ERGONOMICAL STUDIES ON WOMEN AGRICULTURAL WORKERS FOR MANUAL WEEDING AND COB PICKING OPERATIONS

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BY

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This is to certify that this thesis entitled **"Ergonomical studies on women agricultural workers for manual weeding and cob picking operations"** submitted for the degree of **Master of Engineering** in Agricultural Engineering in the subject of **Farm Machinery And Power Engineering** embodies bonafide research work carried out by **Ms. Ambica Mahindrakar** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 19 September 2008.

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I INTRODUCTION

India is the seventh largest country in the world with population of 1,027 million (531.3 million males and 495.7 million females). Seventy per cent of the country's population is dependent on agriculture and related activities. The agriculture sector provides livelihood to about 64 per cent of the labour. Rajasthan is largest state in India, area wise, with geographical area of 34.23 mha. The net sown area is 16.79 mha. According to 2001 census the population of the state was 54.6 million out of which 77.13 per cent lived in rural areas. The total number of farm workers comprising of cultivator and agricultural labour was 9.23 million in 2001, out of which 6.9 million were male workers and 2.23 million were female workers. The state is leading in the cultivation of oilseeds, pulses and small millets. The contribution for pulses, oilseeds and grain in terms of cultivated area stands at 19.5 per cent, 16.1 per cent and 10.7 per cent respectively. The state is contributing almost more than 10 per cent of total production of the country (Anon., 2002).

The farmers in the state are in the category of small and marginal farmers. About 50.26 per cent, 20.83 per cent and 19.83 per cent of farm holdings are in the size group of 0-2 ha, 2-4 ha, 4-10 ha and accounts for 11.04 per cent, 14.99 per cent and 31.14 per cent of total cultivated area respectively. They have to struggle hard for the basic needs of life. In the eastern and northern parts of Rajasthan where there is adequate irrigation and other facilities, farmers have better economic conditions and are rapidly adopting agricultural mechanization. Thus there is a need to empower agricultural workers in the state for improving their social and economic status. The cropping pattern and the labour requirement for agricultural operation have marked influence on the mechanization status of the state.

Ergonomics (or human factors) is an applied science for adjusting work to man in the light of his anatomy, physical and psychology. It aims to enhance the effectiveness, productivity and efficiency, with which work is carried out, and to maintain or enhance such human values as health, safety and job satisfaction, or it is the scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies, data and methods to design in order to optimize human well being and overall system performance. In simple word ergonomics is scientific study of man and his working environment.

Female agricultural workers in India play dominant role in increasing production and productivity. They are involved in various agricultural operations. Their participation varies with region, crops, commodities and socio-economic studies. Due to agriculture mechanization advancement in technology the female workers have been compelled to acquire greater skills, in spite of socio-economic infrastructure. Many of the operation are arduous and require bent or crouched postures for extended hours of work. This is injurious to her health.

The estimated involvement of female in production agriculture for various operations include ploughing (0-5 per cent), drilling with plough (70-80 per cent), weeding with khurpi/sickle (80-90 per cent), manual spraying/dusting (30-50 per cent), harvesting with sickle (60-80 per cent), manual threshing (30-70 per cent), power threshing (25-50 per cent), manual transplanting (60-80 per cent).etc. (Tandon,1999). More and more hand tools, implements are being developed, manufactured and used for various farm operations for increasing productivity. All of them are either operated or controlled by human workers. Hence to achieve better efficiency of performance with more human comfort, it is necessary to design the implement keeping in consideration the operators capabilities and limitations. Further the ergonomical characteristics and physiological cost of male and female workers are different in terms of anthropometric data, muscular strength, maximum aerobic capacity and heart beat. Few studies have been made to collect anthropometric dimensions of female agricultural workers (Geetha and Tewari 2000). But no efforts have been made so far to collect anthropometric data and strength parameters of female farm workers in Rajasthan. Further physiological cost and discomfort experienced by the women agricultural workers is also to be assessed for the various farm operations.

Ergonomical evaluation is necessary to assess the energy expenditure of agricultural workers, their physiological cost and body discomfort suitable for female workers. How long they can work continuously without getting fatigue. Ergonomical evaluation along with mechanical evaluation helps us to make comparison between traditional method and improved methods. The method, which gives better field capacity, less power consumption, low energy expenditure rate and more safety will be recommended to be used in the agricultural operation.

The study was undertaken to collect the anthropometrical data of female agricultural workers that can be used to design or redesign agricultural machines, tools and equipment and evaluate the existing methods. Also to quantify the heart rate, oxygen consumption rate and energy expenditure of female farm workers for manual weeding and cob-picking operations and evaluating body discomfort, while using different methods.

Therefore keeping all the above points in the view, the present study was conducted with the following specific objectives:

1. To measure anthropometric dimensions and strength parameters of women agricultural workers of Udaipur district.
2. To estimate physiological cost of women agricultural worker for weeding and cob-picking operations.
3. To evaluate the body discomfort experienced by the worker during weeding and cob-picking operations.

II REVIEW OF LITERATURE

An attempt has been made to review the literature for the title and the related area. This included, use of human energy and application of ergonomics in agriculture. A comprehensive review of research work carried out is briefly reported.

2.1 Use of Manpower in Indian Farming

Anonymous (1997) reported that the use of human power in crop production per hectare increased from 723 to 766 hours during 1971 to 1991. The report mentioned that the skilled and semi skilled workers increased from 5 to 23 billion mandays during the same period.

Nag and Nag (2004) stated that the small farmers including sharecroppers and tenants (70 million farm holdings having less than 4 ha of land) and the landless labourers constitute the primary workforce. They opinioned that human power will continue to play a dominant role in energy utilization in Indian agriculture.

Pandey (2004) stated that the human workers in Indian agriculture increased from 97.2 million in 1951 to 206 million in 1996. This resulted in an increase of 1.44 workers per hectare in 1996 from 0.82 workers per hectare during 1951.

Anonymous (2006) indicated that the men workforce in agriculture has declined, whereas women workforce showed an increasing trend. The population statistics of men and women workers in agriculture since 1971 and their projected population in the year 2012 and 2025 are given in Table 2.1.

Table 2.1 Population dynamics of agricultural workers in India

Census Year	Agricultural Workers (million)			
	Male	**% of male workers**	**Female**	**% of female workers**
1971	100.6	80.0	25.1	20.0
1981	112.3	75.9	35.7	24.1
1991	138.5	72.4	52.8	27.6
2001	142.8	71.0	91.2	39.0
2007	140	58.1	101	41.9
2012*	132	54.8	109	45.2
2025*	109	45.0	133	55.0

* Projected data

2.2 Ergonomics

Ergonomics as the science of fitting work place conditions and job demands to the capabilities of the working population (Anonymous, 1997). The report further mentioned effective and successful fits which assumed higher productivity, avoidance of illness and injury risk and increase satisfaction among the workforce.

Jafrey (1999) reviewed the concept of ergonomics in alleviating poverty. She opined that ergonomics can help reduce poverty by enhancing economic status of households through increased productive capacity; reducing drudgery and fatigue from work; improving health; and reducing accidents and injuries.

Anonymous (2000) defined ergonomics (or human factors) as the scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies, data and methods to design in order to optimize human well-being and overall system performance. The report further described about domains of specialization within the discipline of ergonomics. These are broadly classified as:

i) **Physical ergonomics** is concerned with human anatomical, anthropometrical, physiological and biomechanical characteristics as they relate to physical activity. These include working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health.

ii) **Cognitive ergonomics** is concerned with mental processes, such as perception, memory, reasoning and motor response as they affect interactions of human and other elements of a system. These include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training.

iii) **Organization ergonomics** is concerned with the optimization of socio-technical system, including their organizational structures, policies and processes. These include communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, tele-work and quality management.

2.3 Anthropometric and strength data of women agricultural workers

Mamansari and Salokhe (1996) conducted an investigation to determine the static strength and physical work capacity of Thai agricultural labourers. Ten male and 10 female subjects were randomly selected from the two provinces of central Thailand. The anthropometry of these labourers was determined by taking 42 body dimensions. It was observed that the composite strength was highest while grip strength was lowest for both male and female subjects. However, static strength of different body parts for all males was higher than that of similar body part for females. Data obtained in this study was also compared with other countries.

Kumar and Parvathi (1998) measured 14 body dimensions of 15 female maize sheller operators. The data were analyzed and three subjects having similar anthropometrical parameters were selected to operate three manually operated maize shellers. The other parameters, like shoulder breadth, shoulder to elbow length, elbow to wrist length, wrist to finger tip length, hand breadth, and ball of foot breadth, enabled comparison of various physical activities of the subjects either in the sitting, bending or standing postures.

Wen *et al.*, (1999) conducted an anthropometrical survey. Twelve body dimensions of 110 female workers were measured. These data were compared with anthropometrical characteristics of Mexican - American females and females of Colombia, Japan, Korea and the USA. The results indicated that anthropometrical characteristics of female workers were significantly different than those of Mexican - American females.

Kathirvel and Ananthaskrishan (2000) conducted an investigation to identify the body dimensions relevant to farm machinery design. They collected and documented anthropometric data of male and female agricultural workers. 42 body dimensions were identified and measured. Mean, standard deviation, 5^{th} and 95^{th} percentile values were computed. The mean stature of male and female agricultural workers was 164.19 cm and 156.53 cm, respectively.

Philip and Tewari (2000) conducted an anthropometrical survey of the female workers in southern region of India. Twenty three body dimensions of the subjects having direct implication on agricultural tools/ implements design were collected from 137 female workers. They compared the data with other ethnic groups and with male farm workers of the same region. The results indicated that Indian female workers were smaller than British, French, German, Egyptian and Turkish female workers. Further male body dimensions were higher than that of female workers.

Vasu and Mital (2000) compared the body dimensions between sample mean percentiles and corresponding population percentile. Seventy male and seventy female subjects were grouped according to their stature in the 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th} percentile categories. Each category had 10 males and 10 females. Twelve body dimensions were measured and recorded on each individual. The results indicated that for females, 5 of the 12 dimensions (acromial height, chest breadth, foot breadth, foot length and hand breadth) were not normally distributed ($p<0.01$). For both male and female, the 5^{th} and 95^{th} percentile values of non-normally distributed body dimensions were provided.

Yadav *et al.*, (2000) conducted an anthropometrical survey of female farm workers of Gujarat. Thirty body dimensions necessary for designing farm equipment were collected from 40 female farm workers in the age group of 18-50 years. They compared the data with those of Indian male workers. The results indicated that Indian female workers were smaller than male in all body dimensions except hip breadth and waist circumference. The female anthropometrical data were also compared with the median values of three different ethnic groups. It was found that Indian females were smaller in all body dimensions as compared to German, USA and Japanese male.

Rahi (2003) conducted anthropometric survey of 50 male and 50 female agricultural workers of Rajasthan State. He identified 28 body dimensions. The mean stature and body weight for male and female agricultural worker were 166.7 cm, 53 kg and 153.7 cm, 44.3 kg respectively.

Singh *et al.,* (2003) developed an anthropometrical database of agricultural workers of Meghalaya State. Total 48 subjects from 20 different villages were selected randomly from three districts of the state. Seventy one body parameters useful for farm machinery design were selected for the study. The results showed that the average weight of female workers was about 13 per cent lower than their male counterpart whereas the average stature of male was nearly 6 per cent higher than the female.

Victor *et al.,* (2003) carried out an anthropometrical survey of female farm workers from Chhattisgarh region, to identify constraints related to the ergonomics during the operation of farm machinery. Nine body dimensions were measured for 300 subjects between the age group of 21 to 48 years. Collected data were statistically analyzed and maximum variation was found in body weight of the subjects. It was observed that the mean value of weight and stature for female farm workers were 49.33 kg and 156.16 cm respectively. The data collected were compared with the available data of other regions of the country as well as with the western data and variations were observed.

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Anonymous (2005) identified sixteen strength parameters useful for the design of agricultural machinery and equipment. Data on those parameters were collected for 846 female agricultural workers of Tamil Nadu. The mean value (±SD) of right and left hand grip strength were 276± 70.71 N and 274.43 ± 74.15 N, respectively. The mean values (±SD) of push and pull strength with both hands in standing posture were 130.34 ± 31.48 N and 168.59 ± 42.94 N, respectively. The mean values (±SD) of pull strength with right and left hand in sitting posture were 137.38 ± 30.44 N and 139.26 ± 33.04 N, respectively. The mean value (±SD) of hand grip torque was 4.10 ± 1.04 N.

Barroso *et al.,* (2005) collected anthropometric data of 399 female and 492 male Portuguese adult workers, with age ranging from 17 to 65 years. Twenty four static anthropometric measurement including body weight was obtained for each individual. Statistical analysis was carried out. The data showed that some statistical parameters, such as the standard deviation and correlation coefficients, behaved as expected, and as observed in other populations.

Agrawal *et al*., (2007) collected isometric leg/foot strength data of 944 male and 757 female agricultural workers from twenty different locations in Madhya Pradesh State. The mean age, stature and weight of the male subjects were 29.8 ± 9.5 years, 1649 ± 59 mm and 51.2 ± 6.4 kg whereas for female subjects the values were 33.7 ± 8.2 years, 1519 ± 54 mm and 45.0 ± 7.3 kg respectively. The mean values for isometric left and right leg strength in sitting posture were 378.5 ± 87.2 N and 414.1 ± 92.2 N respectively for male workers and 243.6 ± 62.1 N and 262.7 ± 66.8 N respectively for female workers. Similarly, the mean values of left and right foot strength in sitting posture were 286.7 ± 76.9 N and 310.4 ± 79.6 N respectively for male workers and 184.0 ± 52.6 N and 197.4 ± 59.4 N respectively for female workers. They reported that the isometric leg and foot strength of male subjects were higher than those of female subjects. The mean left and right leg/ foot strength values were statistically non-significant at 5% level. Weight of the subjects indicated a positive correlation with isometric leg strength values.

Anonymous (2007) collected anthropometric and strength data of 29 female agricultural workers of Arunachal Pradesh. The mean value (±SD) of right and left hand grip strength were 203.07± 82.40 N and 176.58 ± 68.67 N, respectively. The mean values (±SD) of push and pull strength with both hands in standing posture were 190.31 ± 68.67 N and 154 ± 43.16 N, respectively. The mean values (±SD) of pull strength with right and left hand in sitting posture were 114.78 ± 51.01 N and 111.83 ± 40.22 N, respectively. The mean value (±SD) of hand grip force was 11.76 ± 3.92 N.

Dhyani *et al.,* (2007) found significant differences in anthropometric measurements of the female workers of Garhwal and Kumaon regions of Uttarakhand. They also compared the anthropometric dimensions of Uttarakhand women with women from other States. Hundred women from hill regions of Uttarakhand were selected for the study. The mean weight was 40.27 (±5.08) kg where as it was 40.8 (±4.58) and 39.74 (±5.48) kg for Garhwal and Kumaon regions respectively. The mean height of Uttarakhand women was 151.49 (±5.93) cm.

Gite and Majumder (2007) reported 79 body dimensions of 5937 agricultural workers from 12 States of India useful in farm equipment design. The mean stature and weight of agricultural workers ranged 163.3 ± 6.8 cm and 54.7 ± 8.7 kg for male workers and 151.5 ± 6.1 cm and 46.3 ± 7.8 kg for female workers.

Maheshwari and Devendra (2007) collected anthropometric measurements of 350 Male and 250 female farm workers keeping into consideration the requirements of hand tools and machines. They identified 79 body dimensions and 16 strength parameters. They reported that while operating the thresher the maximum permissible height for feeding chute should be decided considering the 5th percentile value of acromian height from this data its value is 129.4 cm. For better operation and more human comfort a proper handle height for those equipments should be between 63.7 to 95.8 cm with 63.7 cm being the 5th percentile value for metacarpal height and 95.8 cm being the 5th percentile of elbow height from recorded value of body dimensions of the mean value, standard deviation, 5th and 95th percentile values were computed and recorded for male and female subjects respectively.

Singh *et al.,* (2007) measured 33 different body dimensions of 1000 female agricultural workers in standing, squatting and bending postures relevant to farm operations. They crated a database to be used by the equipment designers and engineers. The maximum and minimum reaches were also measured. The average height was 141 cm. Mean anthropometric measurements in sitting position showed marginal differences in the selected sample. The average squatting height was 78 cm. The minimum reach for vertical plane was 137 cm and horizontal plane was 36 cm.

Tiwari *et al.,* (2007) identified sixteen strength parameters useful for the design of agricultural machinery and equipment. Data for those parameters were collected for 944 male and 757 women agricultural workers from 20 selected districts of Madhya Pradesh. The female subjects were within the age group of 18-60 years. The mean value (±SD) of right and left hand grip strength were 214.7 ± 70.3 N and 183.8 ± 69.0 N, respectively. The mean values (±SD) of push and pull strength with both hands in standing posture were 175.5 ± 33.9 N and 159.4 ± 42.9 N, respectively. The mean values (±SD) of push and pull strength with right hand in sitting posture were 65.7 ± 14.8 N and 67.2 ± 17.9 N while for left hand strength were 61.2 ± 14.2 N and 52.9 ± 13.6 N, respectively. The mean (±SD) torque applied on a crank of 260 mm arm length in standing posture was 31.9 ± 8.6 N-m with preferred hand and 37.3 ± 10.4 N-m with both hands. The mean (±SD) torque applied on a steering wheel of 420 mm diameter with both hands in sitting posture was 40.5 ± 10.0 N-m.

Yadav *et al.,* (2007) identified 78 body dimensions necessary for the design of agricultural equipments. The study was conducted on 382 female farm workers of Gujarat in the age group of 18 to 50 years. The data was statistically compared with farm workers of the other parts of the country as well as with ethnic groups. The mean stature of the female workers was 152.2 cm while those for male were 163.1 cm.

Dewangan *et al.,* (2008) carried out survey on female agricultural workers of Arunachal Pradesh and Mizoram states. For this three tribes from Arunachal Pradesh, viz. Adi, Apatani and Nishi and one Mizo tribe from Mizoram in the age group of 18–60 years were selected. Four hundred subjects were selected and 76 body dimensions were identified. Data so collected were statistically analyzed and compared with female counter parts of American, British, Chinese, Egyptian, Japanese, Korean, Mexican and Taiwanese. They found that Indian women were 9.27 cm shorter than American women. From the data they concluded most body dimensions are higher in the middle age group and lower with higher age groups. However, body weight is found to increase with age. Same trend was observed for the data on body circumferences and breadth dimensions.

2.4 Parameters used for ergonomic evaluation

Different parameters were used by different scientists for ergonomic evaluation. These parameters are mentioned below:

1. **Heart Rate** (HR) (beats/min): Several scientists used this parameter in their research work, Matthews (1992), Gite (1991), Ghugare *et al.*, (1991), Mathur (1991), Kathirvel and Ananthakrishan (2000), Balasankari *et al.*, (2003). This parameter was commonly used in ergonomical evaluation as index of total stress.
2. **Oxygen Consumption Rate** (OCR) (l/min): Several scientists used this parameter in their research. Saha *et al.*, (1979), Matthews (1992), Gite (1991), Ghugare *et al.*, (1991), Mathur (1991) and Balasankri *et al.*, (2003). This parameter was commonly used as reliable measure of physical work.
3. **Pulmonary Ventilation Rate** (PVR) (l/min): This parameter was used by Legg and Mahanty (1985) to estimate OCR.
4. **Respiratory Rate** (Respirations/min): This parameter was used by Sengupta *et al*., (1979). It can be measured easily but is unreliable and has poor correlation with energy expenditure.
5. **Energy Expenditure Rate** (kJ/min) or (kcal/min): This parameter is commonly used by the researchers in their work. Saha *et al.*, (1979) used this parameter by calculating EER from HR. The EER can also be calculated from OCR of the subjects.
6. **Body temperature** (°C): This parameter has low sensitivity to work load but useful in thermal stress situations. It was used by Legg and Mahanty (1985).
7. **Intra-abdominal pressure** (IAP, mm of Hg): This parameter was used for estimating static load by Legg and Mahanty (1985). Sophisticated instrumentation is required to measure it. Further it is difficult to use it in actual work situation.
8. **Muscle activity** (EMG): This parameter was used by Jager *et al*., (1984) and Tanii and Masuda (1985) in their work. It is difficult to use in actual work situation.
9. **Blood lactic acid and blood glucose**: This Parameter was used by Kath and McArdle (1977). It required sophisticated instrumentation and is difficult to use in actual working conditions.
10. **Blood pressure** (mm of Hg): This parameter was used for estimating static load by Tuure (1992) and Singhal (1994). This is difficult to use in actual work situation.
11. **Visual analogue discomfort scale**, (VAD scale, 0 to 10). This scale was used by Legg and Cruz (2004) and Legg and Mahanty (1985) to assess overall discomfort. It is simpler to use by the workers.
12. **Borg's rated perceived exertion scale,** (RPE scale, 6 – 20): This scale was used by Paperman and Corlett (1983), Legg and Mahanty (1985) and Hanger and Hagberg (1989) to assess overall discomfort in dynamic work situation.
13. **Corlett and Bishop Scale** for **Overall discomfort** (OD scale, 0 –7). This scale was used by Corlett and Bishop (1976), Ghugare *et al*., (1991), Gite (1991) and Rahi (2003).

14. **Corlett and Bishop Score** for **Body part discomfort** (BPD score): This method was used by Corlett and Bishop (1976), Ghugare *et al.,* (1991), Gite (1991) and Rahi (2003). It is useful for detailed analysis, for locating specific problem.

2.5 Physiological cost of operator

Human energy measurements for different agricultural operations performed 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 exceeds, it causes considerable fatigue and large reduction in the alertness of the person making the operation unsafe. Thus the studies on human energy measurement for agricultural operations can provide a rational basis for recommendation of methods and equipment for performing an agricultural operation and improvement in farm equipment design for more output and safety.

Gite and Singh (1997) reported the energy expenditure for major agricultural activities in the rice farming. They are presented in Table 2.2.

Table 2.2 Energy expenditure in some agricultural and allied activities

S. No.	Operation	Energy Expenditure, kJ/min	Source
1	Weeding with wheel hoe	10.50	Gite (1993)
2	Weeding with manual weeders	10.41 to 13.04	Gite *et al.,* (1992)
3	Harvesting with sickle	10.25	Nag *et al.,* (1980)

Kumar and Parvathi (1998) conducted a study to assess the energy expenditure of women labourers for maize shelling using tubular and hand operated maize shellers. They compared their ergonomical performance with traditional methods of maize shelling. They estimated the average energy expenditure for traditional, tubular, modified tubular and hand operated maize sheller as 5.91, 4.97, 6.27 and 5.83 kcal/min respectively.

Gite *et al.,* (1999) compared the performance of improved weeding tool (wheel hoe) and local tool (hand hoe) for weeding and interculture operation in Soya bean crop. They reported that the mean values of heart rate during work were 101.6 and 126.6 beats/min for hand hoe and wheel hoe respectively. The corresponding work pulse (ΔHR) was 21.1 and 40.7 beats/min and the area covered by wheel hoe was about four and half times that of hand hoe i.e. 205.5 m^2/h as against 44.7 m^2/h.

Ananthakrishnan and Kathirvel (2000) conducted study to determine the energy expenditure and rest pauses required for use of hand tools (spade and hand hoe). Effect of size and shape of the cutting edge, blade angle, weight of the tool and handle dimensions on energy expenditure and rest pause was studied. They found that, energy expenditure increased as the weight of the spade increased, whereas energy expenditure and heart rate decreased with the increase in blade angle. Minimum and maximum physiological cost (heart rate, oxygen uptake) were observed at 40 mm and 20 mm handle grip diameter respectively. In case of hand hoe, HR and EER increased as the weight of hand hoe increased and decreased as the blade angle increased.

Gite and Agrawal (2000) evaluated the egronomical performance of local and improved sickles for harvesting wheat crop. Six female farm workers were used for the study. The mean ΔHR values were 27 beats/min and 34.3 beats/min for improved and local sickle respectively. The corresponding increase in heart rate per m^2 of area harvested was 11.1 and 13.3 beats/m^2 for local sickle and improved sickle respectively. The difference in mean values of ΔHR as well as ΔHR /m^2 of area harvested was significantly lower in case of improved sickle. The data showed that drudgery reduction due to the use of improved sickle was about 16.5 per cent as compared to local sickle.

Kathirvel and Ananthaskrishan (2000) conducted an investigation to measure physiological cost of male and female farm workers while performing various rice farming operation. Twenty-four manual rice farming operations were identified. The EER of male workers varied from 2.41 Kcal/min to 4.87 kcal/min, whereas for female workers it varied from 2.25 Kcal/min to 3.5 Kcal/min. Most of the rice farming operations performed by the male agricultural workers were graded as ‘moderately heavy’.

Karunanithi and Tajuddin (2003) measured the physiological response and energy expenditure of male and female agricultural workers in performing different rice farming operations. The energy expenditure of male workers varied from 2.4 to 4.9 kcal/min and for female workers varied from 2.3 to 3.5 kcal/min. Male workers consumed 2 to 10 per cent more energy than female workers for performing the same task.

Rahi (2003) assessed the physiological cost of three female subjects during the weeding in wheat crop with kudali, wheel hoe, indigenous plough and 2-tine cultivator. The mean HR ranged from and 139.6 to 140.5 beats/min for kudali method and 133.9 to 142.9 beats/min for wheel hoe method. The mean HR of the subjects during weeding with indigenous plough ranged from 132.35 to 142.1beats/min and for 2-tine cultivator 131.25 to 143.5 beats/min. The EER ranged from 3.22 to 3.29 Kcal/min for kudali and 3.0 to 3.34 kcal/min for wheel hoe method. The EER expended by subjects while using indigenous plough and 2-tine cultivator ranged from 2.94 to 3.33 Kcal/min and 2.9 to 3.37 Kcal/min respectively.

Tiwari and Philip (2003) reported the energy cost of different agricultural work situation of female agricultural workers in West Bengal. They reported 18.2 kJ/min in load carrying, 15.69 kJ/ min in weeding, 14.88 kJ/min in transplanting, 14.26 kJ/min in threshing and 13.46 kJ/min in harvesting.

Yadav *et al*., (2003) evaluated physiological cost for female agricultural workers during weeding with local sickle and manually operated weeder. The mean HR and EER during weeding with local sickle were found to be 121.1 beats/min and 7.93 kJ/min. The mean HR and EER during manually operated weeder were found to be 157.8 beats/min and 13.57 kJ/min.

Singh *et al.,* (2004) ergonomically evaluated manually-operated fertilizer broadcaster with 11 farm women workers to assess its suitability. The mean working heart rate and ΔHR was 146.7 ± 13 beats/min and 65.4 ± 18.0 beats/min, respectively with full hopper capacity of 9 kg. Based on the study and feedback received from the subjects, the refinement in the hopper capacity, total height of broadcaster, height of crank handle and cushioning on back portion was proposed.

Srisha (2004) reported the energy expenditure of female agricultural workers for selected farm gadgets. These were 13.55 kJ/min for fertilizer broadcaster, 14.42 kJ/min for cono weeder, 13.38 kJ/min for four row paddy seeder, 13.17 kJ/min for cotton stalk puller, 9.98 kJ/min for fruit harvester and 7.02 kJ/min for groundnut stripper.

Jyotsna *et al.,* (2005) ergonomically evaluated rural women while performing wheat harvesting activity. The field experiment was carried out on 20 women, for two age group viz; 25-35 and 35-45 years. Average heart rate of women was found to be 121.5 beats/min, which increased up to 126.7 beats/min at the end of the activity during evening hours. Similarly energy expenditure was found to be 10.5 kJ/min. which increased up to 11.2 kJ/min during evening hours for both the age groups.

Vinay and Sharma (2005) studied physiological stress on women for weeding operation. Thirty farm women ranging from 25-45 years age group were selected. The average heart rate response while performing the activity was 103.57 beats/min with the peak heart rate recorded was 114.0 beats/min. The average energy expenditure while performing weeding was recorded as 7.74 kJ/min with peak energy expenditure of 9.40 kJ/min. This activity was also perceived heavy by the respondents because women had to work in a particular posture for the entire duration, with more stress.

Agarwal and Satapathy (2006) carried out an experiment on 2 male and 2 female agricultural workers of Meghalaya for ergonomical performance evaluation of the two different types of maize shellers. The reduction of workload for male and female workers for plastic covered maize sheller was 33.17 and 36.68 per cent, respectively as compared to the metallic maize sheller. Correspondingly the heart rate (HR) and oxygen consumption rate (OCR) reduced by 17.39 and 31.7 per cent for male and 23.1 and 20.00 per cent for female agricultural workers, respectively.

Singh *et al*., (2006) ergonomically assessed manually operated CIAE and PAU model seed drills for farm women. Based on the observations and feedback, both seed drills were modified to suit 5^{th} to 95^{th} percentile of women's height using anthropometrical information. The modified units were re-evaluated ergonomically with the women subjects. The physiological workload in terms of work pulse reduced by 23 % and 33.9 % in pulling and pushing modes of operation with the modified unit of CIAE seed drill as compared to its original unit. The corresponding values for modified PAU seed drill were 22.8 % and 9.0 %, respectively as compared to its original unit. The saving in terms of energy expenditure with modified units of CIAE and PAU seed drills was 27 % and 24 %, respectively.

Agarwal *et al.,* (2007) conducted the study to quantify the physiological stress of women farmers, who were involved in organic farming in Uttarakhand. They concluded that the total cardiac cost and physiological cost of work were significantly different ($p<0.01$) and were highest during preparation of organic manure and was least during collection of cow dung from cattle shed.

Behera *et al*., (2007) ergonomically evaluated push-pull type weeders namely, rotary peg weeder, wheel hoe and wheel finger weeder with women operators. They reported that the working heart rate varied between 115.80 ± 1.47 to 128.70 ± 1.67 beats/min with highest value in case of wheel hoe and the lowest in case of rotary peg weeder. The work pulse (HR_{work}- HR_{rest}) was found to be above the allowable limit of 40 beats/min for wheel hoe (50 ± 0.89 beats/min). The value for rotary peg weeder was 39 ± 1.58 beats/min and for wheel finger weeder as 38 ± 1.85 beats/min. Work load, which is oxygen consumption rate (OCR) as percentage of $VO_{2\ max}$, was found to be 34 ± 3.2, 52 ± 2.3 and 37 ± 0.74 % for rotary peg weeder, wheel hoe and wheel finger weeder respectively. The energy expenditure rate was found to be maximum in wheel hoe (19.53 kJ/min) whereas it was 13.67 kJ/min and 12.8 kJ/min in case of wheel finger weeder and rotary peg weeder, respectively.

Gandhi *et al.,* (2007) carried out experiment on 30 physically fit women for ergonomic assessment of bundling activity. Bundling consisted of three sub activities viz; collection and preparation of tying material, collection of straws and tying of bundles. Average heart rate was maximum for tying of bundles (120 bpm) followed by collection of straws (110 bpm) and collection of tying material (90 bpm). Correspondingly, energy expenditure for collection of tying material was 5.6 kJ/min, for collection of straws was 9.0 kJ/min and was highest for tying of bundles (10.3 kJ/min). They concluded that collection of tying material and straws was light activity whereas tying of bundles was a heavy activity as indicated by heart rate and energy expenditure.

Kamath and Bhatnagar (2007) evaluated work performed by 60 female workers in Cashew Industry. Activities involved were cutting, peeling and grading of cashew nuts. Average working heart rate for cutting activity was 93 bpm with energy expenditure of 6.08 kJ/min, for peeling cashew it was 90 bpm with energy expenditure of 5.70kJ/min and for grading it was 91 bpm with energy expenditure of 5.70 kJ/min. The workload was classified as "very light to light" category.

Kathirvel *et al.,* (2007a) ergonomically evaluated IISR, OUAT and TNAU sugarcane detrashers with selected male and female subjects. The TNAU sugarcane detrasher with highest stripping capacity and having minimum damage to sugarcane stalks was chosen. Necessary ergo refinements were made. The mean heart rate and energy cost recorded was 112.76 bpm and 16.52 kJ/min respectively. The oxygen consumption rate in terms of per cent $VO_{2\ max}$ and work pulse of female subjects were 47.91 % and 44.35 bpm, respectively. The ergo refinements carried out in sugarcane detrasher was reflected in terms of significant reduction in physiological stress and 4.9 % increase in stripping capacity.

Kathirvel *et al.,* (2007b) ergonomically evaluated IRRI model cono weeder and CIAE improved cono weeder with selected 12 male and female subjects to assess their suitability for men and women workers for reduced drudgery and adequate comfort. The mean value of heart rate, energy cost, oxygen consumption rate in terms of per cent $VO_{2\ max}$ and work pulse of female subjects for weeding operation with IRRI cono weeder was 134.46 bpm, 26.21 kJ/min, 75.29 per cent and 48.62 bpm and for CIAE improved cono weeder was 127.86 bpm, 24.95 kJ/min, 71.69 per cent and 43.53 bpm respectively. They reported maximum weeding efficiency of 66.7 and 68.3 % for IRRI and CIAE cono weeders respectively.

Kathirvel *et al.,* (2007c) ergonomically evaluated available finger type rotary weeders (single row and two row) with selected 12 male and female subjects. The mean values of heart rate, energy cost, oxygen consumption rate in terms of per cent $VO_{2\ max}$ and work pulse of female subjects for weeding operation with ergo refined single row finger type rotary weeder (EFW1) were 121.71 bpm, 24.55 kJ/min, 69.59 per cent and 42.31 bpm respectively. For female workers the maximum weeding efficiency was 79.4 per cent for single row weeder.

Kaur *et al.,* (2007a) compared physiological response between conventional method and improved techniques (improved bag and plucker) of cotton picking activity on selected 60 female respondents. The results of the study exhibited significant reduction in heart rate (7.29 %), energy expenditure (17.30 %), total cardiac cost of work (43.75 %) and physiological cost of work (43.76 %) for improved methods as compared to conventional method.

Kaur *et al.,* (2007b) studied ergonomic cost of potato picking activity performed by improved potato picker II and III by rural women of Punjab. Results of the study showed that average heart rate and energy expenditure of the women were reduced significantly while performing the potato picking activity with the use of improved potato picker III as compared to potato picker II. Total cardiac cost of work, physiological cost of work for potato picking III were also found significantly lower.

Maheshwari and Devendra (2007) conducted a study to assess the heart rate response and physiological workload during agricultural operations. Hundred women farm workers for interculture and transplanting and 50 farm women for harvesting operation were selected for the study. The average heart rate were 101, 104 and 110 bpm for intercultural, harvesting and transplanting operations and corresponding energy expenditure were calculated as 7.44, 7.85 and 8.90 kJ/min respectively. The physical workload based on energy expenditure was graded light for all operations.

Singh and Gite (2007) ergonomically evaluated hand operated paddy winnower using 12 women workers. The mean heart rate of women workers during operation was found to be 112 beats/min. The energy expenditure rate in operation of the equipment was 10.7 kJ/min. The equipment developed was found to be suitable for operation by the women workers as the heart rate, work pulse value and energy expenditure rate are within the acceptable lilmits.

Solanki *et al.,* (2007) studied the ergonomical feasibility of sprayers for farm women with four subjects. Two lever operated and an engine operated sprayer were used. The study indicated that workload in the spraying operation by lever operated sprayer was within the acceptable limits according the ergonomical criteria. The engine operated sprayer was not suitable for female operators due to higher weight, more vibrations and noise caused by the engine.

Swain *et al.,* (2007) ergonomically evaluated cashewnut shelling methods. The results indicated that the hand sheller was not ergonomically superior to the conventional method because of the shelling operation being accomplished in two stages of impulse and tension by the operator. The output of hand sheller was observed to be 10.0 nuts/min as compared to 9.7 nuts/min in case of conventional hand beating method.

Yadav *et al.,* (2007) evaluated ergonomically the paddy transplanting operation. Manually operated six row paddy transplanter was selected for the study. Male and female subjects were selected randomly in the age group of 25-35 years. The average energy expenditure for male and female workers for transplanting operation by manually operated paddy transplanter was found to be 30.70 and 32.58 kJ/min, respectively. The operation was graded as ‘heavy work’ on the basis of heart rate.

Zend *et al.,* (2007) compared the performance of ergonomically modified earhead cutter and local sickle for harvesting sorghum crop. The subjects of the study were farm women in the age group of 20-45 years. Results indicated that there was increase in heart rate by 3-4 bpm while using earhead cutter compared to traditional method, but the total cardiac and physiological cost of work did not increased significantly.

Gandhi *et al.,* (2008) evaluated bajra cobs harvesting performed by farm women from ergonomic consideration. The field experiment was conducted on a sample of 30 physically fit women for 30 min. They reported that bajra cobs harvesting was a drudgerious activity having average working heart rate of 118 bpm and consuming 10 kJ/min of energy. On the basis of heart rate and energy expenditure the operation was scaled as ‘moderately heavy’ activity.

2.6 Grading energy cost of work

To perform manual activity, more muscular movement is necessary which causes stress on the cardio-pulmonary system to meet the demand of extra energy. But looking at the cardio-pulmonary conditions one can therefore assess the degree of physiological stress going to be imposed on our body and how effectively our body will be capable to maintain that condition. This will further help us in evaluating a manual job from the view point of energy requirement, in determining the correct method of performing a task, in optimizing a product design or in determining a better work posture while performing a job manually.

Christensen (1953) classified the manual jobs based on the physiological responses of Nykroppa irons workers in London. The classification of strain in different workload is furnished in Table 2.3.

Table 2.3 EER, OCR, and HR values in different workload conditions

Mode of work	EER (kcal/min)	OCR (l/min)	HR (beats/min)
Very light	Under 2.5	Under 0.5	Under 75
Light	2.5-5.0	0.5-1.0	75-100
moderate heavy	5.0-7.5	1.0-1.5	100-125
Heavy	7.5-10.0	1.5-2.0	125-150
Very heavy	10.0-12.5	2.0-2.5	150-175
Unduly heavy	over 12.5	over 2.5	over 175

Sen (1969) tentatively classified the manual jobs based on the physiological responses of young Indian male workers. The classification of strains in different types of jobs is furnished in Table 2.4.

Table 2.4 Classification of workload in different workload conditions

Physiological workload	Physiological Variables		
	Heart rate (beats/ min)	Oxygen consumption rate (lit/min)	Energy expenditure (kcal/min)
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	Above 175	>1.75	> 8.75

Varghese *et al*., (1994) classified rapid appraisal of occupational workload from modified scale of perceived exertion. The classification of different workload is furnished in Table 2.5.

Table 2.5 HR and EER values in different workload conditions

Scores	Physiological workload	HR (beats/min)	EER (kJ/min)
1	Very light	Up to 90	Up to 5
2	Light	91 - 105	5.1 – 7.5
3	moderate heavy	106 -120	7.6 – 10.0
4	Heavy	121 -135	10.1 – 12.5
5	Very heavy	135 - 150	12.6 – 15.0

Gite *et al.,* (1999) investigated the physiological workload involved in operation of local sickle, improved sickle and self propelled reaper. They reported that the mean values of heart rate data were 105.4, 108.4, 146.4 beats/min for improved, local sickle and self propelled reaper respectively. The corresponding work pulse values were 24.9, 29.8 and 60 beats/min. The mean areas harvested were 184, 270.3 and 3968 m^2/h.

Susheela *et al.,* (2001) evaluated the occupational workload of female agricultural workers for selected agricultural activities like picking of stalks and stubbles, sowing, transplanting, interculturing, weeding and harvesting of wheat and jowar crop. They found that the mean heart rates were 101.0 ± 7.0, 118.6 ± 15.1, 131.0 ± 7.0, 109.1 ± 7.1, 126.0 ± 7.0 and 123.0 ± 5.0 beats/min respectively for selected agricultural activities. The physiological workload of interculture operation and harvesting for wheat and jowar were classified as “heavy”.

2.7 Musculoskeletal discomfort due to physical workload during agricultural operations

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 paddy seedlings.

Mrunalini (2001) reported the body part discomfort of women in paddy cultivation and manual harvesting. Severe pain was reported by 100 percent of subjects at the lower back region followed by 95 per cent in the shoulders, 50 per cent at the neck during paddy transplantation. Severe pain was also reported by about 45 per cent in the calf muscles and ankles due to this activity. The subjects also reported similar responses for paddy harvesting.

Rahi (2003) evaluated body discomfort experienced by the women operator during weeding and cob-picking operation. The ODR for female subjects during weeding with kudali, wheel hoe, indigenous plough and 2-tine cultivator ranged from 7.75 to 9.4, 8.0 to 9.6, 10.0 and 10.0 respectively. The BPDS for female subjects for same tools and implements ranged from 62.7 to 76.75, 62.5 to 78.5, 71.2 to 78.75 and 71.6 to 84.8 respectively. The mean ODR and BPDS during cob-picking operation were 3.52 and 31.83 respectively.

Tewari and Philip (2003) carried out an investigation to evaluate the work situation of female agricultural workers in India, from an ergonomic perspective. Twenty-four female subjects working in paddy fields of different parts of the region were selected randomly for the study. Postures adopted by the workers while performing various operations involved in paddy cultivation were recorded. The body pain mapping assessed the postural discomfort

Hasalkar *et al.*, (2004) carried out studies on weeding tools. They reported a reduction of 4.98 per cent in the average total cardiac cost of work and physiological cost of work while performing weeding with the improved tool (Saral Kurpi) when compared to the traditional tool.

Srisha (2004) studied body discomfort various agricultural tools and equipment. She reported that the over all discomfort rate was maximum (7.55) for fertilizer broadcaster followed by cono weeder (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.

Solanki *et al.*, (2006) ergonomically evaluated three types of hand operated maize shellers with five female subjects. The overall discomfort score varied from 3.5 to 4 i.e. ‘more than light discomfort’ and body part discomfort score was 51 for all the maize shellers.

Dewangan *et al.*, (2007) conducted the study for ergonomic evaluation of sickles by 11 representative female agricultural workers for paddy harvesting. They compared the performance of the local sickle with improved sickles, namely, the Vaibhav and the Naveen sickle. Maximum work related body parts discomfort was observed at lower back to the level of 2.73, 2.73 and 2.80 in Borg (CR - 10) scale by the local, the Vaibhav and the Naveen sickle, respectively.

Nadre *et al.*, (2007) ergonomically evaluated the push and pull type ridgers. The two ridgers were operated by two female subjects. The average field capacity was 141.88 and 117 m^2/h for these ridgers, respectively. The mean overall discomfort rating were 7.2 & 6.3 and 4.0 & 3.5 on 0 – 10 discomfort scale and mean body parts discomfort scores were 80 & 72 and 58 & 50 for push and pull ridgers, respectively.

Ramteke *et al.*, (2007) developed MAU dibbler and evaluated physiological workload on the women operators for dibbling cotton and soybean crops. The mean overall discomfort rating was 5.2 on 0 -10 discomfort scale and mean body parts discomfort score was 52.07. The study indicated that the workload in the dibbling operation by developed dibbler was within the acceptable limit, according to physiological criteria.

III MATERIALS AND METHODS

This chapter deals with procedures followed and methodologies adopted to achieve the objectives of the present investigation. The study was confined specifically to conduct ergonomical studies on female agricultural workers for manual weeding and cob-picking operations. In order to carry out the study an anthropometrical survey including strength parameters was conducted according to AICRP on ESA standards. The collected data were compared with the data of other regions of the country and also with available data of other countries. Field evaluation of selected agricultural implements was conducted. Physiological cost of the operator was measured. Body part discomfort score and overall discomfort rating experienced by the subjects were estimated. The contents of this chapter are described from Section 3.1 through Section 3.10.

3.1 Anthropometric and strength measurements

Anthropometry is the technology of measuring various human physical traits, primarily factors such as size, mobility and strength. Engineering anthropometry is an effort to apply such data to equipment and workplace design to enhance the efficiency, safety and comfort of the operator. Anthropometry is fundamental to successful design of agricultural equipments. It is critical for designer to consider the human being intentionally and thoroughly at the time of conception of the design rather than as a follow up or add-on part of the design. Anthropometric measures vary considerably due to effect of various factors. Gender, race and age are the prime factors that play a dominant role in this variability. In India agricultural equipments are not designed ergonomically for the users population due to limited availability of anthropometric data and thus subjected to different operations and reduction in overall performance efficiency. At present very few studies are available on collection of anthropometrical data on women agricultural workers of the country. Studies have been reported for collection of anthropometric data on Indian agricultural workers most of them are confined to male agricultural workers (Gite and Yadav (1989), Gite (1996), Yadav *et al.*, (1997), Dewangan *et al.*, (2005)). Studies have been reported for collection of anthropometric data on Indian female agricultural workers. (Geetha and Tewari (2000)**,** Yadav *et a*l., (2003), Dewangan *et al.*, (2008)). Till now no effort have been made to collect anthropometric data and strength parameters of female agricultural workers of western India (Rajasthan). Keeping these points into consideration, anthropometric and strength data of female agricultural workers were identified, compiled and analyzed to build the data bank, to be used in the design of agricultural implements/machines to match the limitation, capabilities and power of female farmer and also in work place design.

3.2 Selection of the subjects

3.2.1 Determination of sample size

Subjects were selected to assist in the field trials. They were selected from the existing agricultural workers population of the region. Female agricultural workers were selected. For this selection process a sample size was taken. Anthropometric and strength measurements were carried out on the individual in the selected sample. For determining the sample size the formula suggested by Roebuck *et al.*, (1975) was followed, as given below:

$$N = (K_1 S/ d)^2 \qquad \text{----------- (3.1)}$$

Where,

N= Sample size required,

S= Estimated standard deviation of the data, m

d= The desired accuracy of the measurement, m

K_1= 4.14 (Constant for 5^{th} and 95^{th} percentile)

Following values were selected and substituted in Equation 3.1

S= 0.05 m

d= 0.03 m

K_1= 4.14

$$N = \left(\frac{4.14 \times 0.05}{0.03}\right)^2$$

$$= 47.61$$

$$\approx 50$$

Accordingly, it was decided to select 50 subjects from the available female agricultural workers of the region.

Improved agricultural equipments play dominant role in farm mechanization of the country. Women in rural India play significant and crucial role. At present, the women force in agriculture and allied sector is estimated at about 70.5 million, which amounts to 35 per cent of the total rural workers in the country (Gite and Singh, 1997). Most of agricultural operations are carried out by female agricultural workers. Further due to immigration of male from rural areas to urban areas, farm women have been compelled to perform the agricultural operations and there by acquired technical skill. They are involved in sowing, weeding intercultural operation, harvesting, shelling, cleaning, grading, processing etc. Thus female agricultural force is the integrated component of the agricultural system. Hence to achieve better efficiency of performance and more human comfort, it is necessary to design agricultural equipment, taking into consideration the female anthropometrical and strength data. Further it is also imperative to evaluate and modify the design and performance methods of agricultural operations suitable for male workers, in order to match the muscle strength, maximum aerobic capacity and efficiency of female workers. So that this can operate with greater efficiency, accuracy and safety in correct fortune.

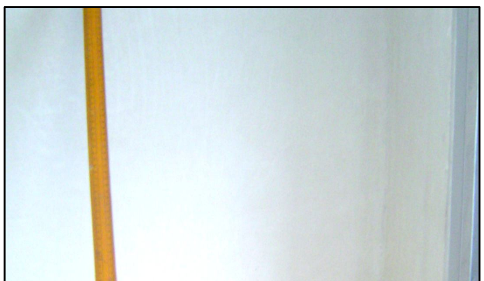
Thus keeping in view their participation in various agricultural operations, 50 agricultural female workers were randomly selected. They were selected from five villages of Udaipur region viz; Sundar vas, Pratap Nagar, Payada, Kaya, Dangiyon Ki Pancholi and Instructional farm of college. The subjects were in the age group of 25-45 years. Their anthropometric and strength measurements were taken.

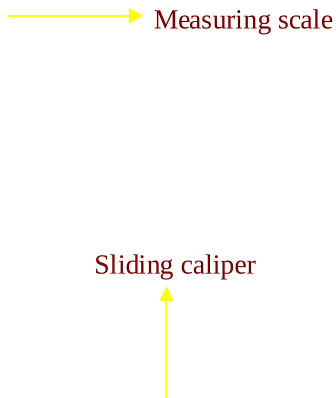
3.3 Measurement of Body Dimensions

Twenty four body dimensions including weight of the subject were identified and selected for the study. Body dimensions were measured with an Integrated Composite Anthropometer (ICA), designed and developed at the Indian Institute of Technology (IIT), Kharagpur, India. These body dimensions and strength parameters were selected keeping in to consideration the design requirements of hand tools, animal drawn equipments, tractors, power operated machines etc. and work place (Gite and Chatterjee, 2000). The various body dimensions selected for the study are presented in Table 3.1

Table 3.1 Selected Body Dimensions useful in Agricultural Equipment Design

S.N.	Standing posture	S.N.	Sitting posture	S.N.	Miscellaneous
1	Weight	11	Sitting height	17	Hand length
2	Stature	12	Vertical grip reach height	18	Hand breadth at metacarpal III
3	Eye height	13	Eye height	19	Palm length
4	Acromial height	14	Acromial height	20	Grip diameter (inside)
5	Elbow height	15	Popliteal height	21	Grip diameter (outside)
6	Olecranon height	16	Elbow rest height	22	Middle finger-palm grip diameter
7	Iliocristale height			23	Grip span
8	Knee height			24	Maximum grip length
9	Arm reach from the wall				
10	Forearm hand length				





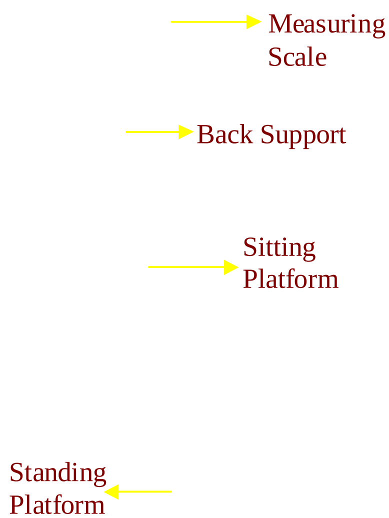


Fig. 3.1 Measuring scale and caliper

Fig. 3.2 Integrated Composite Anthropometer

Fig. 3.3 Grip measuring device

Fig. 3.4 Vernier caliper

The instruments/equipments used for measurement of these body dimensions (Table 3.1) are given below:

(i) Measuring scale and caliper (Fig. 3.1)

(ii) Integrated Composite Anthropometer (least count 1 mm) (Fig. 3.2)

(iii) Grip measuring device (Fig. 3.3)

(iv) Vernier caliper (Fig. 3.4)

(v) Electronic weighing balance

(vi) Measuring tape

3.3.1 Posture of the subject

Most of the measurements were made with the subject in one of two postures: standing erect or sitting erect. The two basic postures are described as follows:

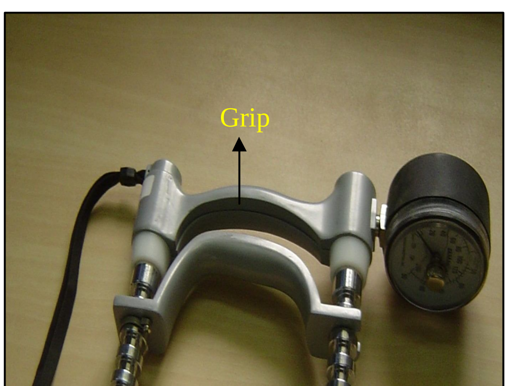
1. Standing erect: The subjects stand erect, looking straight ahead (head in the Frankfort plane), heels together, weight distributed equally on both feet, and with her arms hanging naturally at her side.
2. Sitting erect: The subjects sits erect, looking straight ahead (head in the Frankfort plane), upper arms hanging relaxed, forearms and hands extended forward horizontally, thighs parallel and the feet resting on a surface adjusted so that the knee are flexed 90^0.

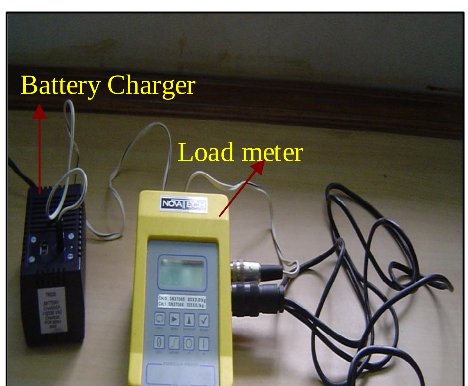
3.3.2 Side of the body

All one-sided measurements were made on the right side of the body.

3.4 Measurement of Strength Parameters

Seven strength parameters were identified and selected for the study. Strength parameters were measured with strength measuring setup, designed and developed at the Central Institute of Agricultural Engineering (CIAE), Bhopal, India. These were selected based on the design of various agricultural equipments particularly for weeding and cob picking operation. These strength parameters are presented in Table 3.2.





Load cell

Dial

Fig. 3.5 Hand Grip Dynamometer **Fig. 3.6 Load meter with Load cell**

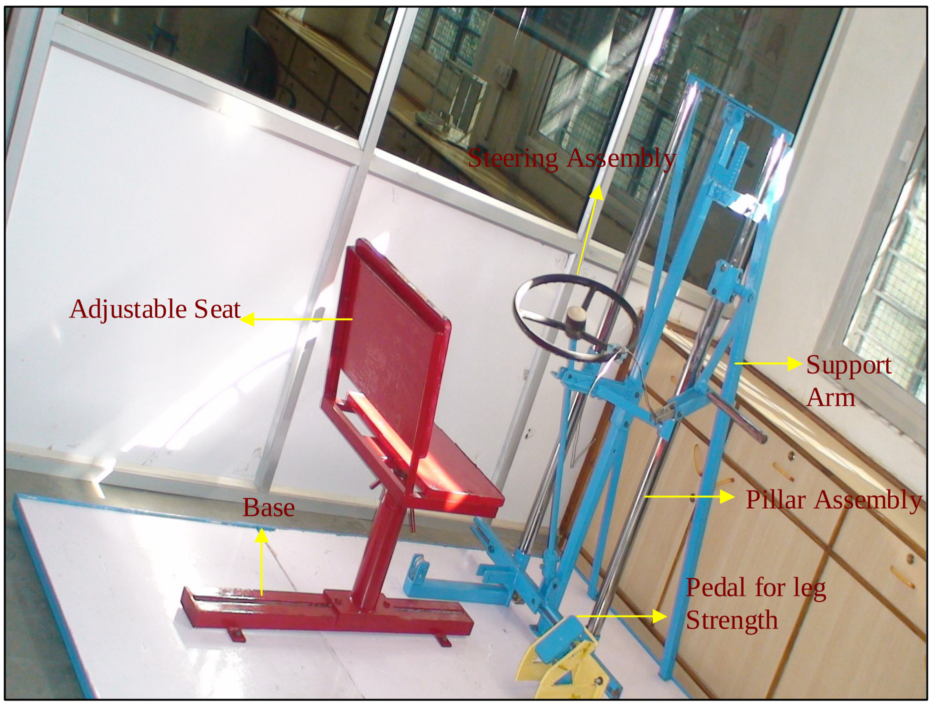


Fig. 3.7 Strength Measuring Setup

Table 3.2 Selected Strength Parameters useful in Agricultural Equipment Design

S.N	Strength parameters
1	Hand grip strength (right)
2	Hand grip strength (left)

3	Push strength with both hands in standing posture
4	Pull strength with both hands in standing posture
5	Right hand pull strength in sitting posture
6	Left hand pull strength in sitting posture
7	Hand grip torque

The instruments/equipments used for strength measurement (Table 3.2) are given below:

1. Grip dynamometer (Fig. 3.5)
2. Load meter with Load cell (Fig. 3.6)
3. Strength measuring setup (Fig. 3.7)

3.5 Definitions and Uses of Body Measurements

Twenty-four body dimensions and seven strength parameters have been identified in this study. Due attention was also given to ISO standard 7250 (1996) (Basic human body measurements for technological design), and the recommendations of the conference on standardization of anthropometric techniques and terminologies (Hertzberg, 1968). Standard terminologies as given in the anthropometric Source Book (NASA, 1978) have been used. There are presented in Section 3.5.1 through Section 3.5.4.

3.5.1 Measurements in standing posture:

1. **Weight:** The weight of the subject is measured with electronic weighing balance. It is used as a general body description.
2. **Stature:** The vertical distance from standing surface to top of the head. It is used as a general body description and in work place design.
3. **Eye height:** The vertical distance from the standing surface to the inner corner of the eye. It is used in design of controls and displays.
4. **Acromial height:** The vertical distance from the standing surface to the acromian. It is used as a general body description, work place layout and body linkages.

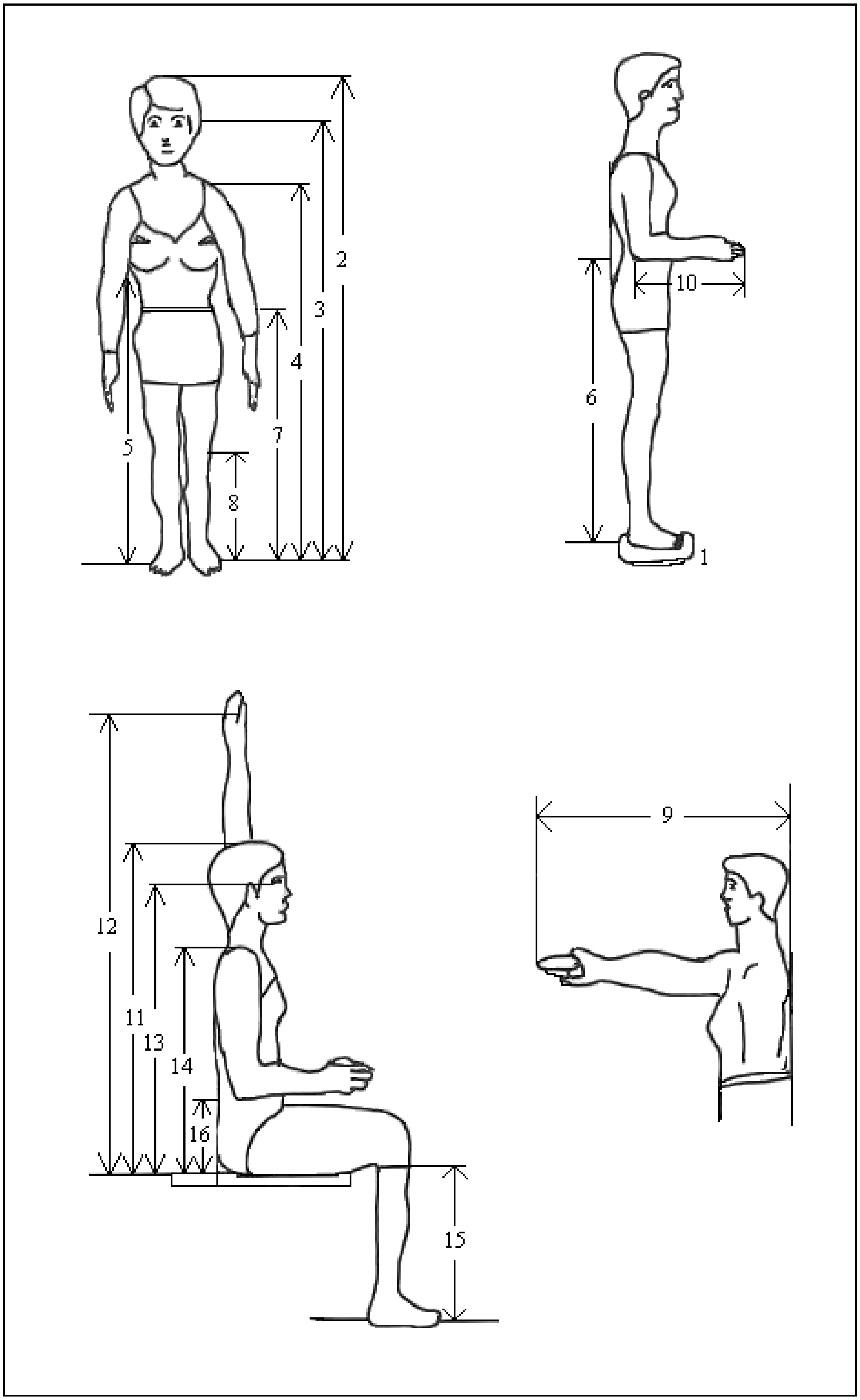


Fig. 3.8 Anthropometric Measurements in Standing and Sitting Posture

5. **Elbow height:** The vertical distance from the standing surface to the top of the radiale. It is used as a general body description, work place layout and body linkages.
6. **Olecranon height:** The vertical distance from the standing surface to the height of the undersurface of the elbow, measure with the arm flexed 90^0 and the upper arm vertical. It is used as a general body description.
7. **Iliocristale height:** The vertical distance from the standing surface to the top of the ilium in mid auxiliary plane. It is used in body linkages safety harness design and safety belt design.
8. **Knee height:** The vertical distance from the standing surface to the mid-point of knee cap. It is used in body linkages and work place design.
9. **Arm reach from wall:** The distance from the wall to the tip of middle finger measured with the subject shoulder against the wall, hand and arm extended forward. It is used in design of control, display panel and work place layout.
10. **Fore arm hand length:** The distance from the base of the hand to the top of the middle finger measured along the long axis of the hand. It is used in control panel design, biomechanics study and handle design.

3.5.2 Measurements in sitting posture

11. **Sitting height:** The height measured from the sitting surface to top of the head. It is used as a general body description, control panel layout and work place layout.
12. **Vertical grip reach height sitting:** The height above the sitting surface of a pointer held horizontal in subjects fist when arm is maximally extended upward. It is used in control panel design and work place layout.
13. **Eye height:** The height from the sitting surface to the external canthus. It is used in display and control panel design, seat design and visual field determination.
14. **Acromial height:** The height from the sitting surface to the top of the acromian. It is used in control panel layout, work place layout and seat design.
15. **Popliteal height sitting:** The height of the underside of the upper leg above the foot rest surface. It is used in seat design and workplace design.
16. **Elbow rest height:** The height of the bottom of the tip of the elbow above the sitting surface. It is used in seat handle design, control design, seat design and work place layout.

All measurements in standing and sitting posture are presented in Fig. 3.8

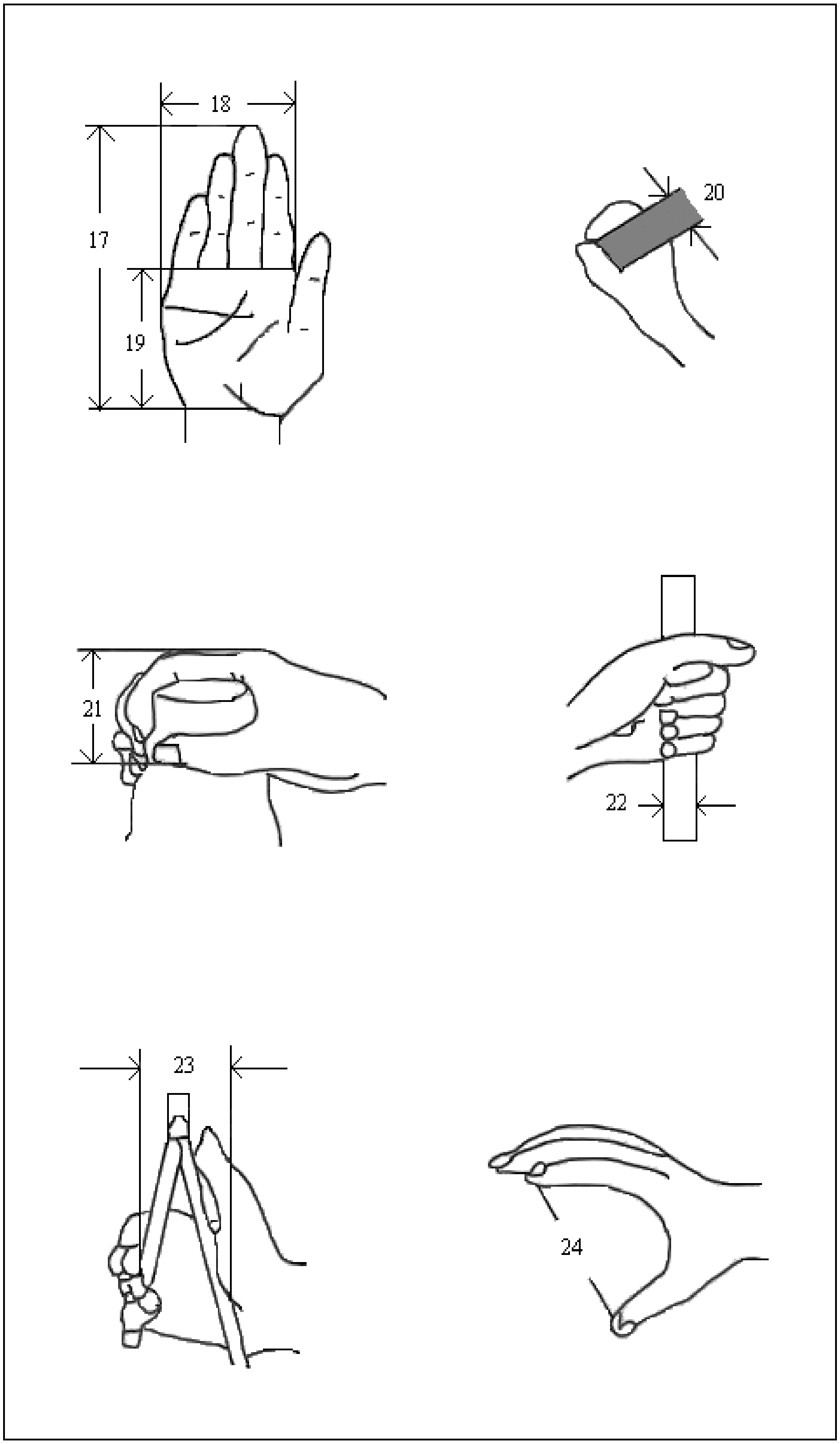


Fig. 3.9 Measurements of miscellaneous Body Dimensions

3.5.3 Miscellaneous body dimensions

17. **Hand length:** The distance from the base of the hand to the top of the middle finger measured along the long axis of the hand. It is used in handle design, control panel design and hand tool design.
18. **Hand breadth:** The breadth of the hand as measured across the distal end of the metacarpal bones. It is used in handle design, control panel design and hand tool design.
19. **Palm length:** The distance from the base of the hand to the furrow where the middle finger folds upon the palm. It is used in handle design and hand tool design.
20. **Grip diameter (inside):** The diameter of the widest level of a cone, which the subject can grasp with his thumb and middle finger touching. It is used in handle design, control design and hand tool design.
21. **Grip diameter (outside):** The distance between the joint of the 1st and 2nd phalanges of the thumb and knuckles of the middle finger measured with the hand to the grip. It is used in handle design and control grip design.
22. **Middle finger-palm grip diameter:** The diameter of the widest level of the cylinder which the subject can grasp with her palm and middle-finger touching. It is used in handle design and control grip design.
23. **Grip span:** The maximum distance between the palm and the fingers in grip position. It is used in design of hand tools.
24. **Maximum grip length:** The maximum length between the tip of the middle finger and the tip of the thumb while the palm, thumb and finger is in grip position. It is used in handle design, control grip design and lid design of sprayer containers.

All miscellaneous body dimensions are presented in Fig. 3.9 unless and otherwise specified in the definition.

3.5.4 Measurements of strength parameters

1. **Right hand grip strength:** The grip strength of right hand measured with hand grip dynamometer when the subject stands erect with her arms hanging downwards. It is used in design of hand control lever, hand clutch and hand break.
2. **Left hand grip strength:** The grip strength of left hand measured with hand grip dynamometer when the subject stands erect with her arms hanging downwards. It is used in design of hand control lever, hand clutch and hand break.

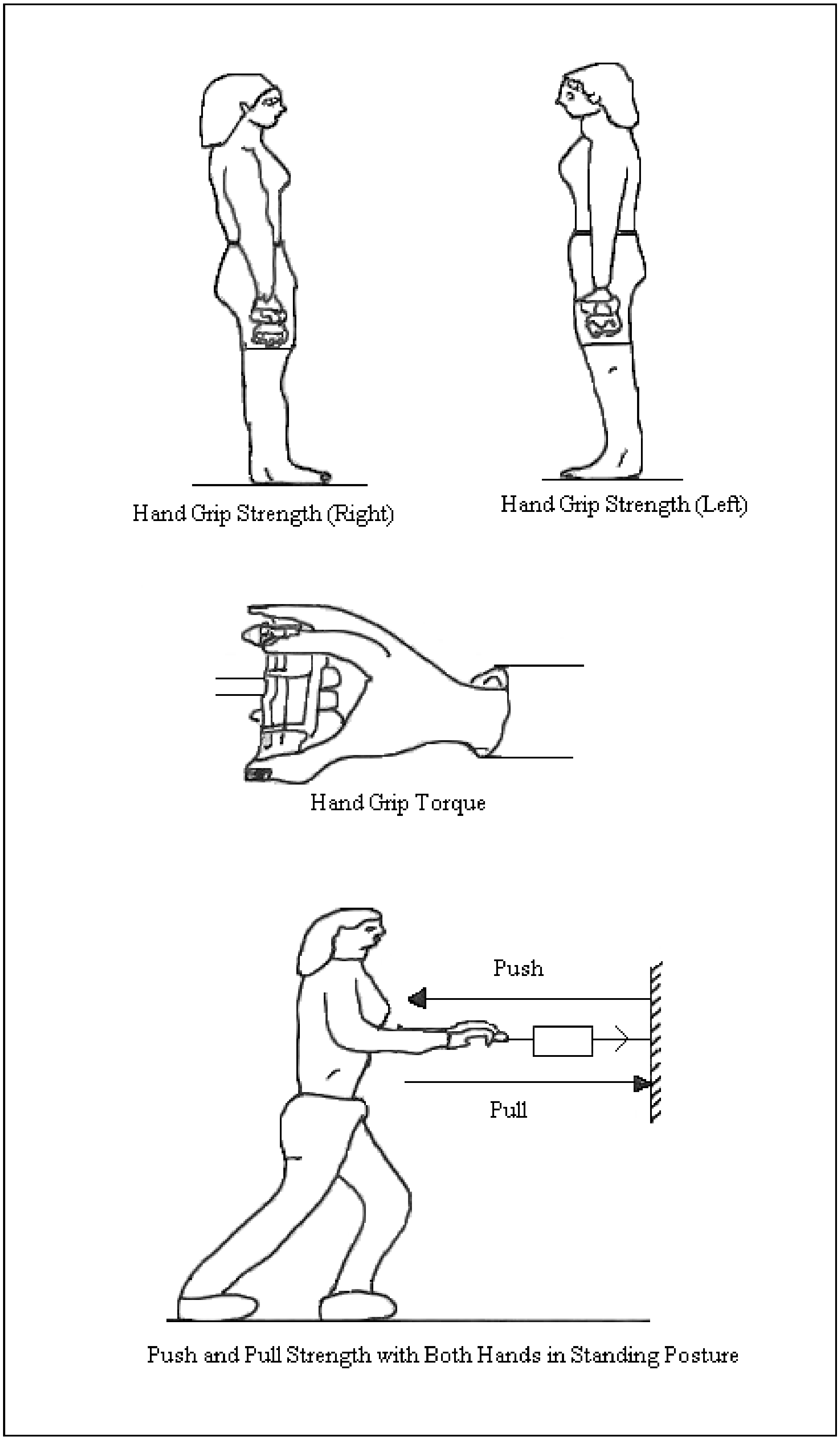
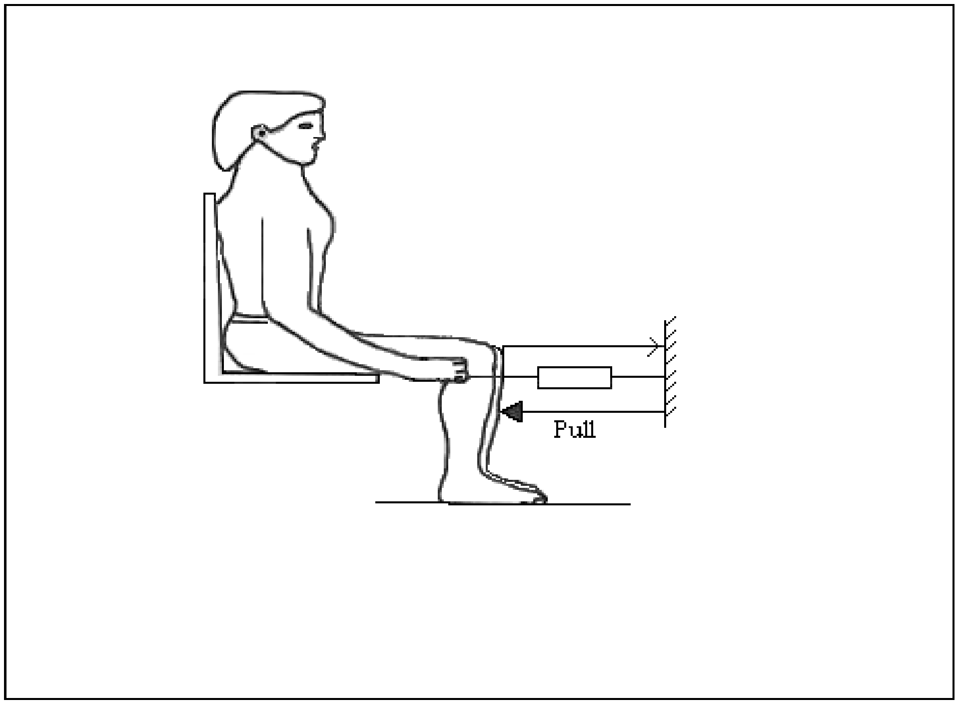
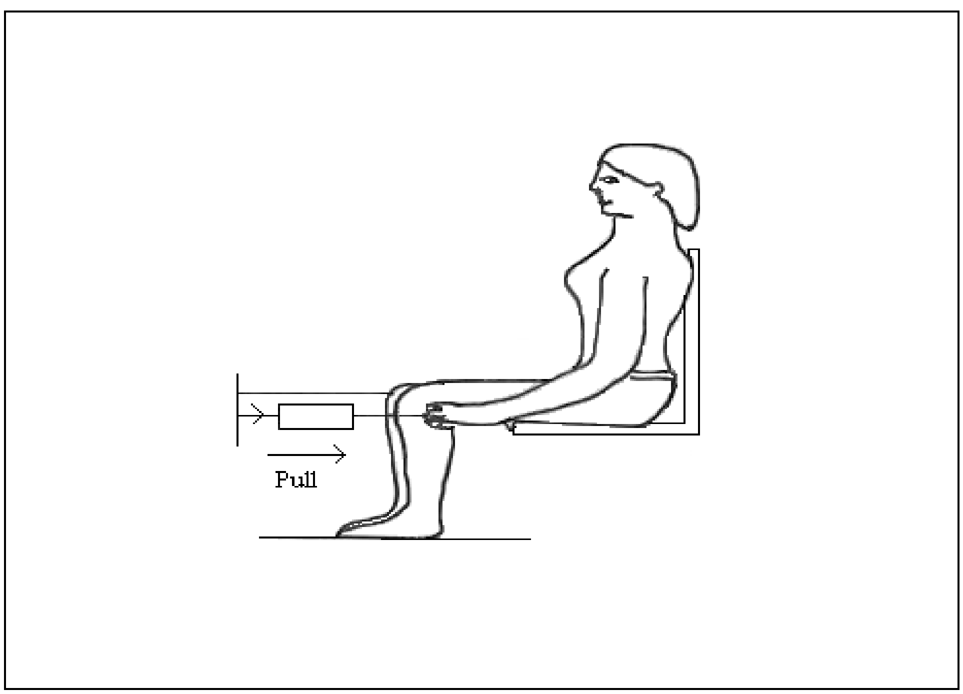


Fig. 3.10 (a) Measurements of Strength Parameters



(a) Right Hand Pull Strength in Sitting Posture



(b) Left hand Pull Strength in Sitting Posture

Fig. 3.10 (b) Measurements of Strength Measurements

3. **Push strength with both hands in standing posture:** The maximum push force applied with both hands on load cell in standing posture with one leg forward. It is used in design of manually operated equipment like wheel hoe, garden mower.
4. **Pull strength with both hands in standing posture:** The maximum pull force applied with both hands on load cell in standing posture with one leg backward. It is used in design of manually operated pulling equipment like long handled weeder.
5. **Right hand pull strength in sitting posture:** The maximum pull force applied with right hand on the load cell at seat height in the horizontal plane while sitting on chair. It is used in design of joystick, gear shift lever and handle lever.
6. **Left hand pull strength in sitting posture:** The maximum pull force applied with left hand on the load cell at seat height in the horizontal plane while sitting on an anthropometric chair. It is used in design of joystick, gear shift lever and handle lever.
7. **Hand grip torque:** The maximum grip torque applied by preferred hand in anti-clock wise direction. It is used in design of knob controls, sprayer lids and opening cover of service point.

All strength parameters are presented in Fig. 3.10 (a) and Fig. 3.10 (b) unless and otherwise specified in the definition.

3.6 Procedure for Anthropometric and strength measurements

3.6.1 Anthropometric Measurements

1. One of the female subject was asked to stand on electronic weighing balance. Her weight was accurately recorded.
2. The subject was than asked to stand on standing platform of the anthropometer (standing posture) and her stature, eye height, acromial height, elbow height, olecranon height, iliocristale height and knee height and arm reach from wall were measured. (Section 3.5.1)
3. The subject was than asked to sit on the sitting platform of anthropometer for measurement in sitting posture. In this position, observations on sitting height, vertical grip reach height, eye height, acromial height, popliteal height and elbow rest height with the help of a measuring scale were measured. (Section 3.5.2)
4. Subject's hand length, hand breadth, palm length, fore arm hand length, grip span and maximum grip length were measured with the help of vernier caliper. (Section 3.5.3)
5. Grip diameter (inside and outside) and middle finger palm grip diameter was measured with the help of grip measuring device and vernier caliper. (Section 3.5.3)
6. Steps 1to 5 were repeated for all the fifty subjects.
7. The collected anthropometrical data of 50 female agricultural workers were statistically analyzed. Range, mean, standard deviation, standard error, coefficient of variation, coefficient of

correlation, 5th, 95th percentile and their difference and stature ratio was found for each body dimension. The 5th and 95th percentile was calculated as follows:

$$5^{th} \text{ Percentile} = \text{Mean} - K_2 \times SD \qquad \text{------------ (3.2)}$$

$$95^{th} \text{ Percentile} = \text{Mean} + K_2 \times SD \qquad \text{------------ (3.3)}$$

Where,

SD = Standard Deviation

K_2 = 1.645 (Constant for 5th and 95th percentile) (Gite and Chatterjee, 2000)

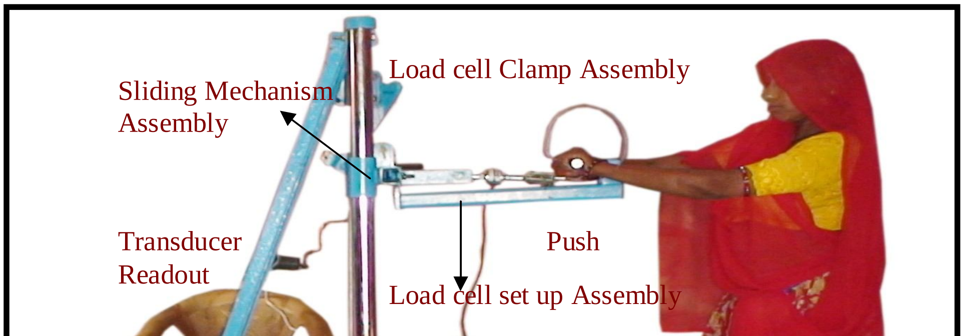
8. Graph were plotted for stature vs other body dimensions and relationship developed for stature vs other body dimensions and correlation coefficient were evaluated.
9. Stature ratio for each body dimension was calculated. This parameter can be used to determine, from the sample population the dimension not available in the sample.
10. The analyzed data were compared with male and female agricultural workers of other regions of India and other countries.

The percentile values can be used to design new agricultural equipment and modify the existing equipment to suit female work force and also for work place design.

Results of this measurement are presented and discussed in Section 4.1.

3.6.2 Measurement of strength parameters

1. One of the subject was asked to stand erect with her arms hanging downwards. She was asked to hold the grip dynamometer tightly in her right hand. The force in Kgf was recorded. Similar procedure was followed for left hand.
2. For the measurement of push and pull strength with both hands in standing posture, the load cell set up assembly was fixed inside the groove of the sliding mechanism assembly of strength measurement setup. Load cell was fixed on the load cell clamp assembly by a clutch wire to ensure its easy movement in the horizontal plane. The complete load cell clamp assembly can be moved vertically within the pillar assembly up to acromian level of the subject. The subject was then asked to stand erect on the platform holding the load cell comfortably. She was asked to apply the maximum push force for 5 seconds with her both hands on the hand lever, with one leg placed forward. Her push strength was recorded on load meter. Similar procedure was followed for the measurement of pull strength (Fig. 3.11).



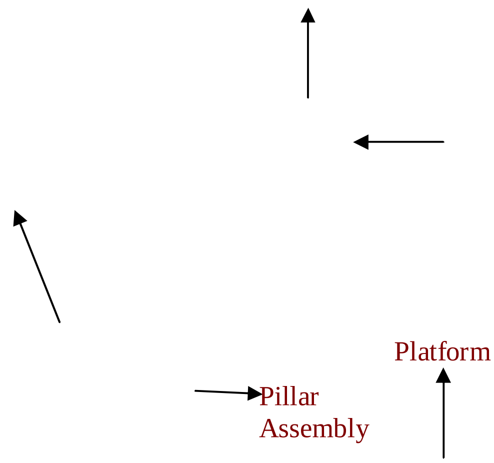


Fig. 3.11 Push strength with both hands in standing posture

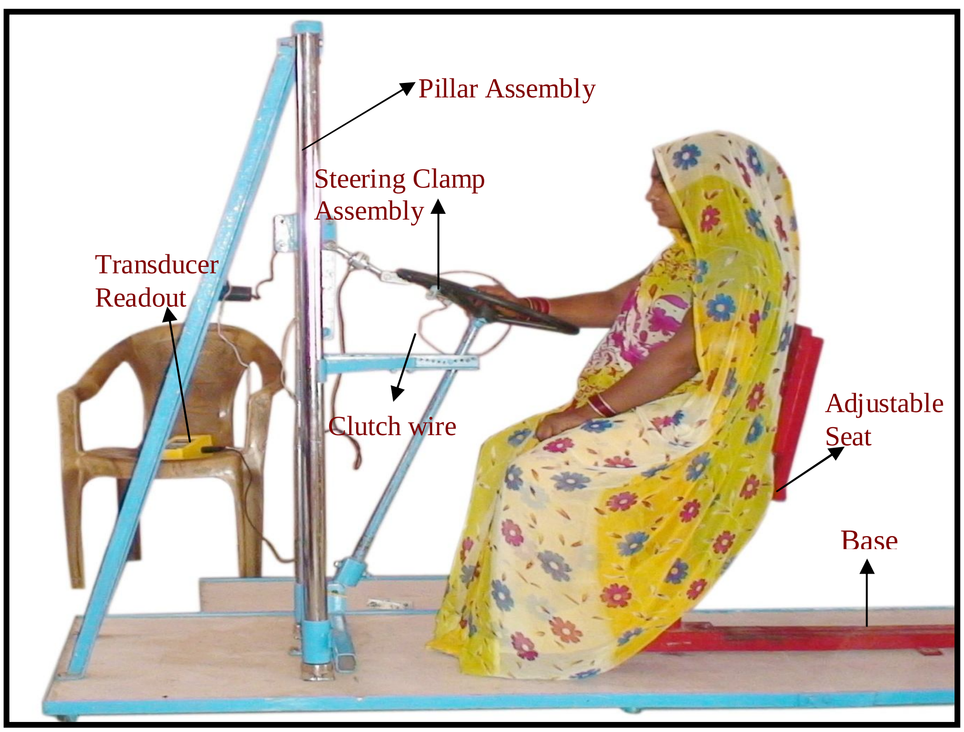


Fig. 3.12 Hand grip Torque

3. For the measurement of pull strength of the right hand and left hand in the sitting posture, adjustable seat was fixed on the base of the setup. The complete load cell clamp assembly was moved within the pillar assembly up to the SRP level of the seat. The subject was asked to sit erect straight on the seat and apply the maximum pull strength by her right hand, on hand lever for 5 seconds. The force applied was recorded on load meter. Similar procedure was followed for left hand pull strength.
4. For the measurement of grip torque by preferred hand one end of the load cell was fitted to the lower clamp nut of the torque strength set up assembly. The clutch wire was attached to the steering clamp assembly at the one end and the other end was attached to the load cell. The subject was asked to apply maximum grip torque by preferred hand in anti-clock wise direction. Her hand grip torque was recorded on load meter (Fig. 3.12).
5. Steps 1 to 5 were repeated for all fifty female subjects.
6. The collected strength data of 50 female agricultural workers were statistically analyzed. Range, mean, standard deviation, standard error, coefficient of variation, coefficient of correlation, 5^{th}, 95^{th} percentile and their difference and stature ratio was found for each body dimension. The 5^{th} and 95^{th} percentile was calculated as follows:

   5^{th} Percentile = Mean - $K_2 \times$ SD ------------ (3.2)

   95^{th} Percentile = Mean + $K_2 \times$ SD ------------ (3.3)

   Where,

   SD = Standard Deviation

   K_2 = 1.645 (Constant for 5^{th} and 95^{th} percentile) (Gite and Chaterjee, 2000).
7. Graphs were plotted for stature vs other strength parameters and stature vs strength parameters. Relationship was developed for stature vs other strength parameters, weight vs strength parameters and correlation coefficient were evaluated.
8. The analyzed data were compared with female agricultural workers of other regions of India.

3.7 Selection of Ten Subjects

Ten female subjects in age group 25-45 years were randomly chosen. They were designated as S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 and S_{10} respectively. Twenty four body dimensions and seven strength parameters of the selected subjects were measured and mean values of body dimensions and strength parameters of the subjects were calculated. They were screened for normal health with medical investigations. The medical investigations include ECG, blood pressure, pulse rate, etc. These subjects were used in the field trials for manual weeding and cob picking operations. Each subject was replicated three times.

The results of the measurements of the selected subjects are presented and discussed in Section 4.2.

3.8 Performance evaluation of weeding and cob-picking operations.

Field experiments were carried out at instructional farm of CTAE to evaluate the performance of the implements/tools for weeding and cob picking operations. Physiological cost and body discomfort for the selected subjects were estimated. In addition, mechanical evaluation of the implements for the operations was also conducted. Following weeding and cob picking operations were involved:

1. **Manual weeding operation:** Four methods were selected to carry out this operation
   1. Kudali (Traditional)
   2. Khurpi (Traditional)
   3. Wheel hand hoe (CIAE model) (Improved manual method)
   4. Wheel hand hoe (PAU model) (Improved manual method)
2. **Cob-picking operation** (manually)

3.9 Physiological cost estimation of operator

When a person does any physical work, she uses her muscle power (energy) and skeletal tissues to do so. During the muscular activity her physiological responses i.e. energy expenditure rate, oxygen consumption rate and heart rate increases. This increase in physiological responses is related to the type, intensity and duration of work and thus sets limits to the performance of heavy work. In the present study oxygen consumption rate and heart rate was used for physiological cost estimation. These parameters were measured by Computerized Ambulatory Metabolic Measurement System K4 b^2. Field experiments were carried out to assess the oxygen consumption rate and heart rate responses during weeding and cob picking operations. Ten female subjects were used for this experiment.

3.9.1 Measurement of OCR and HR by Computerized Ambulatory Metabolic Measurement System (K4 b^2)

Heart rate is the number of ventricular beats per minute and OCR is the volume of oxygen at STPD (0^o, 760 mm Hg, dry) extracted per unit time from the inspired air and is usually expressed as litres per minute. It is a sensitive and fine discriminating measure for evaluating strain in muscular work. In addition to this, heart rate and oxygen consumption rate can be measured and analyzed easily in practice without any disturbance to the worker by using Computerized Ambulatory Metabolic Measurement System. The Computerized Ambulatory Metabolic Measurement System used in the study was of Cosmed make K4 b^2 model.

The K4 b^2 is an electric medical device designed to perform pulmonary function tests. It is to be used by physicians or by trained personnel. It is used in laboratory as well as in field to measure VO_2 and HR. It is fixed to the subject during the test by an anatomic harness. The Personal Unit (PU) of the system contains the O_2 and CO_2 analyzers, sampling pump, UHF transmitter, barometric sensors and electronics. It is powered by the rechargeable battery fixed to the back side of the harness. The system can store data during the experiment in halter mode. The stored data can be downloaded to a computer using its software (Fig. 3.13).

Fig. 3.13 Computerized Ambulatory Metabolic Measurement System (K4 b^2).

3.9.2 Experimental design

Details of design of experiments for evaluating the performance of weeding operation is presented in Table 3.3.

Table 3.3 Details of Design of the Experiment for Evaluation of the Physiological Cost of Selected Female Subjects for Weeding Operation

Independent variables	Dependent variables	Levels	Description
Methods	Heart Rate (HR)	4	Kudali, khurpi, wheel hoe(CIAE model), wheel hoe (PAU model)
	Oxygen consumption rate (OCR)		

3.9.3 Evaluation of physiological cost of the selected subjects during weeding operation

Field experiments were carried out to assess heart rate and oxygen consumption rate response during weeding operation. The operation was performed in groundnut crop (Pratap variety) having a row to row spacing of 25 cm. (Fig. 3.14 and Fig. 3.15). Ten female subjects participated in the experiments.

3.9.3.1 Equipments, instruments and accessories used

1. Kudali
2. Khurpi
3. CIAE model wheel hoe
4. PAU model wheel hoe
5. Computerized Ambulatory Metabolic Measurement System (K4 b^2) (Section 3.9.1).
6. Thermometer
7. Hygrometer
8. Measuring tape
9. Stop watch

Some important specifications of the weeding tools/implements used in this experiment are given in Appendix-C.

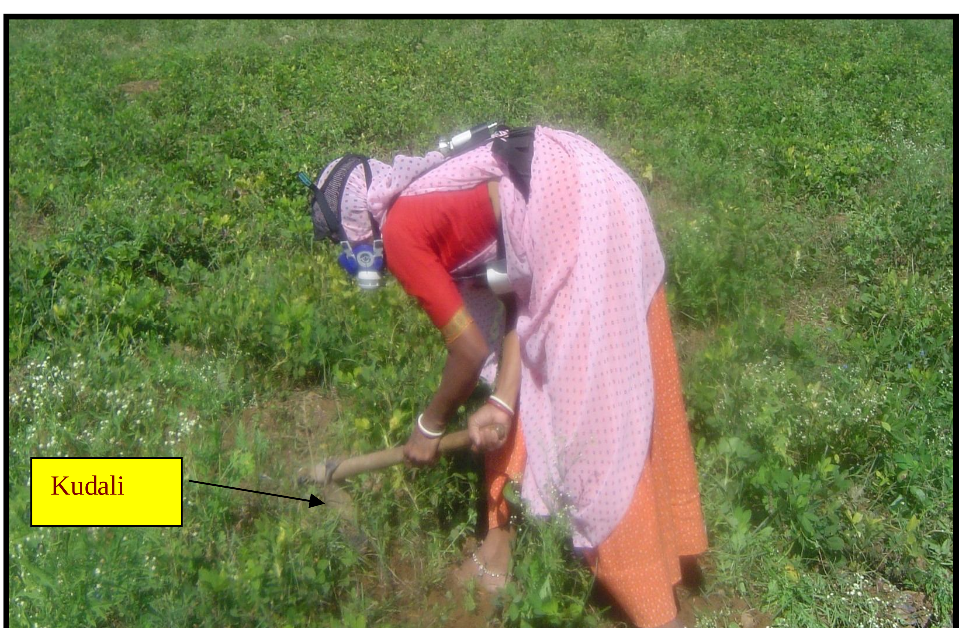
3.9.3.2 Experimental procedure

1. The selected female subjects were asked to report to the field in the morning at 8 am. It was ensured that they were in good health condition, had sound sleep in the previous night, and had a normal breakfast.
2. The environmental temperature and relative humidity was measured with the help of thermometer and hygrometer, respectively.
3. Computerized Ambulatory Metabolic Measurement System ($K4b^2$) was fixed to the operator. All precautions were observed while fitting $K4b^2$.
4. Before the start of the operation subject was asked to take rest for 10 minutes and her resting heart rate and resting oxygen consumption rate was recorded.
5. One of the subject was asked to operate kudali.
6. Observations were taken for 15 minutes working and 10 minutes resting.
7. During the operation, oxygen consumption rate and heart rate were recorded for each 4 second interval and 15 readings were averaged to get the mean heart rate and oxygen consumption rate for that minute. This gave the mean steady state OCR and HR.

8. All OCR values in BTPS were converted into STPD (760 mm Hg dry).
9. Increase in heart rate (ΔHR) and increase in oxygen consumption rate (ΔOCR) was computed from the difference between mean steady state of heart rate and oxygen consumption rate and their resting values respectively. Percent of Aerobic capacity was determined taking into consideration the method suggested by Varghese *et al*., (1995).
10. The energy expenditure rate (EER) was estimated by multiplying the working OCR with the calorific value of oxygen taken as 20.88 kJ/l (Nag and Dutt, 1980).
11. The increase in HR for an area covered ($\Delta HR/m^2$) by the subject was calculated.
12. Weeding efficiency and field capacity were measured, following the standard procedure.
13. Steps 5 to step 11 were repeated for next 9 female subjects.
14. Steps 5 to step 12 were repeated for remaining implements viz; khurpi, wheel hand hoe (CIAE model) and wheel hand hoe (PAU model).
15. No observations were repeated in a day.

3.9.4 Evaluation of physiological cost of the selected subjects during cob-Picking operation

Field experiment was carried out to assess heart rate and oxygen consumption rate response during cob-piking operation for maize crop. Ten female subjects participated in this operation. Some particulars of the crop used in experiment are given in Table 3.4



(a) Kudali

(b) Khurpi

Fig. 3.14 Physiological Cost Assessment for Female Subjects during Weeding Operation

(a) Wheel

hoe (CIAE model)

(b) Wheel hoe (PAU model)

Fig. 3.15 Physiological Cost Assessment for Female Subjects during Weeding Operation

Table 3.4 Some Particulars of the Maize Crop Used for Cob-Picking Operation

S.N.	Particulars	Observations
1	Variety	Pratap Makka 5
2	Plant to plant distance	25 cm
3	Row to row distance	45 cm
4	Average plant height	150 to 200 cm
5	No. of cobs per plant	2 to 3 cobs
6	Moisture content of cobs	17 to 18 per cent

3.9.4.1 Instruments and accessories used

1. Computerized Ambulatory Metabolic Measurement System (K4 b^2)
2. Thermometer
3. Hygrometer
4. Measuring tape
5. Stop watch

3.9.4.2 Experimental procedure

1. Step 1 to step 4 were followed (Section 3.9.3.2).
2. One of the subject was asked to pick the cobs from the standing maize plant. After picking a cob from the plant, she placed it on the ground and repeated this method till all those picked. She then shifted to next plant and followed the same method.
3. Step 2 was repeated for all plants in the assigned field.
4. Steps 6 to step 11 were followed (Section 3.9.3.2).
5. Cob picking efficiency and field capacity were estimated, following the standard procedure.
6. Steps 2 to step 4 were repeated for next 9 female subjects.
7. No observations were repeated in a day.

The results of this experiment are presented and discussed in Section 4.3.2

3.10 Body discomfort during weeding and cob picking operation.

Discomfort is the body pain arising as a result of the working posture and for an excessive stress on muscles due to the effort involved in the activities. It is also called overall discomfort. In many of the agricultural operations, though the work may be within physiological limits, the body discomfort restrict the duration of work depending upon the static loading component involved in it. Drudgery caused due to bad posture is reflected in terms of postural discomfort experienced by the worker. It has been observed by Gite (1996) that muscular discomfort of body is comparatively more important than heart rate and oxygen consumption rate in agricultural operations as limiting factors. For assessment of body discomfort, various subjective rating scale have been developed, but the methods which are commonly followed are Borg (1982), Corllet and Bishop (1976) Visual Analog Discomfort (VAD).

In the present study two methods i.e. Overall Discomfort Rating (ODR) and Body Part Discomfort Score (BPDS) were selected to assess the body discomfort. The overall discomfort rate and body parts discomfort score was obtained by the method/technique suggested by Corlett and Bishop (1976). This technique was used by Gite (1991), Gite (1996), Kathirvel *et al.*, (2003), etc. The overall discomfort rating was obtained with a ten point physiological rating scale (0 = no discomfort, 10 = extreme discomfort). For this purpose a scale of about 70 cm length was fabricated having 0 to 10 digits marked on it at equidistant. A movable pointer was provided to indicate the rating. For BPDS Corllet and Bishop have suggested body map showing its 27 regions as shown in Fig. 3.16.

3.10.1 Assessment of body discomfort during weeding operation

Field experiments were carried out to evaluate the performance of weeding operation in terms of ODR and BPDS. The selected ten female subjects participated in the operation.

3.10.1.1 Experimental design

Details of design of experiments for evaluating the body discomfort for weeding operation is presented in Table 3.5.

Table 3.5 Details of Design of the Experiment for Evaluation of Body Discomfort for Female Subjects during Weeding Operation

Independent variables	Dependent variables	Levels	Description
Methods	ODR	4	Kudali, khurpi, wheel hoe (CIAE model), wheel hoe (PAU model)
	BPDS		

3.10.1.2 Equipments and accessories used

1. Kudali
2. Khurpi
3. CIAE model Wheel hoe
4. PAU model Wheel hoe

5. Stop watch
6. Tape
7. Physiological rating scale
8. Body map showing its 27 regions (Fig. 3.16)

3.10.1.3 Experimental procedure for measuring discomfort

1. The selected female subjects were asked to report on the field in the morning at 8 am. It was ensured that they were in good health, had sound sleep in the previous night, and had a normal breakfast. They were free from stimulated beverages, tobacco and recent exercises.

2. The subjects were explained about the objectives of the experiment and made familiar with the operation to ensure their full cooperation.

3. The environmental temperature and relative humidity were measured with the help of thermometer and hygrometer, respectively.

4. The subject was asked to perform weeding operation with kudali.

5. The duration of each trial was one hour.

6. During the one hour operation, the subject was not given any rest.

7. After the weeding operation with kudali data on overall discomfort rating and body parts discomfort score was recorded as given below:

   a. At the end of each trial subject was asked to indicate their overall discomfort rating on the scale. The overall discomfort rating given by each subject were added and averaged to get the mean rating.

   b. For evaluating BPDS, the subject was asked to mention all body parts with discomfort, starting with most painful, the next most painful and so on till no further areas were referred. The subject was asked to point out on the body part in the order of one point for maximum pain, two points for next maximum pain, and so on. The number of different groups of body parts, which are identified from extreme discomfort to no discomfort, represented the number of intensity levels of pain experienced. The maximum number of intensity levels of pain experienced under different treatment was six categories. The rating was assigned to these categories in an arithmetic order viz; 1st category (body parts experiencing maximum pain) rating was allotted as '6' and for 2nd category (body parts experiencing next maximum pain) rating was allotted '5' and so on, finally for the sixth category (body parts experiencing least pain) rating was allotted as ‘1’. It was found that the number of intensity levels of pain experienced by different subjects might vary. In order to get an ideal analysis of the results after ranking, each data was marked in a numerical way. All the marks were added for each body part. The body discomfort score of all the subjects was added.

8. The steps 4 to 7 were repeated for the next 9 subjects.

9. The Steps 4 to 8 were repeated for remaining three method of weeding operations.

The results of the experiment are presented and discussed in Section 4.4.2.2.

3.10.2 Assessment of Body discomfort during cob-picking operation

Field experiment was carried out to evaluate ODR and BPDS experienced by the subjects. All the selected female subjects participated in this experiment (Fig. 3.17 and Fig. 3.18).

3.10.2.1 Instruments and accessories used

1. Thermometer
2. Hygrometer
3. Measuring tape
4. Stop watch
5. Physiological rating scale
6. Body map showing its 27 regions

3.10.2.2 Experimental procedure for measuring discomfort

1. Step 1 to step 4 were followed (Section 3.10.1.3).
2. One of the Subjects was asked to start cob-picking operation.
3. Steps 5 to step 7 (Section 3.10.1.3) were followed with subject.
4. Area covered during the operation was measured. Cob picking efficiency, field capacity and field efficiency were calculated as per standard procedures
5. Steps 2 to step 3 were repeated for next 9 subjects.

The results of the experiment are presented and discussed in Section 4.4.2.

Fig. 3.17 Subject Showing different Body Regions during BPDS Assessment after Cob-Picking Operation

Fig. 3.18 Subject during Overall Discomfort Rating Assessment after Cob-Picking Operation

IV RESULTS AND DISCUSSIONS

The results of the anthropometric survey and evaluation of the selected farm operations are presented in this chapter under the following headings.

1. Anthropometric and Strength measurements of female agricultural workers
2. Physiological cost of operator for Manual Weeding and Cob-Picking Operations
3. Body discomfort experienced by the operator during Manual Weeding and cob-Picking Operations.
4. Mechanical evaluation of Implements for Weeding Operation

4.1. Anthropometric and strength measurements of Female Agricultural workers

Twenty-four body dimensions and seven strength parameters of fifty female agricultural workers of the region are presented in Appendix-A. Range, mean, standard deviation, standard error, coefficient of variation, coefficient of correlation, 5^{th}, 95^{th} percentile and difference between 95^{th} and 5^{th} percentile were computed. The consolidated data of these dimensions and strength parameters are presented in Table 4.1(a) and Table 4.1 (b). From the Table it appeared that the mean stature and weight of the female agricultural workers were 152.77 cm and 47.13 kg respectively. The 5^{th} and 95^{th} percentile of stature and weight were 145.94 and 159.59 cm and 34.36 kg and 59.60 kg respectively. This suggests that while designing agricultural equipments, the design parameter should not exceed this range. This is in agreement with data collected by Rahi (2003) who mentioned mean stature and weight as 153.7 cm and 44.3 kg respectively. Coefficient of variation for stature was 2.72 per cent where as Rahi (2003) reported this value as 3.99 per cent. The mean right and left hand grip strength were 240.69 N and 229.32 N respectively. The 5^{th} and 95^{th} percentiles of right and left hand grip strength were 149.89 N, 331.48 N and 146.80 N, 311.84 N respectively. The mean push and pull strength with both hands in standing posture were 122.17 N and 140.69 N respectively. The 5^{th} and 95^{th} percentile of push and pull strength with both hands in standing posture were 32.58 N, 211.75 N and 78.63 N, 202.75 N respectively. The mean right and left hand pull strength in sitting posture were 129.22 N and 122.32 N respectively. The 5^{th} and 95^{th} percentiles of right and left hand pull strength in sitting posture were 59.75 N, 198.70 N and 55.21 N, 189.44 N respectively. The mean hand grip torque was 1.09 N-m. The 5^{th} and 95^{th} percentile of hand grip torque was 0.39 N-m and 1.80 N-m respectively.

Table 4.1 (a) indicated that all body dimensions were correlated significantly at 1 per cent level with stature except weight, sitting acromial height, sitting popliteal height, elbow rest height, fore arm hand length, hand length, hand breadth at metacarpal-III, palm length, grip diameter (inside and outside), middle finger pal grip diameter, grip span, maximum grip length. These dimensions were found non significant except for sitting acromial height, sitting popliteal height, fore arm hand length, hand length, grip diameter (inside). They were found significant at 5 per cent level of significance.

Table 4.1 (b) indicated that the seven strength parameters were found non significant when correlated with stature. However they were correlated significantly at 1 per cent level with weight except hand grip strength right and left, pull strength with both hands in standing posture, right and left hand pull strength in sitting posture and hand grip torque. The pull strength with both hands in standing posture was found significant at 5 per cent level of significance.

Correlation between stature and other body dimensions of female agricultural workers are presented in Fig.4.1 (a) through Fig.4.1 (d). From the Fig. 4.1(a) through Fig. 4.1(d) it appeared that there are linear relationship between stature and other body dimensions except weight, elbow rest height, hand breadth at metacarpal-III, middle finger palm grip diameter, grip span and maximum grip length. The correlation coefficient and coefficient of variation ranged from 0.03 to 0.93 and 2.72 to 16.47 per cent for all selected body dimensions respectively. However coefficient of variation of weight was higher for female subjects as compared to other body dimensions. This parameter, as reported by Wen *et al.*, (1999) for female subjects was 17.53 per cent. Fig.4.1 (e) through Fig.4.1 (f) shows the correlation between stature and other strength parameters. The correlation coefficient and coefficient of variation ranged from 0.02 to 0.23 and 21.88 to 44.58 per cent for all selected strength parameters respectively. It can be seen that there is no linear relationship between stature and other strength parameters. Fig.4.1 (g) through Fig.4.1 (h) shows the correlation between weight and other strength parameters. The correlation coefficient ranged from 0.02 to 0.4. It appeared that there are no linear relationships between weight and other strength parameter except push and pull strength with both hands in standing posture.

Table 4.2 shows the comparison between the anthropometric data of female agricultural workers of the present study and study conducted for agricultural workers of Kerala, Gujarat and Arunachal Pradesh. The mean stature of female agricultural workers of the study was found to be about 3.7 per cent higher than Kerala and 1.2 per cent lower than Gujarat. However, nearly same mean stature was observed for Arunachal Pradesh. The mean weight of female agricultural workers of the study was found to be about 1 per cent higher than Kerala workers and 4.8 and 1.8 per cent lower than Gujarat and Arunachal Pradesh workers respectively.

Stature ratio of the present study was compared with the data available for Kerala, Gujarat and Arunachal Pradesh. These are presented in Table 4.3, it can be seen that almost similar stature ratios were obtained. Thus the present study was in broad agreement with Geetha and Tewari (2000), Yadav

(2000) and Dewangan *et al.*, (2008) studies. Further if the stature is known than the other body dimensions can be calculated by the proportions.

The collected anthropometric data and stature ratio of female agricultural workers of present study was compared with other countries (Table 4.4). The mean stature was found to be about 6.7, 6, 3.7, 4.9 and 2.3 per cent lower than American, British, Chinese, Egyptian and Taiwanese respectively. Table 4.5 presents stature ratio of the present study with the countries of selected body dimensions. The Table show almost similar stature ratio of selected body dimensions. Thus the present study was in broad agreement with the earlier studies.

Table 4.6 shows the comparison between the anthropometric data of the present study and male agricultural workers of Rajasthan, Gujarat, Eastern India, North Eastern India, Southern India, Central India and Western India. The mean stature of female agricultural workers of the study was found to be about 8.3, 8.5, 5.7, 7.3, 4.9, 4.5 and 7.1 percent cent lower than Rajasthan, Gujarat, Eastern India, North Eastern India, Southern India, Central India and Western India respectively. The mean weight of the present study was 11.1, 23, 12.1, 16.7 and 4.4 per cent lower than Rajasthan, Gujarat, Eastern India, Southern India, Central India and respectively. Stature ratio of the present study was compared with the data available for Rajasthan, Gujarat, Eastern India, North Eastern India, Southern India, Central India and Western India they are presented in Table 4.7. The Table 4.7 shows almost similar stature ratios. Thus the present study was in broad agreement with the earlier studies. Further if the stature is known than the other body dimensions can be calculated by proportions.

Table 4.8 shows comparison between strength parameters of present study and the study conducted for female agricultural workers of Madhya Pradesh, Arunachal Pradesh and Tamil Nadu. The mean right hand grip strength of female agricultural workers of the study was found to be 12.1 and 18.6 per cent higher than Madhya Pradesh and Arunachal Pradesh and 14.7 per cent lower than Tamil Nadu respectively. The mean left hand grip strength of the present study was found to be 24.8 and 30 per cent higher than Madhya Pradesh and Arunachal Pradesh and 19.7 per cent lower than Tamil Nadu respectively. The mean push strength with both hands in standing posture of present study was 43.6, 55.6 and 6.7 per cent lower than Madhya Pradesh, Arunachal Pradesh and Tamil Nadu respectively.

For the scientific design of agricultural tools, an anthropometric database is a prerequisite. The marginal and small farmers of Western India extensively use various hand tools like khurpi (interculture tool), kudali for intercultural operations. Based on the anthropometric considerations, length of handle, handle diameter for better grip can be considered. During pushing operation of wheel hoe, the blade uproots the weeds. The wheel hoe is brought back by the pull action. The handle of the wheel hoe should be designed such that during operation the operator stands erect as far as possible to reduce musculoskeletal discomfort. The optimum length of handle, can be considered from the geometry adopted by the female operator. Further grip of the handle, inclination of the handle and height from the ground should considered so as to suit the agricultural female worker.

Thus, the study presents a useful compilation of the selected anthropometric and strength data of female agricultural workers of the region. These data could be used in designing new and modifying existing agricultural equipment developed in other parts of the country and even other countries to suit human capabilities and limitations of agricultural workers in western India (Rajasthan). Since female participation in various agricultural operations is increasing at a faster rate in various states of the country and in this region, greater stress should be given to develop new tools and machinery suitable for capabilities and limitation of female agricultural workers. In addition agricultural equipment available for male operators may be redesigned or modified to suit female limitations. Further taking into consideration the range of 5^{th} and 95^{th} percentile of the selected body dimensions adjustable design could be made and range of adjustments may be provided.

Table 4.1 (a) Anthropometric Measurements of 50 Female Agricultural Workers of age group of 25-45 years

S. N	Dimensions	Range	Mean	SD	SE	CV %	R	5th Percentile	95th Percentile	95th percentile -5th percentile
A. Measurements in standing posture										
1	Weight (Kg)	34.30 - 69.20	47.13	7.76	1.18	16.47	0.23 NS	34.36	59.90	25.54
2	Stature	144.00 - 161.40	152.77	4.15	0.59	2.72		145.94	159.59	13.65
3	Eye height	133.00 - 149.40	141.45	3.88	0.55	2.75	0.93*	135.06	147.84	12.78
4	Acromial height	108.50 - 135.40	126.69	4.60	0.65	3.63	0.86*	119.12	134.25	15.13
5	Elbow height	91.00 - 105.00	96.86	3.32	0.47	3.43	0.79*	91.40	102.32	10.92
6	Olecranon height	86.80 - 102.20	93.97	3.40	0.48	3.61	0.80*	88.38	99.56	11.18
7	Illiocrystale height	92.00 - 113.00	92.09	3.50	0.50	13.50	0.68*	91.46	106.06	40.16
8	Knee height	39.00 - 52.50	45.18	2.62	0.37	5.81	0.71*	40.87	49.50	8.63
9	Arm reach from the wall	71.50 - 88.10	79.79	3.81	0.51	4.77	0.43*	73.52	86.06	12.53
10	Forearm hand length	35.80 - 45.00	41.71	2.05	0.29	4.92	0.32**	38.34	45.09	6.75
B. Measurements in sitting posture										
11	Sitting height	65.80 - 83.40	77.15	3.11	0.36	4.03	0.42*	72.04	82.27	10.24
12	vertical grip reach height	100.60 - 120.00	109.16	3.82	0.54	3.50	0.64*	102.88	115.44	12.56
13	Eye height	61.50 - 71.50	66.77	2.51	0.36	3.76	0.40*	62.64	70.91	8.27
14	Acromial height	47.00 - 56.50	52.31	2.34	0.33	4.47	0.35**	48.46	56.15	7.69
15	Popliteal height	35.50 - 43.40	39.45	1.83	0.26	4.64	0.36**	36.44	42.46	6.02
16	Elbow rest height	15.00 - 27.70	22.18	2.62	0.37	11.82	0.18 NS	17.87	26.49	8.62
C. Miscellaneous measurements										
17	Hand length	15.90 - 20.50	17.93	1.03	0.15	5.73	0.34**	16.24	19.61	3.38
18	Hand breadth at metacarpal-III	6.60 - 8.70	7.58	0.44	0.06	5.86	0.05 NS	6.85	8.31	1.46
19	Palm length	8.40 - 11.50	9.69	0.68	0.10	7.02	0.39**	8.57	10.81	2.24
20	Grip diameter (inside)	4.00 - 5.20	4.52	0.32	0.05	7.08	0.31**	4.00	5.05	1.05
21	Grip diameter (outside)	6.20 - 9.00	7.36	0.55	0.08	7.45	0.40*	6.46	8.27	1.81
22	Middle finger palm grip diameter	1.90 - 3.00	2.48	0.27	0.04	10.81	0.16 NS	2.04	2.92	0.88
23	Grip span	5.30 - 8.70	7.12	0.95	0.13	13.28	0.03 NS	5.57	8.68	3.11
24	Maximum grip length	7.20 - 12.70	9.13	1.26	0.18	13.77	0.18 NS	7.07	11.20	4.14

All the dimensions are in cm, unless specified.

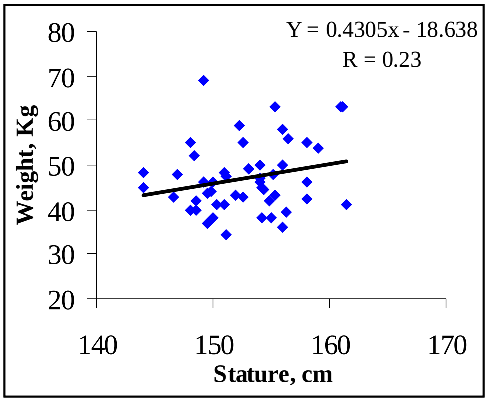
* Significant at 1%level ** Significant at 5%level NS Non significant

Table 4.1 (b) Strength Measurements of 50 Female Agricultural Workers of age group of 25-45 years

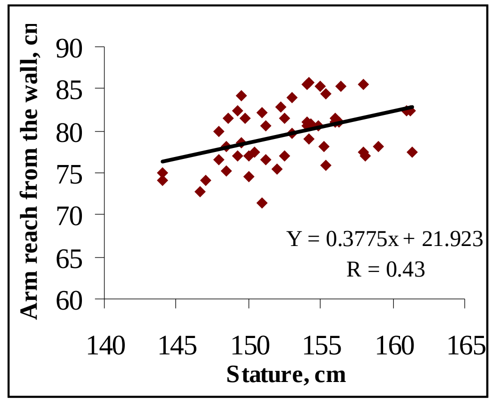
S. N.	Dimensions	Range	Mean	SD	SE	CV%	R		5th Percentile	95th Percentile	95th percentile -5th percentile
							Stature	Weight			
D. Strength Measurements											
1	Hand grip strength (right) (N)	117.60 - 333.20	240.69	55.19	7.81	22.93	0.08^{NS}	0.14^{NS}	149.89	331.48	181.59
2	Hand grip strength (left) (N)	117.60 - 333.20	229.32	50.17	7.09	21.88	0.02^{NS}	0.09^{NS}	146.80	311.84	165.05
3	Push strength with both hands in standing posture (N)	34.30 -323.40	122.17	54.46	7.70	44.58	0.08^{NS}	0.41*	32.58	211.75	179.17
4	Pull strength with both hands in standing posture (N)	58.80 - 274.40	140.69	37.72	5.34	26.81	0.02^{NS}	0.35**	78.63	202.75	124.11
5	Right hand pull strength in sitting posture (N)	55.86 - 245.00	129.22	42.23	5.97	32.68	0.14^{NS}	0.18^{NS}	59.75	198.70	138.95
6	Left hand pull strength in sitting posture (N)	58.80 - 225.40	122.32	40.80	5.77	33.35	0.23^{NS}	0.07^{NS}	55.21	189.44	134.22
7	Hand grip torque (N-m)	1.96 – 0.54	1.09	0.43	9.7	2.57	0.06^{NS}	0.02^{NS}	0.39	1.80	1.40

All the dimensions are in Newton, unless specified.

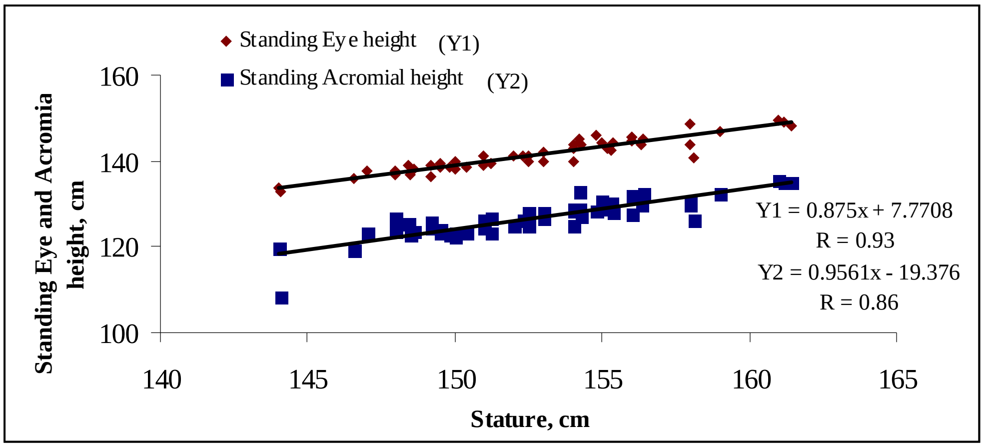
* Significant at 1%level **Significant at 5%level NS Non significant



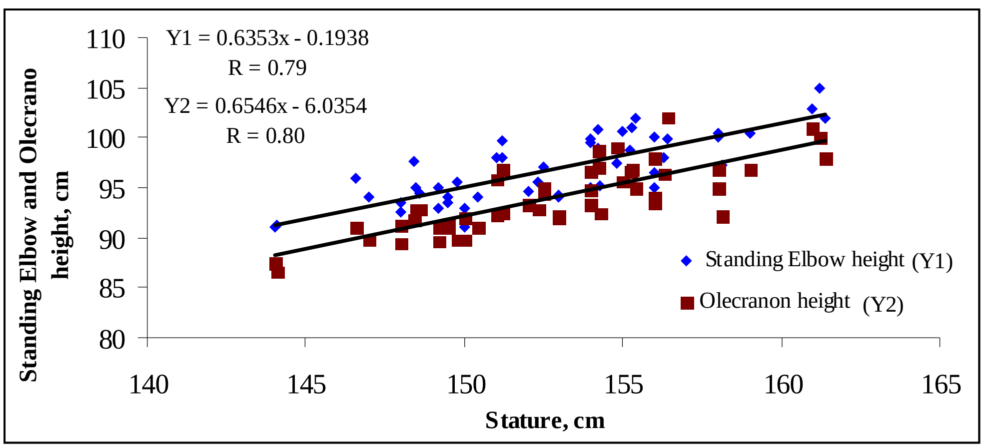
Weight



Arm Reach from the Wall

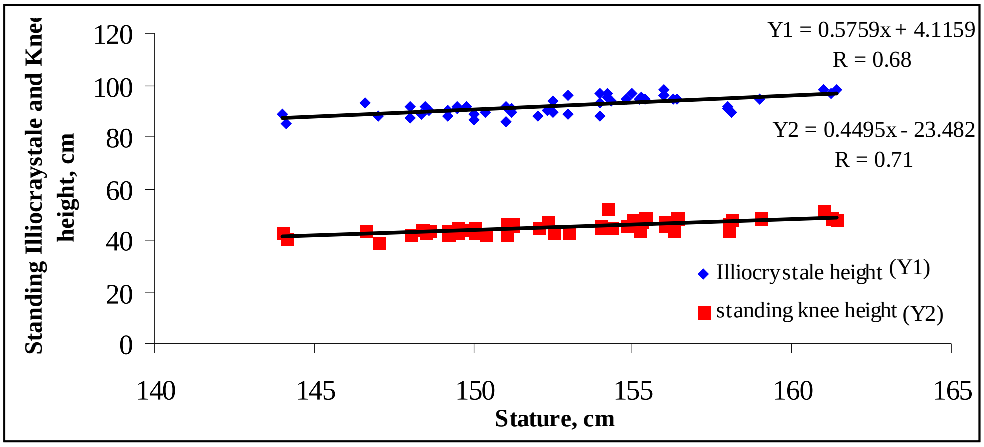


Standing Eye Height and Acromial Height

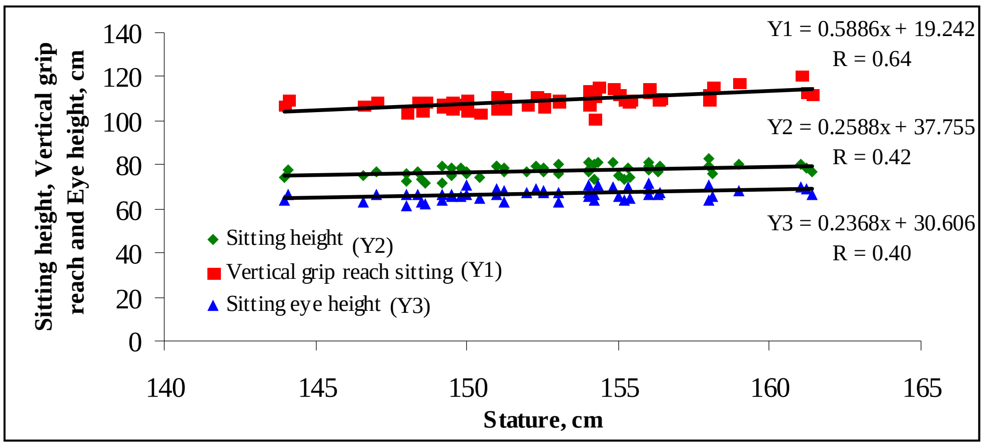


Standing Elbow Height and Olecranon Height

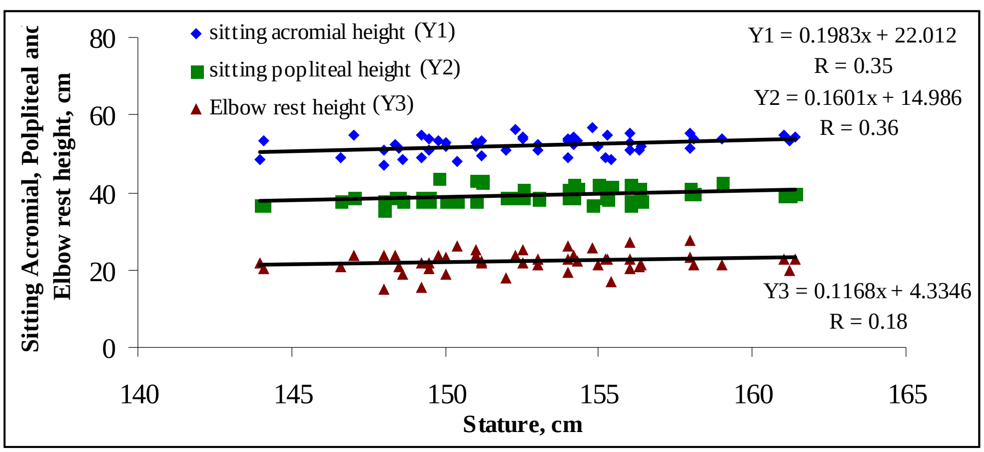
Fig 4.1 (a) Correlation between Stature and other Body Dimensions of Female Agricultural Workers



Standing Illiocrystale Height and Knee Height

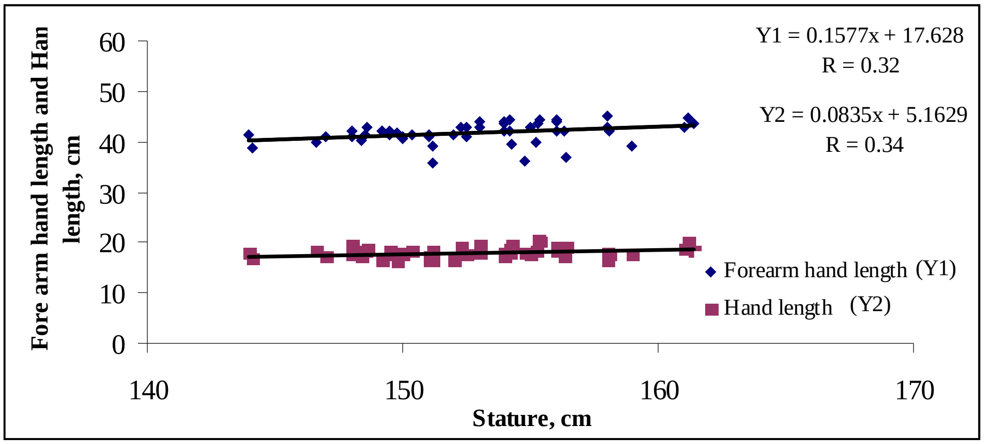


Sitting Height, Vertical Grip Reach and Eye Height

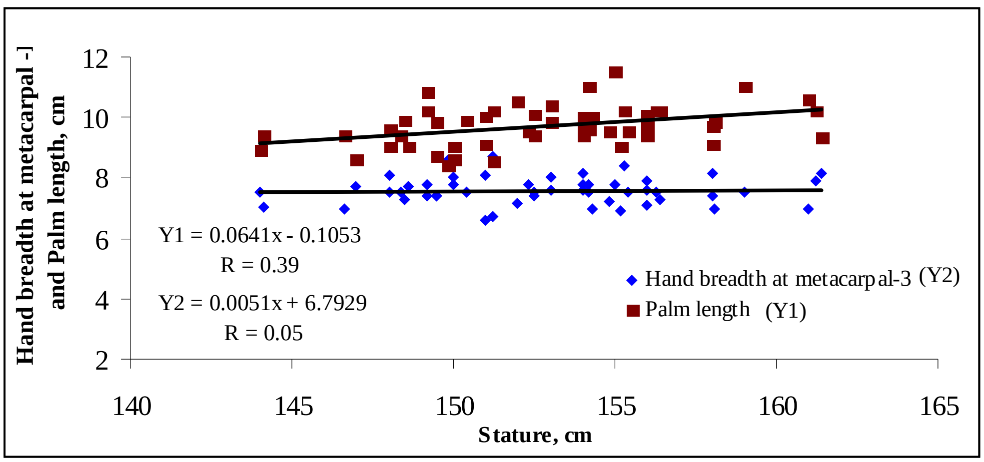


Sitting Acromial, Popliteal and Elbow Rest Height

Fig 4.1 (b) Correlation between Stature and other Body Dimensions of Female Agricultural Workers

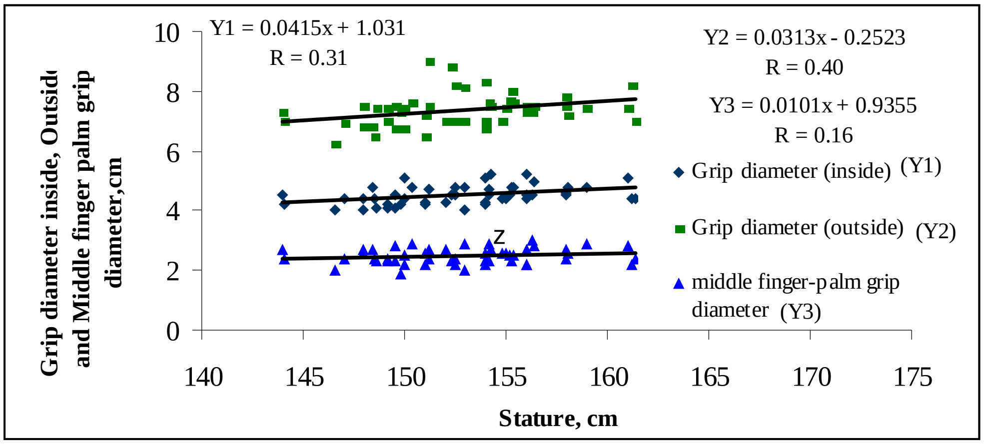


Forearm Hand Length and Hand Length

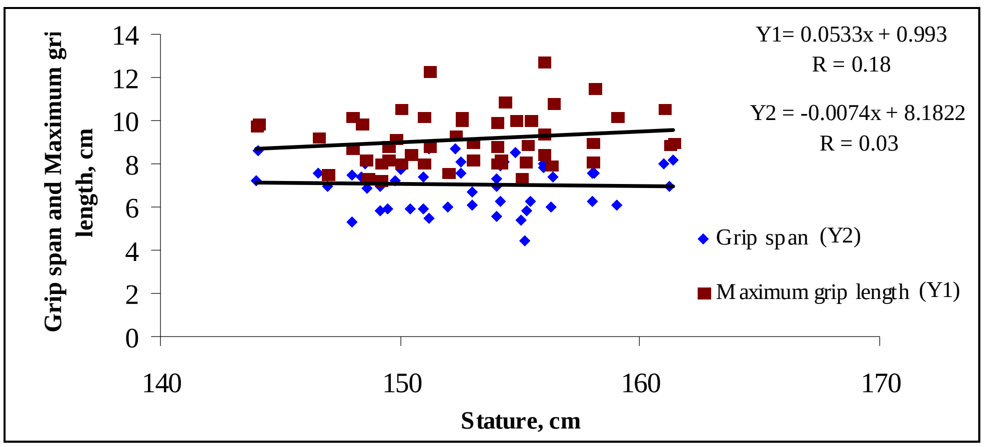


Hand Breadth at Metacarpal- III and Palm Length

Fig 4.1 (c) Correlation between Stature and other Body Dimensions of Female Agricultural Workers

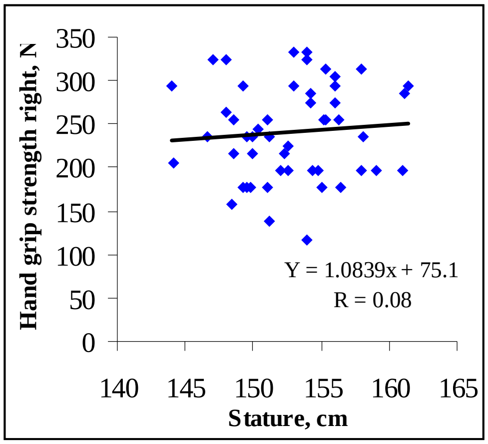


Grip Diameter (Inside), Grip Diameter (Outside) and Middle Finger Palm Grip Diameter

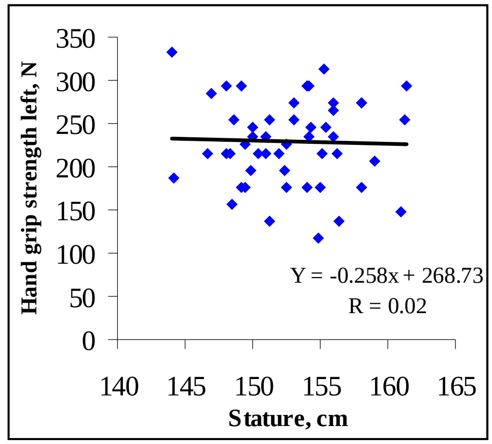


Grip Span and Maximum Grip Length

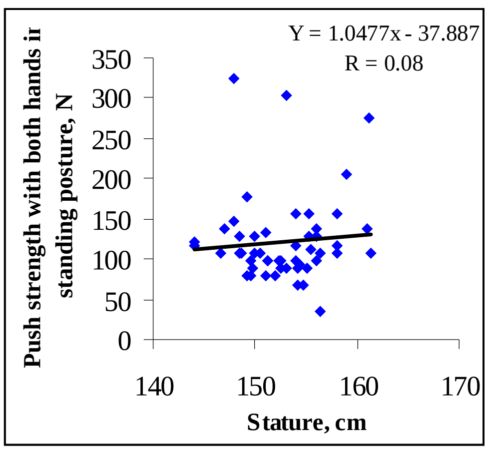
Fig 4.1 (d) Correlation between Stature and other Body Dimensions of Female Agricultural Workers

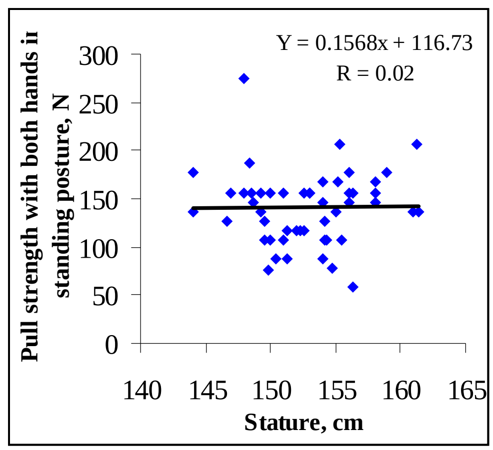


Hand Grip Strength Right



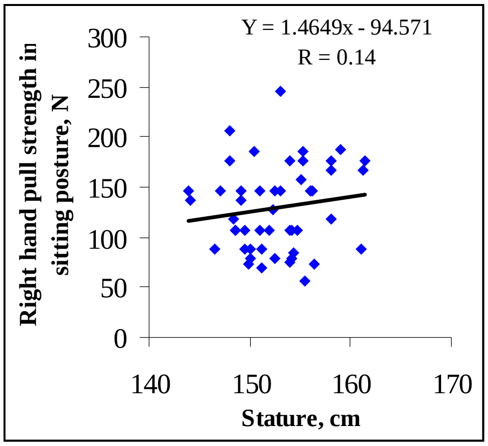
Hand Grip Strength Left

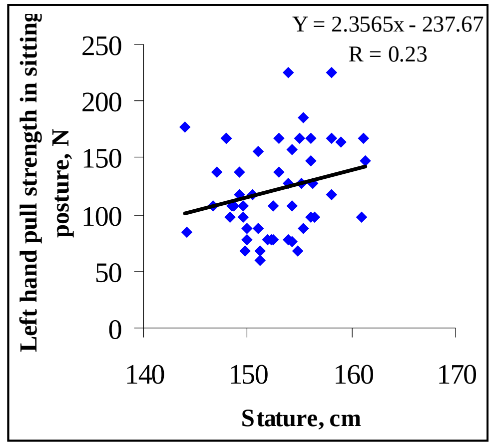




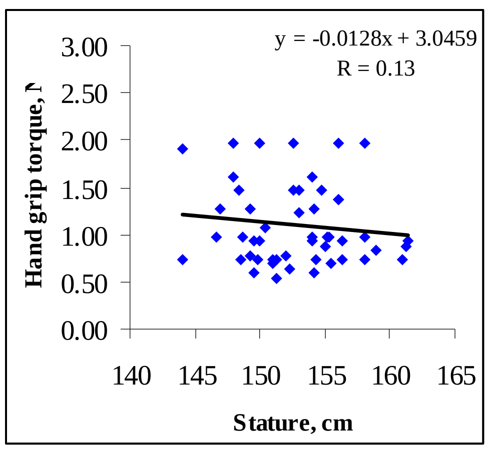
Push and Pull Strength with Both Hands in Standing Posture

Fig 4.1 (e) Correlation between Stature and other Strength Parameters of Female Agricultural Workers



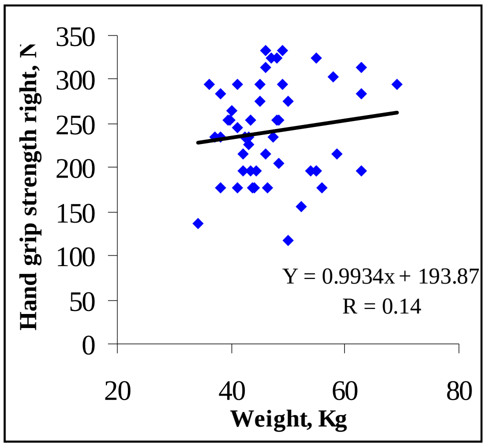


Right and Left Hand Pull Strength in Sitting Posture

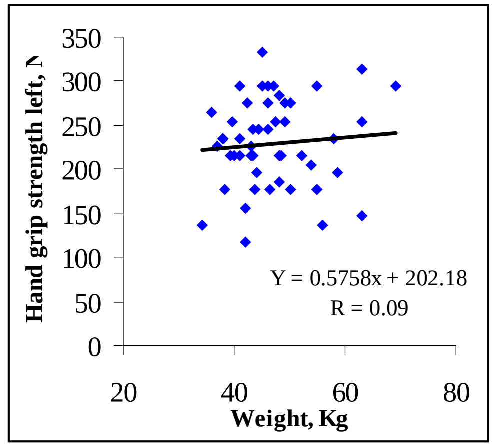


Hand Grip Torque

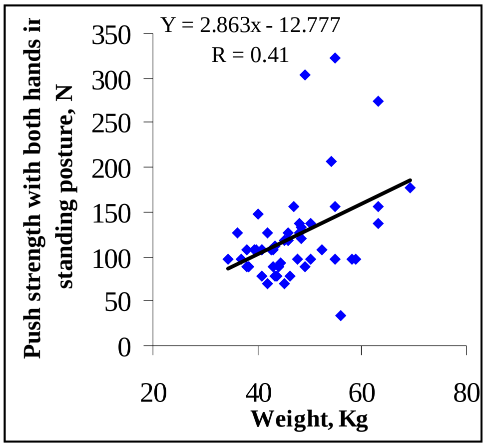
Fig 4.1 (f) Correlation between Stature and other Strength Parameters of Female Agricultural Workers

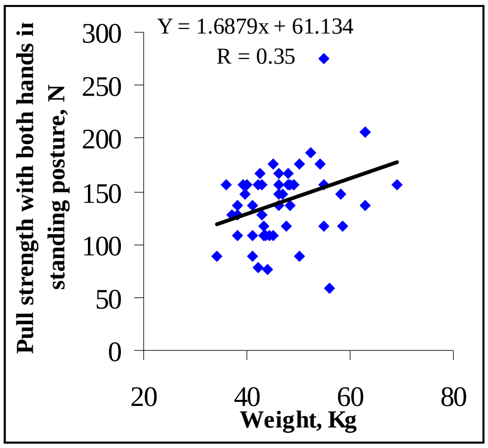


Hand Grip Strength Right



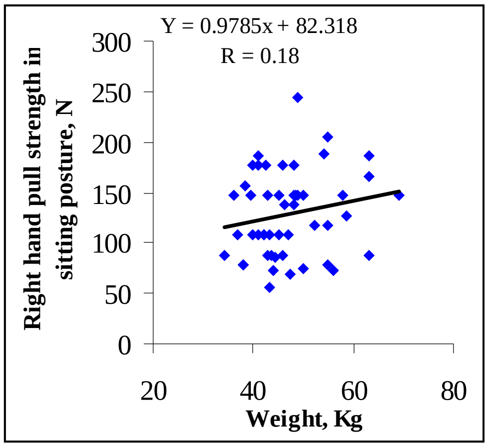
Hand Grip Strength Left

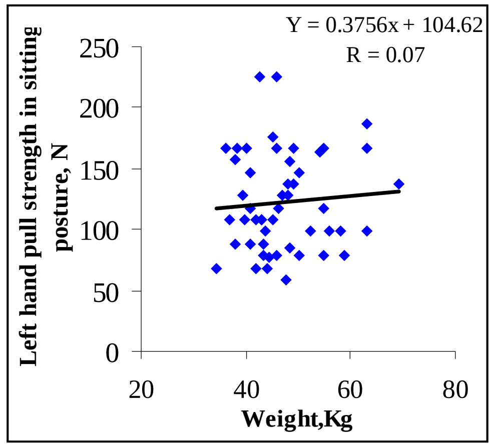




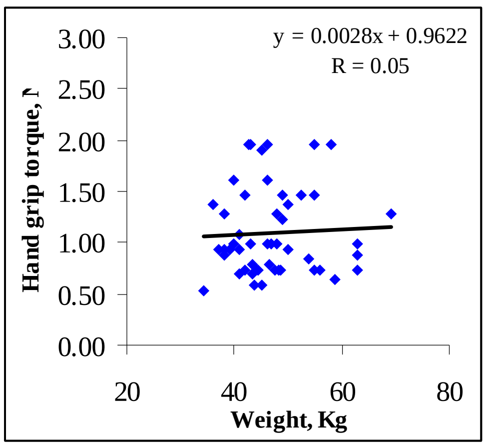
Push and Pull Strength with Both Hands in Standing Posture

Fig 4.1 (g) Correlation between Weight and other Strength Parameters of Female Agricultural Workers





Right and left Hand Pull Strength in Sitting Posture



Hand Grip Torque

Fig 4.1 (h) Correlation between Weight and other Strength Parameters of Female Agricultural Workers

Table 4.2 Comparison of Anthropometric Data of Present Study with Female Agricultural Workers of Kerala, Gujarat and Arunachal Pradesh

All dimensions are in cm, unless specified. ♠♠Data are Mean (±SD)

S.N	**Dimensions**	**Present Study♠♠**	**Kerala ♦**	**Gujarat***	**Arunachal Pradesh ♠**
1	Weight (Kg)	47.13(±7.76)	46.6(±7.4)	49.5(±5.25)	48.01(±4.38)
2	Stature	152.77(±4.15)	147.3(±6.8)	154.6(±6.18)	153.25(±5.50)
3	Standing eye height	141.45±3.88)	140.4(±5.6)	145.3(±5.05)	141.76(±5.16)
4	Standing acromial height	126.69(±4.60)	24.6(±7.7)	127.5(±4.86)	127.09(±4.27)
5	Standing elbow height	96.86(±3.32)	73.6(±13.5)	97.3(±6.68)	96.18(±4.22)
6	Olecranon height	93.97(±3.40)	NA	NA	94.11(±3.98)
7	Illiocrystale height	92.09(±3.50)	NA	NA	89.54(±3.94)
8	Standing knee height	45.18(±2.62)	45.6(±3.1)	NA	41.21(±2.43)
9	Arm reach from the wall	79.79(±3.81)	NA	76.4(±3.63)	73.12(±3.05)
10	Forearm hand length	41.71(±2.05)	41.4(±1.95)	NA	40.70(±1.71)
11	Sitting height	77.15(±3.11)	NA	76.9(±2.45)	80.28(±3.44)
12	vertical grip reach height sitting	109.16(±3.82)	NA	NA	111.0(±4.20
13	Sitting eye height	66.77(±2.51)	NA	65.2(±2.10)	68.74(±2.78)
14	Sitting acromial height	52.31(±2.34)	NA	47.4(±2.62)	54.61(±3.13)
15	Sitting popliteal height	39.45(±1.83)	NA	39.8(±2.14)	35.31(±1.86)
16	Sitting elbow rest height	22.18(±2.62)	NA	17.8(±1.38)	23.39(±2.29)
17	Hand length	17.93(±1.03)	17.3(±2.1)	16.5(±1.28)	16.53(±0.73)
18	Hand breadth at metacarpal-III	7.58(±0.44)	5.1(±1.3)	7.8(±0.76)	6.49(±0.30)
19	Palm length	9.69(±0.68)	NA	NA	9.11(±0.43)
20	Grip diameter (inside)	4.52(±0.32)	NA	3.8(±0.22)	4.35(±0.28)
21	Grip diameter (outside)	7.36(±0.55)	NA	NA	7.37(±0.43)
22	Middle finger palm grip diameter	2.48(±0.27)	NA	NA	1.99(±0.17)
23	Grip span	7.12(±0.95)	NA	NA	5.93(±0.57)
24	Maximum grip length	9.13(±1.26)	NA	NA	9.10(±0.48)

♦Geetha and Tewari (2000) * Yadav (2000) ♠ Dewangan *et al.*, (2008)

Table 4.3 Comparison of Stature Ratio of Present study with Female Agricultural Workers of Kerala, Gujarat and Arunachal Pradesh.

S.N	Dimensions	Stature Ratio			
		Present Study♠♠	Kerala ♦	Gujarat*	Arunachal Pradesh ♠
1	Weight (Kg)	0.31	0.32	0.32	0.31
2	Stature				
3	Standing eye height	0.93	0.95	0.94	0.93
4	Standing acromial height	0.84	0.85	0.82	0.83
5	Standing elbow height	0.65	0.50	0.63	0.63
6	Olecranon height	0.62	NA	NA	0.61
7	Illiocrystale height	0.60	NA	NA	0.58
8	Standing knee height	0.30	NA	NA	0.27
9	Arm reach from the wall	0.52	NA	0.49	0.48
10	Forearm hand length	0.27	NA	0.27	0.27
11	Sitting height	0.51	NA	0.50	0.52
12	Vertical grip reach height sitting	0.71	NA	NA	0.72
13	Sitting eye height	0.44	NA	0.42	0.45
14	Sitting acromial height	0.34	NA	0.31	0.36
15	Sitting popliteal height	0.26	NA	0.26	0.23
16	Sitting elbow rest height	0.15	NA	0.12	0.15
17	Hand length	0.12	0.12	0.107	0.11
18	Hand breadth at metacarpal-III	0.05	0.03	0.05	0.04
19	Palm length	0.06	NA	NA	0.06
20	Grip diameter (inside)	0.03	NA	0.02	0.03
21	Grip diameter (outside)	0.05	NA	NA	0.05
22	Middle finger palm grip diameter	0.02	NA	NA	0.01
23	Grip span	0.05	NA	NA	0.04
24	Maximum grip length	0.06	NA	NA	0.06

All dimensions are in cm, unless specified.

♦Geetha and Tewari (2000) * Yadav (2000) ♠ Dewangan *et al.*, (2008)

Table 4.4 Comparison of Selected Body Dimensions of Present study with Female Agricultural Workers of Other Countries

S.N.	Dimensions	Present Study ♠♠	American[a]	Britsh[b]	Chinese[c]	Egyptian[d]	Mexican[e]	Taiwanes[f]
1	Stature	152.77 (±4.15)	163.71 (±6.21)	162.45 (±5.50)	158.62 (±5.13)	160.60 (±7.18)	153.50 (±5.50)	156.32 (±2.32)
2	Standing Eye height	141.45 (±3.88)	NA	NA	148.03 (±7.60)	149.20 (±6.98)	142.80 (±5.60)	144.98 (±5.24)
3	Standing acromial height	126.69 (±4.60)	135.40 (±5.95)	NA	132.03 (±6.10)	130.6 (±5.99)	NA	128.02 (±4.74)
4	Standing elbow height	96.86 (±3.32)	102.34 (±4.52)	NA	NA	95.50 (±4.35)	95.60 (±3.80)	97.33 (±3.71)
5	Arm reach from the wall	79.79 (±3.81)	NA	NA	78.54 (±3.80)	81.40 (±5.03)	NA	75.44 (±3.50)
6	Forearm hand length	41.71 (±2.05)	45.05 (±3.18)	42.68 (±1.83)	NA	41.20 (±2.60)	41.50 (±1.90)	NA
7	Sitting height	77.15 (±3.11)	NA	NA	84.85 (±3.16)	83.80 (±4.30)	NA	84.48 (±3.00)
8	Vertical grip reach height sitting	109.16 (±3.82)	NA	NA	NA	NA	NA	NA
9	Sitting eye height	66.77 (±2.51)	NA	75.97 (±2.90)	75.3	74.30 (±4.06)	NA	73.20 (±2.99)
10	Sitting acromial height	52.31 (±2.34)	NA	58.02 (±2.50)	NA	55.60 (±4.00)	NA	NA
11	Sitting popliteal height	39.45 (±1.83)	NA	NA	38.27 (±2.08)	NA	NA	NA
12	Sitting elbow rest height	22.18 (±2.62)	NA	NA	23.86 (±2.66)	19.70 (±1.16)	NA	NA
13	Hand length	17.93 (±1.03)	NA	NA	NA	17.1 (±1.24)	16.90 (±0.90)	NA

Measuring units is cm unless specified. ♠♠Data are Mean (±SD)

[a] Marras and Kim (1993) [b] Haslegrave (1980) [c] Shao and Zhou (1990) [d] Moustafa *et al*., (1987)
[e] Liu *et al*., (1999) [f] Wang *et al*., (1999)

Table 4.5 Comparison of Stature Ratio of present study with Female Agricultural Workers of Other Countries

S.N	Dimensions	Stature Ratio						
		Present Study ♠♠	American[a]	Britsh[b]	Chinese[c]	Egyptian[d]	Mexican[e]	Taiwanes[f]
1	Stature							
2	Standing eye height	0.93	NA	NA	0.93	0.93	0.93	0.93
3	Standing acromial height	0.84	0.83	NA	0.83	0.81	NA	0.82
4	Standing elbow height	0.65	0.63	NA	NA	0.60	0.62	0.62
5	Arm reach from the wall	0.52	NA	NA	0.50	0.51	NA	0.48
6	Forearm hand length	0.27	0.28	0.26	NA	0.26	0.27	NA
7	Sitting height	0.51	NA	NA	0.53	0.52	NA	0.54
8	Vertical grip reach height sitting	0.71	NA	NA	NA	NA	NA	NA
9	Sitting eye height	0.44	NA	0.47	0.47	0.46	NA	0.47
10	Sitting acromial height	0.34	NA	0.36	NA	0.35	NA	NA
11	Sitting Popliteal height	0.26	NA	NA	0.24	NA	NA	NA
12	Elbow rest height	0.15	NA	NA	0.15	0.12	NA	NA
13	Hand length	0.12	NA	NA	NA	0.11	0.11	NA

All the body dimensions are in cm unless specified.

[a] Marras and Kim (1993) [b] Haslegrave (1980) [c] Shao and Zhou (1990) [d] Moustafa *et al.*, (1987)

[e] Liu *et al.*, (1999) [f] Wang *et al.*, (1999)

Table 4.6 Comparison of Selected Anthropometric Data of Female Agricultural Workers of Present study with Male Agricultural Workers of Different Regions of India

S.N	Dimensions	Present Study ♠♠	Rajasthan♦	Gujarat●	Eastern India*	North Eastern India ♥	Southern India **	Central India♠	Western India ♣
1	Weight (Kg)	47.13 (±7.76)	53.04 (± 9.15)	61.2 (±15.17)	53.6 (±6.73)	NA	56.6 (±5.14)	49.3 (±5.95)	NA
2	Stature	152.77 (±4.15)	166.67 (±5.97)	167 (±7.48)	162.1 (±5.8)	164.87 (±4.54)	160.7 (±6.0)	160 (±4.95)	164.40
3	Standing eye height	141.45 (±3.88)	155.90 (±6.26)	156.72 (±7.33)	150.8 (±5.1)	153.55 (±5.00)	149.7 (±6.1)	151 (±5.22)	NA
4	Standing aromial height	126.69 (±4.60)	139.68 (±5.50)	NA	131.2 (±4.8)	134.47 (±4.30)	130.1 (±4.6)	134.6 (±4.87)	NA
5	standing elbow height	96.86 (±3.32)	105.29 (±5.39)	106.38 (±4.96)	101.8 (±3.8)	101.91 (±3.56)	98.9 (±3.8)	102.6 (±2.89)	NA
6	Olecranon height	93.97 (±3.40)	103.29 (±4.86)	NA	NA	98.64 (±3.40)	NA	NA	NA
7	Illiocrystale height standing	92.09 (±3.50)	NA	NA	NA	93.10 (±3.20)	NA	NA	NA
8	Standing knee height	45.18 (±2.62)	NA	NA	NA	45.07 (±2.42)	NA	NA	NA
9	Arm reach from the wall	79.79 (±3.81)	82.89 (±4.54)	83.84 (±4.8)	82.8 (±3.9)	NA	NA	83.1 (±3.9)	NA
10	Forearm hand length	41.71 (±2.05)	NA	NA	44.60 (±1.96)	43.20 (±1.97)	40.10 (±2.50)	NA	NA
11	Sitting height	77.15 (±3.11)	85.22 (±4.36)	81.56 (±4.69)	80.9 (±2.2)	84.70 (±2.88)	79.1 (±4.0)	NA	86.20
12	Sitting eye height	66.77 (±2.51)	73.42 (±4.19)	72.02 (±4.59)	71.4 (±2.0)	73.38 (±3.17)	70.3 (±4.6)	NA	NA
13	Sitting acromial height	52.31 (±2.34)	58.17 (±3.16)	NA	53.2 (±2.12)	54.30 (±2.74)	52.9 (±3.9)	NA	NA
14	Sitting popliteal height	39.45 (±1.83)	43.52 (±2.29)	NA	42 (±1.74)	41.25 (±2.56)	47.1 (±3.5)	NA	42.00
15	Sitting elbow rest height	22.18 (±2.62)	21.97 (±2.45)	NA	17.5 (±1.58)	NA	15.4 (±0.60)	NA	NA
16	Hand length	17.93 (±1.03)	19.052 (±1.07)	18.58 (±1.08)	17.8 (±1.61)	17.95 (±0.56)	16.4 (±1.4)	NA	19.10
17	Hand breadth at metacarpal-III	7.58 (±0.44)	8.291 (±0.52)	9.06 (±0.66)	NA	8.59 (±0.44)	NA	NA	NA
18	Palm length	9.69 (±0.68)	11.01 (±0.63)	10.5 (± 0.58)	NA	9.95 (±0.34)	NA	NA	NA
19	Grip diameter (inside)	4.52 (±0.32)	5.04 (±0.37)	NA	NA	4.77 (±0.30)	NA	NA	NA
20	Grip diameter (outside)	7.36 (±0.55)	NA	5.15 (±0.19)	4.3 (±0.39)	NA	NA	4.1 (±0.3)	NA

Measuring units is cm unless specified. ♠♠Data are Mean (±SD)

♦ Rahi (2003) •Yadav (2003) * Yadav *et al.*, (1997) ** Fernandez and Uppugonduri (1992)

♠ Gite and Yadav (1989) ♥ Dewangan *et al.*, (2005) ♣ Sen (1964)

S.N	Dimensions	Stature Ratio

Table 4.7 Comparison of Female Stature Ratio of Present study with Male Agricultural Workers of Different Regions of India

		Present Study ♠♠	Rajasthan♦	Gujarat●	Eastern India*	North Eastern India ♥	Southern India **	Central India♠	Western India ♣
1.	Weight (Kg)	0.31	0.32	0.37	0.33	NA	0.35	0.31	NA
2.	Stature								
3.	Standing eye height	0.93	0.94	0.94	0.93	0.93	0.93	0.94	NA
4.	Standing acromial height	0.84	0.84	0.84	0.84	0.82	0.84	0.84	NA
5.	Standing elbow height	0.65	0.63	0.64	0.63	0.62	0.62	0.64	NA
6.	Olecranon height	0.62	0.62	N.A	N.A	0.60	N.A	NA	NA
7.	Illiocrystale height	0.60	NA	N.A	N.A	0.56	N.A	NA	NA
8.	Standing knee height	0.30	NA	NA	NA	0.27	NA	NA	NA
9.	Arm reach from the wall	0.52	0.50	0.5	0.51	NA	N.A	0.52	NA
10.	Forearm hand length	0.27	NA	NA	NA	0.26	NA	NA	NA
11.	Sitting height	0.51	0.51	0.49	0.5	0.51	0.49	NA	0.52
12.	Sitting eye height	0.44	0.44	0.43	0.44	0.45	0.44	NA	NA
13.	Sitting acromial height	0.34	0.35	N.A	0.33	0.33	0.33	NA	NA
14.	Sitting popliteal height	0.26	0.26	N.A	0.26	0.25	0.29	NA	0.27
15.	Sitting elbow rest height	0.15	0.13	0.11	0.11	NA	0.1	NA	NA
16.	Hand length	0.12	0.11	0.11	0.11	0.12	0.1	NA	0.12
17.	Hand breadth at metacarpal-III	0.05	0.05	0.05	N.A	0.05	N.A	NA	NA
18.	Palm length	0.06	0.07	0.06	N.A	0.06	N.A	NA	NA
19.	Grip diameter (inside)	0.03	0.03	0.03	0.03	0.03	N.A	NA	NA
20.	Grip diameter (outside)	0.05	NA	NA	NA	NA	NA	0.03	NA

All the body dimensions are in cm unless specified.

♦ Rahi (2003) •Yadav (2003) * Yadav *et al.*, (1997) ** Fernandez and Uppugonduri (1992)

♠ Gite and Yadav (1989) ♥ Dewangan *et al*., (2005) ♣ Sen (1964)

Table 4.8 Comparison of Strength Parameters of Present study with Female Agricultural Workers of Madhya Pradesh, Arunachal Pradesh and Tamil Nadu

S.N	Parameters	Present study ♠♠	Madhya Pradesh *	Arunachal Pradesh ♣	Tamil Nadu ♦
1	Hand grip strength (right)	240.69±55.19	214.7± 70.3	202.86±82.32	276.05±70.71
2	Hand grip strength (left)	229.32±50.17	183.8 ± 69.0	176.4±68.6	274.43±74.15
3	Push strength with both hands in standing posture	122.17±54.46	175.5 ± 33.9	190.12±68.6	130.34±31.48
4	Pull strength with both hands in standing posture	140.69±37.72	159.4 ± 42.9	153.86±43.12	168.59±42.94
5	Right hand pull strength in sitting posture	129.22±42.23	67.2 ± 17.9	114.66±50.96	137.38±30.44
6	Left hand pull strength in sitting posture	122.32±40.80	52.9 ± 13.6	111.72±40.18	139.26±33.04
7	Hand grip torque (N-m)	1.09±0.43	0.59±0.2	2.35±0.78	4.10±1.04

All parameters are in Newton, unless specified. ♠♠Data are Mean (±SD)

*Tiwari *et al.*, (2007) ♣ Anonymous (2007) ♦ Anonymous (2005)

4.2. Subjects Selection

Thirty-one body dimensions including strength parameters involved in manual weeding and cob-picking operations of 10 female (S_1 to S_{10}) of Udaipur district were measured. The subjects were randomly selected. Their particulars are given in Table 4.9. The consolidated data on selected body dimensions and strength parameters are presented in Table 4.10. The Table shows that the stature and weight of female subjects ranged from 144.10 cm to 161.00 cm (Mean = 154.62 cm) and 42 kg to 63 kg (Mean = 50.50 Kg) respectively. It may be mentioned here that, these subjects were used for field evaluation of manual weeding and cob-picking operations.

Table 4.9 Particulars of the selected subjects

Subject code	Name of Subjects	Age (years)	Stature (cm)	Weight (Kg)	Left/right handed	Chewing tobacco/pan
S_1	Amba Bai	35	154.80	42.00	Right	No
S_2	Basanti Bai	27	155.40	43.40	Right	No
S_3	Bhamri Bai	40	148.40	52.30	Left	No
S_4	Chandri Bai	32	158.10	42.50	Right	No
S_5	Dali Bai	42	156.40	56.00	Right	No
S_6	Devi Bai	45	159.00	54.00	Right	No
S_7	Heera Bai	45	161.00	63.00	Right	No
S_8	Rami Bai	29	144.10	48.30	Right	No
S_9	Rukmini Bai	35	151.00	48.50	Right	No
S_{10}	Sundar	25	158.00	55.00	Right	No

Table 4.10 Anthropometric and strength measurements of 10 Randomly Selected Female Agricultural Workers of Age group of 25-45 years

Body Dimensions	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	Mean
A. Measurements in standing posture											
Weight (Kg)	42.00	43.40	52.30	42.50	56.00	54.00	63.00	48.30	48.50	55.00	50.50
Stature	154.80	155.40	148.40	158.10	156.40	159.00	161.00	144.10	151.00	158.00	154.62
Eye height	146.00	144.10	138.90	140.90	145.20	146.80	149.40	133.00	139.00	148.50	143.18
Acromial height	128.50	128.20	125.50	126.20	132.50	132.40	135.40	108.50	124.40	130.60	127.22
Elbow height	97.50	102.00	97.60	97.30	99.80	100.50	102.80	91.20	95.70	100.50	98.49
Olecranon height	99.20	95.00	91.90	92.10	102.20	96.80	101.00	86.80	92.40	96.80	95.42
Illiocrystale height	94.30	94.20	88.80	89.50	94.60	94.50	98.50	85.20	85.50	92.00	91.71
Knee height	45.60	49.00	44.20	47.70	48.90	49.00	51.50	40.60	46.60	46.40	46.95
Arm reach from the wall	80.50	76.00	78.10	77.10	85.30	88.10	82.50	74.20	82.20	85.60	80.96
Forearm hand length	36.30	44.40	40.20	42.00	37.00	39.10	42.90	38.60	41.00	42.70	40.42
B. Measurements in sitting posture											
Sitting height	81.00	74.60	77.00	76.00	79.00	81.00	80.00	78.00	80.20	83.40	79.02
vertical grip reach height	114.00	109.00	108.00	115.00	110.00	117.00	120.00	109.00	110.70	109.20	112.19
Eye height	70.40	64.50	66.50	65.50	67.50	68.00	70.00	67.00	69.00	71.00	67.94
Acromial height	56.50	48.40	52.50	54.00	52.00	53.70	55.00	53.50	53.00	55.20	53.38
Popliteal height	37.00	41.70	39.00	40.00	38.00	42.50	39.50	37.00	43.00	41.30	39.90
Elbow rest height	25.70	17.00	23.60	21.40	21.40	21.20	23.00	20.20	24.00	27.70	22.52
C. Miscellaneous measurements											
Hand length	18.00	20.00	17.20	17.50	19.00	17.40	18.60	16.60	16.50	16.50	17.73
Hand breadth at metacarpal-III	7.20	7.50	7.50	7.00	7.30	7.50	7.00	7.20	6.60	7.40	7.22
Palm length	9.50	9.50	9.40	9.80	10.20	11.00	10.60	9.40	10.00	9.10	9.85
Grip diameter (inside)	4.40	4.80	4.80	4.80	5.00	4.80	5.10	4.20	4.30	4.60	4.68
Grip diameter (outside)	7.00	7.60	6.80	7.20	7.50	7.40	7.40	7.00	7.20	7.80	7.29
Middle finger palm grip diameter	2.60	2.50	2.70	2.60	2.80	2.90	2.80	2.40	2.60	2.40	2.63
Grip span	8.50	6.30	7.40	7.60	7.40	6.10	8.00	8.60	5.90	6.30	7.21
Maximum grip length	10.00	10.00	9.80	11.50	10.80	10.20	10.50	9.80	10.20	9.00	10.18
D. Strength Measurements											
Hand grip strength (right) (N)	196.00	254.80	156.80	235.20	176.40	196.00	196.00	205.80	254.80	196.00	206.78
Hand grip strength (left)(N)	117.60	245.00	215.60	274.40	137.20	205.80	147.00	186.20	215.60	176.40	192.08
Push strength with both hands in standing posture (N)	68.60	112.70	107.80	107.80	34.30	205.80	137.20	120.54	132.30	156.80	118.38
Pull strength with both hands in standing posture (N)	78.40	107.80	186.20	166.60	58.80	176.40	137.20	137.20	156.80	156.80	136.22
Right hand pull strength in sitting posture (N)	107.80	55.86	117.60	176.40	73.50	191.10	88.20	137.20	147.00	117.60	121.23
Left hand pull strength in sitting posture (N)	68.60	88.20	98.00	225.40	98.00	163.66	98.00	85.26	155.82	117.60	119.85
Hand grip torque (N-m)	1.47	0.69	1.47	1.96	0.74	0.83	0.74	0.74	0.74	0.74	1.01

All dimensions are in cm, unless specified.

4.3 Physiological Cost of the Workers during the Manual Weeding and Cob-Picking Operations.

Experiments were carried out to assess the physiological cost of the subjects in terms of heart rate (HR), oxygen consumption rate (OCR), and energy expenditure rate (EER). The effect of four methods of manual weeding and cob-picking operations and interaction between these factors on increase in oxygen consumption rate and heart rate were evaluated statistically. The increase in heart rate (ΔHR) and oxygen consumption rate (ΔOCR) is expressed as difference in working heart rate and resting heart rate, as working oxygen consumption rate and resting oxygen consumption rate respectively.

Heart rate (HR) and oxygen consumption rate (OCR) of all selected subjects were measured during manual weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe and cob-picking manually. As the experiment was spread over 40 days, the mean values of HR and OCR were used for comparison of different trials to eliminate the effect of different days as well as the time. The experiment was conducted from 9 AM to 2 PM during a day. Appendix-D and Appendix-E shows the heart rate and oxygen consumption rate response of the subjects during manual weeding and cob picking operations. The estimation of energy expenditure rate from measured HR and OCR is included in the Appendix. The results are given under the following sections.

4.3.1 Heart rate response of the subjects during weeding operation.

The mean dry bulb temperature, wet bulb temperature, relative humidity and wind velocity varied between 8.4 to 23.5^{0}C, 7.6 to 16.6^{0}C, 35 to 85 per cent and 1.6 to 3.2 km/h respectively during the experiments.

Table 4.11 shows that the mean working HR (beats/min) and mean work pulse (ΔHR) of the subjects during all four manual weeding operations. The mean HR of the subjects during weeding operation ranged from 104.9 to124.5 beats/min and 94.9 to 110.6 beats/min for kudali and khurpi respectively. The mean HR of the subjects during weeding with CIAE model wheel hoe and PAU model wheel hoe ranged from 108.5 to 125.7 beats/min and 107.0 to 122.1 beats/min respectively.

Mean work pulse (ΔHR) for all subjects ranged from 27.1 to 48.3 beats/min, 23.5 to 31.3 beats/min, 32.8 to 49.7 beats/min and 32.2 to 48.9 beats/min for weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe respectively.

Table 4.11 Heart Rate Response during Manual Weeding

Methods	Kudali	Khurpi	CIAE model	PAU model

of weeding					Wheel hoe		Wheel hoe	
Subjects	**HR (beats /min)**	**ΔHR (beats /min)**	**HR (beats/ min)**	**ΔHR (beats/ min)**	**HR (beats/ min)**	**ΔHR (beats/ min)**	**HR (beats/ min)**	**ΔHR (beats/ min)**
S_1	110.6	44.1	98.8	25.4	111.1	34.6	113.0	36.5
S_2	117.1	39.7	104.2	26.3	113.9	36.5	119.7	45.5
S_3	109.7	37.8	98.5	24.8	110.7	43.1	107.9	44.7
S_4	119.2	48.3	106.3	27.6	117.2	45.9	109.9	38.0
S_5	104.9	27.1	98.8	26.2	114.6	37.9	122.1	44.7
S_6	106.2	31.4	109.6	29.6	124.1	46.2	121.3	44.5
S_7	114.8	39.9	100.8	25.5	112.2	32.8	107.0	32.2
S_8	124.5	44.5	110.6	31.3	125.7	49.7	119.2	42.7
S_9	115.3	37.7	102.3	25.9	112.5	39.2	118.4	39.6
S_{10}	108.4	29.4	94.9	23.5	108.5	40.0	116.0	48.9
Mean	**113.1**	**38.0**	**102.5**	**26.6**	**115.1**	**40.6**	**115.4**	**41.7**

Mean working HR and work pulse (ΔHR) for all weeding operations are presented in Fig 4.2. The lowest mean working HR was observed as 102.5 beats/min for khurpi and highest was 115.4 beats/min for PAU model wheel hoe method, followed by 115.1 beats/min for CIAE model wheel hoe and 113.1 beats/min for kudali method.

Mean ΔHR value during weeding operation with kudali and khurpi was 38.0 beats/min and 26.6 beats/min respectively. Mean ΔHR for CIAE model wheel hoe and PAU model wheel hoe was 40.6 beats/min and 41.7 beats/min respectively. Mean ΔHR for kudali, CIAE model wheel hoe and PAU model wheel hoe were higher as compared to weeding with khurpi. The mean HR of subjects while, weeding with khurpi was 11.2 per cent lower than PAU model wheel hoe. Mean HR value for CIAE model wheel hoe (115.1 beats/min) and PAU model wheel hoe (115.4 beats/min) was nearly same. The mean work pulse (ΔHR) for the subjects while, weeding with kudali, khurpi, CIAE model wheel hoe was 8.9, 36.2 and 2.6 percent lower than PAU model wheel hoe respectively.

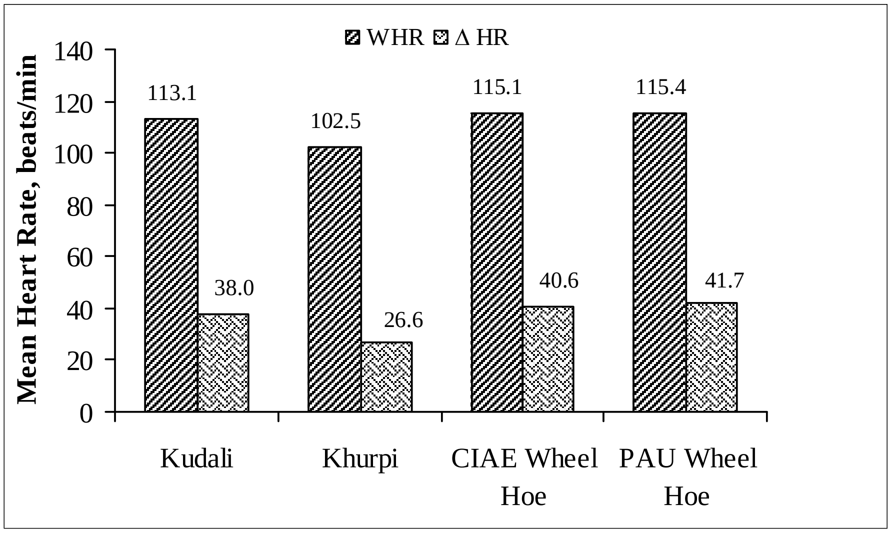


Fig 4.2 Mean working HR and ΔHR for manual weeding

Table 4.12 Increase in Heart Rate/m^2 of the Subjects during different Weeding operations

Method of operation	Increase in heart rate of the area covered HR/m^2	Area covered m^2/h
Kudali	43.0	53
Khurpi	35.5	45
CIAE model wheel hoe	16.0	152
PAU model wheel hoe	17.1	146

Table 4.12 shows the effect of using different methods on heart rate response of the selected subjects during weeding operation. The increase in HR/m^2 of area covered while, weeding with khurpi, CIAE model wheel hoe and PAU model wheel hoe was 17.4, 62.8 and 60.2 per cent lower than kudali method respectively. Weeding with khurpi was superior to kudali method in terms of HR and ΔHR but area covered was less. Though there was no much difference between CIAE model wheel hoe, PAU model wheel hoe and kudali for subjects in terms of HR and ΔHR, both wheel hoes were superior to kudali and khurpi in terms of ΔHR/m^2. Area covered with wheel hoes were 3.38 and 3.24 times more over khurpi operation.

Gite *et al*., (1999) reported mean values of heart rate during weeding work as 101.6 and 126.6 beats/min for hand hoe (khurpi) and wheel hoe. The corresponding work pulse (ΔHR) was 21.1 and 40.7 beats/min. The manual weeding operation with khurpi, CIAE and PAU model wheel hoe method required almost same effort as required in Gite studies. Behera *et al*., (2007) as also observed heart rate between 115.08±1.47 and 128.7±1.67 beats/min for wheel hoe in ground nut crop.

4.3.1.1 Statistical analysis for mean working HR and ΔHR for manual weeding operation.

In order to see the significance of heart rate for different methods of weeding operations, the data were analyzed with statistical software SPSS 12.0 and ANOVA for this operation is presented in Table 4.13. The Table shows that, mean working HR during weeding with the kudali was significantly higher than khurpi and non significant with CIAE model wheel hoe and PAU model wheel hoe. Mean working HR during weeding with khurpi was significantly lower than kudal*i*, CIAE model wheel hoe and PAU model wheel hoe. Similarly mean working HR during weeding with the PAU model wheel hoe was non significant with CIAE model wheel hoe.

Table 4.13 ANOVA Table for HR and ΔHR of the Selected Subjects during Weeding Operation

Parameter		CD	CV	Sum of Squares	df	Mean Square	F_{cal}
HR	Between Groups	5.15	5.11	1120.297	3	373.432	11.576*
	Within Groups			1161.367	36	32.260	
	Total			2281.664	39		
ΔHR	Between Groups	4.73	14.31	1439.016	3	479.672	17.673*
	Within Groups			977.108	36	27.142	
	Total			2416.124	39		

* Significant at 5 per cent

Significant difference in ΔHR for weeding operations was also observed. The mean ΔHR during weeding with the kudali was significantly higher than khurpi and non significant with CIAE and PAU wheel hoe. For khurpi ΔHR was significantly lower than that of kudali, CIAE model wheel hoe and PAU model wheel hoe. There was no significant difference in ΔHR between CIAE and PAU model wheel hoe.

4.3.2 Oxygen consumption rate during manual weeding.

The mean OCR of the subjects during weeding operation ranged from 0.535 to 0.609 l/min and 0.497 to 0.553 l/min for kudali and khurpi respectively. The mean OCR of the subjects ranged from 0.618 to 0.723 l/min and 0.648 to 0.739 l/min for CIAE model wheel hoe and PAU model wheel hoe respectively (Table 4.14).

The mean ΔOCR during weeding operation ranged from 0.377 to 0.458 l/min, 0.356 to 0.393 l/min, 0.471 to 0.569 l/min and 0.494 to 0.579 l/min for kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe method, respectively. The working OCR and ΔOCR for CIAE model wheel hoe and PAU model wheel hoe was higher compared to other method. This may be due to application of more continuous push and pull force as compared to other methods.

Table 4.14 Mean Working OCR and ΔOCR of Manual Weeding

Methods of weeding	Kudali		Khurpi		CIAE model Wheel hoe		PAU model Wheel hoe	
Subjects	**OCR (l/min)**	**ΔOCR (l/min)**	**OCR (l/min)**	**ΔOCR (l/min)**	**OCR (l/min)**	**ΔOCR (l/min)**	**OCR (l/min)**	**ΔOCR (l/min)**
S_1	0.565	0.426	0.514	0.369	0.619	0.471	0.668	0.510
S_2	0.588	0.433	0.529	0.374	0.666	0.514	0.731	0.579
S_3	0.556	0.414	0.513	0.366	0.618	0.478	0.662	0.531
S_4	0.599	0.458	0.535	0.379	0.682	0.538	0.663	0.519
S_5	0.535	0.382	0.513	0.368	0.670	0.518	0.739	0.578
S_6	0.537	0.386	0.550	0.388	0.719	0.559	0.711	0.551
S_7	0.580	0.430	0.519	0.369	0.653	0.487	0.648	0.494
S_8	0.609	0.450	0.553	0.393	0.723	0.569	0.706	0.548
S_9	0.580	0.423	0.525	0.372	0.655	0.509	0.700	0.537
S_{10}	0.536	0.377	0.497	0.356	0.631	0.489	0.691	0.550
Mean	**0.569**	**0.418**	**0.525**	**0.373**	**0.664**	**0.513**	**0.692**	**0.540**

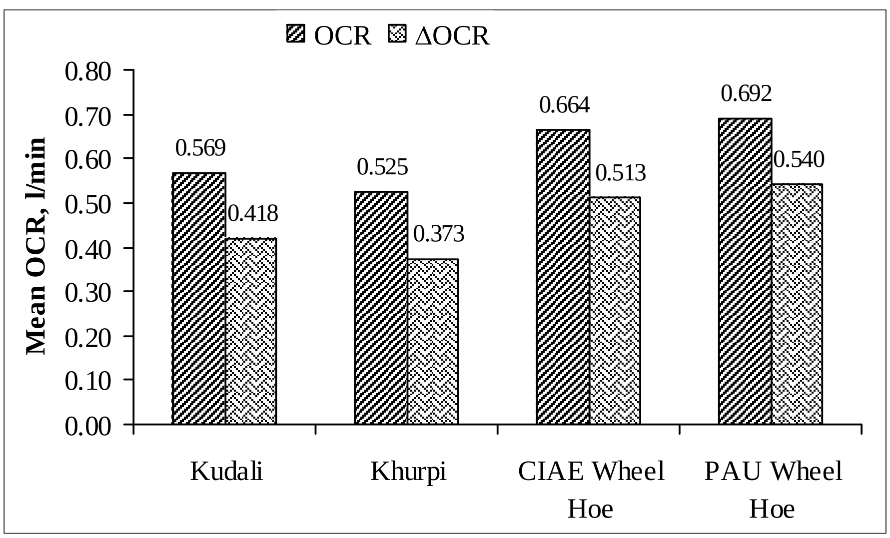


Fig 4.3 Mean working OCR and ΔOCR of weeding operation

Fig 4.3 shows mean working OCR and ΔOCR of weeding operation. Mean OCR of subjects during weeding operation was found to be 0.569, 0.525, 0.664 and 0.692 l/min for kudali, khurpi, CIAE and PAU model wheel hoe methods respectively, i.e 33.27, 30.66, 38.78 and 40.42 per cent of aerobic capacity (Section 3.9.3.2). Thus the value for all weeding operation was within the acceptable limit of 40% of Aerobic capacity (Nag and Chatterjee 1981). Mean working OCR was highest for CIAE model wheel hoe and PAU model wheel hoe because it required more physical effort than other weeding methods. Similar results have been reported by Nag and Dutt (1979). They observed this value in the range of 0.569 to 1.158 l/min.

The ΔOCR were 0.418 l/min, 0.373 l/min, 0.513 l/min and 0.540 l/min for weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe method, respectively. For weeding with khurpi ΔOCR was lowest but it was nearly equal to weeding with kudali, for both methods physical effort requirement was same, while weeding with CIAE and PAU model wheel hoe require maximum push and pull force.

4.3.2.1 Statistical analysis of mean working OCR and ΔOCR of weeding operation.

Table 4.15 shows that mean working OCR and ΔOCR were statistically significant, but was non significant with the same operation for different subjects. Multiple comparisons for manually weeding operation on the basis of dependent variables by Post Hock Method with the help of SPSS 12.0 statistical software shows that there was no significant difference between the mean working OCR during weeding with kudali and khurpi. However this was significantly lower than CIAE and PAU model wheel hoe. The mean working OCR for CIAE model wheel hoe did not differ significantly with mean working OCR for PAU model wheel hoe.

Table 4.15 ANOVA Table for OCR and ΔOCR of the Selected Subjects during Weeding Operation

Parameter		CD	CV	Sum of Squares	df	Mean Square	F_{cal}
OCR	Between Groups	0.03	4.68	0.185	3	0.062	73.646*
	Within Groups			0.030	36	0.001	
	Total			0.216	39		
ΔOCR	Between Groups	0.02	5.58	0.184	3	0.061	88.168*
	Within Groups			0.025	36	0.001	
	Total			0.210	39		

* Significant at 5 per cent

The ΔOCR during weeding with the kudali did not differ significantly with khurpi. However this value was significantly lower than CIAE and PAU model wheel hoe. Similarly the mean ΔOCR for khurpi was significantly lower in comparison to CIAE and PAU model wheel hoe. There was no significant difference between the ΔOCR for CIAE and PAU model wheel hoe.

4.3.3 Energy expenditure rate (EER) in manual weeding.

Since oxygen consumption rate (OCR) is a better parameter than heart rate, the energy expenditure rate was estimated by multiplying the OCR work with the calorific value of oxygen as 20.88 kJ/l (Nag and Dutt, 1980). The energy expenditure rate of the selected subjects in weeding operation is presented in Table 4.16.

Table 4.16 Energy Expenditure Rate in Manual Weeding

Methods of weeding	Kudali	Khurpi	CIAE model wheel hoe	PAU model wheel hoe
Subjects	**EER (kJ/min)**	**EER (kJ/min)**	**EER (kJ/min)**	**EER (kJ/min)**
S_1	11.80	10.73	12.93	13.95
S_2	12.27	11.05	13.90	15.26
S_3	11.61	10.70	12.89	13.83
S_4	12.51	11.18	14.23	13.84
S_5	11.18	10.72	13.99	15.44
S_6	11.21	11.48	15.01	14.85
S_7	12.12	10.84	13.63	13.52
S_8	12.72	11.55	15.10	14.74
S_9	12.11	10.96	13.69	14.63
S_{10}	11.19	10.37	13.18	14.42
Average	**11.87**	**10.96**	**13.85**	**14.45**

Mean Energy expenditure rate in weeding operation ranged from 11.18 to 12.72 kJ/min, 10.37 to 11.55 kJ/min, 12.89 to 15.10 kJ/min and 13.52 to 15.44 kJ/min for weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe method, respectively.

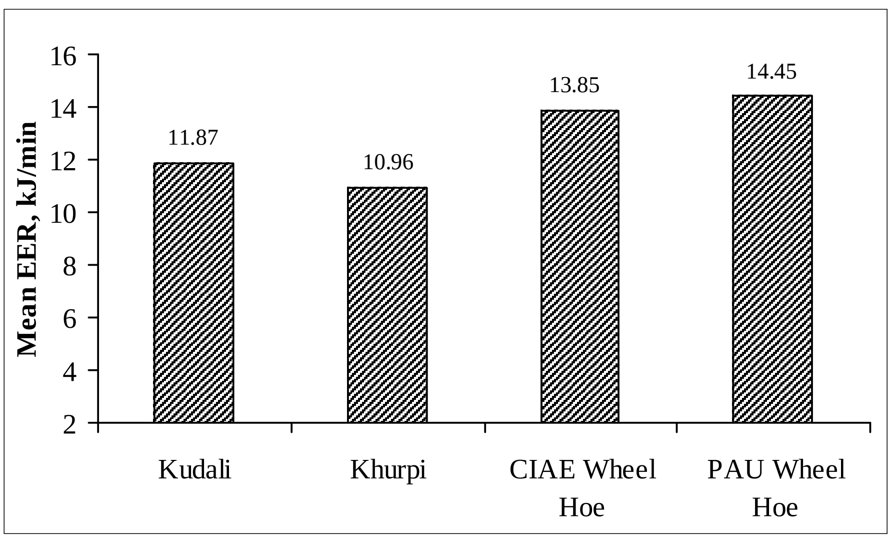


Fig. 4.4 Mean Energy expenditure rate in weeding operation.

The mean energy expenditure rate for all subjects is presented in Fig.4.4. The energy expenditure rate was highest for PAU model wheel hoe (14.45 kJ/min) followed by CIAE model wheel hoe (13.85 kJ/min), kudali (11.87 kJ/min) and khurpi (10.96 kJ/min). The energy expenditure rate for weeding with PAU model wheel hoe and CIAE model wheel hoe was almost same which implies that work load for both the wheel hoes is nearly same. The work load for weeding with kudali was higher than khurpi method.

According to classification suggested by Varghese *et al*., (1994), energy expenditure rate for weeding with kudali and khurpi operation could be scaled in "heavy" category of work load. Whereas weeding with CIAE model wheel hoe and PAU model wheel hoe method could be scaled as "very heavy".

4.3.3.1 Statistical Analysis for EER in Manual Weeding.

In order to see the significance of energy expenditure rate for different method of weeding operation, the data were analyzed with the help of SPSS 12.0 statistical software and ANOVA is presented in Table 4.17. The energy expenditure rate is statistically significant for weeding operations with the different methods. Multiple statistical comparison of EER in weeding operation shows that the EER during weeding with the kudali was significantly higher than khurpi and significantly lower than CIAE and PAU model wheel hoe. EER during khurpi was significantly lower than kudali, CIAE and PAU model wheel hoe. There was no significant difference between CIAE and PAU model wheel hoe.

Table 4.17 ANOVA for EER in Manual Weeding

Parameter		Sum of Squares	df	Mean Square	F_{cal}
EER	Between Groups	242.598	3	80.866	186.962*
	Within Groups	50.173	116	0.432	
	Total	292.771	119		

* Significant at 5 per cent

4.3.4 Recovery time of subjects during weeding operation.

Mean HR of all subjects during recovery time for four methods of weeding operation is presented in Fig.4.5. It can be seen that weeding with kudali and wheel hoe were more arduous than khurpi method. Kudali was more drudgerious as compare to wheel hoe and with less output per unit time, as the subjects performed the operation in bending posture. For better comfort of the subjects, the weeding tools should be operated in an erect posture as far as possible. The deviation of mid-sagittal plane of the subject's body from its normal position in a bending posture would result in a comparatively greater demand for oxygen uptake and hence greater metabolic cost (Tewari, 1991).

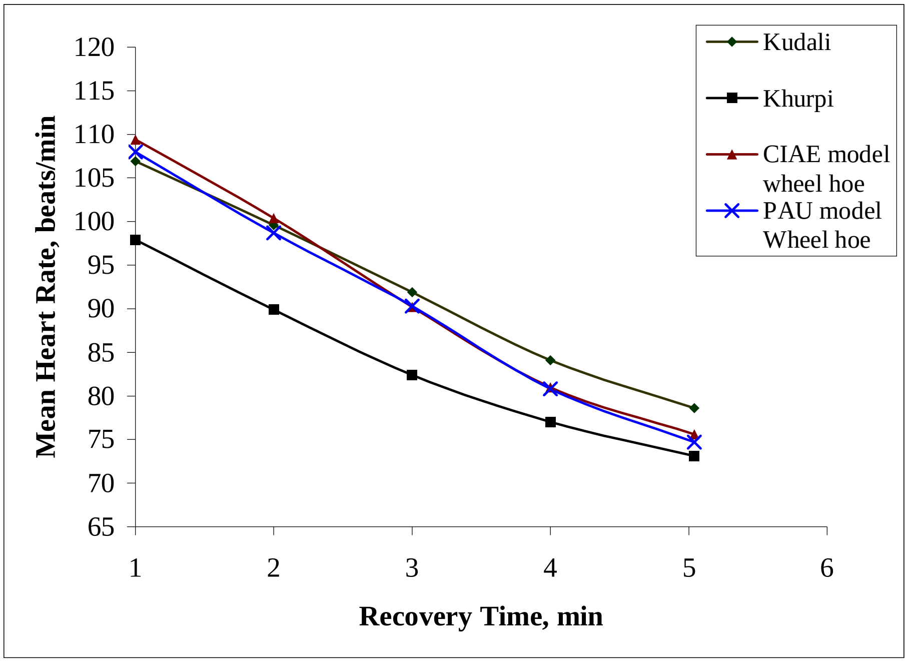


Fig. 4.5 Mean Heart Rate and Recovery Time during four methods of Weeding

4.3.5 Physiological cost of the subjects during cob-picking operation.

Field experiment was carried out to assess the physiological cost of the subjects (HR, ΔHR, OCR, ΔOCR and EER) as per procedure given in (Section 3.8.4.2). The temperature and relative humidity during this experiment were in the range of 32.2 to 38°C and 65 to 82 per cent respectively.

4.3.5.1 Heart rate response of the subjects during cob-picking operation.

Table 4.18 shows the mean heart rate of the subjects during cob-picking operation. The mean heart rate of the subjects during cob-picking was 103.2 beats/min. The HR of the subjects during cob-picking operation ranged from 95.9 to 108.5 beats/min. The mean ΔHR of subjects was 28.3 beats/min. The mean work pulse (ΔHR) of the subjects during cob-picking operation ranged from 22.7 to 31.4 beats/min.

Table 4.18 Mean HR and ΔHR of the Subjects during Cob-Picking Operation

Method	**Cob-Picking**	
Subjects	**HR**	**Δ HR**
S_1	104.8	31.4
S_2	106.5	31.1
S_3	96.6	24.4
S_4	101.7	22.7
S_5	105.4	31.0
S_6	95.9	24.3
S_7	101.4	26.8
S_8	108.5	30.7
S_9	102.4	29.5
S_{10}	108.4	31.1
Average	**103.2**	**28.3**

Table 4.19 Increase in HR/m^2 of the Subjects during Cob-Picking Operation

Subjects	HR beats/min	ΔHR beats/min	Increase in HR/m^2 of the area covered	Area covered m^2/h
Female	103.2	28.3	8.08	210

Table 4.19 shows the increase in HR/m^2 of the subjects during cob-picking operation. The increase in HR/m^2 of the area covered for the subjects was 8.08 beats/min.

4.3.5.2 Oxygen consumption rate during cob-picking operation.

The mean oxygen consumption rate (OCR) of the subjects during cob-picking operation was 0.356 l/min. The mean OCR of the subjects during this operation ranged from 0.335 to 0.376 l/min as shown in Table 4.20.

The mean oxygen consumption rate of subjects during cob-picking operation was 0.356 l/min, i.e 20.79 per cent of aerobic capacity (Section 3.9.3.2). This value was lower than the acceptable limit of 40 per cent of Aerobic capacity for longer work as suggested by Nag and Chatterjee, (1981).

Table 4.20 Mean Working OCR and ΔOCR and EER during Cob-Picking Operation

Method	**Cob-Picking**		
Subjects	**OCR**	**ΔOCR**	**EER**
S_1	0.361	0.226	7.53
S_2	0.368	0.237	7.67
S_3	0.335	0.203	7.00
S_4	0.349	0.193	7.29
S_5	0.361	0.223	7.53
S_6	0.336	0.207	7.01
S_7	0.348	0.209	7.26
S_8	0.376	0.224	7.84
S_9	0.352	0.219	7.34
S_{10}	0.375	0.226	7.82
Average	**0.356**	**0.217**	**7.43**

4.3.5.3 Energy expenditure rate (EER) expended by the subjects during cob-picking operation.

The energy expenditure rate for female subjects during cob-picking operation was calculated from oxygen consumption rate and is presented in Table 4.20. The EER for subjects was 7.43 kJ/min. The energy expenditure rate during cob-picking operation ranged from 7 to 7.84 kJ/min.

According to classification suggested by Varghese *et al*., (1994), the cob-picking operation (manually) could be scaled in “light” category of work load.

4.3.5.4 Recovery time of subjects during cob-picking operation.

Recovery pattern of the subjects during cob-picking operation is illustrated in Fig. 4.6. This indicates that the operation was less tiring for the female agricultural workers.

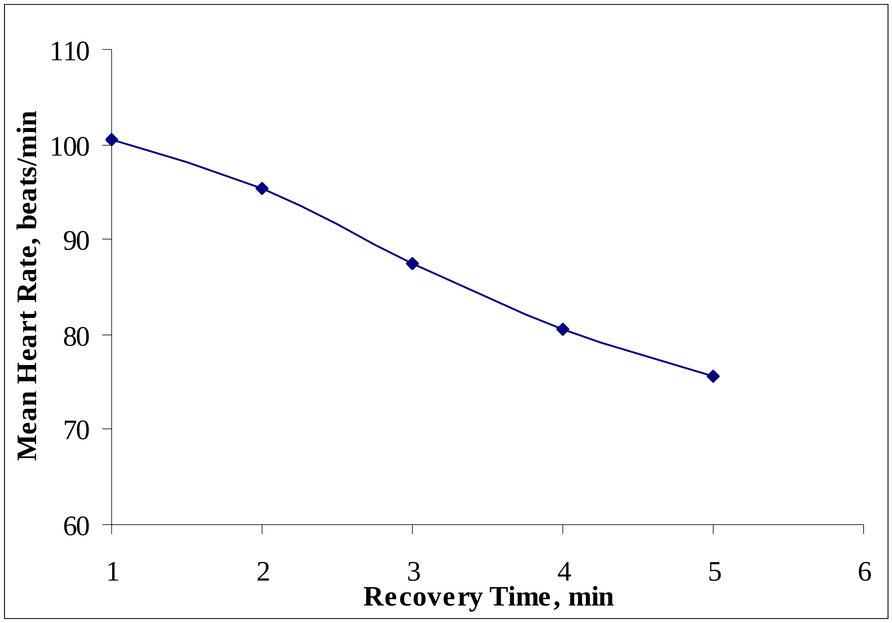


Fig. 4.6 Mean Heart Rate and Recovery Time during Cob-picking Operation

4.4 Assessment of Body Discomfort of the operator during manual weeding and cob-picking operations.

Field experiments were carried out to assess overall discomfort rating (ODR) and body part discomfort score (BPDS) experienced by the selected subjects as per procedure given in (Section 3.9.1.2) for manual weeding and cob-picking operations. The results are given under the following headings.

1. Assessment of body discomfort during weeding operation
2. Assessment of body discomfort during cob - picking operation

4.4.1 Assessment of body discomfort during weeding operation.

The temperature and relative humidity during this experiment were in the range of 32.9 to 38.3 $^{\circ}$C and 65 to 82 per cent respectively. The collected data were analyzed in order to see the effect of methods of operation and interaction between these variables on body discomfort.

4.4.1.1 Over all discomfort rating (ODR) during weeding operation.

ODR experienced by the selected subjects during weeding operation in groundnut crop is presented in Table 4.21. The ODR for subjects during weeding with kudali and khurpi ranged from 7.0 to 8.0 and 4.8 to 5.6 respectively. The ODR for subjects during weeding with CIAE and PAU model wheel hoe ranged from 6.4 to 7.1 and 6.4 to 7.2 respectively. Maximum ODR was observed in kudali method followed by PAU model wheel hoe, CIAE model wheel hoe and khurpi methods. The ODR value for PAU model wheel hoe and CIAE model wheel hoe were nearly same (Fig.4.7). Khurpi was less fatigue to perform weeding operation as compared to wheel hoes and kudali method but area covered was less compared to other methods.

The mean ODR of subjects during weeding with kudali was 9.3 and 8.0 per cent higher than CIAE and PAU model wheel hoe. This may be due to the continuous operation in bending posture. However there was no significant difference between kudali and both wheel hoes.

Table 4.21 Mean Overall Discomfort Rating (ODR) of the Subjects during Weeding Operation

Subjects	Kudali	Khurpi	CIAE Wheel Hoe	PAU Wheel Hoe
S_1	7.6	5.4	6.6	7.2
S_2	8	5.2	6.5	7
S_3	7.6	5.2	6.8	6.9
S_4	7.5	4.8	7.1	6.8
S_5	7.2	4.8	6.8	7.1
S_6	7.6	5	6.4	7.2
S_7	7	5.6	7.1	6.6
S_8	8	5.2	7	6.5
S_9	7.5	5.6	6.9	6.4
S_{10}	7	5	7	7.2
Average	**7.5**	**5.2**	**6.8**	**6.9**

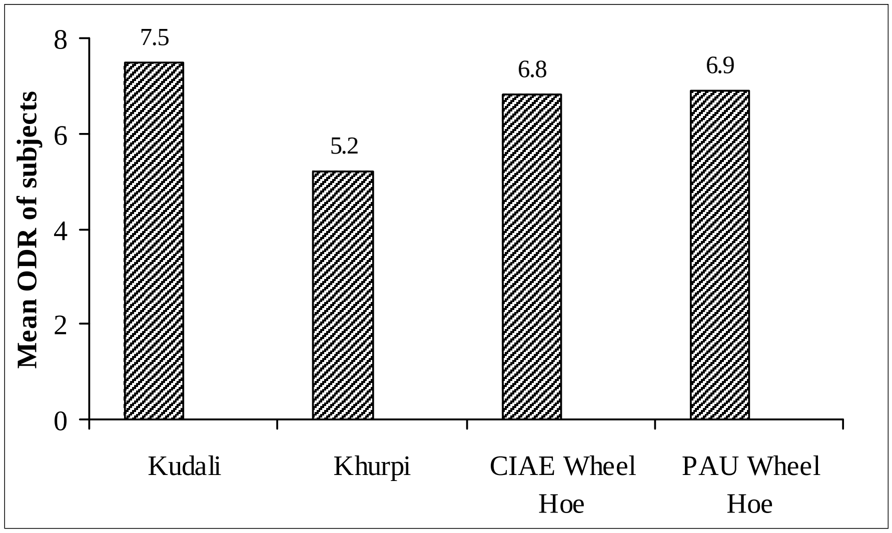


Fig. 4.7 Mean Overall Discomfort Rating (ODR) for the Selected Subjects during Weeding Operation

This rating as reported by Srisha (2004), for cone weeder and for four row paddy seeder was 7.15 and 7.07 respectively.

4.4.1.1.1 Statistical analysis for ODR during weeding.

To see the significance of different weeding operation method for Overall Discomfort Rating (ODR), statistical analysis was done and ANOVA is presented in Table 4.22.

Statistical multiple comparison of ODR for weeding operations is shows that kudali method was significantly higher than khurpi, CIAE and PAU model wheel hoe. The value of ODR for khurpi was significantly lower than kudali, CIAE and PAU model wheel hoe. There was no significant difference between CIAE and PAU model wheel hoe.

Table 4.22 ANOVA for overall discomfort rating for manual weeding

Parameter		Sum of Squares	df	Mean Square	Fcal
ODR	Between Groups	29.588	3	9.8629	108.862*
	Within Groups	3.161	36	0.0906	
	Total	32.850	39		

* Significant at 5 per cent

4.4.1.2 Body part discomfort Score (BPDS) assessment during weeding operation.

Experiments were carried out in order to assess BPDS of subjects during manual weeding operation. The BPDS during weeding with all four methods are presented in Table 4.23.

The BPDS ranged from 67 to 74 for weeding with kudali, 54 to 62 for khurpi, 63 to 70 for CIAE model wheel hoe and 64 to 70 for PAU model wheel hoe method. (Appendix-D)

Table 4.23 Mean BPDS during manual weeding methods

Subjects	Kudali	Khurpi	CIAE wheel hoe	PAU Wheel hoe
S_1	72	62	64	67
S_2	73	55	69	70
S_3	69	56	65	68
S_4	74	57	66	69
S_5	71	60	65	66
S_6	70	54	67	65
S_7	69	58	63	66
S_8	71	61	64	68
S_9	72	56	63	64
S_{10}	67	59	70	67
Average	**70.8**	**57.8**	**65.6**	**67.0**

From Fig.4.8 it can be seen that the minimum mean BPDS was during khurpi method. The maximum mean BPDS for subjects was during weeding with kudali. The mean BPDS for subjects during weeding with kudali was 18.36, 7.3 and 5.4 per cent higher than khurpi, CIAE and PAU model wheel hoe method respectively. However, there was no significant difference between kudali and CIAE and PAU model wheel hoe.

The majority of discomfort was observed at lower back, mid back, right arm, right leg, left leg, right shoulder, neck, clavicle left and clavicle right for all the subjects during kudali operation. This was because of bending posture and application of force by raising the kudali and bringing down with force to remove the weeds. The majority of discomfort was observed at left shoulder, right shoulder, left arm, right arm, upper back, lower back right thigh and left thigh for all the subjects while weeding with khurpi. This was because of

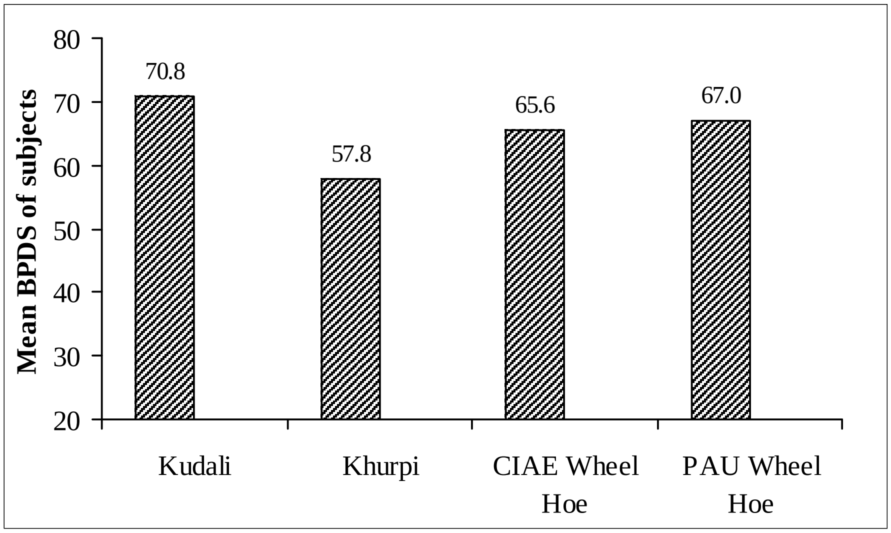


Fig. 4.8 BPDS in Manual Weeding operation

squatting posture and use of wrist during the operation. Whereas, the majority of discomfort was observed at right shoulder, left shoulder, left arm, right arm, upper back, clavicle left and clavicle right for all the subjects for both CIAE and PAU model wheel hoe method. This may be due to the higher speed of the operation during push and pull action to remove weeds and lateral-bending posture to maintain the implements in desired position.

4.4.1.2.1 Statistical analysis for BPDS in manual weeding.

It has observed that muscular discomfort of body is comparatively more important than HR and OCR in agricultural operations as limiting factors (Gite, 1996). The BPDS was observed during weeding operation was analyzed statistically and ANOVA presented in Table 4.24.

Table 4.24 ANOVA for BPDS during Weeding Operations

Parameter		**Sum of Squares**	**df**	**Mean Square**	**Fcal**
BPDS	Between Groups	894.8	3	298.2667	57.853*
	Within Groups	185.6	36	5.1556	
	Total	112.444	39		

* Significant at 5 per cent level

The BPDS was found significant for all methods of weeding operation. The BPDS for for kudali was significantly higher than khurpi, CIAE and PAU model wheel hoe. The value of BPDS for khurpi was significantly lower than kudali, CIAE and PAU model wheel hoe. There was no significant difference between CIAE and PAU model wheel hand hoe.

The BPDS reported by Behera *et al*., (2007), was 83, 67 and 63 for wheel hoe, rotary peg weeder and wheel finger weeder respectively for weeding in ground nut crop.

4.4.2 Assessment of body discomfort during cob-picking operation.

ODR and BPDS for all the subjects during cob-picking operation in maize crop were assessed as per procedure given in Section 3.9.2.2. The temperature and relative humidity during this experiment were in the range32.2 to 38°C and 65 to 82 per cent respectively. The results are given below.

4.4.2.1Overall discomfort rating (ODR) during cob-picking operation.

The mean ODR value of the subjects during cob-picking was 3.1 The ODR for subjects ranged from 2.7 to 3.6.

4.4.2.2 Body part discomfort score (BPDS) during cob-picking operation.

The majority of discomfort was observed at lower back and mid back for all the subjects. This may due to the bending posture followed by subjects while picking the cobs located at different height of a plant and place it on the ground after picking. The BPDS value for subjects ranged from 16 to 24.

4.5 Mechanical Evaluation of Farm implements for the Selected Operations.

Mechanical performance evaluation of all weeding and cob-picking operations was carried out. The results are given below:

Table 4.25 Mechanical Evaluation of Weeding implements

Implements/tools	♦ Weeding efficiency %	Field capacity ha/hr
Kudali	92.30	0.0053
Khurpi	94.40	0.0045
CIAE model wheel hoe	80.90	0.0152
PAU model wheel hoe	78.60	0.0146

Data is average of three replications

♦ Weed density =220 to 250 weeds/m^2 (approx.)

Crop= ground nut

From Table 4.24, it can be seen that the maximum weeding efficiency of about 94.4 per cent was observed while using khurpi followed by kudali, CIAE model wheel hoe and PAU model wheel hoe respectively. The maximum average field capacity for subjects was observed while using CIAE model wheel hoe followed by PAU model wheel hoe, kudali and khurpi respectively. This may be due to the fact that field capacity depends on the speed of the operations and working width of the implement/ tool.

Field capacity, field efficiency and picking efficiency for subjects were observed during cob-picking operation. The average field capacity for female subjects was 210 m^2 /hr. The average field efficiency for subjects was 94.7 per cent. The average picking efficiency for subjects was 97.3 per cent.

V SUMMARY AND CONCLUSIONS

The agriculture sector in India provides livelihood to about 64 per cent of the labour force, which contributes nearly 26 per cent of GDP and accounts for about 18 per cent share of the total value of the country's exports. Rajasthan is the largest state in India, area wise, with geographical area of 34.23 mha. The farmers in the state are in the category of small and marginal farmers. About 50.26, 20.83 and 19.83 per cent of farm holdings are in the size group of 0- 2 ha, 2-4 ha and 4-10 ha accounting for 11.04, 14.99 and 31.14 per cent of total cultivated area respectively. Manual tools and animal drawn implements are extensively used for different farm operations in Rajasthan. These agricultural tools/implements are not designed ergonomically, and this leads to increase in fatigue, health hazards and even accidents to agricultural workers. Proper matching of machine requirements with operator's capabilities is necessary to achieve better performance.

The increased pace of mechanization in Indian agriculture has made the application of ergonomics more relevant in today's situation. The scope of its application includes fitting the demand of work to the efficiency of person in order to reduce stress and design machine, equipment and installations so that they can be operated with great efficiency, accuracy and safety. Drudgery and the resulting strain not only impair health but also affect the quality of work and performance. The effect of physical work on the worker is the cause of concern in this regard for determining the acceptable limits of physiological workload without causing burden, fatigue and strain on the worker. Muscular activity originates from static and efforts and requires expenditure of energy.

The use of female anthropometric and strength data can help in the proper designing of new equipments and modifying the existing one. Body dimensions and strength parameters of agricultural workers vary from country to country as well as from region to region in the same country. However, the designers are now developing ergonomic consciousness and if the anthropometric and strength data of the target population are available, those could be used in the design process. Therefore, keeping all the above points in view, the present study was conducted with the following specific objectives.

1. To measure anthropometric dimensions and strength parameters of women agricultural workers of Udaipur district.
2. To estimate physiological cost of women agricultural worker for weeding and cob-picking operations.
3. To evaluate the body discomfort experienced by the worker during weeding and cob-picking operations.

In order to achieve the specific objectives an anthropometric and strength data survey was conducted. Twenty-four body dimensions and seven strength parameters were identified and measured for 50 female agricultural workers from the sample population of the district. The collected data were analyzed to find mean, 5^{th} and 95^{th} percentile, range, standard deviation, standard error, coefficient of variation, coefficient of correlation, the difference between 95^{th} and 5^{th} percentile and stature ratio.

The mean stature and weight were 152.77 cm and 47.13 kg respectively. The results of the analysis showed that most of the selected body measurements were significantly correlated with stature. The analyzed data were compared with female agricultural workers of other regions of the country and also with other countries as well. The buildup data can be used to design various agricultural equipment and workplace design to match the limitation and capabilities, muscular strength and aerobic capacity of women agricultural worker.

Ten female subjects in age group of 25-45 years were randomly selected. Twenty four body dimensions and 7 strength parameters of the 10 selected subjects were measured and mean values of the subjects were recorded. These subjects were used in the field trials. Field experiments were carried out to assess the physiological cost and body discomfort experienced by the subjects. Mechanical evaluation of the selected farm implements for manual weeding and cob-picking operation was also conducted.

Mean working HR and OCR of the selected subjects ranged from 104.9 to124.5 beats/min, 94.9 to 110.6 beats/min, 108.5 to 125.7 beats/min, 107.0 to 122.1 beats/min and 0.535 to 0.609 l/min, 0.497 to 0.553 l/min, 0.618 to 0.723 l/min, 0.648 to 0.739 l/min for kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe respectively. For cob picking operation the value ranged from 95.9 to 108.5 beats/min and 0.335 to 0.376 l/min respectively.

The mean work pulse (ΔHR) and ΔOCR of the subjects ranged from 27.1 to 48.3 beats/min, 23.5 to 31.3 beats/min, 32.8 to 49.7 beats/min 32.2 to 48.9 beats/min and 0.377 to 0.458 l/min, 0.356 to 0.393 l/min, 0.471 to 0.569 l/min, 0.494 to 0.579 l/min for weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe respectively. For cob picking operation the value ranged from 22.7 to 31.4 beats/min and 0.193 to 0.237 l/min respectively.

The mean energy expenditure rate during weeding operation ranged from 11.18 to 12.72 kJ/min, 10.37 to 11.55 kJ/min, 12.89 to 15.10 kJ/min and 13.52 to 15.44 kJ/min for weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe method, respectively. The EER for cob-picking operation ranged from 7 to 7.84 kJ/min.

The ODR during weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe ranged from 7.0 to 8.0, 4.8 to 5.6, 6.4 to 7.1 and 6.4 to 7.2 respectively. The BPDS ranged from 67 to 74 for weeding with kudali, 54 to 62 for khurpi, 63 to 70 for CIAE model wheel hoe and 64 to 70 for PAU model wheel hoe

Mean ΔHR, ODR and BPDS was less while weeding with Khurpi, as compared to other methods. However, there was no significant difference for female subjects between kudali and both wheel hoe operation in terms of ΔHR, ODR and BPDS. Higher field capacity was obtained for both the wheel hoes. The energy expenditure rate was highest for weeding with CIAE and PAU model wheel hoe followed by kudali and khurpi.

From the results of the anthropometric survey and field evaluation of selected farm implements/operation the following conclusions were drawn:

1. The analysis of anthropometric data suggests that most of the selected body dimensions were linearly related to her stature.
2. No linear relationship was observed for the strength data with stature and weight. However push strength with both hands in standing posture was linearly related with weight.
3. The coefficient of variation was maximum for weight (16.47 %) as compared to other body dimensions.
4. The mean stature was found to be about 3.7 per cent higher than Kerala and 1.2 per cent lower than Gujarat counter parts, with similar stature for Arunachal Pradesh female workers.
5. The mean right and left hand grip strength was found to be 12.1, 18.6 per cent, 24.8 and 30 per cent higher than Madhya Pradesh and Arunachal Pradesh female workers respectively.
6. The mean HR, OCR and EER during weeding with kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe was 113.1 beats/min, 102.5 beats/min, 115.1 beats/min 115.4 beats/min, 0.569 l/min, 0.525 l/min, 0.664 l/min, 0.692 l/min and 11.87 kJ/min, 10.96 kJ/min, 13.85 kJ/min, 14.45 kJ/min respectively.
7. The minimum mean ΔHR and ΔOCR for subjects was observed during weeding with Khurpi, kudali followed by CIAE model wheel hoe, whereas maximum value was observed for PAU model wheel hoe.
8. The increase in HR/m^2 for weeding with CIAE and PAU model wheel hoe was less as compared to kudali and khurpi. For cob picking operation this was observed to be 8.08 beats/m^2.
9. The operation of weeding with kudali and khurpi was scaled as “heavy”, while weeding with CIAE and PAU models were “very heavy”. Cob-picking operation was scaled as “light” operation.
10. The ODR and BPDS for kudali, khurpi, CIAE model wheel hoe and PAU model wheel hoe were 7.5, 5.2, 6.8, 6.9 and 70.8, 57.8, 65.6, 67 respectively. For cob picking operation the ODR and BPDS was 3.1 and 20 respectively.

SUGGESTIONS FOR FUTURE STUDY

On the basis of the investigation, the following suggestions are made for further study:

1. Ergonomical evaluation for other agricultural operations should be conducted with female subjects.
2. New agricultural equipments should be developed and existing agricultural equipments should be modified taking into consideration the anthropometric and strength data of female agricultural workers of the region.

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Appendix-A

Anthropometrical and Strength Measurements of 50 Female Agricultural Workers of Udaipur District

Sl. No.	Weight Kg.	Stature	Eye height	Acromial height	Elbow height	Olecranon height	Illiocrystale height	Knee height	Arm reach from the wall
1	54.00	159.00	146.80	132.40	100.50	96.80	94.50	49.00	78.10
2	48.50	151.00	139.00	124.40	95.70	92.40	85.50	46.60	82.20
3	55.00	158.00	148.50	130.60	100.50	96.80	92.00	46.40	85.60
4	43.40	155.40	144.10	128.20	102.00	95.00	94.20	49.00	76.00
5	34.30	151.20	139.40	123.40	99.70	96.80	89.20	45.50	76.50
6	56.00	156.40	145.20	132.50	99.80	102.20	94.60	48.90	85.30
7	42.00	154.80	146.00	128.50	97.50	99.20	94.30	45.60	80.50
8	48.30	144.10	133.00	108.50	91.20	86.80	85.20	40.60	74.20
9	44.30	154.30	144.00	127.20	95.20	92.50	93.60	45.10	80.80
10	46.00	150.00	140.00	122.50	91.10	92.00	86.80	45.30	77.10
11	52.30	148.40	138.90	125.50	97.60	91.90	88.80	44.20	78.10
12	42.50	158.10	140.90	126.20	97.30	92.10	89.50	47.70	77.10
13	63.00	161.00	149.40	135.40	102.80	101.00	98.50	51.50	82.50
14	47.50	151.20	139.30	126.70	98.00	92.50	90.60	46.50	80.60
15	58.72	152.30	141.00	126.40	95.60	93.00	90.00	47.20	82.80
16	44.00	149.80	138.40	122.80	95.50	90.00	91.80	44.40	81.50
17	54.86	152.50	140.00	128.00	95.00	94.50	89.80	43.40	81.60
18	50.00	154.00	139.80	129.00	99.80	96.60	88.00	45.40	85.60
19	38.04	154.20	145.00	133.00	100.80	98.80	96.60	52.50	85.80
20	43.38	152.00	141.30	124.90	94.70	93.40	88.30	45.00	75.50
21	46.34	149.20	136.40	126.00	93.00	89.80	88.00	44.00	77.00
22	43.62	149.50	138.50	124.00	93.50	91.40	91.00	45.00	84.20
23	39.32	156.30	143.80	130.00	98.00	96.50	94.50	44.00	81.00
24	38.28	155.00	144.40	130.60	100.60	95.70	97.00	48.00	85.20
25	69.20	149.20	139.00	124.60	95.00	91.00	90.00	42.00	82.40
26	55.00	148.00	137.00	123.50	93.50	91.20	87.00	42.50	76.50
27	63.00	155.30	142.50	130.20	101.00	96.80	95.00	47.00	84.50
28	63.00	161.20	149.20	135.20	105.00	100.00	97.00	48.50	82.50
29	49.00	153.00	140.00	126.70	94.20	92.40	89.00	43.00	79.80
30	48.00	155.20	143.00	128.80	98.80	96.60	94.40	43.50	78.20
31	41.00	150.40	138.50	123.40	94.00	91.00	89.50	42.40	77.50
32	45.00	144.00	133.60	119.80	91.00	87.50	89.00	43.00	75.00
33	36.00	156.00	145.50	127.40	100.00	98.00	96.00	46.00	81.60
34	46.00	154.00	143.80	128.50	99.50	94.80	97.00	46.00	81.00
35	40.00	148.00	137.50	126.50	92.50	89.50	91.40	42.50	80.00
36	43.00	152.50	141.00	125.00	97.00	95.00	94.00	43.00	77.00
37	49.00	153.00	142.00	128.00	94.00	92.00	96.00	44.00	84.00
38	39.80	148.60	138.00	123.80	94.50	93.00	90.00	44.00	81.50
39	38.00	150.00	138.00	123.00	93.00	90.00	89.00	43.00	74.50
40	45.00	154.20	144.40	129.00	99.00	97.00	95.00	45.00	79.00
41	43.00	146.60	136.00	119.40	96.00	91.00	93.00	44.00	72.80
42	47.00	154.00	143.00	125.00	95.00	93.40	93.00	46.00	80.60
43	48.00	147.00	137.50	123.00	94.00	90.00	88.00	39.00	74.00
44	42.00	148.50	137.00	122.60	95.00	93.00	92.00	43.00	75.20
45	37.00	149.50	139.50	123.00	94.00	91.00	92.00	43.00	78.60
46	41.00	161.40	148.00	135.00	102.00	98.00	98.00	48.00	77.50
47	58.00	156.00	145.50	132.00	96.50	94.00	98.00	47.00	81.00
48	50.00	156.00	144.50	127.80	95.00	93.50	96.00	47.00	81.00
49	41.00	151.00	141.20	126.40	98.00	96.00	92.00	42.00	71.50
50	46.00	158.00	144.00	130.00	100.00	95.00	91.00	44.00	77.50

Table-A_1 Standing Posture

Table- A_2 Sitting Posture*

* All the dimensions in cm unless specified

Sl. No	Sitting height	Vertical grip reach sitting	Eye height	Acromial height	Popliteal height	Elbow rest height	Forearm hand length
1	80.00	117.00	68.00	53.70	42.50	21.20	39.10
2	79.20	110.70	69.00	53.00	43.00	24.00	41.00
3	82.40	109.20	71.00	55.20	41.30	27.70	42.70
4	74.60	109.00	64.50	48.40	41.70	17.00	44.40
5	76.60	105.00	63.00	49.50	42.50	21.80	39.00
6	79.00	110.00	67.50	52.00	38.00	21.40	37.00
7	81.00	114.00	70.40	56.50	37.00	25.70	36.30
8	78.00	109.00	67.00	53.50	37.00	20.20	38.60
9	81.20	115.00	71.00	53.50	41.40	22.40	39.50
10	76.00	109.00	70.50	53.00	38.00	23.20	41.00
11	77.00	108.00	66.50	52.50	39.00	23.60	40.20
12	76.00	115.00	65.50	54.00	40.00	21.40	42.00
13	80.00	120.00	70.00	55.00	39.50	23.00	42.90
14	78.50	110.40	68.50	53.40	43.00	22.50	35.80
15	79.20	111.00	69.20	56.40	39.00	24.00	43.00
16	78.40	107.60	66.00	53.50	43.40	23.60	41.90
17	78.40	110.00	68.00	54.50	40.50	22.00	42.70
18	77.40	113.50	67.50	53.50	40.50	19.40	44.10
19	73.20	100.60	64.40	52.20	42.00	23.80	44.40
20	77.20	107.00	67.80	51.00	39.00	18.00	41.50
21	72.00	106.00	63.80	49.00	39.00	15.40	42.00
22	75.00	104.60	66.00	51.00	39.00	20.40	41.20
23	77.00	109.00	66.80	51.00	41.00	20.80	42.00
24	75.00	112.00	66.00	52.00	42.00	21.40	43.00
25	79.00	107.60	66.80	54.80	38.00	21.80	42.00
26	76.00	104.00	66.50	51.00	35.50	23.80	41.00
27	78.30	108.80	70.00	55.00	38.50	23.00	43.60
28	78.40	112.80	69.00	53.20	39.50	20.00	44.80
29	75.80	109.40	63.00	52.20	38.50	22.80	44.00
30	73.70	109.00	64.00	49.00	39.00	23.00	40.00
31	74.00	103.50	65.00	48.20	38.00	26.40	41.50
32	74.00	106.50	64.00	48.50	37.00	22.00	41.50
33	79.00	113.00	69.00	53.00	42.00	20.50	43.80
34	76.60	108.50	65.50	49.00	40.00	23.00	43.50
35	72.50	103.60	61.50	47.00	38.00	15.00	42.00
36	77.00	105.80	67.50	53.80	39.00	25.00	41.00
37	80.00	108.50	67.50	51.00	39.00	21.50	42.80
38	72.00	108.50	62.00	48.50	38.00	19.00	43.00
39	77.00	104.50	66.50	52.00	38.00	19.00	40.50
40	80.00	111.00	67.00	54.50	39.00	24.00	42.20
41	75.40	107.00	63.00	49.00	38.00	21.00	40.00
42	81.00	106.50	71.00	54.00	39.00	26.00	42.00
43	77.00	108.50	66.50	54.80	39.00	24.00	41.00
44	73.00	104.00	63.50	51.50	39.00	21.00	41.50
45	78.40	108.40	67.00	53.60	38.00	22.00	42.00
46	76.80	112.00	66.50	54.50	40.00	22.80	43.50
47	81.00	114.50	71.50	55.50	37.00	27.00	42.20
48	78.00	112.60	66.60	51.00	38.00	23.00	44.40
49	79.50	105.00	66.40	52.00	38.00	25.00	41.50
50	79.00	112.00	64.00	51.50	40.00	23.40	45.00

* All the dimensions in cm unless specified

Table- A_3 Miscellaneous Body dimensions*

Sl. No	Hand length	Hand breadth at metacarpal-III	Palm length	Grip diameter (inside)	Grip diameter (outside)	Middle finger-palm grip diameter	Grip span	Maximum grip length
1	17.40	7.50	11.00	4.80	7.40	2.90	6.10	10.20
2	16.50	6.60	10.00	4.30	7.20	2.60	5.90	10.20
3	16.50	7.40	9.10	4.60	7.80	2.40	6.30	9.00
4	20.00	7.50	9.50	4.80	7.60	2.50	6.30	10.00
5	16.40	6.70	8.50	4.70	7.50	2.70	5.50	8.80
6	19.00	7.30	10.20	5.00	7.50	2.80	7.40	10.80
7	18.00	7.20	9.50	4.40	7.00	2.60	8.50	10.00
8	16.60	7.20	9.40	4.20	7.00	2.40	8.60	9.80
9	19.20	7.00	10.00	5.20	7.50	2.70	8.10	10.90
10	17.50	8.00	8.60	5.10	7.40	2.50	8.00	10.50
11	17.20	7.50	9.40	4.80	6.80	2.70	7.40	9.80
12	17.50	7.00	9.80	4.80	7.20	2.60	7.60	11.50
13	18.60	7.00	10.60	5.10	7.40	2.80	8.00	10.50
14	18.20	8.70	10.20	4.70	9.00	2.40	8.70	12.30
15	19.00	7.80	9.50	4.50	8.80	2.30	8.70	9.30
16	15.90	8.60	8.40	4.20	7.30	1.90	7.20	9.10
17	17.40	7.40	10.10	4.80	8.20	2.40	8.10	10.00
18	18.00	7.80	10.00	5.10	8.30	2.20	7.00	9.90
19	18.00	7.50	11.00	4.70	7.60	2.90	6.30	8.00
20	16.50	7.00	10.50	4.30	7.00	2.70	6.00	7.60
21	16.50	7.40	10.20	4.10	7.00	2.40	7.00	8.00
22	17.40	7.40	9.80	4.50	7.50	2.80	5.90	8.20
23	17.00	7.50	10.20	4.50	7.30	3.00	6.00	7.90
24	17.60	7.80	11.50	4.40	7.40	2.60	5.40	7.30
25	16.60	7.80	10.80	4.20	7.40	2.30	5.80	7.20
26	19.20	8.10	9.60	4.40	7.50	2.70	5.30	8.70
27	20.50	8.40	10.20	4.80	8.00	2.30	5.80	8.90
28	20.00	7.90	10.20	4.40	8.20	2.20	7.00	8.90
29	19.50	8.00	9.80	4.80	8.10	2.90	6.70	8.20
30	18.20	6.90	9.00	4.50	7.70	2.50	6.10	8.10
31	18.20	7.50	9.90	4.80	7.60	2.90	5.90	8.40
32	18.00	7.50	8.90	4.50	7.30	2.70	7.20	9.70
33	18.30	7.20	10.10	5.20	7.50	2.70	8.00	9.40
34	17.00	7.60	9.60	4.20	7.00	2.60	6.80	8.00
35	17.50	7.50	9.00	4.00	6.80	2.60	7.50	10.20
36	17.60	7.50	9.40	4.50	7.00	2.20	7.60	10.20
37	18.00	7.60	10.40	4.00	7.00	2.00	6.90	9.00
38	18.50	7.70	9.00	4.10	7.40	2.30	6.90	7.30
39	18.00	7.80	9.00	4.40	6.70	2.20	7.70	8.00
40	18.60	7.80	9.60	4.50	7.50	2.30	7.90	8.20
41	18.20	7.20	9.40	4.00	6.20	2.00	7.60	9.20
42	17.50	8.00	9.40	4.30	6.70	2.30	7.30	8.80
43	17.00	7.70	8.60	4.40	6.90	2.40	7.00	7.50
44	18.20	7.30	9.90	4.40	6.50	2.40	8.00	8.20
45	18.40	7.40	8.70	4.10	6.70	2.30	8.20	8.80
46	18.40	8.00	9.30	4.40	7.00	2.40	8.20	9.00
47	19.00	8.30	9.40	4.40	7.50	2.20	7.80	12.70
48	19.00	7.60	9.70	4.50	7.30	2.20	8.00	8.40
49	17.00	8.10	9.10	4.20	6.50	2.20	7.40	8.00
50	18.00	7.70	9.70	4.50	7.50	2.70	7.60	8.10

* All the dimensions in cm unless specified

Table- A4 Strength Parameters

Sl.No	hand grip strength right, N	Hand grip strength (left), N	Push strength with both hands in standing posture, N	Pull strength with both hands in standing posture, N	Right hand pull strength in sitting posture, N	Left hand pull strength in sitting posture, N	Hand grip torque, N-m
1	196.00	205.80	205.80	176.40	188.16	163.66	0.83
2	254.80	215.60	132.30	156.80	147.00	155.82	0.74
3	196.00	176.40	156.80	156.80	117.60	117.60	0.74
4	254.80	245.00	112.70	107.80	55.86	88.20	0.69
5	137.20	137.20	98.00	88.20	88.20	68.60	0.54
6	176.40	137.20	34.30	58.80	73.50	98.00	0.74
7	196.00	117.60	68.60	78.40	107.80	68.60	1.47
8	205.80	186.20	120.54	137.20	137.20	85.26	0.74
9	196.00	245.00	93.10	107.80	85.26	76.44	0.74
10	215.60	245.00	127.40	156.80	88.20	78.40	1.96
11	156.80	215.60	107.80	186.20	117.60	98.00	1.47
12	235.20	274.40	107.80	166.60	176.40	225.40	1.96
13	196.00	147.00	137.20	137.20	88.20	98.00	0.74
14	235.20	254.80	98.00	117.60	68.60	58.80	0.74
15	215.60	196.00	98.00	117.60	127.40	78.40	0.64
16	176.40	196.00	88.20	76.44	73.50	68.60	0.74
17	196.00	176.40	98.00	117.60	78.40	78.40	1.47
18	117.60	176.40	98.00	88.20	75.46	78.40	0.93
19	284.20	235.20	88.20	127.40	78.40	156.80	1.27
20	196.00	215.60	78.40	117.60	107.80	78.40	0.78
21	176.40	176.40	78.40	137.20	137.20	117.60	0.78
22	176.40	176.40	78.40	107.80	88.20	98.00	0.59
23	254.80	215.60	107.80	156.80	147.00	127.40	0.93
24	176.40	176.40	88.20	137.20	156.80	166.60	0.88
25	294.00	294.00	176.40	156.80	147.00	137.20	1.27
26	323.40	294.00	323.40	274.40	205.80	166.60	1.96
27	313.60	313.60	156.80	205.80	186.20	186.20	0.98
28	284.20	254.80	274.40	205.80	166.60	166.60	0.88
29	294.00	254.80	303.80	156.80	245.00	166.60	1.23
30	254.80	215.60	127.40	166.60	176.40	127.40	0.98
31	245.00	215.60	107.80	88.20	186.20	117.60	1.08
32	294.00	333.20	117.60	176.40	147.00	176.40	1.91
33	294.00	264.60	127.40	156.80	147.00	166.60	1.37
34	333.20	294.00	117.60	166.60	176.40	225.40	1.62
35	264.60	215.60	147.00	156.80	176.40	166.60	1.62
36	225.40	225.40	88.20	156.80	147.00	107.80	1.96
37	333.20	274.40	88.20	156.80	147.00	137.20	1.47
38	254.80	254.80	107.80	147.00	107.80	107.80	0.98
39	235.20	235.20	107.80	107.80	78.40	88.20	0.93
40	274.40	294.00	68.60	107.80	107.80	107.80	0.59
41	235.20	215.60	107.80	127.40	88.20	107.80	0.98
42	323.40	294.00	156.80	147.00	107.80	127.40	0.98
43	323.40	284.20	137.20	156.80	147.00	137.20	1.27
44	215.60	156.80	127.40	156.80	107.80	107.80	0.74
45	235.20	225.40	98.00	127.40	107.80	107.80	0.93
46	294.00	294.00	107.80	137.20	176.40	147.00	0.93
47	303.80	235.20	98.00	147.00	147.00	98.00	1.96
48	274.40	274.40	137.20	176.40	147.00	147.00	1.37
49	176.40	235.20	78.40	107.80	107.80	88.20	0.69
50	313.60	274.40	117.60	147.00	166.60	166.60	0.98

APPENDIX - B

Specifications of Computerized Ambulatory Metabolic Measurement System (K4 b^2)

The Computerized Ambulatory Metabolic Measurement System is designed to measure the level of physiological strain and intensity in sports and exercise. No other use is intended or applied. The oxygen consumption and heart rate are measured in l/min and beats/min, respectively.

Technical specifications:

Portable Unit

Memory	16,000 breaths
Display	LCD 2 lines x 16 characters
Keyboard	waterproof, 6 keys
Serial Port	RS 232C
Power supply	Ni-MH rechargeable batteries 3 hours endurance
Thermometer	0-50°C
Barometer	53-106 Kpa
Dimensions PU	170x55x100 mm,
Dimensions battery	120x20x80 mm
Weight	400g

Receiver Unit

Transmission range:	800 meters
Battery	4 x 1.5 V AA
Dimension	170 x 48 x 90 mm
Weight	550 g
PC interface	RS 232

Battery charger Unit

Power supply	120V - 240 V
Power consumption	25 W

Flowmeter

Type	Bidirectional digital turbine Ø 28 mm
Flow Range	0, 03-20 L/sec
Accuracy	± 2%
Resistance	<0.7 cmH2O s/L @ 12 L/s
Ventilation Range	0-300 litres x min

Oxygen Sensor (O_2)

Response time	<150 ms
Range	7-24% O_2
Accuracy	±0.02% O_2

Carbon Dioxide Sensor (CO_2)

Response time	<150 ms
Range	0-8%
Accuracy	±0.01%

Power Supply

Voltage	100V-240V ±10%; 50/60Hz
Power consumption	60W

Environmental Sensors

Temperature	0-50°C
Barometer	400-800 mmHg
Humidity	0-100%

APPENDIX-C

Salient Features of Implements / Tools used in Weeding operation

C1-Traditional

Specifications	Kudali	Khurpi
Handle height	58 cm	12 cm
Width of cut	7 cm	6.5 cm
Diameter of grip	3 cm	2.5 cm

C2- Improved model

Specifications	CIAE model	PAU model
Height of handle from the ground level	116	106
Handle width	50	52
Width of cut	20	12
Diameter of grip	2.5	3
Diameter of wheel	20	40
Type of blade	V type	sweep

APPENDIX D

BPDS values of subjects during weeding operations

Method Of weeding	Category of pain	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
KUDALI	**I**	18,17,2,3	2,3,18,17	1,2,3,5	17,18,1,3	1,2,3,17	1,2,3	1,4,5	1,17,18	2,3,5	17,18,5
	II	25,24,4,5	22,23,1,16	18,17,16	2,7,24,25	18,5,24,25	18,17,23,22	2,3,18	2,3,4,5	1,24,25	1,2,3
	III	1,6,7	4,5,7	24,25,4	4,5,7	7,6	4,5,7,16	4,5,7,17	6,7,24,25	17,18,4,7	7,24,25,11
	IV	16,8,9	24,25,11	23,22,7	22,23,16	10,11,4	24,25,6	10,11,24,25	6,20,21	11,16,22,23	16,22,23
	V	23,22	10,6,9	10,11,9	10,11,6	22,23,9,15	20,21	22,23,16	11,22,23	6,9,14,15	20,21,4
	VI	14,15,11	20,21	6,14,15	9,14,15	20,21	8,10,11	20,21	14,15	10,20,21	6,10,9
	Score	**72**	**73**	**69**	**74**	**71**	**70**	**69**	**71**	**72**	**67**

Method of weeding	Category of pain	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
KHURPI	**I**	16,18,5	16,18,19	16,18,3	16,18,3	16,18,3	3,4,5	16,18,5	3,5,16	16,18	3,16,17
	II	20,21,3	20,21	4,5,7	20,21	20,21,5,7	16,18	3,20,21	18,20,21	3,5,7	2,4,5
	III	22,23,7	22,23,5	20,21	4,5,20,21	3,4	20,21,7	4,6,7	4,6,7,17	20,21,4,6	20,21
	IV	24,25,2	3,6,7	22,23	6,7	22,23	22,23	17,19	22,23	17,19	6,7,9
	V	1,6,17	24,25	6,24,25	22,23	19,17,1	6,15,17	22,23	24,25	22,23,9	17,24,25
	VI	26,27	26,27	26,27,1	24,25,1	22,15	26,27	24,25,1	26,27	24,25,15	1,26,27
	Score	**62**	**55**	**56**	**57**	**60**	**54**	**58**	**61**	**56**	**59**

Method of weeding	Category of pain	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
CIAE	**I**	6,7,18	6,7,16	4,5,6,7	4,5,18	4,5,6,7	4,5,18	6,7,18	4,5,18	6,7,18	18,6,7,
	II	10,11	4,5,18	16,18	6,7,10,11	17,18	6,7,17	4,5,17	6,7	4,5,17	4,5,10,11
	III	4,5,20,21	8,9,10,11	2,3,10,11	8,9,20,21	8,9,10,11	10,11,20,21	20,21	8,9,10,11	8,9,10,11	8,9,17
	IV	8,9,16,17	20,21,26,27	17,20,21	2,3	20,21,2,3	8,9,26,27	8,9,10,11	16,17,20,21	20,21	20,21,2,3
	V	1,2,3	22,23,1	8,9	16,17	22,23	2,3	2,3,1,16	1,2,3	1,2,3	1,24,25
	VI	22,23	2,3	26,27	22,23	26,27	22,23	24,25	24,25	24,25	26,27
	Score	**64**	**69**	**65**	**66**	**65**	**67**	**63**	**64**	**63**	**70**

Method of weeding	Category of pain	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
PAU	**I**	2,3,16	4,5,6,7	2,3,16	4,5,16	6,7,16	4,5,17	2,3,16	2,3,18	2,3,16	4,5,18
	II	4,5,17	2,3,16	4,5,6,7	2,3,6,7	2,3,4,5	2,3,18	4,5,6,7	4,5,16,17	4,5,17	2,3,16
	III	1,6,7,18	10,11,17,18	10,11,17,18	10,11,20,21	10,11,17,18	6,7,16	10,11,17,18	6,7,1	6,7,12,13	6,7,17,1
	IV	10,11,20,21	1,20,21	20,21	8,9,18	20,21	10,11,20,21	20,21	20,21,10,11	1,10,11	10,11,12,13
	V	8,9	8,9	1,8,9	14,15	8,9	1,8,9	8,9	8,9	20,21	20,21
	VI	14,15	14,15	14,15	12,13	22,23	22,23	14,15	14,15	14,15	14,15
	Score	**67**	**70**	**68**	**69**	**66**	**65**	**66**	**68**	**64**	**67**