0.38	4.4	173.0	199.3
6	Eye height	cm	143.9	184.8	124.0	8.17	0.39	5.7	132.0	159.3
7	Acromion height	cm	128.5	169.7	112.0	7.52	0.35	5.9	117.0	142.0
8	Elbow height	cm	96.8	138.9	80.2	7.48	0.35	7.7	86.0	110.1
9	Olecranon height	cm	95.3	132.9	84.0	6.88	0.32	7.2	86.2	108.4
10	Illio- crystale height	cm	90.1	130.6	79.0	6.99	0.33	7.8	81.0	102.6
11	Illio - spinal height	cm	84.2	123.8	73.1	6.98	0.33	8.3	75.1	96.7
12	Trochanteric height	cm	77.7	119.6	66.6	6.98	0.33	9.0	68.6	90.2
13	Metacarpal – III height	cm	62.2	105.6	51.1	7.07	0.33	11.4	53.1	74.7
14	knee height	cm	41.7	86.9	30.6	7.16	0.34	17.1	32.6	54.5
15	Waist back length	cm	40.3	56.2	6.2	5.18	0.24	12.9	32.0	49.6
16	Scapula to waist back length	cm	52.7	80.0	34.0	6.61	0.31	12.5	44.0	64.2
17	Wall to acromion distance	cm	8.9	85.0	6.0	5.29	0.25	59.7	6.50	12.0
18	Arm reach from wall	cm	79.2	92.3	65.0	5.33	0.25	6.7	72.0	89.4
19	Biacromial breadth	cm	29.3	47.6	17.1	4.07	0.19	13.9	24.5	38.0
20	Bideltoid breadth	cm	35.8	54.1	23.6	4.07	0.19	11.4	31.0	44.5
21	Chest breadth	cm	26.3	45.6	11.5	5.92	0.28	22.6	19.5	35.6
22	Chest depth	cm	22.0	39.0	14.0	3.77	0.18	17.2	16.5	28.7
23	Interscye breadth	cm	30.1	84.0	22.0	4.51	0.21	15.0	25.0	37.5
24	Waist breadth	cm	31.0	45.0	21.0	5.48	0.26	17.7	22.8	42.0
25	Hip breadth	cm	36.0	50.0	26.0	5.48	0.26	15.2	27.8	47.0

Table 4.1 Continued

26	Wall to lumbo sacral joint distance	cm	5.2	12.0	2.5	1.20	0.06	23.1	3.5	7.0
27	Abdominal extension to wall	cm	24.5	43.0	15.0	4.41	0.21	18.0	17.0	33.0
28	Chest circumference	cm	84.3	109.0	60.0	9.32	0.44	11.1	70.5	101.3
29	Waist circumference	cm	85.3	112.0	58.0	11.65	0.55	13.7	64.0	104.4
30	Thigh circumference	cm	42.2	63.0	27.0	6.22	0.29	14.8	32.1	53.5
31	Calf circumference	cm	31.2	41.0	19.0	3.59	0.17	11.5	26.0	38.0
32	Wrist circumference	cm	15.5	21.0	11.0	1.56	0.07	10.1	13.0	18.0
33	Vertical grip reach sitting	cm	112.9	151.8	95.6	7.94	0.37	7.0	100.8	126.9
34	Sitting height	cm	79.0	110.5	61.6	7.60	0.36	9.6	68.1	92.1
35	Sitting eye height	cm	72.5	100.0	55.1	7.42	0.35	10.2	62.2	85.8
36	Sitting acromion height	cm	60.0	90.6	41.0	8.83	0.42	14.7	49.0	75.4
37	Elbow rest height	cm	27.1	58.6	15.0	6.29	0.30	23.2	19.0	39.8
38	Thigh clearance height sitting	cm	17.8	39.9	10.0	4.94	0.23	27.7	11.9	27.1
39	Knee height sitting	cm	46.3	77.3	28.4	7.63	0.36	16.5	35.6	59.6
40	Popliteal height sitting	cm	37.1	68.0	19.8	7.60	0.36	20.5	26.2	50.3
41	Coronoid fossa to hand length	cm	36.9	44.0	3.5	3.20	0.15	8.7	33.1	41.6
42	Buttock knee length	cm	52.7	61.3	37.0	3.51	0.17	6.7	47.0	58.1
43	Buttock popliteal length	cm	45.1	54.0	33.0	3.38	0.16	7.5	39.5	50.5
44	Abdominal depth sitting	cm	25.0	38.0	13.0	5.16	0.24	20.7	15.0	33.5
45	Hip breadth sitting	cm	34.0	52.0	21.5	5.03	0.24	14.8	26.0	41.5
46	Elbow-elbow breadth sitting	cm	39.8	52.1	26.0	5.64	0.27	14.2	29.7	48.5
47	Knee-knee breadth	cm	18.9	27.6	10.2	3.78	0.18	20.0	13.0	25.2
48	Functional leg length	cm	93.6	110.7	72.0	7.53	0.35	8.0	82.0	106.5
49	Thumb tip reach	cm	69.4	85.0	54.0	5.75	0.27	8.3	57.2	78.0
50	Shoulder grip length	cm	64.1	78.8	44.2	7.09	0.33	11.0	50.0	73.6
51	Elbow grip length	cm	37.7	55.3	26.5	5.27	0.25	14.0	29.6	44.0
52	Hand length	cm	16.0	18.9	11.7	0.80	0.04	5.0	14.9	17.5
53	Forearm hand length	cm	42.7	49.6	37.0	2.49	0.12	5.8	39.0	47.7

Table 4.1 Continued

54	Hand breadth across thumb	cm	8.6	93.0	4.6	4.17	0.20	48.5	6.9	10.8
55	Hand breadth at metacarpal III	cm	7.0	9.2	5.3	0.63	0.03	8.9	5.8	8.3
56	Hand thickness at metacarpal – III	cm	2.1	3.0	1.3	0.30	0.01	14.6	1.6	2.7
57	Frist phalanax digit – III length	cm	5.3	10.0	1.6	0.82	0.04	15.3	4.2	6.5
58	Palm length	cm	8.5	12.1	4.3	0.99	0.05	11.6	5.9	9.8
59	Grip diameter (inside)	cm	4.3	6.3	2.6	0.70	0.03	16.3	3.3	5.7
60	Grip diameter (outside)	cm	8.2	10.6	4.5	1.08	0.05	13.3	6.2	10.0
61	Middle finger palm grip diameter	cm	2.8	3.8	2.3	0.36	0.02	13.0	2.4	3.5
62	Grip span	cm	7.0	13.3	4.5	1.40	0.07	20.1	5.5	10.2
63	Maximum grip length	cm	11.7	16.5	5.7	1.91	0.09	16.3	7.8	14.6
64	Index finger diameter	cm	1.3	2.2	0.9	0.34	0.02	25.7	1.0	2.0
65	Span	cm	160.0	185.5	148.0	7.36	0.35	4.6	149.8	173.0
66	Span akimbo	cm	86.3	105.0	71.6	6.32	0.30	7.3	76.0	96.0
67	Foot length	cm	22.3	29.0	15.2	1.70	0.08	7.6	20.0	25.1
68	Instep length	cm	16.9	23.7	9.9	1.74	0.08	10.3	14.2	20.3
69	Foot breadth (ball of the foot)	cm	8.4	13.2	4.6	1.46	0.07	17.5	5.3	10.0
70	Heel breadth	cm	6.0	9.5	3.2	1.30	0.06	21.7	4.0	8.5
71	Medial malleolus height	cm	7.0	9.0	4.6	0.73	0.03	10.5	5.7	8.1
72	Lateral malleolus height	cm	6.2	9.5	3.8	0.76	0.04	12.3	5.1	7.5
73	Bimalleolar breadth	cm	6.0	9.3	4.5	0.87	0.04	14.4	5.0	8.0
74	Head length	cm	17.8	24.8	12.5	2.42	0.11	13.6	14.0	22.6
75	Head breadth	cm	14.5	19.8	8.7	2.69	0.13	18.6	9.9	18.8
76	Menton to top of the head	cm	19.6	23.6	15.6	1.40	0.07	7.2	17.8	22.3
77	Bicep skinfold	cm	0.4	3.1	0.1	0.34	0.02	86.9	0.1	1.3
78	Tricep skinfold	cm	0.9	2.2	0.2	0.31	0.01	35.2	0.4	1.4
79	Subscapular skinfold	cm	1.5	2.9	0.5	0.54	0.03	35.1	0.5	2.4
80	Superailiac skinfold	cm	1.7	2.8	1.0	0.40	0.02	23.7	1.2	2.4

Table 4.2 Analyzed strength measurements of female agricultural workers

Sl. No	Measurements (kg)	Mean	Max	Min	STDV	SEM	CV (%)	Percentile	
								5th	95th
1	Right hand push strength (sitting)	34.7	46.0	15.3	4.90	0.23	14.11	28.4	41.0
2	Right hand pull strength (sitting)	43.2	57.0	16.0	8.73	0.41	20.21	27.0	55.0
3	Maximum right foot strength (sitting)	41.6	59.0	25.6	7.71	0.36	18.55	29.0	51.0
4	Right hand push strength (standing)	53.1	89.0	16.0	18.08	0.85	34.07	25.0	78.0
5	Right hand pull strength (standing)	46.6	85.0	15.0	16.38	0.77	35.17	23.0	75.4
6	Push strength (both hands) standing	45.3	65.0	33.0	7.04	0.33	15.56	35.0	58.0
7	Pull strength (both hands) standing	70.0	100.0	40.0	16.94	0.80	24.19	40.0	95.0
8	Hand grip strength (right hand)	22.0	33.0	10.0	5.34	0.25	24.33	11.6	31.0
9	Hand grip strength (left)	21.9	37.4	10.0	4.96	0.23	22.70	13.5	29.9
10	pinch strength	2.4	7.2	1.2	1.02	0.05	42.59	1.50	4.70

Table 4.3 Correlation coefficient between different anthropometric body dimensions

Body dimensions	Stature	Vertical reach	Vertical grip reach	Eye height	Acromion height	Elbow height	Olecranon height	Illio - crystale height	Illio-spinal height	Trochanteric height	Metacarpal – III height	knee height
Stature	1.00											
Vertical reach	0.96	1.00										
Vertical grip reach	0.95	0.98	1.00									
Eye height	0.84	0.85	0.86	1.00								
Acromion height	0.89	0.89	0.89	0.91	1.00							
Elbow height	0.88	0.88	0.87	0.90	0.95	1.00						
Olecranon height	0.81	0.82	0.82	0.86	0.88	0.89	1.00					
Illio- crystale height	0.86	0.85	0.81	0.86	0.88	0.89	0.96	1.00				
Illio-spinal height	0.81	0.81	0.81	0.86	0.88	0.87	0.92	0.83	1.00			
Trochanteric height	0.83	0.82	0.81	0.86	0.86	0.89	0.99	0.88	0.89	1.00		
Metacarpal – III height	0.81	0.81	0.83	0.86	0.88	0.89	0.98	0.92	0.82	0.86	1.00	
knee height	0.81	0.81	0.81	0.86	0.88	0.89	0.98	0.92	0.88	0.83	1.00	1.00
Waist back length	0.44	0.48	0.46	0.47	0.49	0.49	0.51	0.51	0.51	0.50	0.51	0.51
Arm reach from wall	0.42	0.44	0.47	0.48	0.47	0.46	0.44	0.46	0.45	0.46	0.45	0.45
Bi-acromial breadth	0.43	0.43	0.42	0.49	0.50	0.49	0.47	0.48	0.48	0.48	0.48	0.48
Bi-deltoid breadth	0.43	0.43	0.42	0.49	0.50	0.49	0.47	0.48	0.48	0.48	0.48	0.48
Chest breadth	0.44	0.42	0.43	0.47	0.45	0.44	0.45	0.46	0.46	0.46	0.46	0.46
Vertical grip reach sitting	0.93	0.96	0.99	0.84	0.88	0.86	0.80	0.80	0.80	0.80	0.80	0.80
Sitting height	0.92	0.95	0.97	0.83	0.86	0.84	0.79	0.79	0.78	0.79	0.78	0.78
Sitting eye height	0.92	0.94	0.97	0.83	0.86	0.84	0.79	0.78	0.78	0.78	0.78	0.78
Sitting acromion height	0.57	0.61	0.62	0.63	0.62	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Elbow rest height	0.49	0.50	0.51	0.46	0.48	0.47	0.47	0.48	0.48	0.48	0.49	0.49
Thigh clearance height sitting	0.44	0.46	0.47	0.41	0.41	0.40	0.40	0.41	0.41	0.41	0.41	0.41
Knee height sitting	0.92	0.94	0.97	0.83	0.86	0.84	0.79	0.78	0.78	0.78	0.78	0.78
Popliteal height sitting	0.91	0.94	0.97	0.82	0.86	0.83	0.78	0.78	0.78	0.78	0.78	0.77
Span	0.49	0.51	0.54	0.47	0.47	0.44	0.39	0.40	0.39	0.39	0.39	0.39
Span akimbo	0.42	0.40	0.44	0.32	0.35	0.31	0.24	0.24	0.24	0.24	0.24	0.24

NOTE: (All body dimensions are in cm)

Table 4.3 Continued

Waist back length	Arm reach from wall	Bi-acromial breadth	Bi-deltoid breadth	Chest breadth	Vertical grip reach sitting	Sitting height	Sitting eye height	Sitting acromion height	Elbow rest height	Thigh clearance height sitting	Knee height sitting	Poplitea l height sitting	Span	Span akimbo
1.00														
0.23	1.00													
0.33	0.30	1.00												
0.33	0.30	1.00	1.00											
0.17	0.24	0.67	0.67	1.00										
0.44	0.47	0.41	0.41	0.41	1.00									
0.44	0.46	0.40	0.40	0.42	0.95	1.00								
0.43	0.45	0.41	0.41	0.43	0.98	0.90	1.00							
0.22	0.47	0.38	0.38	0.55	0.63	0.64	0.63	1.00						
0.19	0.11	0.33	0.33	0.57	0.50	0.52	0.52	0.60	1.00					
0.15	0.11	0.26	0.26	0.53	0.48	0.52	0.51	0.56	0.87	1.00				
0.44	0.45	0.40	0.40	0.42	0.98	1.00	0.99	0.64	0.53	0.53	1.00			
0.43	0.44	0.39	0.39	0.42	0.98	0.99	0.99	0.63	0.52	0.52	1.00	1.00		
0.26	0.53	0.26	0.26	0.27	0.54	0.53	0.53	0.42	0.06	0.12	0.53	0.53	1.00	
0.12	0.35	0.14	0.14	0.34	0.45	0.46	0.45	0.37	0.19	0.18	0.45	0.45	0.73	1.00

NOTE: (All body dimensions are in cm)

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Table 4.4 Best fit linear regression equations between stature(X) and other pertinent body dimensions (Y)

Dimensions	Unit	Equations	F	Correlation coefficient
Vertical reach	cm	$1.22\ X + 7.36$	4988.6**	0.96
Vertical grip reach	cm	$1.23\ X - 2.15$	3765.1**	0.95
Eye height	cm	$1.99\ X - 23.64$	1097.02**	0.84
Acromion height	cm	$1.07\ X - 35.18$	1780.17**	0.89
Elbow height	cm	$1.04\ X - 63.05$	1503.34**	0.88
Olecranon height	cm	$0.89\ X - 40.56$	863.48**	0.81
Illio - crystal height	cm	$0.90\ X - 47.36$	842.86**	0.86
Illio - spinal height	cm	$0.89\ X - 52.98$	836.67**	0.81
Trochanteric height	cm	$0.92\ X - 59.56$	839.28**	0.83
Metacarpal III height	cm	$0.91\ X - 76.61$	831.73**	0.81
Knee height	cm	$0.92\ X - 98.62$	828.57**	0.81
Vertical grip reach sitting	cm	$1.03X_1 + 31.51$	15095.3**	0.93
Sitting eye height	cm	$0.97\ X_1 - 4.32$	57279.13**	0.92
Knee height sitting	cm	$1.13\ X_1 - 32.78$	54136.8**	0.92
Pop little height sitting	cm	$0.99X_1 - 41.56$	41495.8**	0.91
Thigh clearance height sitting	cm	$0.68\ X_2 - 0.69$	1410.8**	0.87
Span akimbo	cm	$0.57\ X_3 - 4.65$	350.52**	0.73
Grip diameter (outside)	cm	$1.08\ X_4 + 3.51$	434.32**	0.7

**significant ($p<0.01$), X = Stature, X_1 = Sitting height, X_2 = Elbow rest height, X_3 = Span, and X_4 = Grip diameter (Inside)

4.2 SELECTION OF SUBJECTS

Ten subjects were selected based on the age and having anthropometric dimensions conforming to statistical requirements from the anthropometric data base of the study region. The details of the selected subjects were furnished in Table 4.5.

Table 4.5 Details of the subjects selected for the study

Subject	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

All the subjects were equally trained in the operation of the selected rice transplanters. The age of the selected subjects varied from 32 to 40 years since the maximum percentage of work could be expected from 20 to 40 years (Ardle *et al.* 2001). The body mass index score of selected subjects was within the normal range and varied from 20 to 25.75 kg m^{-2}. As per BMI score, the selected subjects have good health status (Garrow, 1987).

4.2.1 Medical fitness

The selected ten subjects were screened for normal health with the medical tests such as blood pressure, electro cardio graph and bio-clinical analysis. The results of the medical investigations carried out were furnished in Table 4.6. It was observed that all the ten subjects had normal ECG results. Also the values of blood pressure, blood test results and urine test results were within the normal range. This indicative of the fact that the selected subjects had normal health ruling out any ailments for medical fitness. So, the workers will be able to do work properly without any unusual health problems.

Table 4.6 Results of medical and bio – clinical investigations

Sl. No	Items	Permissible value	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
1	Blood Group	-	A	O	O	O	O	O	O	A	A	A
2	Rh Factor	-	positive	positive	Positive	Positive	Positive	Positive	Positive	Positive	Negative	Positive
3	Hemoglobin (g per cent)	12 to 16	13.2	12.8	12.6	13.6	13.59	13.1	13.2	13.1	13.83	15.46
4	ESR (mm hr^{-1})	0 to 10	9	7	8	8	5	5	7	6	8	10
5	Blood Sugar (mg dl^{-1})	70 to 110	93	88	85	85	93	98	94	95	109	105
6	Cholesterol (mg dl^{-1})	150 to 220	204	160	172	150	176	196	189	173	198	202
7	Blood Pressure (mm of Hg)	120/80	110/74	110/78	111/82	105/75	100/79	95/68	100/70	100/70	105/76	110/70
8	Urea (mg dl^{-1})	10 to 55	27.66	21.28	34.05	23.41	23.41	25.54	27.66	20.22	13.83	25.54
9	Urine Sugar (mmol l^{-1})	-	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
10	Urine Albumin (µg)	-	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
11	ECG	-	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal

4.3 CALIBRATION OF SUBJECTS

The selected ten subjects were calibrated in the laboratory conditions by indirect assessment of oxygen uptake. Sanders and McCormick (1993) suggested the calibration of each person to determine the relationship between heart rate and oxygen consumption.

4.3.1 Basal metabolic rate

The basal metabolic rate of the subject was measured by following the procedure explained in section 3.4.2.1. The computed values of basal metabolic rate of the subjects were furnished in Table 4.7. It was observed from the table that the basal metabolic rate of the subjects varied from 1603.1 to 2003.7 kcal day^{-1}. A sample calculation of basal metabolic rate of subject was shown below. These values were in close agreement with values of 1900 kcal day^{-1} reported by Passmore (1956) and 1450 to 1750 kcal day^{-1} by Karunanithi (1997).

Table 4.7 Basal metabolic rate of the subjects

Subject	Basal metabolic rate (kcal day^{-1})
1	1703.1
2	1803.3
3	2003.7
4	1603.0
5	1903.5
6	1803.3
7	1703.1
8	1603.0
9	1853.4
10	2003.7

Computation of BMR (Subject 1)

Age of the subject, years = 32

Weight of subject, kg = 48

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Height of subject, m = 1.48

Room temperature (T_2), °K = 303

Room pressure (P_2), bars = 0.99

Oxygen consumption

For a period of 6 min (V_2), cc = 1700

Standard temperature (T_1), °K = 273

Standard pressure (P_1), bars = 1.0325

Oxygen consumed under

standard Temperature and pressure, l $\frac{P1V2}{T2} \times \frac{T1}{P1}$

$$= \frac{0.99 \times 1.7 \times 273}{303 \times 1.0325} = 1.4686$$

Energy produced in 6 min, kcal = 1.1489 × 4.832 = 7.096 kcal

Energy per day, kcal $= \frac{7.096 \times 60 \times 24}{6}$

Basal Metabolic Rate, kcal day^{-1} = 1703.1

4.3.2 Indirect assessment of oxygen uptake

The selected subjects were calibrated in the laboratory by following the procedure explained in section 3.4.2.2. Astrand and Rodhal (1977) found in their study that there existed a linear relationship between the oxygen consumption and heart rate during calibration. By using the data on heart rate and oxygen consumption, a calibration chart was prepared with heart rate as the ordinate and the oxygen consumption as the abscissa for the selected subjects. The calibration chart was shown in Figure 4.1.

It was observed that the relationship between the heart rate and oxygen consumption of the subjects was linear for all the subjects, which was in close agreement with the results reported by Kroemer and Grandjean (2000) and Sam (2014). It was observed that for different subjects the linear relationship between heart rate and oxygen consumption was different due to physiological differences of individuals. The relationship between two parameters oxygen consumption (Y) and heart rate (X) was expressed by the linear equations and presented in Table 4.8.

Table 4.8 Linear equations of Oxygen consumption (Y) and heart rate (X)

Subject	Linear equations	R^2
1	Y = 0.0146 X – 0.905	0.9888
2	Y = 0.0143 X – 0.802	0.9589
3	Y = 0.0172 X – 1.204	0.9871
4	Y = 0.0148 X – 0.867	0.9842
5	Y = 0.0162 X – 0.964	0.9996
6	Y = 0.0189 X – 1.197	0.9651
7	Y = 0.0107 X – 0.558	0.9829
8	Y = 0.0173 X – 1.074	0.9943
9	Y = 0.0175 X – 0.963	0.9927
10	Y = 0.0126 X – 0.642	0.9949

It showed that the R^2 value was very high for the all subjects selected for this study which means they attained a good fit between the oxygen consumption and heart rate. The variation in oxygen consumption was accounted by a range of 95.89 to 99.96 per cent by the heart rate for the all the subjects.

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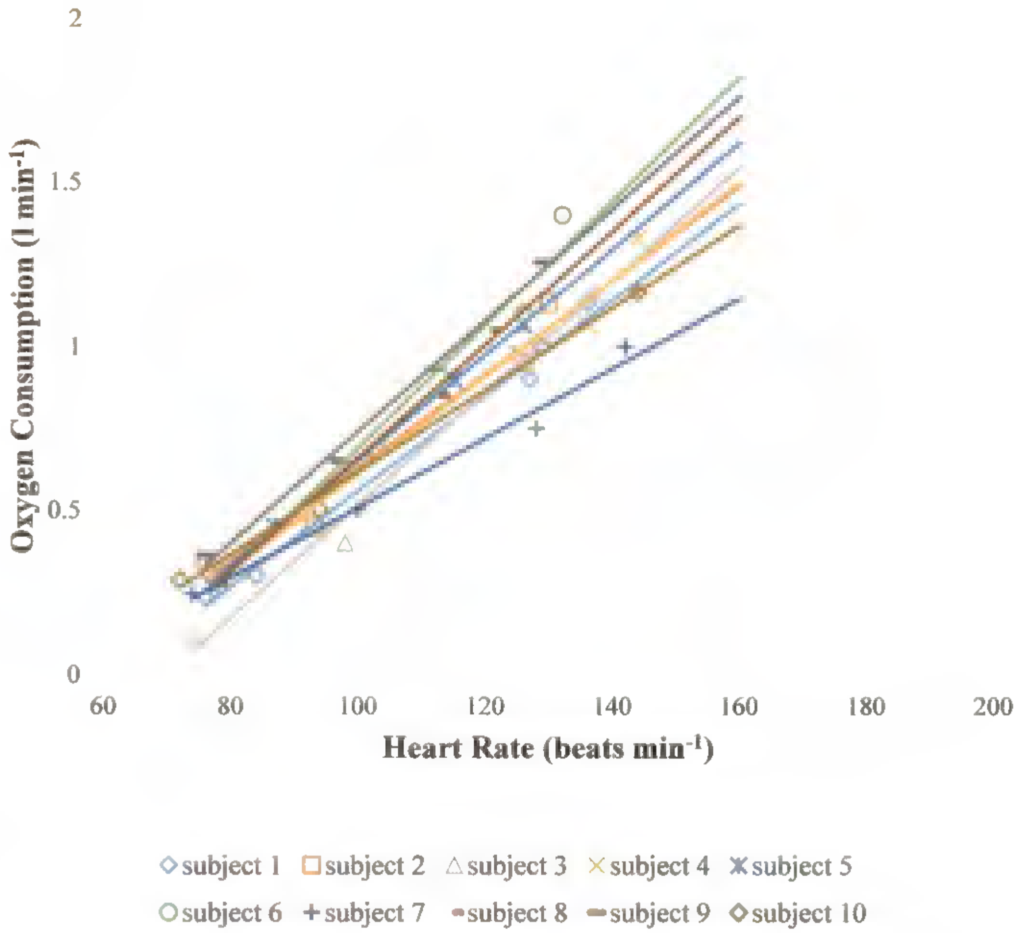

Fig. 4.1 Calibration chart of female subjects

4.4 ENERGY EXPENDITURE OF OPERATION

The energy expenditure was worked out for selected rice transplanters and traditional method for all the subjects on the basis of mean heart rate and mean oxygen consumption as explained in section 3.5.2.Variation of heart rate and energy expenditure of female subjects for selected rice transplanters and for traditional method were statistically analyzed at 5 per cent level of significance and were given in the Tables 4.9 and 4.10 respectively.

The result of the study (table 4.9) showed that significant difference in heart rate was noticed in all the selected rice transplanters for all subjects. It was seen that subjects showed minimum heart rate for Yanmar rice transplanters followed by

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Redlands and Yanji rice transplanters. The maximum heart rate was recorded significantly higher in traditional method.

In case of subject 1, there was no significance difference between heart rate of Yanji rice transplanter (145.6 beats min^{-1}) and traditional method (150.2 beats min^{-1}) and but significantly differed in Yanmar and Redlands rice transplanters. However in subject 3, there was no significant difference in Yanmar rice transplanter and Redlands rice transplanter, but subject showed significant difference in Yanji rice transplanter (136.3 beats min^{-1}) and traditional method (151.7 beats min^{-1}). In case of subject 7, the Redlands rice transplanter and Yanji rice transplanters showed no significant difference whereas Yanmar rice transplanter and Traditional method of transplanting) showed significant difference. The minimum heart rate of Yanmar rice transplanters was 96.5 beats min^{-1} and it was noticed in subject 7, while maximum heart rate of Yanmar rice transplanter was 114.2 beats min^{-1} and it was observed in subject 10. In case of traditional method, the minimum heart rate observed was 150.2 beats min^{-1} in subject 1 and maximum heart rate was 168.7 beats min^{-1} in subject 8.

The results of the study (table 4.10) showed that significant difference of energy expenditure was noticed in all the selected rice transplanters for all subjects except subject 1, 3 and 7. A similar trend in energy expenditure was observed as in previous case. The lowest energy expenditure was observed in Yanmar rice transplanter when compared to other selected rice transplanters.

The minimum energy expenditure of Yanmar rice transplanter was 9.89 kJ min^{-1} for subject 7 whereas maximum value was observed in subject 9 (18.99 kJ min^{-1}). In the case of traditional method, the minimum energy expenditure was noticed as 24.01 kJ min^{-1} for subject 1 and maximum energy expenditure was 39.68 kJ min^{-1} for subject 6. In the case of subject 1, the minimum energy expenditure was observed in Yanmar self-propelled 8 row transplanter with a value of 12.76 kJ min^{-1} and while maximum value observed was 26.88 kJ min^{-1} in traditional method. The energy expenditure of traditional method was increased to the tune of

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52.52 per cent when compared to Yanmar rice transplanter. In the case of Redlands self-propelled rice transplanter, the energy expenditure was 18.09 kJ min^{-1} for subject 1. It was increased by 29.46 per cent when compared to energy expenditure of Yanmar self-propelled rice transplanter. The energy expenditure of Yanji rice transplanter was 25.51 kJ min^{-1} for subject 2 and it was increased by 43.11 per cent compared to energy expenditure of Yanmar rice transplanter.

It was observed that energy expenditure varies among the subjects for the same implement under the similar conditions and it may be due to the variation of strength, physiological differences and skill level of the subjects. All the selected subjects strongly opined that Yanmar transplanter was very easy to operate. It had good spatial requirements with reference to anthropometric dimensions and good pedal transmission for easy control. Less pedal force and comfortable seating arrangement helps the operator for comfortable operation. These might be the reason for the comparatively less energy expenditure in case of Yanmar compared to other transplanters.

The existing dimensions of each part (mainly which were in human interface) of rice transplanters were compared quantitatively with anthropometric data of women agricultural workers and were satisfied in case of Yanmar rice transplanter. The detailed description of spatial requirements of selected rice transplanters will be furnished in section 4.12.

The subjects showed more energy expenditure in Yanji self-propelled transplanter when compared to Redlands self-propelled transplanter. In the case of Redlands transplanter, the self-starter of transplanter made the operation very easy and plastic (PP) hollow float also helps for easy moment in the field when compared to Yanji self-propelled rice transplanter.

Table 4.9 Variation of average heart rate (beats min^{-1}) of female subjects while operating selected rice transplanters

Subject / Transplanters	1	2	3	4	5	6	7	8	9	10
Yanmar	103.8^{a}	106.0^{a}	109.0^{a}	105.0^{a}	109.2^{a}	107.2^{a}	96.5^{a}	107.3^{a}	110.2^{a}	114.2^{a}
Redlands	121.3^{b}	127.2^{b}	118.0^{a}	123.3^{b}	120.0^{b}	134.0^{b}	128.2^{b}	130.8^{b}	128.0^{b}	132.2^{b}
Yanji	145.6^{c}	143.8^{c}	136.3^{b}	140.5^{c}	141.5^{c}	145.3^{c}	134.3^{b}	141.0^{c}	136.7^{c}	148.3^{c}
Traditional method	150.2^{c}	156.3^{d}	151.7^{c}	155.8^{d}	157.0^{d}	163.8^{d}	159.7^{c}	168.7^{d}	166.5^{d}	163.7^{d}

(**Note:** In column, mean values followed by the same letter do not differ significantly at P=0.05 according to Post hoc tests)

Table 4.10 Variation of average energy expenditure (kJ min^{-1}) of female subjects while operating selected rice transplanters

Subject / Transplanters	1	2	3	4	5	6	7	8	9	10
Yanmar	12.76^{a}	14.91^{a}	14.1^{a}	14.34^{a}	16.79^{a}	17.28^{a}	9.89^{a}	16.34^{a}	18.99^{a}	16.63^{a}
Redlands	18.09^{b}	21.22^{b}	17.23^{a}	20.08^{b}	20.46^{b}	27.87^{b}	16.97^{b}	24.83^{b}	25.32^{b}	21.37^{b}
Yanji	25.51^{c}	26.21^{c}	23.82^{b}	25.31^{c}	27.73^{c}	32.34^{c}	18.34^{b}	28.50^{c}	28.40^{c}	25.62^{c}
Traditional method	26.88^{c}	29.93^{d}	29.32^{c}	30.05^{d}	32.97^{d}	39.68^{d}	24.01^{c}	38.49^{d}	38.98^{d}	29.65^{d}

(**Note:** In each column, mean values followed by the same letter do not differ significantly at P=0.05 according to Post hoc tests)

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4.4.1 Energy expenditure as influenced by time of operation

The experiments were conducted two times in a day at different time intervals that, before 9 AM and after 11 AM in order to find out the changes in energy expenditure and heart rate due to environmental conditions. The statistically analyzed data of heart rate (beats min^{-1}) and energy expenditure (kJ min^{-1}) at 5 per cent level of significance was presented in Table 4.11.

Table 4.11 Variation of heart rate and energy expenditure for selected rice transplanters before 9 AM and after 11 AM

Time of operation	Average Heart rate (beats min^{-1})	Average energy expenditure rate (kJ min^{-1})
Before 9 AM	124.2^{a}	20.7^{a}
After 11 AM	142.6^{b}	26.6^{b}

(**Note:** In each column, mean values followed by the different letters were differ significantly at P=0.05 according to Post hoc tests).

The results showed that time of operation was significantly influenced the heart rate and energy expenditure of subjects for selected rice transplanters. There was a significant difference in heart rate and energy expenditure before 9 AM and after 11 AM. It was observed that, average heart rate was minimum before 9 AM (124.2 beats min^{-1}) and maximum after 11 AM (142.6 beats min^{-1}). The heart rate after 11 am was increased by 12.9 per cent which compared to heart rate before 9 am. It was further noticed that the average energy expenditure before 9 am was 20.7 kJ min^{-1} while after 11 am it was increased to 26.6 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.

4.5 GRADE OF WORK

Based on the physiological response of the workers during transplanting with selected rice transplanters, the work was classified in accordance with Sen (1969) classification as explained in the section 3.5.2. Table 4.12 shows the grading of work of subjects for selected rice transplanters.

Table 4.12 Grade of work of subjects during transplanting with selected transplanters

Sl. No	Selected transplanters	Grade of work
1	Yanmar	Moderately heavy
2	Redlands	Heavy
3	Yanji	Very heavy
4	Traditional method	Extremely heavy

Based on the average heart rate of the subjects, the Yanmar self-propelled rice transplanter was graded as "moderately heavy". The grade of work was "heavy" for Redlands rice transplanter while it was "very heavy" for Yanji rice transplanter. During the transplanting operation with the Redlands and Yanji rice transplanters, the operator required more force to steer the machine for taking sharp turns in muddy field and also operator had to apply more force for functioning of hydraulic rod to climb ridges and move from one paddy field to other. These might be the reasons for comparatively more heart rate and energy expenditure in case of Redlands and Yanji rice transplanter and were graded as heavy and very heavy, respectively. In case of Yanmar rice transplanter, the dynamic balance system made the operation very easy for the operator especially to move from one field to other field and this may be the reason for grading of work of Yanmar as moderately heavy compared to other transplanters.

The traditional method of transplanting was graded as "extremely heavy". This might be due to, tedious bending posture adopted by female subjects while transplanting. In the distorted posture, the muscles have to contact 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. The major portion of energy expended was consumed in bending and walking in the puddle field. The workers had to spend more energy for taking out their legs out of the puddle field at each and every step.

4.6 ACCEPTABLE WORK LOAD

Saha *et al*. (1979), had given an acceptable workload (AWL) for Indian workers as the work consuming 35 per cent of VO_2 max for endurance of 8 h work. The rate of energy expenditure and corresponding heart rate at this level of work would be 18 kJ min^{-1} and 110 beat min^{-1} respectively.

4.6.1 Maximum aerobic capacity

Maximum aerobic capacity of each subject was determined from the calibration chart as explained in section 3.5.3.1. Table 4.13 shows the maximum aerobic capacity female subjects.

Table 4.13 Maximum aerobic capacity of female subjects

Subject	Maximum heart rate (beats min^{-1})	Maximum aerobic capacity (l min^{-1})
1	179.2	1.71
2	174.0	1.69
3	178.6	1.87
4	174.0	1.71
5	176.0	1.89
6	174.0	2.09
7	174.0	1.30
8	174.0	1.94
9	175.3	2.02
10	179.2	1.62
Mean	175.8	1.78

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Table 4.14 Oxygen consumption in terms of VO_2 max of female subjects

	Mean VO_2 ($l\ min^{-1}$)	Oxygen consumption in terms of VO_2 Max (per cent)	AWL (35 per cent of VO_2 max)
Yanmar	0.73	35.0	AWL
Redlands	1.02	47.1	> AWL
Yanji	1.25	59.7	> AWL
Traditional method	1.53	82.0	> AWL

It was observed that the all the values were much higher than that of the AWL limits of 35 per cent except Yanmar self-propelled rice transplanter. It is indicating that the Redlands, Yanji and traditional method could not be operated continuously for 8 hours without frequent rest pauses. The oxygen consumption in terms of VO_2 max was minimum for Yanmar rice transplanter with 35 per cent for female operators. The maximum VO_2 max was observed to be 82 per cent for traditional method.

4.6.2 Limit of continuous performance

Work pulse is the difference between working pulse and resting pulse. The average values of the heart rate at rest level and at working condition were used for calculating resting pulse and working pulse. Work pulse of female subjects while operating selected rice transplanters were given in the Table 4.15.

Table 4.15 Work pulse of female subjects for selected rice transplanters

Selected rice transplanter	Work pulse ΔHR (beats min^{-1})	LCP (40 beats min^{-1})
Yanmar	21.36	< LCP
Redlands	30.46	< LCP
Yanji	42.67	> LCP
Traditional method	69.12	> LCP

It was observed that in selected rice transplanters, the work pulse values of Yanmar rice transplanter (21.36 beats min^{-1}) was below the limit of continuous performance of 40 beats min^{-1} which indicates that workers can operate the transplanter continuously for 8 h duration. It was seen that work pulse observed in Redlands rice transplanter was 30.46 beats min^{-1} which was less than 40 beats min^{-1} indicated that workers can operate the transplanter with less frequent rest pauses. In case of the Yanji rice transplanter, the work pulse value (42.67 beats min^{-1}) was above the limit of continuous performance of 40 beats min^{-1}, which indicates that workers could not operate the rice transplanters for 8 h duration. The subjects need more rest time at frequently. The work pulse for traditional method was 69.12 beats min^{-1} and the value was well above the limit of continuous performance of 40 beats min^{-1}. This indicates that, the women workers need more rest pauses frequently in traditional method.

4.7 SUBJECTIVE RATING SCALES

Ergonomic evaluation of the selected rice transplanters was done and each subject were asked to rate those transplanters according to ease of operation, comfort, safety and pain of body parts. The data were averaged for getting mean score of each transplanter. The mean score of ODR, OER and OSR for female subjects were presented in the following tables 4.16, 4.17 and 4.18.

Table 4.16 Overall Discomfort Rating (ODR) of selected rice transplanters

Rice transplanters	ODR of female subjects	
Yanmar	Score	2.5
	Scale	>No discomfort
Redlands	Score	3.6
	Scale	>Light discomfort
Yanji	Score	3.8
	Scale	>Light discomfort
Traditional method	Score	7.1
	Scale	>More than Moderate discomfort

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It was observed that discomfort rate was high for traditional method with score of 7.1 and it was scaled as “> more than moderate discomfort”. This might be due to, during transplanting the workers adopt strongly bent posture in the muddy field for a long time and also the planting task requires high repetitive trunk forward bending and laterally twisting while standing on muddy surface filled with water.

The Yanmar rice transplanter discomfort score (2.5) was very low compared to other selected rice transplanters. The lower values of ODR were confirmative the earlier results that the energy expenditure was less for Yanmar rice transplanter when compared to other rice transplanters.

Redlands rice transplanter showed a score of 3.6 with the scale of “>Light discomfort”. Compared to Redlands, the Yanji rice transplanter have more discomfort score of 3.8. It might have been due to the less spatial requirements and uncomfortable seating which made discomfort to the operator. In general the ODR values were lower for machine operation than manual operation.

Table 4.17 Overall Safety Rating (OSR) of selected rice transplanters

Rice transplanters	**OSR of female subjects**	
Yanmar	Score	2.1
	Scale	>secure and meager fear
Redlands	Score	4.5
	Scale	>moderately secure and less fear
Yanji	Score	4.7
	Scale	>moderately secure and less fear
Traditional method	Score	1.2
	Scale	>completely secure and no fear

It was seen that the safety was less for Redlands and Yanji rice transplanter and scaled as “>moderately secure and less fear” with a score of 4.5 and 4.7 respectively. More safety was observed for Yanmar rice transplanter with a safety rating of 2.1 and scaled as “>secure and meager fear”. This might be due to the more 128 comfortable seating arrangement, good spatial requirements and with less effort to operate the transplanters.

Table 4.18 Overall Ease of Operation Rating (OSR) of selected rice transplanters

Rice transplanters	OER of female subjects	
Yanmar	Score	3.1
	Scale	>Easy
Redlands	Score	3.3
	Scale	>Easy
Yanji	Score	5.1
	Scale	>Less difficult
Traditional method	Score	1
	Scale	Very easy

From the Table observed that, the Yanji rice transplanter (5.1) was found difficult to operate compared with other rice transplanters. In the case of Yanmar and Redlands rice transplanters the rating on ease was comparatively less with scores of 3.1 and 3.3 respectively.

4.8.1 Body part discomfort score (BPDS)

Based on the Corlett and Bishop (1976) technique, the body part discomfort score (BPDS) of all subjects with all selected rice transplanters was determined according to the procedure furnished in the section 3.5.4.4. The values of body part discomfort score of selected rice transplanter were presented in Table 4.19. The number of body parts experienced discomfort in terms of most discomfort, more than moderate, moderate and light discomfort of subjects for selected rice transplanters were presented in Figure 4.2.

Table 4.19 Body Part Discomfort Score of selected rice transplanters

Selected rice transplanter	BPDS
Yanmar	14.5
Redlands	34.9
Yanji	42.3
Traditional method	46.8

It was observed that the, body part discomfort score was maximum for traditional method with a score of 46.8 followed by Yanji rice transplanter (42.3) and Redlands rice transplanter (34.9) while it was minimum for Yanmar rice transplanter with a score of 14.5. It was seen that body part discomfort was different for different rice transplanters.

In the case of traditional method, the discomfort was experienced in 13 body parts. In this method, the subjects were experienced most discomfort mainly in 6 body parts namely lower back, upper back, neck, shoulders, elbows and knees. This might be due to the continuous bending posture in muddy field in sweltering weather and repetition movement of more body parts. In case of Yanmar rice transplanter, light discomfort was experienced in 6 body parts namely right and left shoulders, palms, knees and neck. But comparing with other models, Yanmar rice transplanter was more comfortable for subjects because of the comfortable seat, arrangement of all controls near the operator, and ease of operation. In Redlands and Yanji rice transplanters, most discomfort happened (4 body parts) in lower back, upper back, neck and shoulders. This might be due to, the improper seating arrangement in both rice transplanters compared to Yanmar rice transplanter.

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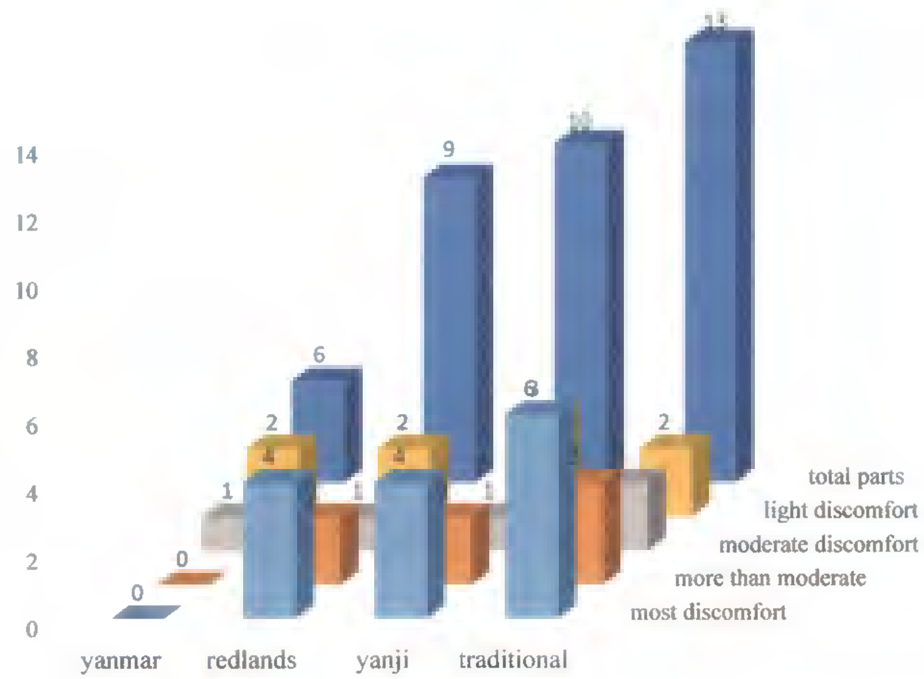

Fig. 4.2 Number of body parts experienced by the subjects with selected rice transplanters

4.8 WORK REST CYCLE

The rest time of the subjects for the selected rice transplanters was calculated as explained in section 3.5.5. The calculated rest time was compared with the actual rest time taken by the subjects in the 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 work rest cycle for achieving functional effectiveness of the selected transplanters and for maintaining or enhancing the human comfort were arrived and detailed in Table 4.20.

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Table 4.20 Proposed work rest cycle for the selected transplanters

Sl. No	Selected rice transplanters	Work rest cycle, min
1	Yanmar	30 minutes of work followed by 2 min rest to the operator
2	Redlands	30 minutes of work followed by 9 min rest to the operator
3	Yanji	30 minutes of work followed by 14 min rest to the operator
4	Traditional method	30 minutes of work followed by 15 min rest to the operator

The rest time, for achieving functional effectiveness during transplanting the paddy by Yanmar rice transplanter, was found to be 2 minutes followed by 30 minutes of work. This result was closely followed the acceptable work load and limit of continuous performance. The rest pause for Redlands and Yanji self-propelled rice transplanter were 9 minutes and 14 minutes followed by 30 minutes of work. The rest pause for traditional method was 15 minutes followed by 30 minutes of work.

4.9 MUSCULOSKELETAL DISORDERS

4.9.1 Musculoskeletal disorders of subjects in traditional transplanting method

Based on standardized Nordic Musculoskeletal Questionnaire, the musculoskeletal problems (occupational health problems) of the women workers engaged in rice transplanting operation were determined according to the procedure furnished in the section 3.6.1. The questionnaire used for the study was showed in Appendix A.1 and it is mainly deals with nine anatomical body regions namely neck, shoulders, elbows, wrists/hands, upper back, lower back, hips/thighs, knees and ankles.

The average age of the sample data was 43.5 ± 10.04 years. Out of 330 participants, 26 per cent of the participants were aged less than 40 years, 45 per cent were in the age range of 40 to 50 years, and the remaining 29 per cent were in the 132 range of 50 to 58 years. The average weight of the sample data was 52.5 ± 10.34 kg and average height was 155.4 ± 6.26 cm. All participants had given their responses, which were analyzed. 80 per cent of the women workers reported that they had experienced MSD in the past seven days; 37 per cent reported that they had experienced one or more MSD over the past 12 months. Table 4.21 showed the percentages of the women workers experiencing MSD in different body areas during the previous seven days and during the previous 12 months.

Table 4.21 Observed prevalence rates for musculoskeletal problems

Area of body affected	Occurrence in last 7 days, n (per cent)	Occurrence in last 12 months, n (per cent)
Neck	320 (97)	95 (28.8)
Shoulders	310 (94)	76 (23.0)
Elbows	300 (91)	59 (17.9)
Wrists/ Hands	269 (82)	30 (9.1)
Upper Back	330 (100)	99 (30.0)
Lower Back	330 (100)	110 (33.3)
One/ Both Hips/ Thighs	312 (95)	10 (3.0)
One/Both Knees	320 (97)	85 (25.8)
One/Both Ankles/Feet	280 (85)	19 (5.8)

(n = 330 women agricultural workers and Values in parentheses indicate percentage).

It was seen that from Table 4.21, during past 12 months, 33.3 per cent of women labourers who were involved in manual transplanting had pain in lower back while 30 per cent of respondents suffering from pain in upper back. However all the respondents (cent per cent) were experienced both lower and upper back pain during past 7 days. These values were in close agreement with the values of 95.2 per cent and 94.6 per cent in lower back pain and upper back pain respectively reported by Kar *et al.* (2012). Around 28.8 per cent of respondents reported neck pain during manual transplanting for the last 12 months followed by 23 per cent in shoulders. However last 7 days of manual transplanting, 97 per cent women labours experienced 133 pain and discomfort in neck followed by shoulders (94 per cent). About 25 per cent respondents reported knee pain in past 12 months and 97 per cent experienced pain and discomfort in knee for the last 7 days.

The respondents reported that lower back and upper back pain might be due to the adoption of bending posture for longer time during transplanting work. This leads to chronic low back pain among the workers. Sometimes they were compelled to twist their trunk frequently. The spinal rotation may cause chronic stain as when the workers twist their waist during work. Most of the women workers reported that occurrence of pain increases with the progress of the working hours in the muddy field and it reaches highest after finishing the job.

Some participants experienced that minimum lower limb (thigh, knees and foot/ankles) discomfort. It might be due to the less movement of lower limb. A great amount of static load was imposed on the upper leg muscles during working in bending posture. The problems were not much severe in other parts of lower limb.

In addition to the nine body anatomical body parts, cent per cent of women workers experienced pain in finger. This might be due to the cumulative effect of repeated finger movement during work. The transplanting of rice seedlings was made by piercing the finger in to mud, which caused friction with solid and hard materials present in the mud causing the pain in fingers.

The women agricultural workers also have job related health problems other than musculoskeletal disorders. Among them, fatigue, digestive disorder, and headache were prevalent. Different types of eye related problems such as pain in eyes, burning sensation in the eyes, watering and blurred vision have been found in this investigation. Health surveillance of respondents was presented in Table 4.22.

With regard to the medical treatment, 92 per cent of respondents were taking medical treatment. 81 per cent of respondents reported that they were taking the treatment themselves. 11 per cent of respondents (having pain in low back, upper back and neck) reported that they were consulting doctor for treatment. It was seen

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that 86 per cent of respondents took the treatment for back ache followed by body ache (80 per cent), head ache (75 per cent), fore arm pain (67 per cent) and pain in trunk (59 per cent). About 33 per cent of total respondents agreed that they were taking the treatment for stiffness in joints.

Table 4.22 Health surveillance of respondents

Sl. No	Question	Women
1	You Take the Medical Treatment	301 (92)
2	Take the Treatment from	
	Personal doctor	35 (11)
	Self	266 (81)
	Others	------
3	Take the Treatment for	
	Headache	248 (75)
	Body ache	265 (80)
	Irritation on eyes	10 (3)
	Stiffness in hand joints	110 (33)
	Burning sensation in fingers	125 (38)
	Pain in palm	------
	Forearm pain	220 (67)
	Pain in cuff muscles	120 (35)
	Numbness in fingers	16 (5)
	Cough/cold	68 (21)
	Pain in trunk	196 (59)
	Back ache	285 (86)
	Shoulder pain	65 (20)
4	Did the Treatment Help?	280 (85)

(Note: Values in parentheses indicate percentage).

Around 35 per cent of women workers were taking treatment for pain in calf muscles. Of all the women workers, 67 per cent indicated that they took the medicine for forearm pain. A total of 38 per cent respondents had agreed that they have taken the treatment for burning sensation in fingers. Nearly 20 per cent of the total respondents also took the treatment for shoulder pain followed by 5 per cent (numbness in fingers) and 3 per cent (irritation on eyes). A total of 85 per cent respondents were satisfied with the medical and self-treatment.

4.9.2. Musculoskeletal disorders of subjects in selected rice transplanters

The work related musculoskeletal problems and the body pain perceived by the workers in selected rice transplanters were also checked by administering of standardized Nordic questionnaire according to procedure furnished in the section 3.7.2. All the selected subjects (10 subjects) had given their responses after seven days of transplanting. It was found none of the subjects had experienced pain or discomfort in any of the body parts after 7 days of operation in selected rice transplanters. After performing the transplanting activity in traditional method, majority of the women complained severe pain in upper back, lower back and neck, moderate pain in shoulders and knees and complained light and very light pain in elbows, wrist/hands ankles/feet and hips/thighs since they adopted bending and squatting body posture for longer duration and performed the tasks in repetitive motions. The results were in close agreement with results explained in section 4.9.1.

4.9.3 Postural analysis

The RULA analysis for four postures adopted by the operator with selected rice transplanters and traditional method was analyzed using CATIA V5 software according to the procedure furnished in the section 3.6.3. By using DHM technique, the human manikin was developed based on posture adopted by the operator in selected rice transplanters and in traditional method and shown in Plate from 4.1 to 4.4. Detailed RULA analysis window for left side and right side for all postures determined were shown from Plate 4.5 to 4.8. Table 4.23 presents RULA score for all the postures considered in this study.

Plate 4.1 Human model posture attained by an operator in traditional method

Plate 4.2 Human model posture attained by an operator in Redlands rice transplanter (posture 2)

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Plate 4.3 Human model posture attained by an operator in Yanmar rice transplanter (posture 3)

Plate 4.4 Human model posture attained by an operator in Yanji rice transplanter (posture 4)

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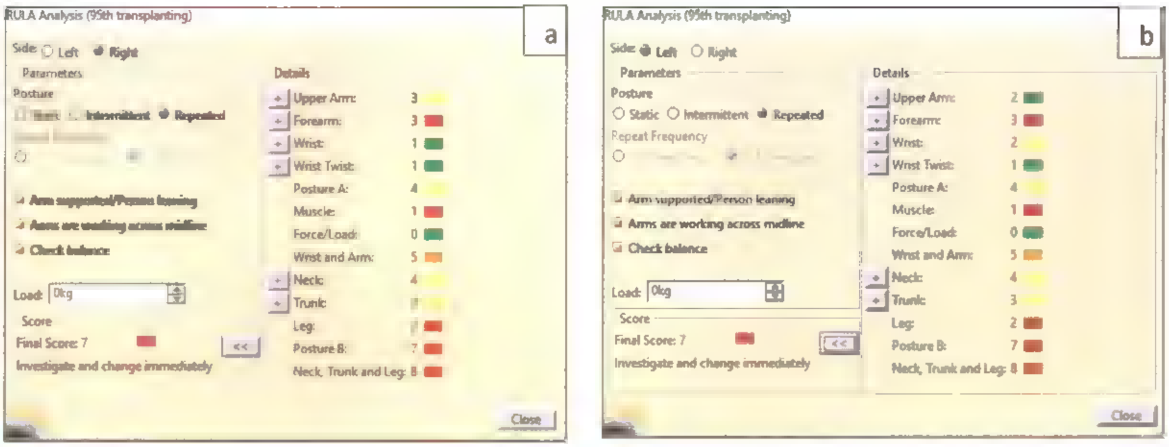

Plate 4.5 RULA analysis windows (a) for Right side of body (b) for Left side of body for posture 1

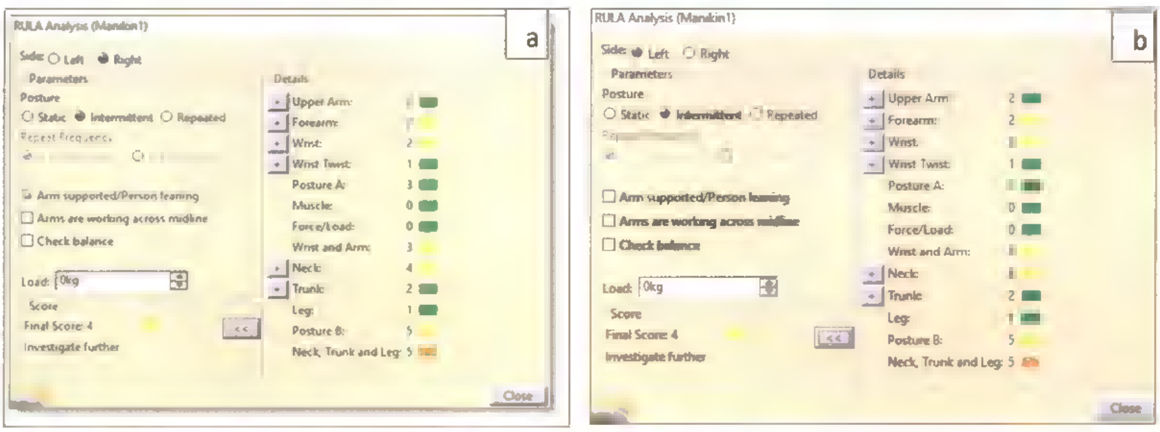

Plate 4.6 RULA analysis windows (a) for Right side of body (b) for Left side of body for posture 2

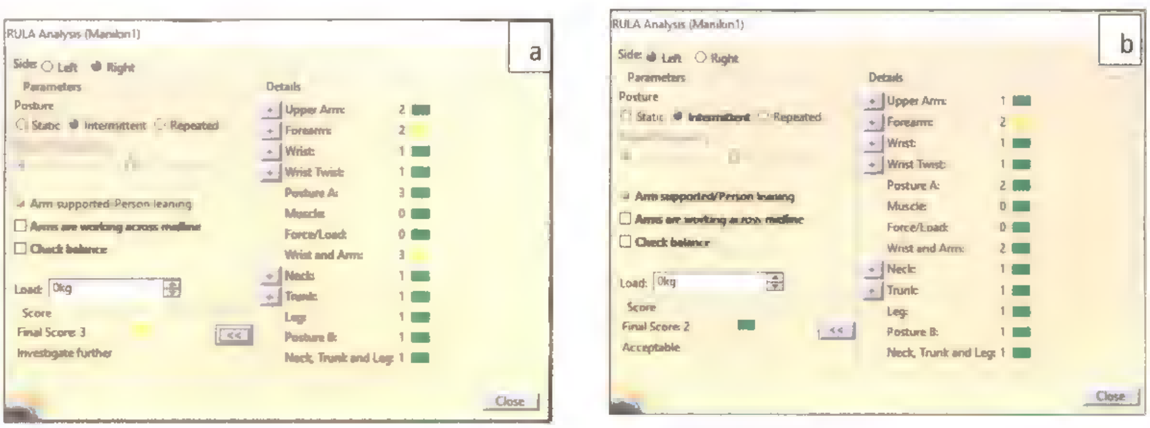

Plate 4.7 RULA analysis windows (a) for Right side of body (b) for Left side of body for posture 3

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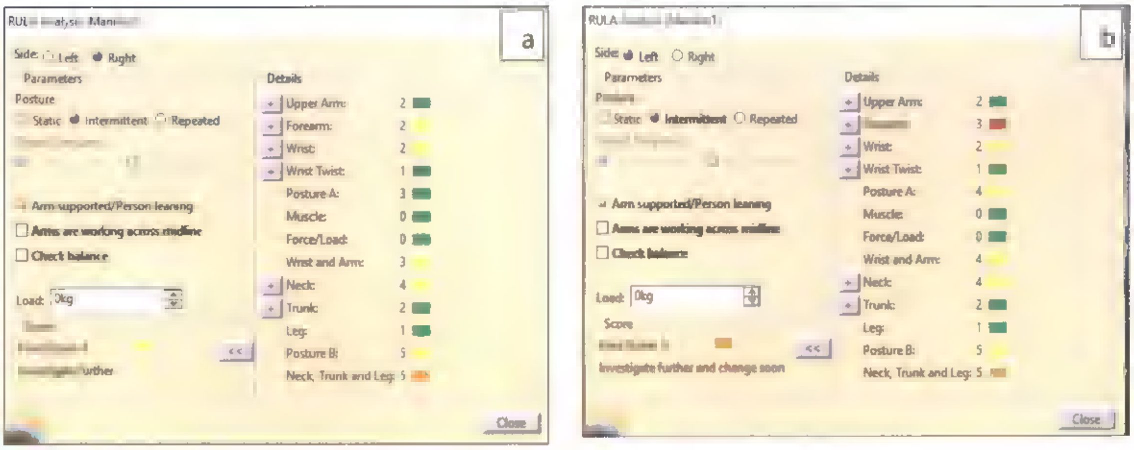

Plate 4.8 RULA analysis windows (a) for Right side of body (b) for Left side of body for posture 4

Table 4.23 RULA final score for key postures of the operator while transplanting with selected rice transplanters and by traditional method

Posture	RULA Score (Right side)	RULA Score (Left side)
1	7	7
2	3	2
3	4	4
4	4	5

It was observed that, the RULA final score was very high for posture 1(traditional method) and low for posture 3 (Yanmar rice transplanter). The score for posture 2 (Redlands rice transplanter) and posture 4 (Yanji rice transplanter) was more or less same. The RULA analysis showed that existing working posture1 of the operator was highly dangerous (score 7) which was the maximum score and must be changed by in depth investigation of workstation/working pattern in order to keep away the worker from musculoskeletal disorders. The posture 3 result showed that this posture was acceptable to the operator. The RULA result of posture 2 showed that, further investigation is needed to decrease the discomfort of operator. The posture 4 score showed that the posture changes were needed soon and also needs further improvement in the seat design.

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Results of this study indicated that posture 1 performance to pose the highest compressive load on lumbar spine, as well as induce the highest risk level of low back injury, primarily due to force and postural factors. The findings suggested a need for developing interventions and guidelines for farmers to minimize risk factors of low back injury with focus on reducing forceful exertion and awkward posture during transplanting process. Posture 2 and 4 results indicated that the posture performance to pose medium force on forearm, neck, trunk and legs. The findings suggested to focus on reducing repetitive motion and posture correction.

4.10 SOUND LEVEL MEASUREMENT IN SELECTED RICE TRANSPLANTERS

The sound level for selected rice transplanters was measured according to the procedure furnished in section 3.7. The observations were given in Table 4.24.

Table 4.24 Sound level in selected rice transplanter

Selected position	**Noise level, dB (A)**		
	Yanmar	**Redlands**	**Yanji**
Travelling			
Planting clutch 'OFF' position	91	94	97
Stationary			
Planting clutch 'ON' position	93	99	103
Planting clutch 'OFF' position	91	97	99

The sound level of the Yanmar rice transplanter was varied from 91 to 93 dB (A) at different modes and it was very low noise level when compared to Redlands (94 – 99 dB (A)) and Yanji rice transplanter (97 - 103 dB (A)). According to OSHA -1910.95, the permissible exposure level is 90 dB (A). Continuous exposure to noise may lead to undesirable psychological reactions: hearing loss, increased strain and physical illness (McCornick, 1970). It is suggested that the noise level at operators' ear should be measured during operation of transplanters using microphone for further investigation.

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4.11 VIBRATION MEASUREMENT IN SELECTED RICE TRANSPLANTERS

The vibration in terms of acceleration (m s^{-2}) was measured for selected three rice transplanters in planting gear and neutral gear in stationary condition at different machine parts (mainly parts which are directly contact with the operator), according to procedure explained in section 3.8. The vibration measurement values of selected rice transplanters were furnished in the Table 4.25, 4.26 and 4.27.

From tables 4.25 to 4.27, it was clear that vibration intensity in root mean square (RMS) acceleration was maximum in Yanji rice transplanter at different parts compared with Yanmar and Redlands rice transplanters. The results showed that the magnitude of vibration intensity was more in planting gear than neutral gear.

It was observed that the vibration intensity in seat pan of Yanji rice transplanter was maximum in planting gear with a value of 134.4 m s^{-2} followed by Redlands transplanter (87.6 m s^{-2}) and Yanmar rice transplanter (58.8 m s^{-2}). The vibration intensity was increased to the tune of 32 per cent for Redlands transplanter and 56.25 per cent for Yanji rice transplanters respectively when compared with the Yanmar rice transplanter. However the maximum root mean square acceleration in back rest of operator seat in Yanji was increased to 58.8 per cent followed by 25 per cent in Redlands rice transplanter.

The magnitude of vibration intensity in steering wheel of Yanmar rice transplanter was 88. 6 m s^{-2} whereas, RMS acceleration in Redlands transplanter was 98.3 m s^{-2} and 149.7 m s^{-2} in Yanji rice transplanter. The vibration intensity in steering wheel was increased by a level of 5.3 per cent in Redlands and 40.8 per cent in Yanji. A similar trend was observed in different parts of the selected rice transplanters.

Table 4.25 Measured values of acceleration in Yanmar rice transplanters

Sl. No	Measuring points		Stationary condition			
			Neutral gear		Planting gear	
			RMS max	RMS min	RMS max	RMS min
1	Operators seat	Seat pan	17.4	13.4	58.8	30.2
		Backrest	23.3	7.5	50.5	47.5
2	Steering wheel		90.7	58.6	88.6	52.9
3	Platform	Left	111.7	23.9	98	19.2
		Right	102.6	20.3	91.4	30.9
		Middle	71.7	29.2	102.6	8.8
4	Float	Left	30.5	22.6	58.3	32.1
		Middle	21.5	16.5	561.2	38.9
		Right	35.6	28.5	65.8	40.5
5	Hydraulic planting lever		77.6	43.6	115.7	29.8
6	Main shifting lever		65.8	56.2	70.4	42.3
7	Hill space shift lever		45.8	19.5	66.8	20.5
8	Differential lock paddle		35.9	20.5	55.8	36.2
9	Accelerator paddle		23.9	21.9	65.9	9.5
11	Speed control paddle		83.2	36.5	100.6	45.2
12	Brake paddle		92.5	25.8	98.5	66.2
14	Unit clutch lever	First	42.5	20.8	65.9	35.7
		Second	35.6	30.2	68.6	30.2
		Third	32.6	12.8	60.3	21.5
15	Hydraulic sensing adjusting lever		84.7	50.0	89.1	49.5
16	Planting depth lever		65.3	30.2	86.5	39.8
19	Planting arm shaft		86.2	30.9	96.2	42.3

(Note: All dimensions are in m s^{-2})

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Table 4.26 Measured values of acceleration in Redlands rice transplanter

Sl. No	Measuring points		Stationary condition			
			Neutral gear		Planting gear	
			RMS max	RMS min	RMS max	RMS min
1	Operators seat	Seat pan	46.8	45.5	87.6	49.5
		Backrest	18.7	15.4	68.0	33.9
2	Steering wheel		97.7	66.4	98.3	77.2
3	Platform	Right	33.1	16.5	40.9	37.7
		Left	45.5	27.2	47.5	20.0
		Middle	29.8	27.2	48.2	35.0
4	Float	Right	31.8	31.1	21.9	16.7
		Left	19.3	10.6	18.0	14.1
		Middle	24.6	21.3	24.6	21.9
5	Hydraulic planting gear		78.3	63.9	18.7	16.7
6	Main shifting lever		8.2	7.3	12.1	9.5
7	Steering wheel tilt lever		42.3	20.6	52.6	16.9
8	Hill space shift lever		32.5	21.6	39.5	30.2
9	Accelerator lever		68.9	42.1	62.3	52.1
10	Brake lever		75.2	29.8	82.6	13.9
11	Planting depth lever		65.2	28.6	86.4	20.3
12	Number of seedling adjustment		47.2	20.8	52.1	19.7
13	Planting arm shaft		13.4	11.5	14.1	12.8

(Note: All dimensions are in m s^{-2})

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Table 4.27 Measured values of acceleration in Yanji rice transplanter

Sl. No	Measuring points		Stationary condition			
			Neutral gear		Planting gear	
			RMS max	RMS min	RMS max	RMS min
1	Operators seat	Seat pan	125.6	110.2	134.4	113.7
		Backrest	120.3	89.2	122.6	109.8
2	Steering wheel		142.3	120.3	149.7	145.6
3	Platform	Right	116.2	100.6	120.2	113.7
		Left	106.5	95.2	151.6	138.6
		Middle	49.6	39.2	58.0	56.0
4	Float	Right	80.6	74.7	90.6	84.7
		Left	79.6	67.2	89.6	77.2
		Middle	94.5	73.3	104.5	83.3
5	Hydraulic planting gear		92.6	81.4	102.6	91.4
6	Main shifting lever		142.3	102.8	152.3	112.8
7	Steering wheel tilt lever		137.8	116.5	147.8	126.5
8	Hill space shift lever		129.2	92.3	139.2	102.3
9	Accelerator lever		143	126	153.0	136.0
10	Brake lever		159.8	110.9	169.8	120.9
11	Planting depth lever		116.9	69.2	126.9	79.2
12	Number of seedling adjustment		53.9	51.9	63.9	61.9
13	Planting arm shaft		146.2	118.2	156.2	128.2

(Note: All dimensions are in m s^{-2})

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4.12 SPATIAL, VISUAL AND CONTROL REQUIREMENTS OF THE OPERATOR

After completion of experimental trails with selected rice transplanters, subjects response were collected about the spatial, visual and control requirements of the selected rice transplanters according to the procedure furnished in the section 3.9.1. All the subjects opined that it was very difficult to reach the first platform of the Yanmar rice transplanter in muddy field compared to the other rice transplanters. In Yanmar rice transplanter, the subjects were satisfied with location of seat and seating posture. The seat had adequate legroom and kneeroom and comfortable seat and backrest with adjustable mechanism to suit all operators. They were not adopted twist/awkward postures during work in Yanmar rice transplanter.

In the case of Yanji and Redlands rice transplanters, the women subjects complained on seat pan width, back rest height and backrest width. These transplanters had the facility of adjusting the seat longitudinal only, whereas for backrest there was no vertical adjustment mechanism and height of backrest also very less. The backrest width and height of the machine should give adequate support to the upper lumbar region of the operator otherwise it leads to cause severe back pain with the increase of duration of work (Mehta *et al.* 2000). Due to the longitudinal seat adjustment facility in the selected rice transplanters, the position of hand/foot controls was within the operators range. A little force was required to operate the all controls and there was no any discomfort to operate the controls.

The subjects were satisfied with the displays provided in the selected rice transplanters. The visibility requirements were satisfied by upright seating posture with easy movements of head and upper body from the front, to side in selected rice transplanters. In Yanmar rice transplanter, back side transplanting area was visible with the rear view mirrors. In Redlands and Yanji rice transplanters, the helpers in both side of the operator has given information about rear view to the operator. And also, the display area was very near to the operator's line of vision which requires only minimum eye movements away from his task.

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The subjects were complained on more noise and vibration intensity level in Yanji and Redlands rice transplanters. The subjects were feeling discomfort at afternoon time (after 11 AM) compared to early morning (before 9 AM) while doing work with selected rice transplanters. According to procedure furnished in section 3.9, the spatial, visual and control requirements of the operator were observed and measured. The work place dimensions were measured from operator seat to different controls of the machine for each transplanter. The existing spatial dimensions of selected rice transplanters with reference to the operator seat were presented in Table 4.28, 4.29 and 4.30.

4.12.1 Spatial, visual and control requirements of Yanmar rice transplanter of the operator

It was observed from the Table 4.28 that the back rest width provided at the bottom side and top side of the seat of Yanmar self-propelled rice transplanter was 40 and 25 cm respectively. It should be within the range of interscye breadth of 5th and 95th percentile values. The 5th and 95th percentile values of interscye breadth of female agricultural workers of the study region were 25 and 37.5 cm respectively. Hence the seat back rest width provided at the bottom side and top side of the seat of Yanmar self-propelled rice transplanter was within the normal range.

The measured value of the seat pan width of Yanmar transplanter was 44 cm. It should be above the value of sitting hip breadth of 95th percentile of workers. The 95th percentile values of sitting hip breadth was 41.5 cm in the present study. It was seen that the seat pan width of transplanter was above the hip breadth sitting of 95th percentile value. Adjustable seat was also provided in the transplanter. So all the operators can comfortably sit and ride the Yanmar rice transplanter.

In the transplanter, the distance from footrest to seat pan was 35 cm. The 5th percentile value of popliteal height sitting of women agricultural workers was also 35.4 cm. Hence the seat height (from foot rest to seat pan) of Yanmar rice transplanter was comfortable to the operator.

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Table 4.28 Existing machine part dimensions of Yanmar rice transplanter in relation to anthropometric dimensions of women agricultural workers

Sl. No	Machine dimensions		Measurements (cm)	Body dimensions	5^{th} (cm)	95^{th} (cm)	
1	Operator seat	Back rest width (Top and bottom side)	25 and 40	Interscye breadth	25	37.5	Acceptable
		Seat pan width	44	Sitting hip breadth	-	41.5	Acceptable
		Seat height	35	Popliteal height sitting	35.4	-	Acceptable
2	Steering wheel	Rim diameter	3.5	Middle finger grip diameter	3.3	5.7	Acceptable
		Back rest to steering wheel	50	Shoulder grip length	50	-	Acceptable
		Steering height from footrest	55	knee height sitting + Elbow rest height	57	-	Acceptable
3	Hand controls		50 to 70	Shoulder grip length	50	73.6	Acceptable with longitudinal seat adjustment
	Hydraulic planting lever		70				
	Main shifting lever		60				
	Hill space shift lever		58				
	Differential lock paddle		60				
	Parking brake lever		55				
	Speed control paddle		60				
	Brake paddle		55				
	Brake pedal length		7				
	Brake pedal width		5				
	Hydraulic stopper		65				

	Unit clutch lever	First	60				
		Second	63				
		Third	66				
	Hydraulic sensing adjusting lever		67				
	Planting depth lever		58				
	Number of seedlings adjustment lever		66				
	Feed control adjustment lever		68				
	Planting arm shaft		70				
5	Foot controls		50 to 70	Functional leg length	82	93.6	Acceptable with longitudinal seat adjustment
6	Accelerator pedal	Length	20	Toe length = foot length – instep length	-	4.8	Acceptable
		Width	5	Foot breadth	-	10	Not acceptable
7	Brake pedal	Length	5	Toe length	-	4.8	Acceptable
		Width	5	Foot breadth	-	10	Not acceptable
8	Step height	Ground to step height	72	Knee height	35.6	-	Not acceptable

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The measured rim diameter of steering wheel was 3.5 cm. This value should be in the range of middle finger grip diameter values of 5th (3.3 cm) and 95th (5.7 cm) percentile of subjects. Here for design of grip diameter of steering, 5th percentile value was used. So the rim diameter of steering is within the recommended range. The steering distance from the operator was 50 cm. It should be within the value of shoulder grip length of the 5th percentile of workers of this region. The 5th percentile value of female agricultural workers was 50 cm. So the steering distance is also satisfied and it is within the limits. The steering height from foot rest was 55 cm. The 5th percentile knee height sitting plus elbow rest height was 57 cm. Hence the steering height is within the range and comfortable to the operator.

The accelerator pedal was a toe operated control. The 95th percentile value of toe length of agricultural workers was usually taken for design of pedals. The minimum toe length is equal to difference of 95th percentile values of foot length and instep length (ISO 12343, 1998). In the present study, the 95th percentile value of foot length was 25.1 cm and instep length was 20.3 cm. So the minimum toe length of women agricultural workers was calculated as 4.8 cm. The measured accelerator pedal length of Yanmar rice transplanter was 20 cm and it is above the minimum toe length of women operator. So the pedal length of Yanmar rice transplanter was comfortable to the female workers.

It was found that the accelerator pedal width of Yanmar rice transplanter was 5 cm. The pedal width should be more than the 95th percentile of foot breadth of the agricultural workers. In this study the foot breadth of 95th percentile of women workers was 10 cm. The width of accelerator pedal (5 cm) was less than the foot breadth of the 95th percentile (10 cm). So it should be increased. The main reason for increasing pedal width is the accelerator pedal moves in such a direction that the vibrations induced by driving over obstacles will not cause the foot and pedal to shake and vibrate. Otherwise, the engine speed will not remain steady. This can be almost completely prevented by allowing the heel of the foot to rest on a steady support. This is same in the case of brake pedal also. The brake pedal width also (5 cm) is not within the range of 95th percentile of foot breadth value (10 cm).

All the hand and foot controls should be positioned in relation to seat in such a way that these can be operated with ease and with minimum possible efforts by the operator in seated position. Here the seat adjustments provided 15 cm of fore and aft movement and 10 cm of vertical movement for accommodating larger size operators. It was clear from the Table (4.30) that the placement of hand controls and foot controls dimensions with respect to seat reference point were arranged within the range. The distance from the seat to hand controls and foot controls was within the range when compared with the 5th percentile value of shoulder grip length (50 ± 7.09 cm) and functional leg length of agricultural workers (82 ± 7.53 cm).

The transplanter first step height from ground was 72 cm .causing more uncomfortable to the women operators to reach the transplanter first platform in muddy field. The measured height was more than the knee height (35.6 cm) of the 5th percentile. So the height should be decreased to 40 ± 7.6 cm.

4.12.2 Spatial, visual and control requirements of Redland and Yanji rice transplanter of the operator

The existing machine part dimensions of Redlands and Yanji rice transplanter in relation to anthropometric dimensions of women agricultural workers were presented in table 4.29 and 4.30. It was observed that the different parts of dimensions of Redlands and Yanji rice transplanters were almost same. In Yanji and Redlands rice transplanters, the seat adjustments provided 15 cm of fore and aft movement for accommodating larger size operators. So, all the foot and hand controls can be operated by both 5th and 95th percentile operators.

It was observed from the table 4.29 and 4.30, the main operator seat and helper seat dimension of Redlands and Yanji rice transplanters were not within the range of anthropometric dimensions. So a new design of seat was suggested based on the anthropometric dimensions of female agricultural workers of this region and considering the space facilities of the rice transplanters.

Table 4.29 Existing machine part dimensions of Redlands rice transplanter in relation to anthropometric dimensions of women agricultural workers

Sl. No	Machine dimensions		Measurements (cm)	Body dimensions	5^{th} (cm)	95^{th} (cm)	
1	Back rest	Breadth	16	Interscye breadth	25.0	37.5	Not acceptable
		Height	28	Sitting acromion height	49.0	-	Not acceptable
		Cushion	5				Not acceptable (Mehta, 2008)
	Seat pan	Breadth (rear and bottom side)	30 and 22	Sitting hip breadth	-	41.5	Not acceptable
		Length	40	Buttock popliteal length	39.5 ± 3.4	-	Acceptable
		Cushion	10				Acceptable
	Seat height		40	Pop liteal height sitting	35.4 ± 7.6	-	Acceptable
2	Steering rim diameter		3.5	Middle finger grip diameter	3.3	5.7	Acceptable
3	Hand controls		40 to 70	Shoulder grip length	50.0	73.6	Acceptable
	Main shifting lever		80				
	Hydraulic planting gear		40				
	Steering wheel tilt lever		50				
	Hill space shift lever		80				
	Accelerator lever		50				
	Brake lever		90				
	Planting depth lever		80				
	Planting arm shaft		80				
4	Foot controls		40 to 70	Functional leg length	82.0	93.6	Acceptable
5	Helper seat diameter (Ø)		25	Hip breadth sitting	-	41.5	Not acceptable

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Table 4.30 Existing machine part dimensions of Yanji rice transplanter in relation to anthropometric dimensions of women agricultural workers

Sl. No	Machine dimensions		Measurements (cm)	Body dimensions	5^{th} (cm)	95^{th} (cm)	
1	Back rest	Breadth	16	Interscye breadth	25.0	37.5	Not acceptable
		Height	28	Sitting acromion height	49.0	-	Not acceptable
		Cushion	5	-			Not acceptable (Mehta, 2000)
	Seat pan	Breadth (rear and bottom side)	30 and 22	Sitting hip breadth	-	41.5	Not acceptable
		Length	37	Buttock popliteal length	39.5 ± 3.4	-	Acceptable
		Cushion	5	-			Not Acceptable
	Seat height		40	Pop liteal height sitting	35.4 ± 7.6	-	Acceptable
2	Steering rim diameter		3.5	Middle finger grip diameter	3.3	5.7	Acceptable
3	Hand & foot controls		50 to 80	Shoulder grip length	50.0	73.6	Acceptable
	Main shifting lever		80				
	Hydraulic planting gear		40				
	Steering wheel tilt lever		50				
	Hill space shift lever		80				
	Accelerator lever		50				
	Brake lever		90				
	Planting depth lever		80				
	Planting arm shaft		80				
4	Foot controls		50 to 80	Functional leg length	82.0	93.6	Acceptable
5	Helper seat diameter (Ø)		25	Hip breadth sitting	-	41.5	Not acceptable

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4.12.3 Main operator seat design

Seat design provides the interface between a mechanical system, the machine, and the delicate and sensitive biological system, the human operator. The machine seat is most closely linked with the operator's comfort and it must be able to provide with comfortable and controlled seated posture to the operator. The dimensions of the seat, i.e. width, depth and height are important parameters where anthropometric data can be very useful.

The anthropometric dimensions, i.e. popliteal height sitting (5th percentile), hip breadth sitting (95th percentile), buttock popliteal length (5th percentile), interscye breadth (5th and 95th percentile) and sitting acromion height (5th percentile) of agricultural workers were taken into consideration for design of seat height, seat pan width, seat pan length, seat backrest width and seat backrest height, respectively, of a transplanter. So a seat is designed, to accommodate equally well to the total population of rice transplanter women operators, with a reasonable range of individuals, usually from 5th to 95th percentiles.

4.12.3.1 Seat back rest height

The 5th percentile value of sitting acromial height of women agricultural workers was 49 cm. A high back rest prevents full mobility of the arms and shoulder in rear viewing. Thus, leaving 100 mm so as to have a free shoulder movement, the height of seat back rest should be 39 cm. In the present study, the back rest height was only 28 cm for Yanji and Redlands transplanters. So, it is not within the range and hence recommended to provide as adjustable back rest.

Many researchers suggested that back rest should have an open area of at least 12.5 cm to 20 cm to accommodate sacrum and fleshy parts of buttocks just above seat pan and to allow the lumbar region to fit firmly into the backrest (Tewari and Prasad, 2000). Thus the open area was selected as 18 cm. The suggested back rest height with adjustable link and selected open area was shown in Plate 4.9.

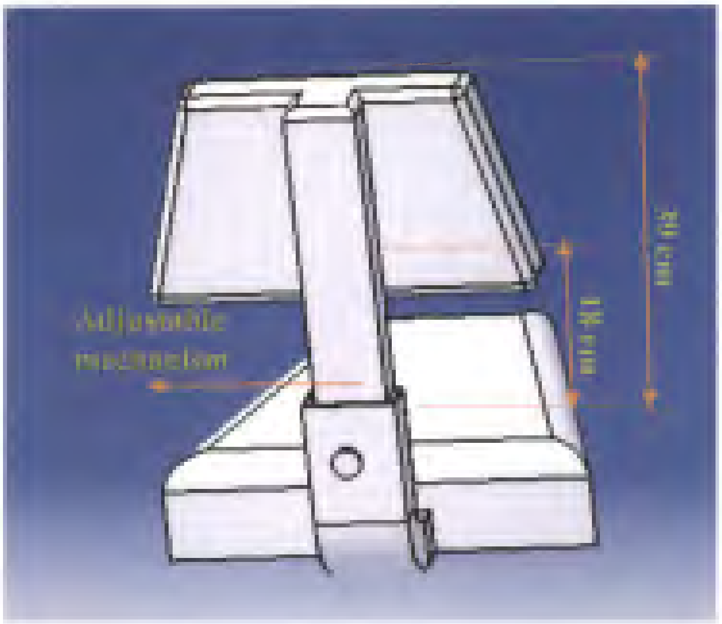

Plate 4.9 Suggested seat backrest height model in CATI V5 6R21 software

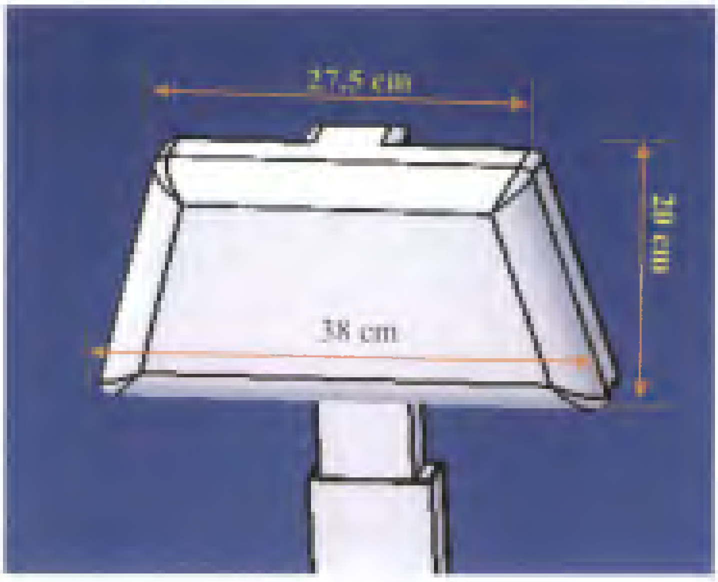

Plate 4.10 Suggested trapezoidal seat backrest width model

4.12.3.2 Seat back rest width

The 5th and 95th percentile values of interscye breadth of women agricultural workers were 25 cm and 37.5 cm respectively. Therefore, trapezoidal shape backrest may be provided on transplanter with smaller length on the upper part to have free hand movement. Thus, the backrest width at the bottom and top were selected as 38 cm and 27.5cm respectively including allowances for operators' cloths and it was shown in Plate 4.10.

4.12.3.3 Seat pan length

The seat pan length should be lower than 5th percentile value of buttock popliteal length keeping in view that there should be enough clearance between back of lower leg and front edge of the seat for the 5th percentile operator. The 5th percentile value of buttock popliteal length of the women agricultural workers was 39.5 cm. Therefore, for women operators, the seat length was selected as 40 ± 3.4 cm and it was shown in Plate 4.11. The seat pan length of Yanji and Redlands rice transplanters were 38 and 40 cm respectively. So, the suggested seat pan length is within the range of seat pan length of these rice transplanters. The seat pan length is satisfied with the anthropometric dimensions of female agricultural workers of this region.

4.12.3.4 Seat pan width

Seat pan width is the horizontal distance between the outside edges of the seat surface measured in a plane perpendicular to the median plane of the seat or the width measured along a horizontal transverse line passing through the seat index point (SIP) (ISO 12343, 1998). In order to assure operator comfort and convenient posture change, the seat pan width should be wider than the value of hip breadth sitting of 95th percentile operator.

In rice transplanters, trapezoidal shape bottom seat may be provided with smaller width on the front part and bigger width at rear part to have free sitting. The

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hip breadth sitting for 95th percentile of women agricultural workers in the present study was 41.5 cm. As per BIS, it should not be less than 45 cm (ISO 12343, 1998). However, based on anthropometric dimensions of women workers this value may be taken as 43 cm width at rear side and 30 cm width at front side of seat (Plate 4.14).

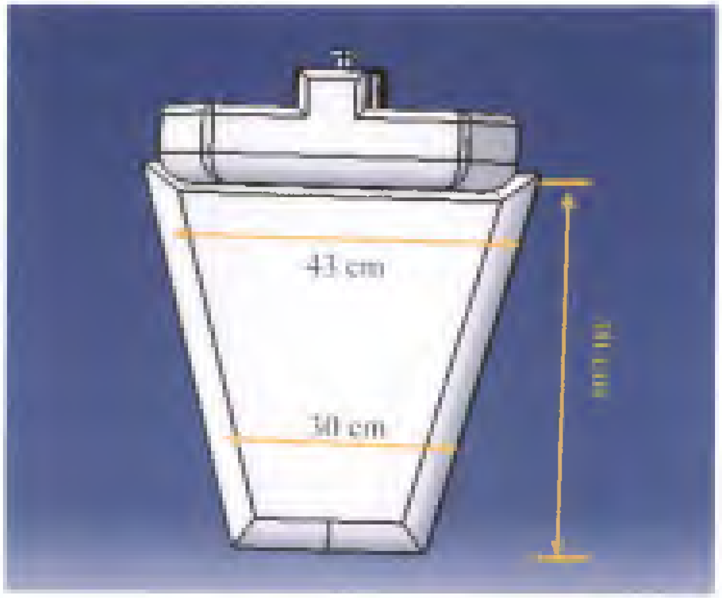

Plate 4.11 Suggetsed seat length and trapezoidal seat pan width model

4.12.3.5 Cushion height

Weight of buttocks and thighs should be properly supported by a seat cushion. Human buttocks have bony structure known as ischial tuberosities are capable of transmitting body weight directly and uniformly from spinal column to the seat cushion. If seat cushion is not properly designed according to physiology of buttock region, after a prolonged time (2 to 4 hours) it may result in high degree of discomfort or pain to the operators (Purcell, 1980).

Since the major excitation of vibration is engine and it was transmitted to the operator through seat, proper cushion height should be provided to protect the operator. According to Mehta (2000), the seat with synthetic rubber foam cushion materials (thickness=10 cm and ρ =70 kg m^{-3}) and composite (layers of coir and medium density foam) seat back rest cushion material (thickness=8 cm and ρ = 47 kg m^{-3}) should be considered. Hence the seat cushion height of 10 cm and backrest cushion height of 8 cm was selected for more comfortable seating and as shown in Plate 4.12. In the present steady, the existing seat cushion height dimensions of Yanji and Redlands transplanters were 10 cm respectively. This value is within the range of suggested value. The existing backrest cushion height dimension was 5 cm for both rice transplanters and it should be increased up to as suggested as above.

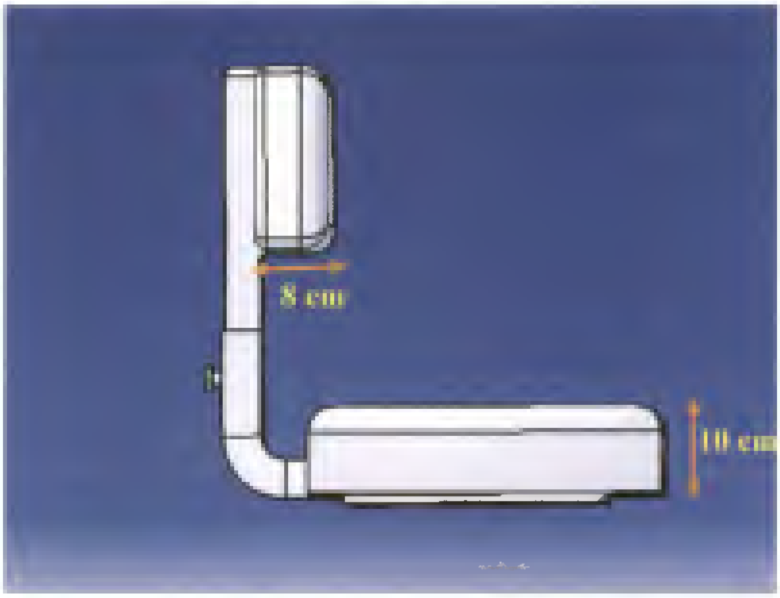

Plate 4.12 Suggetsed seat and back rest cushion height model

4.12.4 Helper seat design

The measured diameter of helper seat was 25 cm. The women workers were feeling very uncomfortable to sit while transplanting in field and causing more back pain. By keeping in view of space facilities in Redlands and Yanji rice transplanters, it is recommended to design a new seat based on anthropometric data (5^{th} and 95^{th} percentiles) to increase the comfort and safety to the women workers. The value of hip breadth sitting of 95^{th} percentile of women agricultural workers is 41.5 cm. So, the diameter of seat was selected as 35 cm and was shown in Plate 4.13.

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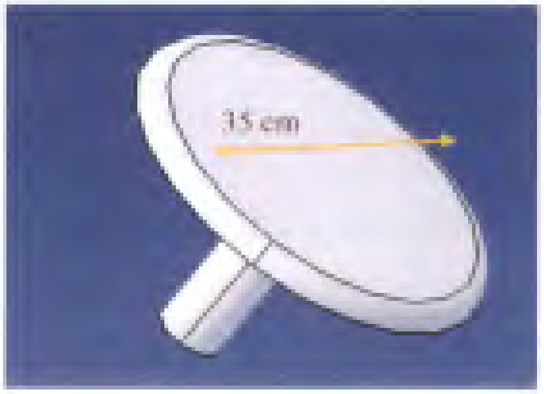

Plate 4.13 Suggetsed helper seat diameter model

The overall suggested main operator seat dimensions and helper seat dimensions of Redlands and Yanji rice transplanter were presented in table 4.31 and 4. 32.

Table 4.31 Suggested seat dimensions of Redlands rice transplanter

Sl. No	Machine dimensions		Existing dimensions (cm)	Suggested dimensions (cm)
1	Back rest (Trapezoidal shape)	Width x length x height	16 x 16 x 10	38 x 27.5 x 20
		Total Height	28	39
		Open area of back rest	15	18
		Cushion	5	8
	Seat pan, (Trapezoidal shape)	Width (rear and bottom side)	30 and 22	43 and 30
		Length	40	40
		Cushion height	10	10
2	Helper seat diameter (Ø) (circular shape)		25	35

Table 4.31 Suggested seat dimensions of Yanji rice transplanter

Sl. No	Machine dimensions		Existing dimensions (cm)	Suggested dimensions (cm)
1	Back rest (Trapezoidal)	Width x length x height	16 x 12 x 10	38 x 27.5 x 20
		Height	28	39
		Open area of back rest	10	18
		Cushion height	5	8
	Seat pan (Trapezoidal)	Breadth (rear and bottom side)	30 and 22	43 and 30
		Length	37	40
		Cushion height	5	10
2	Helper seat diameter (Ø) (circular shape)		25	35

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Kerala is one of the traditional states of rice cultivation and lush green of rice fields is one of the most captivating features of Kerala's landscape. Rice cultivation in Kerala has witnessed a steady decline since the 1980's. The rice farming sector in Kerala is experiencing a multitude of problems like labour in peak season, lack of trained labour and high cost of available labour. Presently the transplanting of the rice crop depends completely upon manual labour. In many areas, the transplanting operation is generally done by women labourers. During transplanting, the women workers adopt upright bending posture in the muddy field for a long time in sweltering weather. The continuous bending posture, putting hands support on knees and repetitive movement of hands for planting of seedlings in different and adverse environmental conditions cause great discomfort and develop risk factors. The developed risk factors leads to musculoskeletal disorders (MSD).

In order to overcome all these and to ease the transplanting work various types of rice transplanters were developed by researchers and there are available in the markets. These equipment are primarily developed keeping men workers in consideration, despite rice transplanting being performed mostly by women workers. The safety and efficiency aspects of these transplanters with respect to women workers are not being studied. Ergonomically designed equipment not only minimize drudgery of the labour but also increase productivity at reduced expenditure levels. Thus an ergonomic evaluation was conducted on three selected rice transplanters and in traditional method with women operators.

An anthropometric survey was conducted in three zones of Kerala. A sample of 150 women agricultural workers selected from each zone. Seventy nine body dimensions including weight and age and strength measurements necessary for the design/design modifications of agricultural machines from ergonomic considerations were selected. Ten subjects were selected who had anthropometric dimensions conforming to statistical requirements and screened for normal health by medical investigations. All the subjects were calibrated in the laboratory to determine the relationship between heart rate and oxygen consumption.

The Yanmar 8 row self-propelled riding type transplanter, Redlands 8 row self-propelled riding type transplanter and Yanji 8 row self-propelled riding type transplanter were selected for ergonomic evaluation. The energy expenditure of work of these selected rice transplanters were compared with the traditional transplanting method. The field experiments were conducted in 13 acres of farmer's field, Nadiyapadam Ela, Sooranad North and Kollam. All the selected subjects were equally trained persons in the operation of the selected rice transplanters.

Heart rate was measured for each subject with each selected model after 30th minutes of operation. From the values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects for all the selected rice transplanters were predicted from the calibration chart of the subjects. The energy expenditure of selected rice transplanters were computed by multiplying the oxygen consumed by the subject during the trial period with the calorific value of oxygen as 20.88 kJ l^{-1} for all the subjects.

The parameters used for the ergonomical evaluation of all the selected rice transplanters include heat rate and oxygen consumption, energy expenditure rate, grade of work, acceptable work load, limit of continuous performance, work rest cycle and discomfort rating. Noise level and vibration level were measured for each selected rice transplanters. The analysis was done with RULA (Rapid Upper Limb Analysis) tool and DHM (Digital Human Manikin) tool in CATIA V5 software. Based on the analysis of the results the following conclusion were drawn.

i. The stature was significantly correlated with all the 76 dimensions except wall to acromion distance, body circumferences (chest, thigh, calf and wrist), abdominal depth sitting, index finger diameter and all skin folds.
ii. Weight was significantly correlated with all 76 body dimensions except elbow grip length, hand breadth at Metacarpal III, grip diameter, maximum

grip length, foot breadth, head length and breadth and menton to top of the head.

iii. In present anthropometric survey, 18 body dimensions can estimated with simple linear regression equation. For estimation of 18 body dimensions, 5 body dimensions were required. Thus the measurement of 79 body dimensions can be reduced to 56.

iv. The basal metabolic rate of the subjects varied from 1603.1 to 2003.7 kcal day^{-1}

v. The relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects.

vi. The significant difference in heart rate was noticed in all the selected rice transplanters for all subjects.

vii. The subjects was showed minimum heart rate for Yanmar rice transplanters followed by Redlands and Yanji rice transplanters. The maximum heart rate was recorded significantly higher in traditional method.

viii. In case of subject 1, there was no significance difference between heart rate of Yanji rice transplanter (145.6 beats min^{-1}) and traditional method (150.2 beats min^{-1}) and but significantly differed in Yanmar (103.8 beats min^{-1}) and Redlands (121.3 beats min^{-1}) rice transplanters.

ix. In case of subject 7, the Redlands rice transplanter (128.2 beats min^{-1}) and Yanji rice transplanters (134.3 beats min^{-1}) showed no significant difference whereas Yanmar rice transplanter (96.5 beats min^{-1}) and Redlands rice transplanter (128.2 beats min^{-1}) showed significant difference.

x. The significant difference of energy expenditure was noticed in all the selected rice transplanters for all subjects except subject 1, 3 and 7.

xi. The lowest energy expenditure was observed in Yanmar rice transplanter when compared to other selected rice transplanters.

xii. The minimum energy expenditure of Yanmar rice transplanter was 9.89 kJ min^{-1} for subject 7 whereas maximum value was observed in subject 9 (18.99 kJ min^{-1}). In the case of traditional method, the minimum energy expenditure was noticed as 24.01 kJ min^{-1} for subject 1 and maximum energy expenditure was 39.68 kJ min^{-1} for subject 6.

xiii. The time of operation was significantly influenced the heart rate and energy expenditure of subjects for selected rice transplanters. There was a significant difference in heart rate and energy expenditure before 9 AM and after 11 AM.

xiv. The heart rate after 11 am was increased by 12.9 per cent which compared to heart rate before 9 am and the average energy expenditure before 9 am was 20.7 kJ min^{-1} while after 11 am it was increased to 26.6 kJ min^{-1}.

xv. The Yanmar self-propelled rice transplanter was graded as "moderately heavy". The grade of work was "heavy" for Redlands rice transplanter while it was "very heavy" for Yanji rice transplanter. The traditional method of transplanting was graded as "extremely heavy".

xvi. Maximum aerobic capacity of female subjects varied from 1.30 to 2.02 l min^{-1}.

xvii. The oxygen consumption in terms of VO_2 max was minimum for Yanmar rice transplanter and maximum for traditional method.

xviii. The overall discomfort rate was maximum for transplanting by traditional method followed by transplanting with Yanji, Redlands and Yanmar rice transplanters.

xix. More safety was observed for Yanmar rice transplanter with a safety rating of 2.1 and scaled as ">secure and meagre fear". The safety was less for Redlands and Yanji rice transplanter and scaled as ">moderately secure and less fear" with a score of 4.5 and 4.7 respectively.

xx. Body part discomfort score was maximum for traditional method with a score of 46.8 followed by Yanji rice transplanter (42.3) and Redlands rice transplanter (34.9) while it was minimum for Yanmar rice transplanter (14.5). Major discomfort happened in low back, upper back, neck and shoulders while working in selected rice transplanters.

xxi. The work rest cycle for achieving functional effectiveness of the selected rice transplanters and traditional method for maintaining and enhancing the human comfort were 30 minutes of work followed by 2 minutes rest for

Yanmar rice transplanter, 30 minutes of work followed by 9 minutes rest for Redlands, 30 minutes of work followed by 15 minutes rest for Yanji rice transplanter and 30 minutes of work followed by 15 minutes rest for traditional method of rice transplanting.

xxii. 80 per cent of the women workers reported that they had experienced MSD in the past seven days; 37 per cent reported that they had experienced MSD problems over the past 12 months.

xxiii. About 33.3 per cent of women labourers had pain in lower back during past 12 months while 30 per cent of respondents suffering from pain in upper back. However all the respondents (cent per cent) were experienced both lower and upper back pain during past 7 days.

xxiv. Around 28.8 per cent of respondents reported neck pain during manual 107 transplanting for the last 12 months followed by 23 per cent in shoulders. However last 7 days of manual transplanting, 97 per cent women labours experienced pain and discomfort in neck followed by shoulders (94 per cent).

xxv. In addition to the nine body anatomical body parts, cent per cent of women workers experienced pain in finger.

xxvi. About 86 per cent of respondents took the treatment for back ache followed by body ache (80 per cent), head ache (75 per cent), fore arm pain (67 per cent) and pain in trunk (59 per cent). About 33 per cent of total respondents agreed that they were taking the treatment for stiffness in joints. A total of 85 per cent respondents were satisfied with the medical and self-treatment.

xxvii. In selected rice transplanters, none of the subjects had experienced pain or discomfort in any of the body parts after 7 days of operation.

xxviii. In traditional method, majority of the women complained severe pain in upper back, lower back and neck, moderate pain in shoulders and knees and complained light and very light pain in elbows, wrist/hands ankles/feet and hips/thighs.

xxix. The RULA score was very high for posture 1(traditional method) and low for posture 2 (Yanmar rice transplanter). The score for posture 3 (Redlands rice transplanter) and posture 4 (Yanji rice transplanter) was more or less same.

xxx. The RULA analysis showed that existing working posture of the operator in traditional method were highly dangerous (score 7) which was the maximum score and must be changed by in depth investigation of workstation/working pattern in order to keep away the worker from musculoskeletal disorders.

xxxi. The RULA result of Yanmar rice transplanter showed that this posture was acceptable to the operator. The RULA result of Redlands rice transplanter showed that, further investigation is needed to decrease the discomfort of operator. The posture Yanji rice transplanter score showed that the posture changes were needed soon and also require further improvement in the seat design.

xxxii. The sound level of the Yanmar rice transplanter was varied from 91 to 93 dB (A) at different modes and it was very low noise level when compared to Redlands (94 – 99 dB (A)) and Yanji rice transplanter (97 - 103 dB (A)).

xxxiii. The vibration intensity in root mean square (RMS) acceleration was maximum in Yanji rice transplanter at different parts compared with Yanmar and Redlands rice transplanters. The results showed that the magnitude of vibration intensity was more in planting gear than neutral gear.

xxxiv. The vibration intensity in seat pan of Yanji rice transplanter was maximum in planting gear with a value of 134.4 m s^{-2} followed by Redlands transplanter (87.6 m s^{-2}) and Yanmar transplanter (58.8 m s^{-2}). The vibration intensity was increased to the tune of 32 per cent for Redlands transplanter and 56.25 per cent for Yanji rice transplanters respectively when compared with the Yanmar rice transplanter.

xxxv. In Yanmar rice transplanter, the subjects were satisfied with location of seat and sitting posture. The subjects opined that it was very difficult to reach the first platform of the Yanmar rice transplanter in muddy field compared to the other rice transplanters.

xxxvi. In the case of Yanji and Redlands rice transplanters, the women subjects complained on seat pan width, back rest height and backrest width.

xxxvii. Due to the longitudinal seat adjustment facility in the selected rice transplanters, the position of hand/foot controls was within the operators range. A little force required to operate the all controls and there was no any discomfort to operate the controls.

xxxviii. The subjects were satisfied with the displays provided in the selected rice transplanters. The display area is very near to the operator's line of vision which requires only minimum eye movements away from his task.

xxxix. The visibility requirements were satisfied by upright seating posture with easy movements of head and upper body from the front, to side in selected rice transplanters.

xl. A main operator seat design and helpers seat design was suggested for Yanji and Redlands rice transplanters based on anthropometric dimensions of agricultural women workers and spatial requirements of transplanters.

xli. The dimensions recommended for the seat based on anthropometric dimensions of women operators were as seat backrest height (39 cm), trapezoidal seat back rest width (38 cm-bottom side, 27.5 cm top side), seat back rest open area (18 cm), trapezoidal seat length (40 ± 3.4 cm), trapezoidal seat width (43 cm-top side, 30 cm-bottom), seat cushion height (10 cm) and backrest cushion height (8 cm). The diameter of 35 cm was suggested for helper seat for more comfortable sitting.

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Appendices

APPENDIX I

Musculoskeletal discomfort form

Job/Position: ______________________________
Gender: M F Age: _______ Height: ____ ft.____ in. Weight: _____________
How long have you been doing this job? ___years ___ months
How many hours do you work each week? _____

Table 1: Trouble with the locomotive organs (First group of questions)

To be answered by everyone	To be answered by those who have had trouble	
Have you at any time during the last 12 months had trouble (ache, palm discomfort) in:	Have you at any time during the last 12 months been prevented from doing your normal work (at home, or away from home) because of the trouble?	Have you had trouble at any time during the last 7 days
Neck 1. No 2.Yes	1 No 2 Yes	1 No 2 Yes
Shoulders 1. No 2. Yes, in the right shoulder 3. Yes, in the left shoulder 4. Yes in both shoulders	1 No 2 Yes	1 No 2 Yes
Elbows 1. NO 2. Yes, in the right elbow 3. Yes, in the left elbow 4. Yes in both elbow	1 No 2 Yes	1 No 2 Yes
Wrists/hands 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
Upper back 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
Low back (small of the beck) 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
One or both hips/thighs 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
One or both knees 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
One or both ankles/feet 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes

Table 2. Questionnaire about low back trouble (Second group of questions)

1. Have you ever had low back trouble (ache, Pain or discomfort)? **1 No 2 Yes**
if you answered NO to question 1/ do not answer questions 2-8

2. Have you ever been hospitalized because of low back trouble? **1 No 2 Yes**
3. Have you ever had to change jobs or duties because of low back trouble? **1 No 2 Yes**
4. What is the total length of time that you have had low back trouble during the last 12 months? **1.O days** **2.1--7 days** **3.8--30 days** **4.More than 30 days, but not every day** **5.Every day**
If you answered O days to question 4, do not answer the questions 5—8
5. Has low back troubled caused you to reduce your activity during the last 12 months? a) Work activity (at home or away from home)? **1No 2 Yes** b) Leisure activity? **1No 2 Yes**
6. What is the total length of time that low back trouble has prevented you from doing your normal work (at home or away from home) during the last 12 months? **1. 0 days** **2. 0-7 days** **3. 8-30 days** **4. More than 30 days**
7. Haw you been seen by a doctor, physiotherapist, chiropractor or other such person because of low back trouble during the last 12 months? **1 No 2 Yes**
8. Have you had low back trouble at any time during the last 7 days? **1No** **2 Yes**

Table 3. Questionnaire about neck and shoulder trouble (Second group of questions)

A) Neck
1. Have you ever had neck trouble (ache, Pain or discomfort)? **1 No 2 Yes**
if you answered NO to question 1/ do not answer questions 2-8uestions 2—8
2. Have you ever hurt your neck in an accident?

1No 2 Yes
3. Have you ever had to change jobs or duties because of neck trouble? **1No 2 Yes**
4. What is the total length of time that you have had neck trouble during the last 12 months? **1.O days** **2.1--7 days** **3.8--30 days** **4.More than 30 days, but not every day** **5.Every day**
If you answered O days to question 4, do not answer the questions 5—8
5. Has neck troubled caused you to reduce your activity during the last 12 months? a) Work activity (at home or away from home)? **1 No 2 Yes** b) Leisure activity? **1 No 2 Yes**
6. What is the total length of time that neck trouble has prevented you from doing your normal work (at home or away from home) during the last 12 months? **1. 0 days** **2. 0-7 days** **3. 8-30 days** **4. More than 30 days**
7. Haw you been seen by a doctor, physiotherapist, chiropractor or other such person because of neck trouble during the last 12 months? **1 No 2 Yes**
8. Have you had neck trouble at any time during the last 7 days? **1 No 2 Yes**
B) Shoulder
9. Have you ever had shoulder trouble (ache, Pain or discomfort)? **1 No 2 Yes**
if you answered NO to question 9/ do not answer questions 10-17questions 2—8
10. Have you ever hurt your shoulder in an accident? **1 NO** **2 Yes, in the right shoulder** **3 Yes, in the left shoulder** **4 Yes, in both shoulders 4**
11. Have you ever had to change jobs or duties because of shoulder trouble? **1 No 2 Yes**
12. Have you had shoulder trouble during the last 12 months? **1 NO** **2 Yes, in the right shoulder** **3 Yes, in the left shoulder**

4 Yes, in both shoulders
13. What is the total length of time that you have had shoulder trouble during the last 12 months? **1.O days** **2.1--7 days** **3.8--30 days** **4.More than 30 days, but not every day** **5.Every day**
If you answered O days to question 12, do not answer the questions 13—17
14. Has neck troubled caused you to reduce your activity during the last 12 months? a) Work activity (at home or away from home)? **1 No 2 Yes** b) Leisure activity? **1 No 2 Yes**
15. What is the total length of time that shoulder trouble has prevented you from doing your normal work (at home or away from home) during the last 12 months? **1. 0 days** **2. 0-7 days** **3. 8-30 days** **4. More than 30 days**
16. Haw you been seen by a doctor, physiotherapist, chiropractor or other such person because of shoulder trouble during the last 12 months? **1 No 2 Yes**
17. Have you had shoulder trouble at any time during the last 7 days? **1 No 2 Yes**

APPENDIX II

Heart rate, oxygen consumption and energy expenditure of subjects while transplanting by Yanmar rice transplanter

		Before 9 am			After 11 am		
Subjects	**Replications**	**Avg. HR (beats min^{-1})**	**OCR (l min^{-1})**	**EER (kJ min^{-1})**	**Avg. HR (beats min^{-1})**	**OCR (l min^{-1})**	**EER (kJ min^{-1})**
1	R1	90.0	0.41	8.54	110.0	0.70	14.64
	R2	100.0	0.56	11.59	112.0	0.73	15.25
	R3	98.0	0.53	10.98	113.0	0.75	15.56
2	R1	88.0	0.46	9.53	115.0	0.84	17.59
	R2	101.0	0.64	13.41	119.0	0.90	18.79
	R3	95.0	0.56	11.62	118.0	0.89	18.49
3	R1	103.0	0.57	11.85	116.0	0.79	16.52
	R2	107.0	0.64	13.29	113.0	0.74	15.44
	R3	99.0	0.50	10.41	116.0	0.79	16.52
4	R1	105.0	0.69	14.34	111.0	0.78	16.20
	R2	97.0	0.57	11.87	101.0	0.63	13.11
	R3	111.0	0.78	16.20	105.0	0.69	14.34
5	R1	104.0	0.72	15.05	118.0	0.95	19.79
	R2	106.0	0.75	15.73	112.0	0.85	17.76
	R3	105.0	0.74	15.39	110.0	0.82	17.08
6	R1	98.0	0.65	13.67	112.0	0.92	19.19
	R2	101.0	0.71	14.85	116.0	0.99	20.77
	R3	105.0	0.79	16.43	111.0	0.90	18.80
7	R1	78.0	0.28	5.76	109.0	0.61	12.69
	R2	86.0	0.36	7.55	108.0	0.60	12.47
	R3	89.0	0.39	8.22	109.0	0.61	12.69
8	R1	98.0	0.62	12.97	115.0	0.92	19.11
	R2	100.0	0.66	13.69	120.0	1.00	20.92
	R3	95.0	0.57	11.89	116.0	0.93	19.47
9	R1	106.0	0.84	17.52	113.0	0.96	20.00
	R2	99.0	0.72	15.03	120.0	1.08	22.49
	R3	109.0	0.89	18.58	114.0	0.97	20.36
10	R1	114.0	0.79	16.59	119.0	0.86	17.91
	R2	105.0	0.68	14.22	120.0	0.87	18.17
	R3	109.0	0.73	15.28	118.0	0.85	17.64

Heart rate, oxygen consumption and energy expenditure of subjects while transplanting by Redlands rice transplanter

		Before 9 am			After 11 am		
Subjects	Replications	Avg. HR (beats min^{-1})	OCR (l min^{-1})	EER (kJ min^{-1})	Avg. HR (beats min^{-1})	OCR (l min^{-1})	EER (kJ min^{-1})
1	R1	113	0.75	15.56	136.0	1.08	22.57
	R2	116	0.79	16.47	132.0	1.02	21.35
	R3	105	0.63	13.12	126.0	0.93	19.52
2	R1	119	0.90	18.79	139.0	1.19	24.76
	R2	113	0.81	17.00	146.0	1.29	26.85
	R3	106	0.71	14.91	140.0	1.20	25.06
3	R1	111	0.71	14.72	120.0	0.86	17.96
	R2	115	0.77	16.16	116.0	0.79	16.52
	R3	111	0.71	14.72	135.0	1.12	23.34
4	R1	104	0.67	14.03	135.0	1.13	23.61
	R2	101	0.63	13.11	138.0	1.18	24.54
	R3	120	0.91	18.98	142.0	1.23	25.78
5	R1	102	0.69	14.37	135.0	1.22	25.54
	R2	109	0.80	16.74	128.0	1.11	23.17
	R3	116	0.92	19.11	130.0	1.14	23.84
6	R1	123	1.13	23.53	129.0	1.24	25.90
	R2	130	1.26	26.29	146.0	1.56	32.61
	R3	128	1.22	25.50	148.0	1.60	33.40
7	R1	105	0.56	11.80	156.0	1.11	23.19
	R2	103	0.54	11.35	145.0	0.99	20.73
	R3	119	0.71	14.92	141.0	0.95	19.84
8	R1	119	0.98	20.56	136.0	1.28	26.70
	R2	125	1.09	22.72	148.0	1.49	31.03
	R3	125	1.09	22.72	132.0	1.21	25.25
9	R1	107	0.86	17.87	140.0	1.42	29.58
	R2	121	1.09	22.84	149.0	1.57	32.78
	R3	113	0.96	20.00	138.0	1.38	28.87
10	R1	119	0.86	17.91	156.0	1.32	27.64
	R2	109	0.73	15.28	149.0	1.24	25.80
	R3	118	0.85	17.64	142.0	1.15	23.96

Heart rate, oxygen consumption and energy expenditure of subjects while transplanting by Yanji rice transplanter

		Before 9 am			After 11 am		
Subjects	Replications	Avg. HR (beats min^{-1})	OCR (l min^{-1})	EER (kJ min^{-1})	Avg. HR (beats min^{-1})	OCR (l min^{-1})	EER (kJ min^{-1})
1	R1	133.0	1.04	21.65	148.0	1.26	26.23
	R2	140.0	1.14	23.79	156.0	1.37	28.66
	R3	138.0	1.11	23.18	159.0	1.42	29.58
2	R1	130.0	1.06	22.07	152.0	1.37	28.64
	R2	138.0	1.17	24.46	155.0	1.41	29.54
	R3	130.0	1.06	22.07	158.0	1.46	30.43
3	R1	133.0	1.08	22.63	146.0	1.31	27.29
	R2	125.0	0.95	19.75	139.0	1.19	24.78
	R3	126.0	0.96	20.11	149.0	1.36	28.37
4	R1	122.0	0.94	19.60	164.0	1.56	32.57
	R2	119.0	0.89	18.67	159.0	1.49	31.03
	R3	120.0	0.91	18.98	159.0	1.49	31.03
5	R1	129.0	1.13	23.51	162.0	1.66	34.67
	R2	125.0	1.06	22.15	148.0	1.43	29.93
	R3	129.0	1.13	23.51	156.0	1.56	32.64
6	R1	128.0	1.22	25.50	168.0	1.98	41.29
	R2	131.0	1.28	26.69	162.0	1.86	38.92
	R3	126.0	1.18	24.72	157.0	1.77	36.95
7	R1	132.0	0.85	17.83	138.0	0.92	19.17
	R2	125.0	0.78	16.26	145.0	0.99	20.73
	R3	124.0	0.77	16.04	142.0	0.96	20.06
8	R1	129.0	1.16	24.17	158.0	1.66	34.64
	R2	120.0	1.00	20.92	169.0	1.85	38.62
	R3	117.0	0.95	19.83	153.0	1.57	32.84
9	R1	120.0	1.08	22.49	155.0	1.67	34.91
	R2	128.0	1.21	25.33	147.0	1.54	32.07
	R3	119.0	1.06	22.13	151.0	1.60	33.49
10	R1	128.0	0.97	20.27	168.0	1.48	30.80
	R2	138.0	1.10	22.91	161.0	1.39	28.96
	R3	131.0	1.01	21.06	164.0	1.42	29.75

Heart rate, oxygen consumption and energy expenditure of subjects while transplanting by traditional method

		Before 9 am			After 11 am		
Subjects	Replications	Avg. HR (beats min^{-1})	OCR ($l\ min^{-1}$)	EER (kJ min^{-1})	Avg. HR (beats min^{-1})	OCR ($l\ min^{-1}$)	EER (kJ min^{-1})
1	R1	140	1.14	23.79	168.0	1.55	32.32
	R2	139	1.12	23.48	156.0	1.37	28.66
	R3	146	1.23	25.62	152.0	1.31	27.44
2	R1	135	1.13	23.57	163.0	1.53	31.93
	R2	149	1.33	27.75	166.0	1.57	32.82
	R3	156	1.43	29.84	169.0	1.61	33.72
3	R1	155	1.46	30.53	159.0	1.53	31.96
	R2	134	1.10	22.98	157.0	1.50	31.24
	R3	140	1.20	25.14	165.0	1.63	34.12
4	R1	146	1.29	27.01	165.0	1.57	32.88
	R2	148	1.32	27.63	170.0	1.65	34.43
	R3	139	1.19	24.85	167.0	1.60	33.50
5	R1	143	1.35	28.24	168.0	1.76	36.70
	R2	159	1.61	33.65	158.0	1.60	33.32
	R3	162	1.66	34.67	152.0	1.50	31.29
6	R1	153	1.69	35.37	165.0	1.92	40.11
	R2	175	2.11	44.05	163.0	1.88	39.32
	R3	165	1.92	40.11	162.0	1.86	38.92
7	R1	155	1.10	22.97	165.0	1.21	25.20
	R2	160	1.15	24.08	155.0	1.10	22.97
	R3	156	1.11	23.19	167.0	1.23	25.65
8	R1	170	1.87	38.98	176.0	1.97	41.15
	R2	168	1.83	38.26	158.0	1.66	34.64
	R3	175	1.95	40.78	165.0	1.78	37.17
9	R1	159	1.74	36.33	172.0	1.96	40.94
	R2	172	1.96	40.94	168.0	1.89	39.52
	R3	166	1.86	38.81	162.0	1.79	37.39
10	R1	148	1.22	25.54	170.0	1.50	31.32
	R2	159	1.36	28.43	165.0	1.44	30.01
	R3	178	1.60	33.43	162.0	1.40	29.22

APPENDIX III

Overall discomfort rating, overall safety rating and overall ease of operation rating of selected rice transplanters

Transplanter		Yanmar			Redlands			Yanji			Traditional method		
Subjects	**Name**	**ODR**	**OSR**	**OER**	**ODR**	**OSR**	**OER**	**ODR**	**OSR**	**OER**	**ODR**	**OSR**	**OER**
1	Sujatha	0	2	0	7	4	4	3	5	5	7	1	1
2	Sree Latha	3	2	2	3	2	4	5	5	6	6	2	1
3	Sajitha	0	0	0	3	2	2	3	4	5	8	2	1
4	Sheeja	2	2	4	5	4	5	3	5	5	5	1	1
5	Shyamala	3	2	0	0	0	2	5	5	4	4	1	1
6	Shobana Kumari	3	2	6	3	6	4	3	5	5	7	1	1
7	Suja Achankunju	5	2	6	4	6	2	3	4	5	6	1	1
8	Thara	5	2	6	5	4	2	5	5	6	5	2	1
9	Vijayalakshmi	2	3	4	4	4	4	3	5	5	8	1	1
10	Jaya Sree	2	2	3	2	3	4	5	4	5	6	2	1
	Mean	**2.5**	**1.9**	**3.1**	**3.6**	**3.5**	**3.3**	**3.8**	**4.7**	**5.1**	**6.2**	**1.4**	**1**

APPENDIX IV

Body part discomfort score of subjects for selected Yanmar and Redlands rice transplanters

Transplanters		Yanmar					Redlands				
Sl.No	Subjects	Most Discomfort (6)	Moderate Discomfort (4.5)	Morethan Moderate (3)	Light Discomfort (1.5)	Final score	Most Discomfort (6)	Moderate Discomfort (4.5)	Morethan Moderate (3)	Light Discomfort (1.5)	Final score
1	Sujatha	0	0	1	2	6	4	2	1	2	39
2	Sree Latha	0	0	1	2	6	3	2	1	2	33
3	Sajitha	0	0	1	2	6	3	2	1	2	33
4	Sheeja	0	0	1	2	6	3	1	1	2	28.5
5	Shyamala	0	0	1	2	6	4	2	1	2	39
6	Shobana	0	0	1	2	6	3	2	1	2	33
7	Achankunju	0	0	1	2	6	3	2	1	2	33
8	Thara	0	0	1	2	6	4	2	1	2	39
9	Vijayalakshmi	0	0	1	2	6	3	2	1	2	33
10	Jaya Sree	0	0	1	2	6	4	2	1	2	39
	Mean					**6**					**34.95**

Body part discomfort score of subjects for selected Yanmar and Redlands rice transplanters

Transplanters		Yanji					Traditional method				
Sl.No	Subjects	Most Discomfort (6)	Moderate Discomfort (4.5)	Morethan Moderate (3)	Light Discomfort (1.5)	Final score	Most Discomfort (6)	Moderate Discomfort (4.5)	Morethan Moderate (3)	Light Discomfort (1.5)	Final score
1	Sujatha	5	2	1	1	43.5	6	2	2	0	51.0
2	Sree Latha	4	2	1	2	39.0	4	2	1	1	37.5
3	Sajitha	5	2	1	2	45.0	6	3	2	2	58.5
4	Sheeja	5	1	1	2	40.5	4	2	1	1	37.5
5	Shyamala	5	2	1	1	43.5	6	3	2	1	57.0
6	Shobana	4	2	1	2	39.0	5	2	2	2	48.0
7	Achankunju	4	2	1	2	39.0	4	3	2	0	43.5
8	Thara	5	2	1	2	45.0	5	2	1	0	42.0
9	Vijayalakshmi	5	2	1	1	43.5	6	3	2	1	57.0
10	Jaya Sree	5	2	1	2	45.0	4	2	1	0	36.0
						42.3					46.8

Abstract

ASSESSMENT OF ERGONOMIC PARAMETERS OF RICE TRANSPLANTERS FOR WOMEN OPERATORS

By

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ABSTRACT OF THESIS

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ABSTRACT

Paddy transplanting is a highly labour intensive operation. To ease the transplanting work, research organizations have developed various types of rice transplanters. These equipments are primarily developed keeping men workers in consideration, despite rice transplanting being performed mostly by women workers. At present there are different models of rice transplanters available in the market. The safety and efficiency aspects of these transplanters with respect to women workers are not being studied. Therefore a study was undertaken to evaluate the existing models of three 8 row self-propelled riding type rice transplanters namely Yanmar, Redlands and Yanji on the ergonomic basis. The physiological cost of work of these transplanters were compared with the traditional method. An anthropometric survey was conducted with 450 women agricultural workers in three zones of Kerala. Ten women subjects were selected, conforming to statistical requirements of anthropometric dimensions and were calibrated in the laboratory by indirect assessment of oxygen uptake.

The energy expenditure was minimum for Yanmar rice transplanter with a value of 9.89 kJ min^{-1}. The energy expenditure of traditional method was increased to the tune of 52.52 per cent when compared to Yanmar rice transplanter followed by Yanji rice transplanter (43.11 per cent) and Redlands rice transplanter (29.46 per cent). A significant difference in heart rate and energy expenditure was noticed in all the selected rice transplanters for all the subjects. The time of operation was significantly influenced the heart rate and energy expenditure of subjects for selected rice transplanters. The average energy expenditure before 9 am was 20.7 kJ min^{-1} while after 11 am it was increased to 26.6 kJ min^{-1}. The oxygen consumption in terms of VO_2 max was varied from 35 to 85 per cent and indicating that the Redlands, Yanji and traditional method could not be operated continuously for 8 hours without frequent rest pauses except Yanmar rice transplanters.

The overall discomfort rate was maximum for transplanting by traditional method followed by transplanting with Yanji, Redlands and Yanmar rice transplanters. The operation of Yanmar rice transplanter was more safe and easy when compared with other transplanters. Body part discomfort score was maximum for traditional method with a score of 46.8 while it was minimum for Yanmar rice transplanter with a score of 14.5. The discomfort was noticed in low back, upper back, neck and shoulders of subjects while working with selected rice transplanters. The work rest cycle was 30 minutes of work followed by 2 minutes rest for Yanmar rice transplanter, 9 minutes rest for Redlands, 14 minutes rest for Yanji rice transplanter and 15 minutes rest for traditional method of rice transplanting.

In musculoskeletal disorders survey, 80 per cent of the women workers reported that they had experienced MSD in the past seven days while 37 per cent had experienced MSD problems over the past 12 months. In selected rice transplanters, none of the subjects had experienced pain in any of the body parts after 7 days of operation. In posture analysis, the RULA score was maximum for traditional method (7) followed by Yanji (4), Redlands (4) and Yanmar rice transplanters (2). The sound level of the Yanmar rice transplanter was varied from 91 to 93 dB at different modes when compared to Redlands (94 to 99 dB) and Yanji rice transplanter (97 to 103 dB). The root mean square acceleration was maximum in Yanji rice transplanter at different parts compared with Yanmar and Redlands rice transplanters. An operator seat and helpers seat designs were suggested for Yanji and Redlands rice transplanters based on anthropometric dimensions of agricultural women workers and spatial requirements of transplanters. The recommended dimensions for the operator's seat were as seat backrest height (39 cm), trapezoidal seat back rest width (38 cm-bottom side, 27.5 cm top side), seat back rest open area (18 cm), trapezoidal seat length (40 ± 3.4 cm), trapezoidal seat width (43 cm – top side, 30 cm –bottom), seat cushion height (10 cm) and backrest cushion height (8 cm). A diameter of 35 cm was suggested for helpers circular seat for more comfortable sitting.