

**INVESTIGATION ON DESIGN PARAMETERS OF HAND TOOLS
IN RELATION TO OPERATIONAL COMFORT OF AGRICULTURAL
WORKERS**

Thesis submitted in part fulfilment of the requirements for the Degree
of **Master of Engineering** (Agriculture) in Farm Power and Machinery to
the Tamil Nadu Agricultural University, Coimbatore

By

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**DEPARTMENT OF FARM MACHINERY
COLLEGE OF AGRICULTURAL ENGINEERING
TAMIL NADU AGRICULTURAL UNIVERSITY
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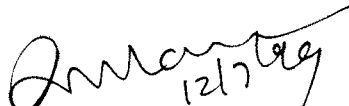
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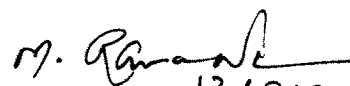
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C.RAMANA

ABSTRACT

“ INVESTIGATION ON DESIGN PARAMETERS OF HAND TOOLS IN RELATION TO OPERATIONAL COMFORT OF AGRICULTURAL WORKERS ”

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Inspite of improved farm mechanisation the use of hand tools in some agricultural operations are inevitable, such as seedbed preparation, forming and clearing irrigation channels, weeding, digging in terrace cultivation etc. Four majorly used and high energy of demanding soil working tools Spade, Hand hoe, Shovel and Digger fork were selected for optimising its design parameters in relation to operational comfort.

Eight subjects, four male (age 30.8 ± 2.6 years, stature 163.1 ± 10.2 cm, weight 63.0 ± 16.2 kg) and four female (age 33.0 ± 2.1 years, stature 149.3 ± 7.1 cm, weight 50.3 ± 3.3 kg) farm workers were selected than screening process for their age, medical fitness and familiarity with tools. The work

measurements and physiological strains were evaluated for selected operations for varied design parameters of farm tools such as weight, blade angle and handle girth. After evaluating the above tools, the design parameters which were demanding least energy without sacrificing the work measurement were selected to develop prototype. These prototype was evaluated and compared with mean values of energy demands and work measurements of existing hand tools.

In this study spade operation was found to be highest energy demanding, mean energy value be 29.74 ± 2.57 kJ/min and 176.31 ± 27.80 kJ/m³ of soil and was reduced to (4.4 per cent) less value 28.43 ± 1.89 kJ/min and (10.3 per cent) less value 158.72 ± 14.99 kJ/m³ of soil with the optimised design parameters i.e., weight 1.75kg; Girth 4 cm and blade angle 35-40°; and further reduced in energy consumption to (7.1 per cent) less value 27.63 ± 2.9 kJ/min and (12.42 per cent) less value 154.4 ± 12.02 kJ/m³ of soil with weight 1.75kg, Girth 4 cm and blade angle 65-70°. The average area covered with spades be 2.15 ± 0.14 m²/min was improved by 5.6 per cent to 2.77 ± 0.08 m²/min with optimised designed parameters.

The next high energy consuming one in the selected tools is Digger fork. It requires energy of 25.64 ± 1.68 kJ/min and 479.94 ± 75.81 kJ/m³ of soil. The reduction in this energy requirement due to modified design parameters of weight 2.5 kg and fork angle 12.5-15° is 24.07kJ/min (i.e., 6.1 per cent less value) and (6.5 per cent less value) 448.54 kJ/m³ of soil for the same work measurement.

The Shovel consumed energy of 23.93 ± 1.53 kJ/min and 202.30 ± 12.55 kJ/m³ and reduced to 22.81 kJ/min i.e., 4.7 per cent less and 193.3 ± 12.3 kJ/m³ of soil i.e., 4.4 per cent less with the modified design parameters of weight 2.5 kg and angle 15°. The difference in work measurement is from 1.98 ± 0.11 m²/min to 2.0 m²/min.

The Hand hoe being least energy demanding tool, consuming energy of 20.96 ± 1.9 kJ/min and 316.29 ± 41.48 kJ/m³. This is further reduced with the modified design parameters of weight 0.55 kg, handle diameter 2 cm and bent handle 30° - 60° is 17.79 kJ/min i.e., 17.8 per cent less and 272.2 ± 32.23 kJ/m³ of soil i.e., 13.9 per cent less than the average value of energy requirement. Bent handle was designed to facilitate the workers to work in more upright posture than the 30° blade angle hoe for same weeding efficiency.

Cardio respiratory stress was quantified with the help of Fatigue factor (H/R), which were 3.35 ± 0.10 for Spade; 3.66 ± 0.34 for Digger fork; 2.95 ± 0.12 for Shovel and 2.48 ± 0.05 for Hand hoe.

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Introduction

CHAPTER - I

INTRODUCTION

India, one of the principal countries depending on Agriculture having geographical area of 329 million ha out of which about 140 million ha is the cultivated area. In India as per the 1995-96 statistics 70 per cent of the population is dependent on agricultural and related activities. In agricultural and allied activities, work force engaged is estimated about 206 millions of which 35 per cent are female workers. Out of total power available for agriculture, human power contributes about 11 per cent (Sathish Verma and Prathap Singh, 1994).

In the process of machanisation/modernisation of Indian agriculture, the improved designs of agricultural machinery in the country were introduced by adopting imported designs from developed countries with some modifications to suit Indian field conditions. This had enhanced the use of farm machinery and equipment during last three decades. Though all these machines / equipment were either operated or controlled by human workers, no little modification was done in design of equipment or work place to suit size, capabilities and limitations of Indian workers. Hence the health and safety measures were not in pace with the increased use of farm machines. Inturn created safety and health problems like loss of hearing backache, bent

shoulders etc. in the farm workers. This entail a cut back in use of farm machines and equipments.

And also in the past studies emphasis was given to develop the efficient tools/equipment which can give greater output per unit time, without giving due consideration to the human factors such as comfort or physiological cost. This necessiated the need for associating man's comfort and safety with all work studies in man-machine complex.

1.1 Ergonomics

Productivity of any work environment not only depends on the quality and complexity of the machine / tools being used, but also on the human being involved towards operating the tool and his work environment. It was during the world war II inspite of technological sophistication military equipment failed to perform satisfactorily. During 1949, scientist from all over the Globe realised that it was not only the sophistication of the equipment itself, but also the operator to be given equal importance while designing tool or equipment.

'Ergonomics' is the science dealing with man-machine -environment relationship to get the optimum output from it with less human cost.(Gour G.Ray, 1998)

Ergonomics can also be defined as an inter disciplinary study aimed at optimising work systems with respect to physical and physiological characteristics of a person. The knowledge can be employed to investigate complex and usually imprecise relationships between people, machines, and physical environments (Grandjean, 1982). The main objective of such investigation was to identify and minimise the existing incompatibilities between human capacities and task demand and make the work place safe, comfortable, healthy and productive. Generally while designing the machine/tool, designer would take utmost care on the technical part of the machine and forgets about operator. As a result most of the controls were positioned beyond normal human accessibility or they had to be operated in cramped or awkward posture. In many cases such dimensional incompatibility leads to serious consequences, resulting unnecessary strain on human body might cause failure of man-machine system. A good number of accidents would be due to lack of proper anthropometric consideration while designing the machine / tool.

For any ergonomist, it is therefore essential to design the work environment based on the 'Anthropometric' limitations of the operator. The term work environment here includes the work station and the tools to be used.

The term 'Anthropometry' refers to human body measurements or the external characteristics of the operator, which includes different body

4

dimensions, strength, speed and range of joint motions. These data can be utilised for design of an equipment/tool, work place layout etc.,

1.2 Ergonomics in Agriculture

The importance of ergonomics has been well established in Industry and Military applications, but not to the extent required in Agriculture.

Agriculture is an industry with tremendous opportunities for the application of ergonomics principles, since the human power is majorly involved and inseparable. And also working conditions were extremely difficult due to severe environmental conditions, long working hours, strenuous work and the use of mobile equipment. Hence the application of ergonomics is essential to improve the efficiency and thereby productivity of the works without jeopardising their health.

A lot of research work had been done in developed countries in this field. However, the results available from those studies cannot be applied as such to Indian situations. Anthropometric data available for other countries cannot be applied to Indian requirements (Gupta et. al, 1983), because agriculture as well as ergonomics are region specific entities.

1.3 Ergonomics in hand tool/equipment design

In developing country like India inspite of the progress in farm mechanisation and irrespective of farmer catogory (small, medium, largesize

farmers), certain operations like sowing, transplanting, hoeing, weeding etc. were best performed manually with hand tools and equipment only.

Earlier, most of the hand tools and animal drawn equipment were fabricated by village artisans where the user's physical dimensions were generally given some consideration. Now hand tools and equipment are being manufactured on mass scale in factories which are far away from the user. Now mild steel has replaced the wood and any modification at the job site is also difficult.

The various state agricultural universities and other research institutes had developed a quite large number of hand tools and agricultural equipment. Most of the designers of agricultural equipment had concentrated to improve the efficiency and durability, but none of these gave due importance to the operators comfort and treated operator as an other part of a man-machine system. Kaul and splinter (1964) mentioned that a hand tool which gives greater output per unit time might not be acceptable, if human energy cost involved is too high. Nwuba (1989) concluded that the bending posture, increased the energy requirements of various agricultural tasks and imposed painful strain at the base of the spine. These strain were increased when work was with more load.

With the advent of technology, such disregard for human factor is no longer possible. Hence there is an urgent need to critically analyse these

agricultural tools/equipment for its ergonomics to improve the man-machine system efficiency with out sacrificing performance.

1.4. Objectives of investigation

The application of ergonomics principles were more relevant in present day situation to have proper design of hand tools and other farm equipment.

In view of this, the study entitled "Investigation on design parameters of Hand tools in relation to operational comfort of Agricultural workers" was under taken with the following objectives.

1. Identification of agricultural operations requiring hand tools.
2. Determination of energy expenditure and rest pause required for the use of the hand tools under the study.
3. Optimising the design parameters of hand tools considering operational comfort of agricultural workers.
4. Field evaluation of modified hand tools of optimum design parameters with respect to human factors.

Review of Literature

CHAPTER - II

REVIEW OF LITERATURE

To review briefly the work done in the field of "Investigation on design parameters of hand tools in relation to operational comfort of agricultural workers" and allied activities were summarised under the following sections and sub-sections.

1. Research on Ergonomics in Agriculture
2. Anthropometric data of Agricultural workers
3. Physiology of work
 - i. BMR and calibration
 - ii. Physiological cost
 - iii. Energy expenditure
 - iv. Work classification and acceptable work load
4. Studies related to hand tools/manually operated equipment
 - i. Spades
 - ii. Shovels
 - iii. Hand hoes/weeders
 - iv. Other tools

2.1. Ergonomics research in agriculture

Ergonomics concept is 50 years old and recognised during world war II. Ergonomics is the scientific study of relationship between a person and his/her working environment. The goal of ergonomics is to increase efficiency and thereby productivity of the workers without jeopardizing their health and safety.

Suggs and Splinter (1958) carried out the time and energy analysis of different agricultural tasks. Heinrich Dupois (1959) conducted the study on effect of agricultural tractor operation on human stress and suggested that the locations of controls for human comfort and forces were necessary for operation.

Shrivastava *et al.* (1962) compared an Indian sickle with other sickle and scythe in terms of energy expenditure and work output. Koul and Splinter (1964) estimated the physiological cost of some hand operated as well as motorized tillage implements. Rao *et al.* (1965) reported a study on some agricultural operations.

Schertz. (1967) have investigated on the energy expended by citrus pickers, performing some of the component functions like general picking, ground zone fruit picking, ladder zone fruit picking, carrying and setting the ladder and carrying to quantify the physiological costs. Harinder singh *et al.* (1972) estimated the human energy requirements of selected farm operations

like spading, spraying and some manual methods of load transport. Moitra *et al.*, (1974) experimentally found that rotary mode for operating a low lift hand pump was more comfortable and gave better output than reciprocating pump.

Yadav *et al.* (1976) found that operation of rolling wheel type hand hoes were more comfortable to operator than plane hand hoe and with better output. Crolla (1976) concluded that the agricultural tractor ride vibration (vertical) levels were reduced upto 50 per cent in heavy and 30 per cent in light land with five furrow plough. Ghadge (1977) conducted the experiments on a rotary device for finding the optimum human performance. Verma *et al.* (1979) investigated on human accidents in wheat threshers and reported that about 73 per cent of accidents owned their occurrence due to human factors such as over work, ignorance, inattentiveness and physical capabilities.

Nag *et al.* (1980) did his studies on effective heat load on agricultural workers during summer season. Abdul Baqui and Lantin (1982) concluded that the energy expenditure in rice planting using the IRRI manual rice transplanter and traditional transplanting method were 3.79 and 3.09 k cal/min respectively. Tewari *et al.* (1983) tested for ergonomics suitability of the four row paddy seeder and concluded that it cannot be operated by a single man comfortably and two row seeder appears to be optimum one. Gohlich. (1984) concluded that total cab suspension system and front axle

suspension would provide increased comfort and safety in agricultural tractor design. Gite and Yadav. (1990) carried out a study to determine optimum handle height for pull and push dryland weeder and suggested the handle height as 0.7 to 0.8 of shoulder height of a subject so that the physiological cost and muscular fatigue would be minimum. Ghugare *et al.* (1991) indicated that the work load in spraying operation was within acceptable limits according to physiological criteria and there was a need to make improvements in the mounting of the sprayer on the operators back to reduce the postural discomfort. Gite and Singh. (1997) studied about the body discomfort during agricultural operations and concluded that there was need to reduce drudgery through proper design so as to have higher man-machine system efficiency and also for improving the workers comfort and health.

2.2. Anthropometric data of agricultural workers

One of the major key factor among several factors towards determining the efficiency of any tool or work system is the users "Anthropometry". Anthropometry deals with the measurement of physical features of human body including linear dimensions like weight and volume. A tool/machine might be sophisticated but design and dimensional incompatibility with anthropometric criteria would fail to give optimum output.

Sen *et al.* (1977) reported that anthropometric dimensions of unorganised workers including agricultural workers were similar to those of industrial workers. Therefore in the absence of specific data of agricultural

workers, anthropometric data of industrial workers may be used for design of agricultural equipment. Gupta and Sharma. (1979) reported that the anthropometric data was used to determine the size and shape of the equipment which was operated by a man and to determine the space in which a man has to work.

Grandjean. (1982) assumed that the average women had about 2/3 of the muscular strength as that of men. Gupta *et al.* (1983) compared the anthropometric data of Indian (Panjab state) population with US population and concluded that the anthropometric data available for other countries/places cannot be applied in India/all the places. It was also concluded that linear relationships exist between the standing height and other dimensional elements, hence other dimensions can be predicted from the standing height for studies.

Das and Bhattacharya (1984) concluded that in hand cranking mode of working, heart beat rate was minimum when the horizontal location of a rotary device was 77 per cent of arm reach and vertical location was 77 per cent of shoulder height. Length of the crank should be less than 30 per cent of arm reach. And in oscillation mode of working horizontal and vertical location were 72 per cent of arm reach and 93 per cent of shoulder height respectively. Kinoshita. (1985) concluded that 40 per cent of body weight as the limit for a load to be carried during continuous operation and 30 per cent of body weight could be easily carried by healthy individuals.

Gite and Yadav. (1989) concluded that the use of anthropometric data could help in the proper design of equipment for better efficiency and more human comfort. It was also identified that 52 body dimensions which were necessary for design of these equipments/tools. It was also mentioned that handle height for animal drawn equipment was 65 to 95 cm for comfortable handling. Similarly permissible feeding chute height was 126.6 cm for comfortable operation. Nwuba (1989) recommended that the pole length in shadoof irrigation should be kept in such a way that operator could operate by standing posture and the optimum bucket weight was about 17 per cent of the body weight of the subject.

Wilfried Hammer. (1991) studied the influence of age on safety and concluded that the height risk appears to young people (<25 years) due to low level of professional ability, training experience and caution. It was also suggested Somatographic drawings (anthropometrically scaled contour of the human body and its posture of work) to describe and analyse body posture related to alternative equipment design. Gite and Singh (1997) concluded that the agricultural operations required various strength parameters, namely hand grip strength, arm strength, leg strength and push and pull capacity were necessary for optimal design. It was also concluded that the lot of variation in strength between Indian and Western workers and depended on race, body weight and life style. The strength also varied with age, its maximum value being in the age group of 25-35 years. Older age group 50 and 60 years could produce 75-85 per cent of that of younger group.

Kathirvel and Manian (1998) reported that the energy expenditure was influenced by the weight and handle height of power tiller and the anthropometric suitability of the subject. Karunanithi *et al.*, (1998) concluded that 46 body dimensions were necessary for the design of agricultural hand tools and implements. Mathematical model was developed to assess other body dimensions when the standing height was known.

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

$$\text{5th percentile} = \text{Mean} - F \times \text{SD}$$

$$\text{95th percentile} = \text{Mean} + F \times \text{SD}$$

Where SD = Standard Deviation of mean

$$F = 1.645$$

2.3. Physiology of work

2.3.1 Basal Metabolic rate (BMR) and calibratin of subject

Passmore. (1956) measured the energy required in bed for 8 hours as 500 k cal plus 1400 k cal for sedentary time, totalling 1900 k cal/day. Lehman (1958) stated that the maximum energetic output of a normal man who could afford in the long run was 4800 k cal/day subtracting his estimate of basal

and leisure requirements of 2300 k cal/day and left a maximum of 2500 k cal/day available for working. This comes to 5 k cal/min, he also mentioned that 2000 k cal/day as a mere normal load was 4 k cal/min.

Leblanc. (1957) quantified the work output in terms of heart beat rate by conducting an experiment on tread mill with 18 subjects at speeds varying from 4.2 to 15.2 kph. He found that the energy expenditure to increase beyond the critical speed of 8.1 Kph and the recovery time was also found to increase remarkably.

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

Clarke and Clarke. (1965) reported that one of the most widely used techniques for exercise physiology research was treadmill in which specification may vary, but in general two variables that should be considered were speed and inclination.

Jean bogert. (1966) expressed the BMR in relation to human body weight. For male it was 1 k cal/h for each kg of body weight and for female it was 10 per cent less. Edholm (1967) suggested that the 2000 k cal/day expenditure should be considered as maximum and work level should be kept

below this. Robinson (1967) reported that about 33 per cent of the BMR is used by organs such as the heart, kidneys and lungs and remaining 67 per cent for oxidation in resting tissues especially in maintenance of muscle tone. This rate was obtained by measuring the oxygen consumption in a period of 6 to 8 minute. Although BMR varied from individual to individual the average for adults ranged from 1500 to 1800 k cal/day. Tuttle and Schottelius. (1969) estimated that the adult who leads a fairly sedentary life uses 2400 k cal/day.

Brockway. (1978) stated that the heart beat rate predicted the energy expenditure. Durnin. (1978) correlated the heart beat rate and oxygen consumption by indirect calorimetry and indicated the possibility of extrapolating the energy expenditure from the stabilised heart beat rate. Sharma and Gupta. (1979) considered the treadmill as better equipment for calibrating the subject and the mechanical energy of the subject could be calculated as follows.

$$\text{Horse power, hp} = \frac{WV \sin \theta}{4500}$$

W = Weight of the subject, kgf

V = linear speed of the belt conveyor, m/min

θ = angle of inclination of the belt conveyor with the horizontal, degree.

Robinson. (1978) reported that the human size, shape and body weight would affect the BMR and the range of basal metabolic rate of an adult was 1300 to 1800 k cal/day.

Kathirvel. (1986) analysed the energy expenditure pattern of power tiller operator and estimated the BMR of the subjects which varied from 1441 to 1565 k cal/day. Saraswathy Eswaran *et al.* (1987) investigated the energy expenditure pattern of rural women in Tamil Nadu and reported that average metabolic rate of women was 1332 k cal/day. The energy consumption for various domestic activities varied from 1.950 to 2.868 k cal/min. Narsingh Rao (1997) investigated the ergonomics of man-machine system on sprayer estimated the BMR of subjects ranged from 1507 to 1744 k cal/day. Karunanithi. (1997) investigated the ergonomics of selected rice farming operations and equipment. The BMR estimated for male subjects varied from 1462 k cal/day to 1721 k cal/day and for female it varied from 1080 K.Cal/day to 1152 k cal/day.

2.3.2 Physiological cost

Physiological cost involved in any operation was expressed in terms of cardiorespiratory response of subjects during work and the main parameters measured were heart beat rate and oxygen consumption rate.

Curteon. (1947) indicated that the basal metabolic rate, heart beat rate and oxygen consumption rate were the pertinent parameters for assessing the human energy for performing various types of operation. Leblanc. (1957) concluded that human energy could be measured by the open circuit indirect

method using the heart beat rate as measuring index. He also stated that heart beat rate remains constant for some seconds i.e., about 10 to 20 seconds after the cessation of a task before it starts to decrease.

Suggs and Splinter. (1961) concluded that a hot humid environment, depress the output of human workers and also deduced that the human work output (fixed at a cost air optimum level) was not effected by temperature at a low relative humidity of about 30 per cent. In the same way, at moderate temperature (about 21°C) the optimum work output was not affected by humidity. But at temperatures above this level, high humidity reduced the optimum work output, and below these level it increased the optimum output.

Swift and Fisher. (1964) the basal metabolism represented that friction of total energy metabolism that was needed to maintain the vital life processes of the body not under volumary control i.e, heart beat, kidney function, respiratory mechanism. It may be defined as the heart production of subject during physical digestive and emotional rest.

Margaria . (1965) correlated the speed and inclination of tread mill with oxygen consumption, while studying the oxygen consumption on the onset of muscular exercise of man and observed that the exertion in 3 min for light and 30 seconds for heavy works could be the limit of endurance time.

Yadav *et al.* (1976) concluded that the force required to operate the plane hoe through soil was less as compared to the wheel hoe but it caused more fatigue to the operator due to the lifting action. Pawar (1978) investigated the human energy requirements for power tiller operation and reported that 5.50 per cent of additional human effort was required for walking in puddled soil. The contribution of posture towards human energy expenditure was in the range of 8.91 to 11.81 per cent.

Nag and Dutt. (1979) studied the effectiveness of seven weeders with reference to physiological responses. The mean heart beat rate varied from 105 to 120 beats/min and oxygen uptake from 0.569 to 1.158 l/min in weeding operation. In this study, wheel hoe type weeder was found better than other weeders. Saha *et al.* (1979) concluded that generally work load required oxygen at a rate of about 35 per cent of VO_2 max was considered as acceptable worked load for Indian workers which works out to a work consuming 0.7-1.0/min of oxygen. Corresponding heart beat rate at this work load was 110 beats/min.

Nag. (1981) stated that max volume of oxygen (VO_2) max was conceived as an international reference standard of cardio-respiratory fitness. The VO_2 max was dependent on many factors such as race, age, sex, body buildup and training. For Western population, it ranged from 3 to 4 l/min. However for Indians VO_2 max was about 2.0 l/min for male workers and

1.8 l/min for female workers which showed a vast difference between the work capacity of Indian workers and Western workers.

Yadav and Srivastava. (1984) studied on sugar cane harvesting knives, and conducted that the increase in heart beat rate during work varied from 39 to 59 beats/min for different knives and the energy expenditure varied from 16.25 to 24.58 kJ/min.

Gill and Chowdary. (1987) carried out ergonomic evaluation of four manually operated dryland weeders and observed that the lighter implements had lower physiological cost. Nwuba and Kaul. (1987) measured the energy requirements of hand tools for wood cutting by indirect open circuit method using the heart beat rate as measuring index and reported that the weight of the hand tools directly influence the human energy requirements apart from the season. Lower energy expenditure was registered with chain saw. Nag and Pradhan (1992) concluded that the oxygen consumption increased marginally with higher stroke rates in hoeing operation and also concluded that high lift hoeing relatively slower pace (23 to 37 strokes / min). The heart beat rate reached 176 and 182 beats / min in the selected two types of hoe.

Intaranont and Srithongchai (1993) concluded that all activities in the field were affected by relative humidity, body weight, age and lifting tasks.

(1997) summarised the data available on major activities as reported by various research workers in the below Table 1.

2.3.8. Energy Expenditure

Human energy expenditure towards the different operations performed under different environmental conditions were essential. These values were also important from the safety point of view, so that the equipment / tools could be designed within the safe limit of energy requirements.

Lehman. (1958) considered 4 k cal/min of energy expenditure rate was the normal allowable work load for 8 hour/day. According to him a task demanding greater energy expenditure rate more than 4 k cal/min necessitated a fatigue allowance. Srivastava *et al.* (1962) investigated on the energy requirements, harvest rates and efficiencies of grain harvesting equipment and concluded that there was a difference in the energy expenditure of different persons using the same harvesting equipment under the same conditions.

Nag and Dutt.(1980) observed that though bending required slightly more oxygen usage, weeding either in the sitting posture (11.27 kJ/min) or bending posture (12.18 kJ/min) could not caused a marked difference. However, uprooting rice plants demanded the greater physiological cost in the bending posture (13.7 kJ/min) than in the sitting posture. The drudgery caused due to bending posture was mainly reflected in terms of postural

discomfort. Considering these aspects he suggested that when work can be done in sitting posture, then it should be done in the same posture, but it should not be done in a bending posture. Unlike respiratory responses, there was not much consistency in pulse rate response with severity of work. Abdulbaqui and Latin. (1982) compared the human energy expenditure in rice transplanting using the IRRI manual rice transplanter with the traditional hand transplanting method by means of indirect calorimetry. The max energy expenditures were 3.79 and 3.09 k cal/min in machine and manual transplanting respectively.

De and Sen. (1986) ergonomically evaluated the ploughing operation in paddy cultivation. Energy requirement in this task was found to be 14.70 kJ/min. They observed that the routine operation caused excessive strain at the lumbosacral regions besides shoulder, calf thigh, upper arm and back. Nwuba and Kaul (1986) found that the traditional hoe having 56 cm long handle demanded 7.70 kJ/min and 34.50 kJ/m³ of soil. He also estimated the energy demand of the traditional tillage hoe (short handle) ranged from 7.00 to 9.50 kJ/min which was too high when compared with the optimum limit of continuous energy output of man was 4.50 kJ/min (75w).

Nwuba and Kaul (1987) found that the environment E2 (temperature 30 to 33°C, relative humidity 47 to 60 per cent) the highest energy and lowest output. And conversely environment E1 (temperature 21° to 23°C, relative humidity 15 to 19 per cent) recorded the lowest energy and the highest

output. While E_3 (temperature 26 to 28°C, humidity 65 to 80 per cent) fell in between this in agreement with the findings of Suggs and Splinter.

Nag. (1987) reported the maximum oxygen uptake (VO_{2max}) conceived as the measure of working capacity of farmers was obtained through ergometric testing on a bicycle ergometer. The average VO_2 max of the subjects was 2.13 ± 0.21 L/min in 41.9 ± 5.5 ml/kg/min.

Intaranont and Srithongchai (1993) concluded that all activity in the field were affected by relative humidity, body weight, age and lifting task. Gite *et al.* (1997) summarised the energy expenditure for major agricultural and allied activities as given in table 2.1 and 2.2.

He also discussed about the different calorific values of oxygen used by different researchers as follows.

Researcher	Cal.Value used for O_2
Nag <i>et al.</i> (1980)	20.86 kJ/l
Grandjean. (1982)	20.09 kJ/l
Anony. (1987)	20.93 kJ/l
(When Oxylog is used for)	

Table 2.1. Physiological response of male workers in different agricultural operations

Sl. No	Operations	Physiological responses		Source
		Heart rate(HR) beats/min	Oxygen uptake (VO ₂) l/min	
1.	Digging soil with pick axe	155.2	-	Kaul & Splinter (1964)
2.	Digging soil with spade	134.9	-	Kaul & Splinter (1964)
		-	1.545	Singh & Kaul (1972)
		131.2	0.948	Nag et al. (1980)
		172.0	1.586	Pradhan <i>et al.</i> (1986)
3.	Ploughing with animal drawn wooden plough in wetland	131.2	0.997	Nag <i>et al.</i> (1980)
4.	Ploughing with animal drawn mould board plough in dryland	105.4	0.544	Gite (1991)
5.	Harrowing with animal drawn plough	103.9	0.536	Gite (1992)
6.	Fertilizer application by broadcasting	126.3	0.433	Nag et al. (1980)
7.	Seeding with manual seeder in wetland	154.0	1.638	Nag & Dutt (1980)
8.	Transplanting of rice in wetland in bending posture	109.2	0.618	Nag <i>et al.</i> (1980)
9.	Weeding by uprooting the weeds in bending posture	114.0	0.578	Nag et al. (1979)
10.	Weeding by uprooting the weeds in sitting posture	113.3	0.573	Nag & Dutt (1979)

Table Contd...

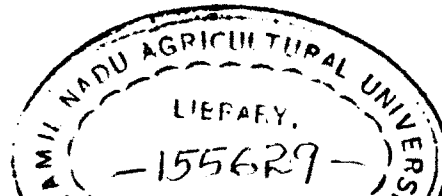
11.	Weeding with hand tools in sitting posture	98.0	-	Yadav & Gite (1987)
12.	Weeding with manual weeder	120.4	0.932	Nag & Dutt (1979)
		120.4	0.932	Nag & Dutt (1979)
		113.7	0.848	Gite et al. (1992)
13.	Spraying of pesticides	125.5	0.656	Nag et al. (1980)
		-	0.495	Singh & Kaul (1972)
		94.6	0.454	Ghugare et al. (1991)
14.	Watch-keeping to scare birds	-	0.912	Shrivastava et al. (1962)
15.	Harrowing with sickle	-	0.488	Nag et al. (1980)
16.	Rice threshing with pedal thresher	140.8	1.310	Nag & Dutt (1980)
17.	Rice threshing with pedal	135.8	0.920	Nag & Dutt (1980)
18.	Winnowing (standing)	124.3	0.808	Nag et al. (1980)
19.	Groundnut decortication	107.2	0.656	Singh (1993)

(Note : For 8-hour duration, a work requiring oxygen consumption less than 0.7 l/min is considered as the acceptable one. The corresponding heart rate for this oxygen consumption rate will be about 110 beats/min.)

Table 2.2. Energy expenditure in some agricultural and allied activities

Sl.No	Operation	Energy expenditure (kJ/min)	Source
1.	Digging soil with spade	22.50	Nag et al. (1980)
2.	Ploughing with animal drawn wooden plough in wetland	18.89	De & Sen (1986)
3.	Ploughing with animal drawn wooden plough	20.96	Nag et al. (1980)
4.	Ploughing with mould board plough	11.40	Gite (1991)
5.	Harrowing with animal drawn blade harrow	11.20	Gite (1992)
6.	Fertilizer application by broadcasting	9.07	Nag et al. (1980)
7.	Seeding with manual seeder in wetland	33.40	Nag & Dutt (1980)
8.	Transplanting rice in wetland	13.00	Nag et al. (1980)
9.	Weeding with wheel hoe	10.50	Gite et al. (1993)
10.	Spraying with knapsack sprayer	13.72	Nag et al. (1980)
11.	Watch keeping to scare birds	4.49	Nag et al. (1980)
12.	Harvesting with sickle	10.25	Nag et al. (1980)
13.	Rice threshing by beating	19.26	Nag et al. (1980)
14.	Rice threshing on pedal thresher	27.56	Nag et al. (1980)
15.	Winnowing (Standing)	17.06	Nag et al. (1980)
16.	Groundnut decorticaion using decorticator	13.73	Singh (1993)

(Note : The limit for acceptable work load for Indian workers according to Saha et al. (1979) is considered as 14.6 kJ/min).



Narsingh Rao. (1997) carried out ergonomic analysis of man - machine system on sprayers and reported that the energy expenditure of rocker sprayer operator varied from 2.21 to 4.43 K.cal/min at an operating pressure ranged from 30 to 70 k Pa.

Karunanithi. (1997) measured the energy requirements of selected rice farming operations by male and female workers and concluded that the highest energy expended operation are threshing by manual and digging soil in wetland with spade. (4.87 and 4.70 k cal/min respectively). Similarly the maximum energy of 3.50 k cal/min was required for harvesting with sickle by female workers. He also found the relationship between body weight, leg sinkage and leg pulling force. The energy lost for walking in puddled soil was found to be 3.14 k cal/min which amounts to 72.40 to 86.70 per cent of energy spent for different operations in puddled land by male workers and 82.80 to 89.30 per cent by female workers.

Kathirvel *et al.* (1998) measured the energy expenditure for power tiller operation and reported that the energy expenditure varied from 3.05 to 4.75 kcal/min.

2.3.4. Work classification and acceptable work load

Christenson. (1953) determined energy expenditure and oxygen consumption for different grades of work levels as below.

Work grade	Energy expenditure k cal/min	O ₂ consumption l/min
Unduly heavy	> 12.5	> 2.5
Very heavy	10.0-12.5	2.0-2.5
Heavy	7.5-10.0	1.5-2.0
Moderate	5.0-7.5	1.0-1.5
Light	2.5-5.0	0.5-1.0
Very light	< 2.5	< 0.5

Lucienbrouha. (1960) classified the work loads in terms of physiological cost as below.

Work grade	Energy expenditure k cal/min	O ₂ consumption l/min	H/R beats/min
Light	2.5-5.0	0.5-1.0	60-100
Moderate	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

Kath and Mc Ardle. (1977) classified the works as below

Work grade	Energy expenditure k cal/min
Very heavy work	> 10.5
Heavy work	7.5 - 9.9
Moderate work	5.0-7.4
Light work	2.5-4.9

Sharma and Gupta. (1979) indicated the following classification of work after assessing the work load of agricultural workers as below.

Work grade	Heart beat rate beats/min	O ₂ consumption l/min
Unduly heavy	> 175	> 2.5
Very heavy	150-175	2.0-2.5
Heavy	125-150	1.5-2.0
Moderate	100-125	1.0-1.5
Light	75-100	0.5-1.0
Very light	< 75	<0.5

Saha *et al.* (1979) concluded that generally work load which required oxygen at a rate of about 35 per cent of VO₂ max was considered as

acceptable work load for Indian workers corresponding values would be 0.700 l/min and 0.63l/min for male and female workers respectively.

Nag and Dutt. (1980) expressed the heart beat rate and oxygen uptake (VO_2 max) initial and during work, the relative severity of the jobs as the percentage of VO_2 max. The work load ranging between 26 to 50 per cent of VO_2 max was considered as moderately heavy. The value from 51 to 75 per cent of VO_2 max were taken as heavy jobs and beyond the level, the job was classified as extremely heavy.

Anon. (1987) suggested that when Oxylog is used for measurement of oxygen consumption rate the energy expenditure rate is to be computed by using the calorific value of 20.93 kJ/l of oxygen.

Gite and Singh. (1997) concluded that the heart beat rate and oxygen consumption were depending upon the work load and maximum values which could be attained in normal healthy individuals, were about 190 beats/min for heart beat rate and 2.00 l/min (i.e., upto VO_2 max) for oxygen consumption rate. He also mentioned that at this extreme work load, a person could work only for few seconds.

2.4. Studies related to hand tools/ manually operated equipment

2.4.1. Spades

Harinder Singh and Kaul. (1972) concluded that oxygen consumptions for spades varied from 1.91 l/m (625.25 kg.m/min to 2.03 l/min (680.19 kg.m/min) for two different spades of weight 2.43 and 2.63 kg respectively.

Fraser (1980) indicated that the handle should be cylindrical for hand tool, some enlargement at the end to prevent slippage and diameter of handle was in the range of 25-40 mm.

Parikh. (1980) suggested an angle of 65° to 70° between blade and handle for proper working. He also suggested the use of long handle tools to avoid bending posture of operator during work. Pradhan *et al.* (1986) recommended a spade of about 2 kg weight having an angle of blade with the handle as 65° to 70°, a handle diameter of 40mm and handle length of 700 mm for various operation in agriculture.

Nwuba and Kaul. (1987) concluded that the increased handle length of hand tool (matchet) from 63 cm to 86 cm lowered the energy expenditure significantly and suggested that handle could be padded to avoid friction on the palm of the handle.

Gite and Yadav. (1989) concluded that anthropometrically, the handle diameter of hand tool should be in such a way that while an operator grips

the handle his longest finger should not touch the palm, at the sametime it should not exceed the internal grip diameter. Thus handle diameter would range between 32 and 36mm.

Nag and Pradhan. (1992) classified hoeing (spading) operation in two ways a) low lift (a person adopted bent back posture without rising arms above shoulder level) and b) high lift (a person holds the handle and lifts the tools upward above the head and strikes the tool to the ground. It was also mentioned that the cutting and breaking of soil depends on a) soil characteristics b) curvature of the blade c) Frictional characteristics d) thickness of the tip of the blade and e) clearance angle between the circular trajectory and the back face of the blade. It was also indicated that in "Low lift" hoeing task (spading task), the area and weight of soil dug increased when the depth of soil dug consistantly reduced with the higher stroke rate.

The cardiovascular load as reflected in heart beat rates had an increasing trend with the stroke rates. The heart beat rates were very high level i.e., 161 to 172 beats/min and 172 to 176 beats/min in two types of hoes, which were in heavy to extremly heavy (Naget al, 1980) work grades i.e., relative energy demand ranged from 71 to 89 per cent of VO_2 max.

Author finally suggested the design parameters of hoe (spade) as weight 2 kg; blade handle angle 65° to 70° ; blade length 25 to 30 cm; blade width 22 to 24 cm; handle length 70 to 75 cm and handle diameter 3 to 4 cm.

Yokou Takao *et al.* (1996) concluded that the sensory evaluation of optimum grasping diameter was difficult for children under age ten due to insufficient growth of skeletal structure. The optimum grasping diameter for age above ten depended upon the hand size. In the case of adults the optimum grasping diameter depended on the dimensions concerned with the length of the hand but only depended slightly on the hand breadth for male were 30 to 40 mm which were about 10 per cent larger than those evaluated for females.

It was also found that tube could be grasped well by a human hand if all finger tips and the entire palm area contact it.

Abdul Kareem. (1996) indicated that the different angles of spade were used for different purposes like 10° for scraping, 27° and 42° were for earth work and digging and 85° angle for digging in hard soil and cutting the roots.

Karunanithi. (1997) confirmed that digging the soil with spade required maximum energy i.e., 4.70 k cal/min and corresponding heart beat rate was 131 beats/min next to the manual threshing i.e., 4.87 k cal/min and 132 beats/min of energy expenditure and heart beat rate respectively.

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2.4.2 Shovels

Degani *et al.* (1993) modified shovel design with two perpendicular shafts and regular shovel were evaluated and concluded that the significant reduction was found in Electromyography (EMG) values of the lumbar paraspinal muscles and consistent reduction in perceived exertion ratings while the modified shovel was being used for removing dirt in digging trenches upto 90 cm in depth.

Hansson and Oberg (1996) studied the effect of shaft length, shaft angle, alternative shaft design and variation in operator anthropometry when lifting a loaded shovel from the ground and concluded that the forces loading the spine could be decreased by using a shovel with its shaft angled to allow a more upright working posture. The another conclusion was that the anthropometry of operator had major effect on biomechanical load levels in the performed task.

2.4.3 Hand hoes and weeders

Yadav *et al.* (1976) measured the work rest schedule of operator with wheel hoe and plane hoe in which operator needed 37 minutes of rest after 90 minutes of continuous work with wheel hoe to bring down his heart beat rate ratio to normal and 15 minutes of rest after 29 minutes of continuous work with plane hoe.

Nag and Dutt (1979) studied the effectiveness of seven weeders with reference to physiological responses. The heart beat rate varied from 105 to 120 beats/min and oxygen uptake varied from 0.569 to 1.158 l/min in weeding operation. In this study wheel hoe type weeder was found to be better than other weeders.

Nag *et al.* (1980) observed that weeding either in squatting or bending posture did not cause a marked difference in energy expenditure i.e., 11.2 kJ/min and 12.18 kJ/min respectively, but drudgery caused due to bending was reflected in terms of postural discomfort experienced by the worker.

Tiwari and Datta. (1983) observed that weeding blades with 15 to 20 cm working width would be within the human limitation.

Nwuba and Kaul. (1986) concluded that the spinal muscle force and lumbo sacral joint reaction, while using the traditional hoe modified with a 150 cm long handle were only 20 per cent and 38 per cent of those of the short handle hoe respectively.

Bansal *et al.* (1987) studied the power requirements, weeding efficiency, work output and total human energy requirements of intercultural hand tools viz. kurpa hand hoe and wheel hoe were studied in wheat and maize crops. Energy requirements calculated for kurpa in maize crop 4.356 kJ/m² (52.26 Watts) and 1.476 kJ/m² (78.4 Watts) for wheat, corresponding

for hand hoe and wheel hoe were 1.584 kJ/m^2 (37.28w) 0.345 kJ/m^2 (38.74 watts) for maize and 1.116 kJ/m^2 (63.09w), 0.324 kJ/m^2 (42.6w) for wheat. The area covered by kurpa, hand hoe and wheel hoe are $43.25 \text{ m}^2/\text{h}$, $84.06 \text{ m}^2/\text{h}$ and $97.89 \text{ m}^2/\text{h}$ respectively in maize field.

Tandon *et al.* (1995) calculated the area covered by khurpi as $1.91 \text{ m}^2/\text{min}$ and working heart beat rate as 79 beats/min and also concluded that khurpi operation required less energy consumption compared with wheel and hand hoe.

Chatizwa. (1997) concluded after evaluating four hand weeders from an ergonomic and mechanical point of view that manual weeding was found to be strenuous and physically demanding. The highest work rate was achieved with a garden hoe with little discomfort.

2.4.4 Other tools

Drills *et al.* (1963) surveyed on striking tools and concluded that the average striking tool head weight 1.40 kg or about 2 per cent of users weight and average length of handle was found to be 0.60m and about 35 per cent of users height.

Kaul and Splinter. (1964) mentioned that reduction in drudgery was one of the important criteria of improved farm equipment, according to

authors, a hand tool gave greater output per unit time might not be acceptable if human energy cost involved was too high.

Nwuba and Kaul. (1987) concluded that type of tool selection was very important factor, since a diversity of tools were available. It was also proved that the environment-implement interaction was very highly significant for the work expended per unit area and unit volume of work, it implied that one has to select the right tool for the right environment.

It was also concluded that the weight of hand tool directly influenced the human energy requirement for their use. The heavy tools demanded more energy and rest-stops than the light tools.

Bochlemann *et al.* (1994) analysed three different handles of electric hedge clippers and concluded that stress and strain during manual tool handling not only depended on factors such as weight to be handled but were also determined by the design of the man-machine interface. It was also concluded that significant difference in physiological cost depending on both work height and handle shape.

Kim Joe young *et al.* (1996) carried out the experiment to measure the position of the fingers and the maximum finger forces at four different postures. It was found that the finger forces were significantly affected by the subjects, the finger, and grip postures. It was also found that the maximum

force of women was 62 per cent of men's force. Gite and Singh. (1997) found that the output of a worker with traditional hand tools was very low i.e., upto 80 m²/h as against the manual weeders i.e., 100 to 200 m²/h and measured the energy expenditure for weeding with wheel hoe as 10.5 kJ/min.

Parvathi *et al.*(1998) measured the energy expenditure of rural women of selected postures during their farm operation in cotton cultivation and concluded that the thinning operations required about 22 per cent more energy than other three operations i.e., sowing, hoeing and cotton picking. Energy expenditure for thinning operationd was 2928 k cal/day and other operations viz., hoeing, sowing and picking required 2404, 2285 and 1921 k cal/day respectively.

Materials and Methods

CHAPTER - III

MATERIALS AND METHODS

In this chapter, brief description about the materials used, procedures adopted for selecting the tools and subjects were given. Also it explains methods adopted for estimating the energy expenditure of different agricultural hand tools. These details were discussed under the following heads.

- i. Selection of hand tools
- ii. Selection of subjects
- iii. Caliberation of subjects
- iv. Experimental design
- v. Development of prototype
- vi. Field evaluation of prototype

3.1. Selection of hand tools

The farm tools used in Indian Agriculture were estimated as about 800 millions (CIAE, 1987). Some of these hand tools were neglected for its improvement, though they were essential for farming operations irrespective of the farm size. To investigate the design parameters of all existing hand tools for its human comfort is highly impractical and not much of use. Hence the above study was confined to few hand tools, which would render some help to the farming community. The criteria chosen for selecting the hand

tools were energy demand and be largely used by the farmer i.e., well accepted so that study could improve the working environment by reducing maximum human drudgery.

The hand tools for the study were selected after extensive survey both in farmers fields and in research farms. In this study it was found that, though there were a good number of agricultural hand tools developed in the state agricultural universities and other institutes for better output, they were rare in use excepting in very few cases. And the farmers were still using age old traditional hand tools and methods because of its versatality and adoptability. Hence the study was extended for the tools which were largely accepted and were in use, than the improved hand tools.

After selecting the tools for its usage, they were sieved for high energy demanding tools. In this process, it was also noticed from the experienced farmers, farm workers and literature Sen and Bhattacharya, (1976), Nag, *et al.*, (1980) De and Sen (1986), Gite (1991) that high energy demanding tools are soil working tools. Accordingly the soil working tools were selected from the array of tools for the study.

Finally the following agricultural hand tools were identified for the study "Investigation on design parameters of hand tools in relation to operational comfort of agricultural workers".

1. Spade
2. Shovel
3. Digger fork and
4. Hand hoe

3. 2. Selection of subjects

The following criteria were used for the selection of subjects.

- i. Age
- ii. Anthropometric data
- iii. Medical fitness

3.2.1. Age

It is evident that the maximum strength/power can be expected from the age group of 25 to 35 years, Gite *et al.* (1997). Hence from the available workers, 4 numbers of male and 4 numbers of female who were belonging to the age group 25 to 35 years were chosen considering their experience with the farm tools selected for the study.

3.2.2. Anthropometric data

The anthropometric data of all selected farm workers both male and female were collected, by using anthropometric data measuring kit developed. For the collected anthropometric data 5th and 95th percentile were calculated. The selected workers were categorised under these 5th and 95th percentile groups i.e., A type and B type groups respectively.

Percentile : Engineering designers and ergonomists often use average value (the mid point of the study sample which covers only 50 per cent of study population) to design any equipment which has got no importance. But actual interest should be more concerned to make the design comfortable for

the maximum percentage of the population. It could be achieved by using 5th or 95th percentile value as demanded by the design. The term PERCENTILE indicates percentage of persons within the population having body dimensions lower than the specified value. In this study 5th and 95th percentiles were calculated for the anthropometric survey data by using the equations suggested by Vasudha Atreya and Gaur G.Ray (1998).

For proper matching of tool/ equipment requirement with human capabilities, it is necessary for the measurement of body dimensions. In the study the measurements were made with the following :

1. Anthropometric data measuring kit.
2. Hand grip diameter measuring tool.

3.2.2.1. Anthropometric data measuring kit

This kit consists of two units namely (1) Platform (2) Chair.

i. Platform

A platform of size 3.01 x 1.15 m was made of 75 x 35 x 5 mm mild steel channel section. The platform was mounted with a sliding level-bar and tong unit. The level-bar and tong assembly were incorporated its provisions to move to any position on the platform. The level bar could be raised or lowered to measure the height of the subject. The sideways moving tongs could be adjusted to measure the breadth at any point of the body of the subject.

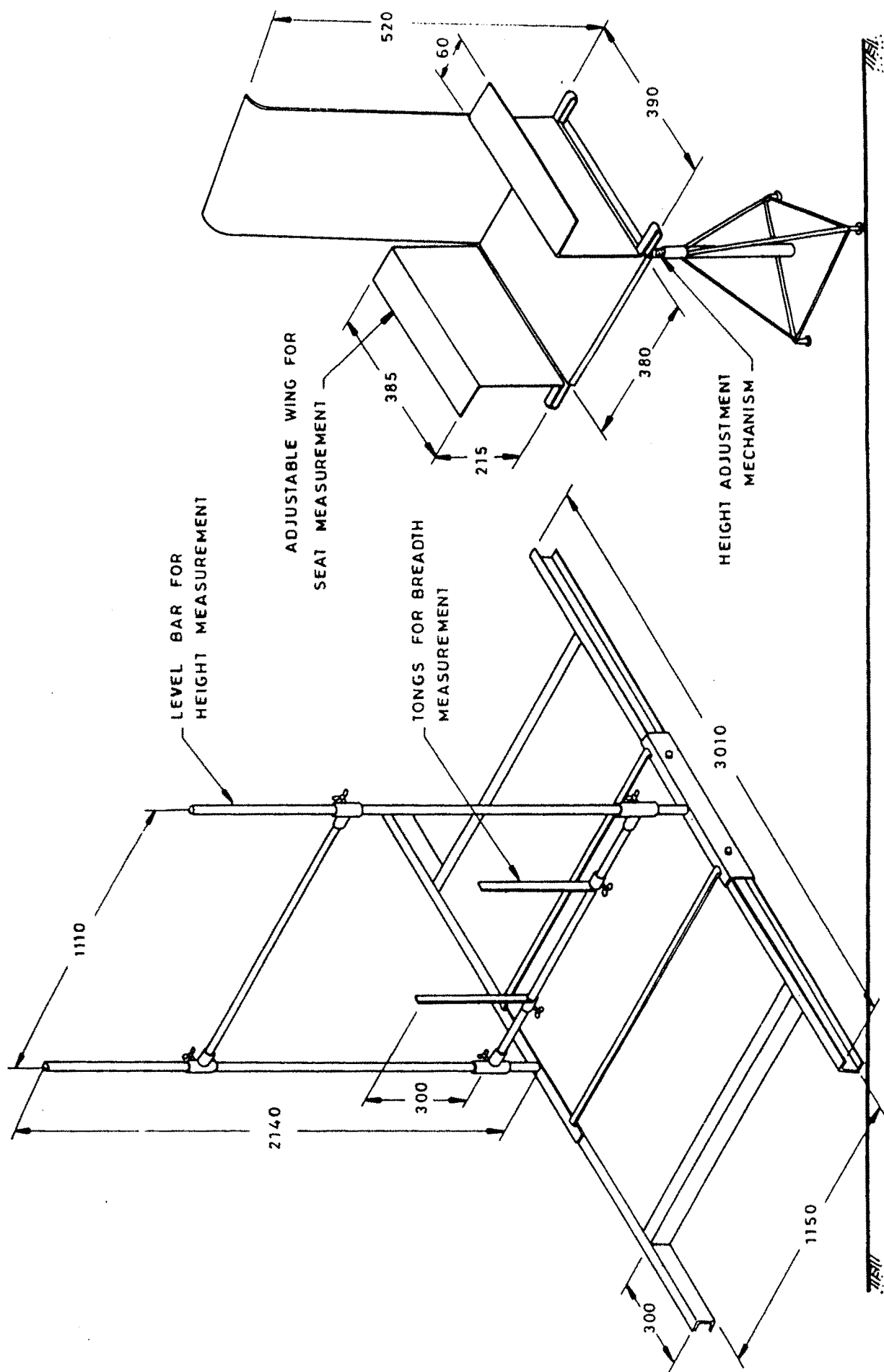


Fig.3.1. ANTHROPOMETRIC DATA MEASUREMENT KIT

ii. Chair

The chair was made of 16 gauge mild steel sheet. The chair was mounted on a tripod made of 20 mm diameter mild steel conduit pipe. It had provision to raise or lower the seat (450 to 600 mm) from ground level by rotating a spindle attached to the base of the chair. This facilitated measurement of sitting height, knee height and other pertinent dimensions in sitting posture. The sides of the seat were made in such a way that the wings could be moved inward or outward to measure the hip breadth ranging from 200 to 700 mm.

3.2.2.2. Hand grip diameter measuring tool

Handle design of a hand tool had very important role, since improved handle could eliminate the acute wrist bending thereby reducing carpal tunnel syndrome and early muscular fatigue (Gaur G. Ray 1998). In this handle design, one of the important factor to be considered was handle girth measurement which had to be assimilated for user anthropometry in general and hand grip diameter in particular. This necessitated the development of a tool to measure the hand grip diameter.

The tool developed was very simple, made of circular acrylic shaft, which was turned to taper from 60 mm to 20 mm. It facilitates to measure hand grip diameters of all subjects (ranged from 26 to 42 mm) surveyed in the studies.

3.2.3. Medical fitness

The following medical tests were conducted for the subjects to assess their medical fitness for the study.

1. Blood pressure
2. Electro Cardio Graph (ECG)
3. Bio-clinical analysis

3.2.3.1. Blood pressure

The blood pressure of the subject changes momentarily according to the psychological tension, excitement and physical activity. So these were considered as sensitive indicator to check the subjects physical soundness to assign the task. The blood pressure was measured for each subject using the Electronic digital blood pressure monitor. It mainly consists of two units; viz. main unit and cuff unit. The main unit has a power switch, to ON and OFF the unit, a microphone jack to connect the microphone plug, an air connector to connect the tube from cuff and a display unit which displays the systolic/diastolic blood pressure, inflation indicator, deflation indicator. The cuff unit has a fastening tape, a microphone and its positioning mark, a cuff ring, a microphone plug to insert it into microphone jack, a rubber tube plug to insert it into air connector and a rubber bulb with air release adjustment valve. The source of power is a 9 volt battery.

The cuff unit was fastened to the subject with the help of positioning mark and the systolic, diastolic blood pressure were noted from the display

unit. The same procedure were adopted for all subjects and the blood pressures measured were tabulated.

3.2.3.2. Electro Cardio Graph (ECG)

It is recording of electrical potential produced in association with heart beat. The upward deflection is a positive potential and the downward deflection is a negative potential. The uses of ECG are to identify the

- i. Arterial and ventricular hypertrophy
- ii. Myocardial infarction (heart attack)
- iii. Arrhythmia
- iv. Pericarditis
- v. Effect of drugs on heart
- vi. Electrolyte disturbances especially K^+

The unit is a Cardiomin, supplied with two types of electrode cables. The three electrode cables used to pickup the electric potential due to heart beat alone. The other cable with five electrodes, used to diagnose the cardiological problems of the subject. The electrodes were properly identified and attached to the subject at the specified position on the body according to the colour code. Using the cardiomin unit with mediscopes, continuous visual display as well as graphical tracing can be obtained.

For recording the ECG of a subject, the skin of the subject was cleaned at specified positions and the electrode jelly was applied on the cleaned

portion and on the electrodes. The electrodes were kept on the position and fastened with the belts.

The electrode cable was connected to the recorder. The recorder was standardized by keeping the OFF/ON/RUN control in RUN position and by pressing 1 mv button to obtain deflection. The deflection was adjusted to 10 mm with sensitivity control. The lead selector switch was turned to position lead I and OFF/ON/RUN control to RUN position and the graphical record was obtained for lead I. Similar records were obtained by turning the lead selector to lead II, lead III, AVR, AVL and AVF. For recording chest lead, the chest electrode position was changed from position V1 to V6 on the chest and graphical records were obtained. Similarly the graphical records for all the subjects were obtained.

3.2.3.3. Bio-clinical analysis

The bio-clinical analysis of the blood was carried out for blood sugar, blood urea, hemoglobin, serum cholesterol for hypertension ailments and hypothyroid diseases and urine analysis for diabetes, for all the subjects in clinical laboratory. Based on the analysis, 4 male and 4 female subjects were selected.

3.3. Calibration of subjects

Before starting of the actual experiment, all subjects were properly trained on the tread mill by connecting various instruments separately and

in combinations. The instrument handling procedure was practically demonstrated to the subjects to familiarize them with the instruments. All treatments, including calibration of the subjects were randomly carried out. Before the start of the days work, the subjects were asked to relax for about half an hour and the blood pressure and heart beat rate were measured. If these measures were within the normal ranges, the subjects were assigned the task, otherwise the work was postponed to other day. The subjects were calibrated in the laboratory by measuring oxygen consumption and the corresponding heart beat rate.

3.3.1. Oxygen consumption

The oxygen consumption was measured using

- i. Benedict Roth apparatus
- ii. Oxylog-2 apparatus

3.3.1.1. Benedict Roth apparatus

The apparatus consists of a 6 litre spirometer with a four speed recording unit. The spirometer bell is chain compensated and counter weighed over a pulley. The counter weight carries the light perspex ink writing pen. The main base is made of aluminium casting with levelling screws. It houses the kymograph gear box, 3 stop cocks, one serve as water outlet and the other two for oxygen, and other gases. The two outlets provided on the left side of the base and are connected to the stop cock. One of the outlet houses a rubber outlet valve and the other has provision to take a

thermometer. The two way stop cock (Breathing valve) is carried by an adjustable arm and fitted with a rubber mouth piece through a corrugated rubber tube. The speed of the spirometer is adjusted to 20 min per revolution with the help of the speed selector.

3.3.1.2. Oxylog-2 apparatus

The Oxylog-2 is a portable instrument of 18.5 x 8.2 x 21.5 cm size (including fabric case) and 1800 g weight. Plate : 1 The instrument was designed to measure the oxygen consumption of an ambulatory subject. This has basically three components

- i. Face mask
- ii. Main instrument
- iii. Battery charger

i. Face mask

It is made of rubber material which has provision to fix the belt for fastening on the face. And it has two ports to accommodate (a) Air flow meter (TURBINE type flow transducer) in order to enable the measurement of inspiratory volume in the range of 5 - 500 litres. This turbine flow meter is also equipped with a temperature sensor to sense temperature at turbine meter. Both air and temperature will be measured and transmitted through chord with multiple pin male socket to process the data and (b) Flexible tube entry spout to transfer expired air to the main instrument for further processing.



Plate 3.1 Oxylog-2 apparatus and its components

ii. Main instrument

The instrument is provided with three membrane buttons/switches linked to a crystal display. It has a system clock and memory which will be maintained even in the non-active power down mode, with battery backup system, even when the Liquid Crystal Display (LCD) is blank. This LCD, of 4 row by 20 column display on test panel the following displays can be found.

1. Test indicator (A,B, ...P. i.e 16 subjects)
2. Minutes of test completed (0-999)
3. Minutes of breath count (Max reading 999 breath)
4. Total breath count (Max reading 9999)
5. Minute inspired volume (Maximum 999.99 litres)
6. Total inspired volume (Maximum reading 99999 litres)
7. Minute O₂ consumption (Maximum reading 99.99 litres)
8. Total O₂ consumption (Max reading 9999 litres)
9. Time and date.

The Oxylog-2 measures the inhaled air volume and the exhaled air volume. It compares oxygen presence in the exhaled air with room air oxygen through the drying columns. Oxygen difference in these two will give the consumption of oxygen by the subject with respect to the volume of air inhaled and exhaled. Oxygen sensor in the instrument used is Galvanic-type Fuel cells. The volume of oxygen shown on the instrument's LCD is thus calculated in STPD terms (ie. at 760 mm Hg and 0°C).

iii. Data storage

There is sufficient storage capacity available with the Oxylog-2 to record 2000 min of run - time data. This storage can be distributed among 16 individual tests. There is no absolute limit to the duration of the tests other than the total (cumulative) period of any or all tests cannot exceed 2000 min. If there is an attempt to exceed this limit, a warning would be displayed on LCD that Oxylog-2 had ceased storing data.

iv. Battery charger

A Specially designed battery charger is supplied along with the Oxylog-2. Since even when Oxylog-2 is in power down mode, it consumes a small amount of power from battery to maintain the functions of memory. The battery should be recharged periodically even if the instrument is not in frequent use. At the same time, battery should not be left permanently on charge which will damage NiCol cell. A 10 - hour charge should suffice to render batteries replete. The battery charger should not be left switched 'ON' for more than 24 hours continuously. However fully charged battery will maintain the functions of the memory and internal circuits for about three months.

There is a provision to download the information stored in Oxylog-2 for which battery charger unit was also used. A 9- way cannon female socket is located on the charger unit is connected to standard serial cable for the



purpose of data transfer to a computer which had been programmed to extract and process the stored data.

3.3.2. Heart beat rate

The heart beat rate was measured using

- i. Telemetry system
- ii. Polar pacer heart rate monitor

3.3.2.1. Telemetry system

The telemetry System consists of (Plate : 2)

- i. Encoder
- ii. Decoder
- iii. Mediscope.

i. Encoder

The encoder is 138 x 74 x 38 mm in size with an amplifier, modulator and transmitter. An electrode cable with three wires were connected to encoder and at the other end a button type electrodes were fitted, which were fixed on the body of the subject. The heart beat signals picked by the electrodes were fed to amplifier which amplifies and decouples DC.

ii. Decoder

The decoder consists of a double frequency demodulating circuit and a tuner. When the decoder was switched ON the antenna picks up the signals



Plate 3.2 Telemetry system

coming from the encoder. The antenna provided with the decoder was adjustable directionally to have proper tuning strength. The decoder was connected to mediscop unit through a cable.

iii. Mediscope

The mediscope unit has digital and graphical display provision, of the heart beat rate ranging from 0 to 200 beats per minute.

For recording the heart beat rate of a subject on work, the encoder was fixed on the waist of the subject with the help of a belt. The chest skin of the subject was cleaned and some electrode jelly was provided. Red electrode was fixed near the left mid clavicular line directly below clavicle. The yellow electrode was fixed just to right of sternum and in intercostal space. The black electrode was fixed near left mid clavicular line directly below clavicle. The three electrode fixed with the help of tape to avoid disturbance of the electrodes while walking. The power switch of encoder was put ON when the subject was walking on the tread mill for calibration. It transmitted the heart beat rate signals to decoder and the decoder fed the decoded signals to mediscope which displayed the heart beat rate in digital form. These heart beat rate readings were noted down.

3.3.2.2. Polar pacer heart rate monitor

It is a compact portable instrument to monitor the heart beat rate plate : 3. This can be used in the field directly where the telemetry system cannot be used. This polar pacer has three basic components

- i. Chest Belt transmitter
- ii. Elastic strap
- iii. Receiver unit

i. Chest Belt transmitter

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

ii. Elastic strap

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

iii. Receiver

This is a unit which receives the signals from the transmitter and displays it on screen with the help of battery CR 2025 fixed in it. This receiver unit must be placed within one meter range and it can be fitted either in watch strap or mount it on Bike Mount supplied as accessory with



Plate 3.3 Polar pacer heart rate monitor

the unit. This receiver has two buttons below the screen to operate the heart beat rate monitor. This has provision to set up high target zone and low target zone limits. When the subject reaches that limits of heart beat it will indicate through alarm, or visual alarm, so that we can stop exerting the subject beyond this level. Similarly the low heart beat rate target zone will be helpful in certain critical condition. And also this receiver is water resistant to 20 metre water column.

3.3.3. Training of subjects

The subject were trained in a Venky's tread mill. It consists of a walking belt track and the control panel. The speed of the belt can be varied from 0 to 12 kph. The slope of the belt can be varied from 0 to 25 per cent. In the front end of the tread mill, a rectangular supporting frame along with an emergency OFF switch is provided for the convenience of the subject.

The control panel houses a speedometer which shows the speed of the belt, and a reset switch to know the distance travelled by the subject during exercise. The panel has a speed control knob to adjust the speed according to the requirement. The control panel had four other switches, one for power ON, second for power OFF, third for increasing the slope of the belt and the fourth was for reducing the slope.

3.3.4. The Calibration and energy audit process

- i. Energy conversion in human
- ii. Basal metabolic rate.
- iii. Calibration of subject
- iv. Fatigue factor.

3.3.4.1. Energy conversion in human

The ability of the subject to perform the task essentially depends on the physical structure of the body, skeletal muscles, nerves system and metabolic process. The human skeletal system is made up of a large number of muscle fibers which were bound together in bundles. The chemical energy is converted into mechanical work when these muscles are contracted and relaxed.

The muscle fibre contains proteins, among which action and myosin contributes to the muscular contraction and relaxation. During muscle contraction mechanical energy is developed at the expense of energy rich phosphate compounds namely adenosine triphosphate (ATP) which break down into low-energy adenosine diphosphate. The low-energy phosphate compounds are continuously converted back to the high energy state in the muscle, so that the reserves of energy remains unchanged. This regeneration process of high-energy phosphate compounds consume energy which is obtained from glucose and from components of fat protein which are present in the circulating blood.

During regeneration process, the energy compounds are converted by various stages into pyruvic acid. If the blood gets sufficient oxygen, the pyruvic acid is further broken down by oxidation, the end products being water and carbon dioxide. During heavy muscular activity of the subject, more energy is needed for the muscular contraction and relaxation. If the oxygen supply is not in phase with the activity, instead of pyruvic acid oxidation, it is converted into lactic acid, a form of metabolic waste product. Lactic acid plays a vital role in creating symptoms of muscle of fatigue. Ultimately the subject ceases the activity to pay back the oxygen debt.

3.3.4.2. Basal Metabolic Rate (BMR)

The energy required to maintain the body in an inactive state is known as basal metabolic rate. This is measured when the subject is in post absorptive state. The BMR was estimated by using Benedict Roth apparatus and Oxylog-2 apparatus.

i. BMR by using Benedict Roth apparatus

Benedict-Roth apparatus spirometer bell was filled with oxygen from the storage oxygen cylinder. The subjects were given complete rest for half an hour in a semi reclining position before the commencement of the test. The subject was fitted with a mouth piece. The nose was clipped with the help of nose clip plate : 4. The subject initially inhales atmospheric air for some time. After normalization of breathing rate the saddle valve was turned on to oxygen which was present in the spirometer bell. The kymograph recorded



Plate 3.4 Estimation of BMR, using Benedict Roth apparatus

the oxygen consumption on the strip chart. A satisfactory uninterrupted section of exactly six minutes were chosen from the chart, obtained during the above process. The oxygen consumption was measured from the above section and recorded. The above process was repeated three times and the average was worked out. Same procedure was adopted for all subjects to determine the basal metabolic rate.

ii. BMR by using Oxylog-2

To estimate BMR, as preparatory measure the subject was allowed to take half an hour rest to attain normality in cardio-respiratory response. It was also ascertained that the subject was free from tension and fear for which the subject was detailed about the instrument and the experiment. Then face mask was fastened to the subject face and the flexible tube and cable were connected to the instrument (plate : 5). The rear outlet portion of an instrument was kept free of obstruction. To test the sample of exhaled air, tube was connected to one of drying columns. By using the membrane buttons the Oxylog-2 is started and the subject was allowed to inhale the air through mask. The oxygen consumption will be displayed on the LCD screen. After stabilising for one or two minutes the oxygen consumption was noted for uninterrupted six minutes. Then average value is taken for computing BMR of subject. The oxygen consumption per minute was displayed on LCD which can be externally noted down or after the experiment, it can be down loaded to computer as described above.



Plate 3.5 Estimation of BMR, using Oxylog-2 apparatus

3.3.4.3. Calibration of subjects

The subjects were calibrated to arrive the relationship between the heart beat rate and oxygen consumption by using Tread mill, Benedict Roth apparatus and Telemetry system. The oxygen consumption and heart beat rate with respect to time was recorded during the test as explained below.

By tread mill: the tread mill conveyor belt slope was kept constant at 5 per cent and the velocity varied at an interval of 1.5 kph from a starting speed of 1.5 kph to 7.5 kph for the calibration. The electrodes of cable were attached to the subject at appropriate position of the body, and the encoder unit was tied to the waist. The encoder switch was put ON and the subject was asked to walk on the tread mill. The conveyor belt speed was slowly brought to required level by adjusting the speed control knob. The Benedict Roth apparatus spirometer bell was filled with the oxygen and the mouth piece was given to the subject by placing the nose clip in position (plate : 6). The subject inhales the atmospheric air through mouth piece at the initial stage. Heart beat rate was monitored on the mediscope digital display unit. After the heart beat rate reaches the steady state, the saddle valve was turned ON to oxygen. The keymograph starts recording the oxygen consumption pattern of the subject on the chart continuously. Simultaneously the heart beat rate was noted down by the observer at an interval of 5 sec. The procedure was continued for about ten minutes and the saddle valve was turned OFF, simultaneously the speed of the tread mill was reduced.

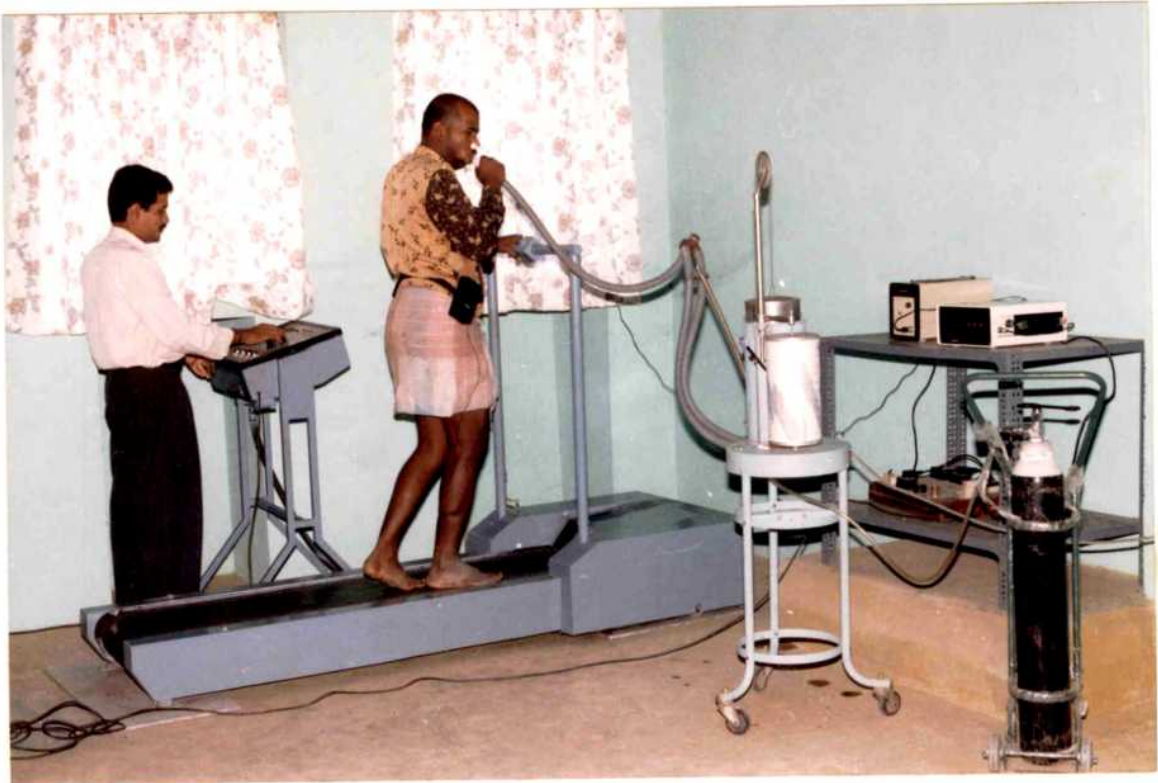


Plate 3.6 Calibration of subject using Benedict Roth apparatus, Telemetry system and Tread mill

The heart beat rate was averaged for the above period and oxygen consumption rate was measured from the chart for six uninterrupted minutes. The same procedure was repeated by setting different speeds and allowing the subject to exercise on the tread mill. The oxygen consumption rate was converted into energy units for each speed setting and calibration graph was prepared between the heart beat rate and the energy units. Same procedure was adopted for all the subjects and calibration graphs were drawn.

3.3.4.4. Fatigue factor (H/R)

This is the ratio of heart beat rate to respiration rate. This is used as an index of cardio respiratory stress (Moitra *et al.*, 1974).

The heart beat rate of a subject during the field work was measured from the polar pacer heart beat rate monitor as explained in section 3.3.2.2. The aspiration rate was estimated through Oxylog-2 apparatus. From these values the Fatigue factor for different works was computed and analysed.

3.4. Experimental Design

The experiment design was planned and executed under two major parts

- i. Modification of tools for study
- ii. Methodology adopted for field evaluation

3.4.1. Modification of tools for study

This part explains the agronomy behind the selection of design parameters for modification and methods used for achieving the desired modification in the selected farm tools for the study.

The farm tools, under the study, mainly consist of a slightly curved iron blade / fork and wooden handle. Over the years these tools had undergone many design changes, keeping the basic frame unaltered (Raghavan, 1960; Hopfen, 1969). It is important to critically analyse the human strain and performance in any operation. The stresses on the body during hoeing / digging task are the results of force vector of both potential and kinematic components effected through articulated body segments (Huzayyin, *et al.*, 1980). Load moments/torque generated about a joint axis were countered by maximum muscular movements. Physiological and biomechanical assessments of the hoeing/digging operation is of practical importance in devising optimal rate of work and also the design features of the tools. Basic design features of tools explained were size and shape of cutting edge and angle between blade and handle (Nag and Pradhan, 1992).

Hence the following design parameters were enlisted for causing the human drudgery and comfort.

- i. Size and shape of the cutting edge
- ii. Handle and blade angle
- iii. Weight of the tool
- iv. handle dimensions

To study the effect of above identified parameters on the physiological cost, the following modifications in the selected agricultural hand tools were carried out.

Since all the similar hand tools of same size and were newly made, the size and shape of the cutting edge was same. Hence it was considered as constant. To vary the remaining design parameters identified and to study its effect on human comfort the final changes were made in

- i. Change of angle
- ii. Change of weight and
- iii. Change of handle girth

3.4.1.1. Change of angle

The variation of angle were selected by doing the indepth survey with farmers tools. The existing angle for the spade and hand hoe were not constant and was varied from 25 to 45°, which was most neglected parameter by the user. And also the recommended angle for the spade was 60-70° for minimum energy expenditure (Pradhan *et al.*, 1986).

Keeping the above facts in mind the angles selected for the Spade were 20-25°; 35-40°; 50-65° and 65-70° (Plate : 7). Hand hoe - the existing angle of blade with handle ranged between 20 to 50°. Hence the different angles selected for the study were 20-25°; 30-35°; 40-45° and 50-55°.



Plate 3.7 Spades with different angles

The hand hoes were used for weeding and very light interculture operation, hence the force to be exerted by the tool was very less. Due to which, unlike in the other operations the hand hoeing was done with single hand either by right or left as per the hand preference of a subject. But to reach the handle for keeping the proper blade angle with ground surface, the subjects were forced to bend much (Fig.4.12) which was causing maximum drudgery to the subject (Parvathi, *et al.*, 1998).

To overcome this drudgery and to ease a operation the new handle was developed which was inclined upwards 60° within blade (Fig 4.2). This new handle facilitates the subject to reach the handle without bending much, at the same time maintaining proper blade angle with the ground i.e., 30° . The hand hoe fitted with above handle was tested for the energy requirement along with other angles.

In similar way the angle for Shovel and Digger fork were selected as 10° , 15° , 20° and 10° , 12.5° , 15° respectively. These desired angles, i.e., blade angle with handle were attained on the blacksmith table by altering the neck angles in the Spade and Shovel and fork curvature in the Digger fork.

3.4.1.2. Change of weight

Weight of the tool was the very important parameter which mainly influences the energy requirement Numba and Kaul, (1987), Kinoshita,

(1985), Ghugare, *et al.*, (1991). In the same survey it was also found that farmers are having these selected hand tools in the different range of weights i.e Spades were ranged from 1.70 kg to 2.75 kg; Shovels of 2.50 to 3.00 kg; Digger forks were of 1.75 kg to 3.50 kg and Hand hoes from 0.50 kg to 0.85 kg (all including handle weights).

Hence the weight of the tools selected for optimisation were varied in such a way that the range lied in the same range of their respective existence i.e., Spade of 1.75 kg, 2.00 kg, 2.25 kg and 2.50 kg; Shovels of 2.00 kg, 2.5 kg and 3.00 kg; Digger fork of 1.75 kg, 2.5 kg and 3.0 kg and Hand hoes of 0.55 kg, 0.65 kg, 0.75 kg and 0.85 kg.

3.4.1.3. Change of handle girth

Generally two parameters of handle size were handle girth and handle length. Since all the farmers were uniformly having the length of handle as 65 cm to 70 cm, this parameter was unaltered and kept constant. The Handle grip diameter was not constant and not given much importance. Hence to assimilate selected tool handle design for subjects anthropometry based on ergonomic principle, handle grip diameter was varied.

For which the hand grip diameters of subjects were collected by using the "Hand grip diameter measuring tool" developed for the purpose. From these 5th and 95th percentile values of the handle grip diameters, the handle

grip diameters were decided as 20, 30, 40 and 60 mm for spades (Plate : 8) and 15, 20, 30 and 40 mm for hand hoes.

Since the weight of the handle was proportion to their volume, to avoid difference in weights due to different sizes, very light weight wood (silver vove) was selected for larger size handles so that the total weight of the tool was unaltered.

3.4.2. Methodology adopted for field evaluation

3.4.2.1. Evaluation of hand tools selected for study

To evaluate the effect of identified design parameters (angle of blade with handle, weight of tool and girth of the handle) on the energy expenditure and comfort of the operator, the following field studies were carried out.

The selected tools with appropriate modifications were tested in the field. The field was selected in such a way that soil condition was same for entire study.

Before starting the test the subject was allowed to take enough rest to bring heart beat to normal. The polar pacer heart monitor was fixed to the subject with the help of elastic tape after properly wetting the electrodes. Then the subject was asked to dig a measured piece of unploughed land by using the selected hand tool with necessary modification at their usual pace of work. The measured piece of land was 5m x 3m size for all tools excepting



Plate 3.8 Handles of different diameters

for Digger fork in which the size of land was taken as 5m x 1m. The work measurements included strokes rates, depth of soil dug, time taken to complete the task and the weed counts. The physiological responses like heart beat rate, oxygen consumption were noted down.

Each experiment was repeated three times, allowing enough time interval in between the spells of work.

The same procedure was followed for all the subjects and for all the tools selected for the study.

After collecting the oxygen consumption either from the calibration chart or from the Oxylog-2 it was converted to energy units by standard procedure and the data was analysed.

Model Calculation for computing BMR :

$$\begin{aligned}
 \text{Oxygen consumed in six min.} &= X \text{ l} \\
 &X \\
 \text{Oxygen consumed in one hour} &= \frac{\text{-----}}{6} \times 60 \text{ l} \\
 &= Y \text{ l}
 \end{aligned}$$

Adjusting the volume of oxygen consumed to dry gas at standard temperature and pressure (STPD) using gas law.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

At standard condition,

$$P_1 = 760 \text{ mm of Hg} = 1.01325 \text{ bar}$$

$$T_1 = 0^\circ\text{C} = 273^\circ\text{K}$$

$$V_1 = \text{Volume of oxygen at STPD}$$

The average conditions during the period of basal metabolic rate estimation were

$$\text{Average pressure} \quad P_2 = 990 \text{ millibar} = 0.99 \text{ bar}$$

$$\text{Average temperature} \quad T_2 = 28^\circ\text{C} = 301^\circ\text{K}$$

$$\text{Volume of oxygen} \quad V_2 = \text{Oxygen consumed by the subject, } Y \text{ l}$$

Now, substituting these values in the equation

$$\frac{1.01325 \times V_1}{273} = \frac{0.99 \times Y}{301}$$

$$V_1 = Z \text{ l/hr.}$$

Taking oxygen equivalent as 4.825 k cal. per l.

$$\text{Basal Metabolic Rate} = Z \times 4.825 \times 24 \text{ k cal.}$$

3.4.2.2. Weeding efficiency

It is the ratio of weeds removed by weeding to the weeds present before weeding expressed in percentage. Weeding efficiency was computed as given by V.S.Mani *et al.* (1973).

$$\eta = \frac{W_c - W_t}{W_c} \times 100$$

η = Weeding efficiency, per cent

W_c = Total weed count in control plot

W_t = Total weed count in after weeding

This was done by taking the weed count in unit area with the quadrant (randomly), before and after inter culture operation with selected hand hoes.

This efficiency was estimated to quantify the effect of angle on the weed and metal interaction during hoeing (weeding) operation.

3.4.2.3. Clod size distribution

This is the mean clod size distributed in the field after tillage operation. The measurement of clod size was done by physical measurement, since the soil dug was neither aggregate nor small particles size i.e., < 8 mm to do the mechanical sieve analysis. The data was analysed and mean clod size was computed.

3.5. Development of prototype

After conducting the designed experiments with different variables, work measurements and physiological responses were analysed. From the analysis, dimensions of the parameters demanding least physiological cost without sacrificing work output, were chosen as optimised parameter. The prototype tools were prepared with these respective optimised parameters.

3.6. Field evaluation of prototype

The prototype tools with optimised design parameters were evaluated for the fitness in the field. The same size and condition of a plots as used in the above experiments explined in 3.4.2.1. were used to test the prototype. The physiological responses and work measurements were calculated and compared with the mean values of existing tools.



Plate 3.9 Field evaluation of subjects

Results and Discussion

CHAPTER - IV

RESULTS AND DISCUSSION

The results of the study "Investigation on design parameters of hand tools in relation to operational comfort of Agricultural workers", and related test results i.e., Anthropometric survey, Blood pressure, Electro Cardio Graph, Bio-clinical analysis, Basal metabolic rate, the change in design parameters of selected hand tools and its effect on the physiological responses and work measurements were presented. The effect of above changes on the Fatigue factor (H/R) and comfort were also discussed.

4.1. Selection of hand tools

Four hand tools were selected for the study by adopting the procedure discussed in Section 3.1. The selected tools were i) Spade, ii) Hand hoe iii) Shovel and iv) Digger fork as shown in Figure 4.1, 4.2, 4.3 and 4.4 respectively.

The linear dimensions of existing hand tools were presented in Table 4.1. To optimise, the design parameters varied in the selected tools ^{are} ~~were~~ enlisted in Table 4.2.

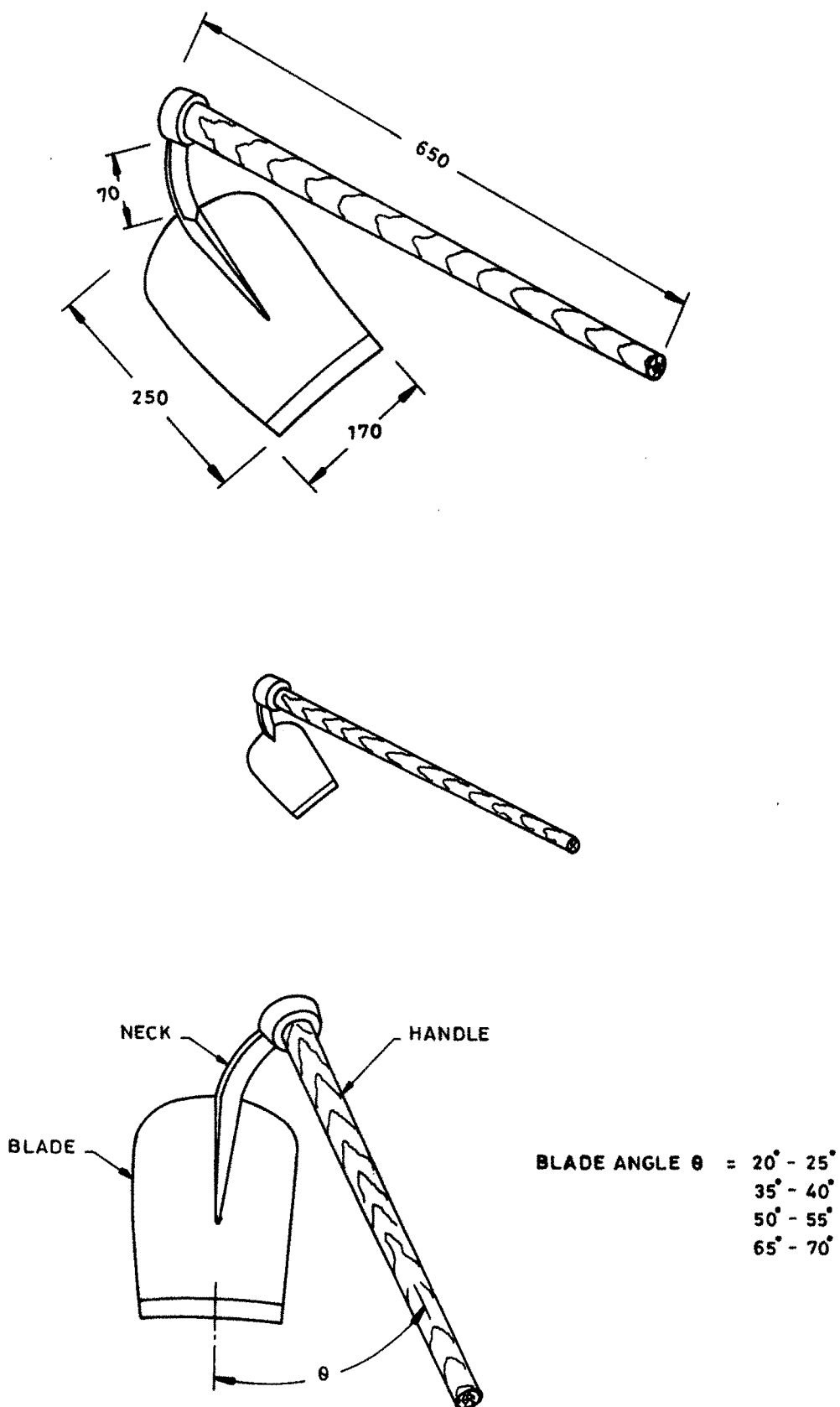


Fig.4.1. SPADE

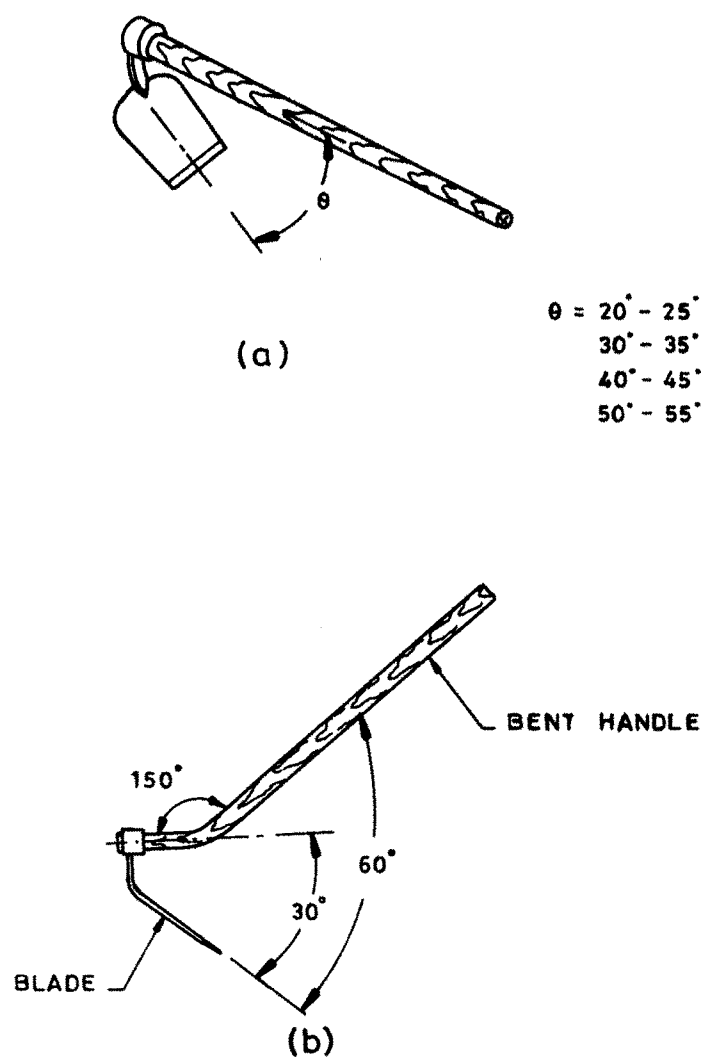
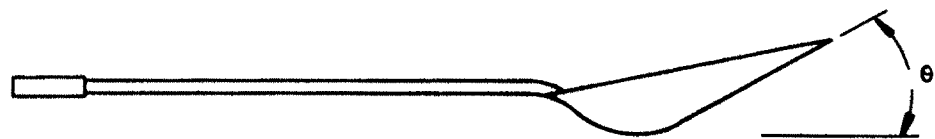
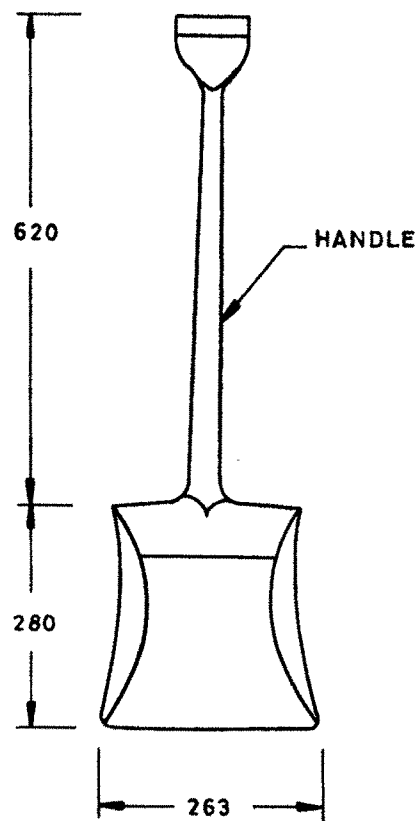


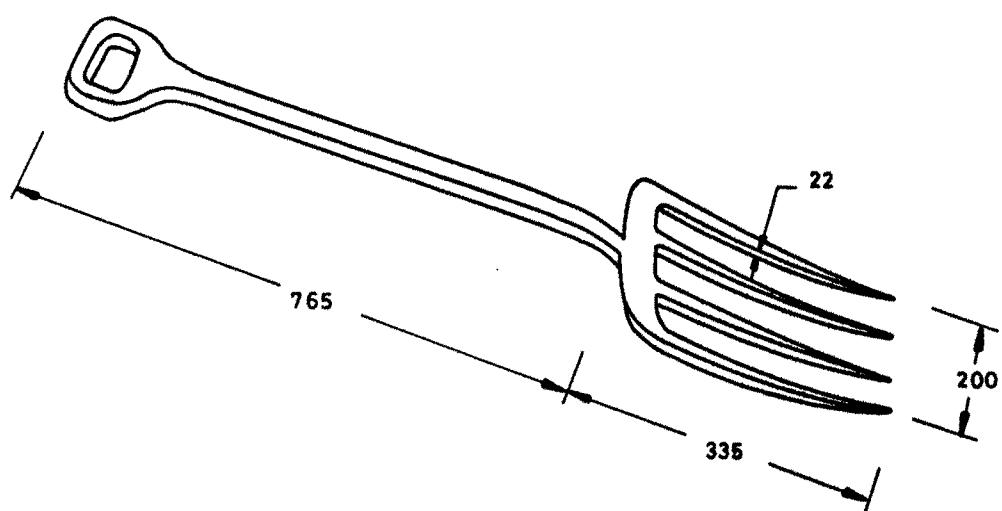
Fig.4.2. HAND HOE

- a) HOE WITH STRAIGHT HANDLE
- b) HOE WITH BENT HANDLE



$\theta = 10^\circ, 15^\circ \text{ AND } 20^\circ$

Fig.4.3.SHOVEL



FORK ANGLE $\theta = 10^\circ, 12.5^\circ \text{ AND } 15^\circ$

Fig.4.4. DIGGER FORK

Table 4.1. Linear dimensions of the selected hand tools

S.No	Name of Tool	Component	Length cm	Breadth cm	Diameter cm
1.	Spade	i) Blade	25	17	-
		ii) Neck	7	3	-
		iii) Handle	70	-	3 - 4
2.	Hand hoe	i) Blade	10	7.5	-
		ii) Neck	5	2	-
		iii) Handle	33	-	2 - 3
3.	Shovel	i) Blade	28	26.5	-
		ii) Handle	62	-	1 - 3
4,	Digger fork	i) Fork	32.5	20	-
		ii) Handle	76.5	-	5 - 7

Table 4.2. Design parameters varied for the study

S.No	Tool	Design parameter	No.of variations	Variation range
1.	Spade	i. Weight [*]	4	1.75 - 2.5 kg
		ii. Angle ^{**}	4	20 - 70 ⁰
		iii. Handle diameter	5	20-60mm
2.	Hand hoe	i. Weight [*]	4	0.550 to 0.850 kg
		ii. Angle ^{**}	4	15 - 50 ⁰
		iii. Handle diameter	4	15 - 40mm
3.	Shovel	i. Weight [*]	3	2.00 - 3.00 kg
		ii. Angle ^{***}	3	10 - 20 ⁰
4.	Digger fork	i. Weight [*]	3	1.75 - 3.25 kg
		ii. Angle ^{***}	3	7.5 - 12.5 ⁰

* - Total weight including handle

** - Angle of the blade with the handle

*** - Angle between centre line of handle and blade/fork

4.2. Selection of subjects

Subjects were selected by following the procedure described in the section 3.2.

4.2.1. Anthropometric survey

The basic objective of the study was to reduce human drudgery by assimilating the human factors with design parameters of agricultural hand tools, for which physical characteristics and dimensions were measured in the Anthropometric survey. The data was analysed and 5th and 95th percentiles for male and female subjects were estimated and presented in Table 4.3.

From above four male farm workers, in which two 'A' type subjects of age 32 ± 1.4 years; weight 48.5 ± 0.7 kg; stature 153.6 ± 1.3 cm and hand grip diameter 3.05 ± 0.1 cm and two 'B' type subjects of age 29.5 ± 3.5 years; weight 77.5 ± 2.1 kg; stature 172.6 ± 0.6 cm and hand grip diameter 3.5 ± 0.1 cm were selected.

Similarly four female subjects of two 'A' type of age 34 ± 1.4 years; weight 47.5 ± 2.12 kg; stature 155.4 ± 1.7 cm; hand grip diameter 2.8 ± 0.1 cm on and two 'B' type subjects of age 32 ± 2.8 years; weight 53.5 ± 2.1 kg; stature 143.2 ± 2.8 cm; hand grip diameter 2.8 ± 0.1 cm were selected.

Table 4.3. Anthropometric survey data

Sl. No	Dimensions	Male Subjects				Female Subjects			
		Mean	sd	5 th percentile	95 th percentile	Mean	sd	5 th percentile	95 th percentile
1.	Age, Years								
2.	Weight, kg								
3.	Standing height (Stature), cm	164.61	6.41	154.06	175.15	149.32	7.183	137.50	161.14
4.	Eye height, cm	153.63	6.09	143.61	163.64	138.72	6.67	127.75	149.69
5.	Over head reach, cm	206.25	8.15	192.84	219.65	191.75	7.03	180.19	203.3
6.	Forward reach, cm	84.78	5.38	75.93	93.63	86.025	3.122	80.89	91.160
7.	Maxibody width, cm	45.47	3.45	39.49	50.85	42.9	1.28	40.79	45.006
8.	Crotch height, cm	76.14	4.18	69.26	83.02	69.62	6.05	59.67	79.57
9.	Sitting height, cm	84.97	3.56	79.11	90.83	106.35	11.96	80.68	126.02
10.	Sitting eye height, cm	74.59	3.10	69.49	79.69	96.15	9.0	81.35	110.96
11.	Buttock to popliteal length, cm	4.69	2.76	39.15	48.23	43.3	0.774	42.02	44.58
12.	Sitting shoulder height, cm	59.15	2.67	54.76	63.54	51.2	2.81	46.57	55.82
13.	Buttock to knee length, cm	54.92	3.02	49.95	59.89	52.025	3.21	46.74	57.31
14.	Popliteal height - sitting, cm	43.12	3.49	37.38	48.86	41.2	4.28	34.16	48.24
15.	Knee height - sitting, cm	52.38	3.09	47.30	57.46	46.47	2.37	42.57	50.37
16.	Thigh clearance - sitting, cm	13.55	1.57	10.97	16.13	12.625	0.899	11.15	14.10
17.	Elbow to fingertiplength - sitting, cm	46.66	2.64	42.38	50.96	40.55	2.972	35.66	45.434
18.	Waist depth, cm	25.58	4.13	18.79	32.37	20.875	0.906	19.38	22.37
19.	Elbow rest height, cm	22.21	3.40	16.62	27.80	19.7	1.25	17.64	21.76
20.	Buttock to heel length, cm	98.65	5.6	89.36	107.94	89.07	5.459	80.09	98.05
21.	Shoulder width, cm	42.30	2.30	38.52	45.08	40.675	5.795	31.142	50.21
22.	Hip breadth sitting, cm	6.76	4.47	29.41	54.02	37.57	4.21	30.64	44.50

23.	Fore arm to fore arm breadth, cm	46.68	5.17	38.16	55.17	41.7	1.462	39.30	44.10
24.	Interpupillary breadth, cm	6.80	0.28	6.34	7.26	6.874	0.573	5.93	7.817
25.	Head breadth, cm	15.64	1.05	13.91	17.37	14.3	1.80	11.34	17.26
26.	Head length, cm	18.90	1.70	16.10	21.69	19.725	0.974	18.12	21.33
27.	Head length (max), cm	21.68	1.47	19.26	24.10	21.1	0.804	19.78	22.42
28.	Hand grip diameters, cm	3.40	0.28	3.00	3.60	2.85	0.27	2.70	3.00
29.	Chin to eye height, cm	11.99	1.12	10.15	13.83	4.25	0.602	8.26	10.24
30.	Hand length, cm	18.14	0.60	17.15	19.13	17.55	1.525	15.04	20.06
31.	Hand breadth at thumb, cm	10.30	0.76	9.05	11.55	10.7	0.1825	10.40	11.00
32.	Hand breadth at metacarpal, cm	8.40	0.48	7.61	9.18	1.02	0.309	8.51	9.53
33.	Hand thickness at metacarpal, cm	3.17	0.14	2.45	3.89	.425	0.793	1.171	3.78
34.	Foot length, cm	24.94	4.29	22.82	27.06	2.77	1.883	19.67	25.874
35.	Ball of foot width, cm	10.25	0.788	8.953	11.54	9.325	0.125	9.11	9.53
36.	Shoulder circumference, cm	104.43	6.937	93.0	115.84	94.17	4.355	87.01	101.33
37.	Chest circumference, cm	92.53	7.02	800.982	104.077	93.625	6.03	83.69	103.55
38.	Waist circumference, cm	89.96	9.834	73.78	106.136	81.7	7.677	69.07	94.32
39.	Hip circumference (standing), cm	96.50	6.142	86.3	106.6	94.325	3.35	88.80	94.32
40.	Hip circumference (sitting), cm	104.60	6.73	93.529	115.07	102.37	4.62	94.77	109.97
41.	Head circumference, cm	254.96	1.809	51.984	57.935	53.75	0.506	52.91	54.58
42.	Neck circumference, cm	37.58	3.75	31.41	43.74	28.85	2.76	24.3	33.39

4.2.2. Blood pressure

The blood pressure of the four male and four female subjects selected for the study were measured using the Electronic digital blood pressure monitor and presented in Table 4.4. From the table, it is observed that the blood pressure of subjects A₁, A₂, B₁, B₂, A_{F1}, A_{F2}, B_{F1}, and B_{F2} were normal.

4.2.3. Electro Cardio Graph (ECG)

The electro cardio graphs were recorded for all the subjects. From the graph it was found that the auricle rate, ventricle rate, rhythm, P waves (the right and left arterial contraction), PR intervals (the time interval between the sino arterial node), the ST segments (recovery phase of heart contraction) and atrioventricular node and T wave (diastole) were normal for all subjects (Table 4.4).

4.2.4. Bio-clinical analysis

The bio-clinical analysis of blood and urine were carried out at clinical laboratory to find out the related ailments of the subjects. The results of the bio-clinical analysis were presented in Table 4.4. From the table, it is observed that the blood true glucose, hemoglobin and blood serum cholesterol for all the eight subjects were within the allowable limits. The urine test results for albumin, sugar and deposit were normal for all the subjects.

Table 4.4. Bio-Clinical analysis

S. No	Investigation	Permisible value	Male Subject				Female subject			
			I	II	III	IV	I	II	III	IV
1.	Electro cardio graph	-	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
2.	Blood Pressure	120/80	118/78	120/80	125/81	118/80	118/79	120/80	120/80	121/82
3.	Blood Test									
	i. Hemoglobin	14 gm	14.2	14.0	15.2	14	13.2	12.9	13.9	14
		100%	100%	98%	107%	99%	98%	96%	98%	100%
	ii. Blood True glucose	60-110 mg/dl	62.1	61.2	60.4	64.6	73.3	69.8	68.2	61.3
	iii. Blood cholestrol	130-250	248.6	168.8	204.9	240.4	190.3	162.3	205.1	220.7
	iv. Blood group	-	A1	B	O	B	B	AB	O	B
	v. Rh (anti-D) factor	-	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
4.	Urine Test									
	i. Albumin	-	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	ii. Sugar	-	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	iii. Deposit	-	0-1	1-2	0-1	0-1.5	0-1	1-2	0-1	0-1.5

The blood tests were carried out to assess the gross pathological changes in the human system. There were slight variation in the results due to the normal physiological variation in the human body and also these variations did not affect the efficiency of the subjects. Hence the above subjects were free of any gross pathological changes.

Therefore, based on the medical background, all the four male subjects and four female subjects found to be fully fit.

4.3. Basal Metabolic Rate (BMR)

The oxygen consumption was measured using Benedict Roth apparantus and presented in Figure 4.5a. The BMR was computed as explained in section 3.3.4.2.

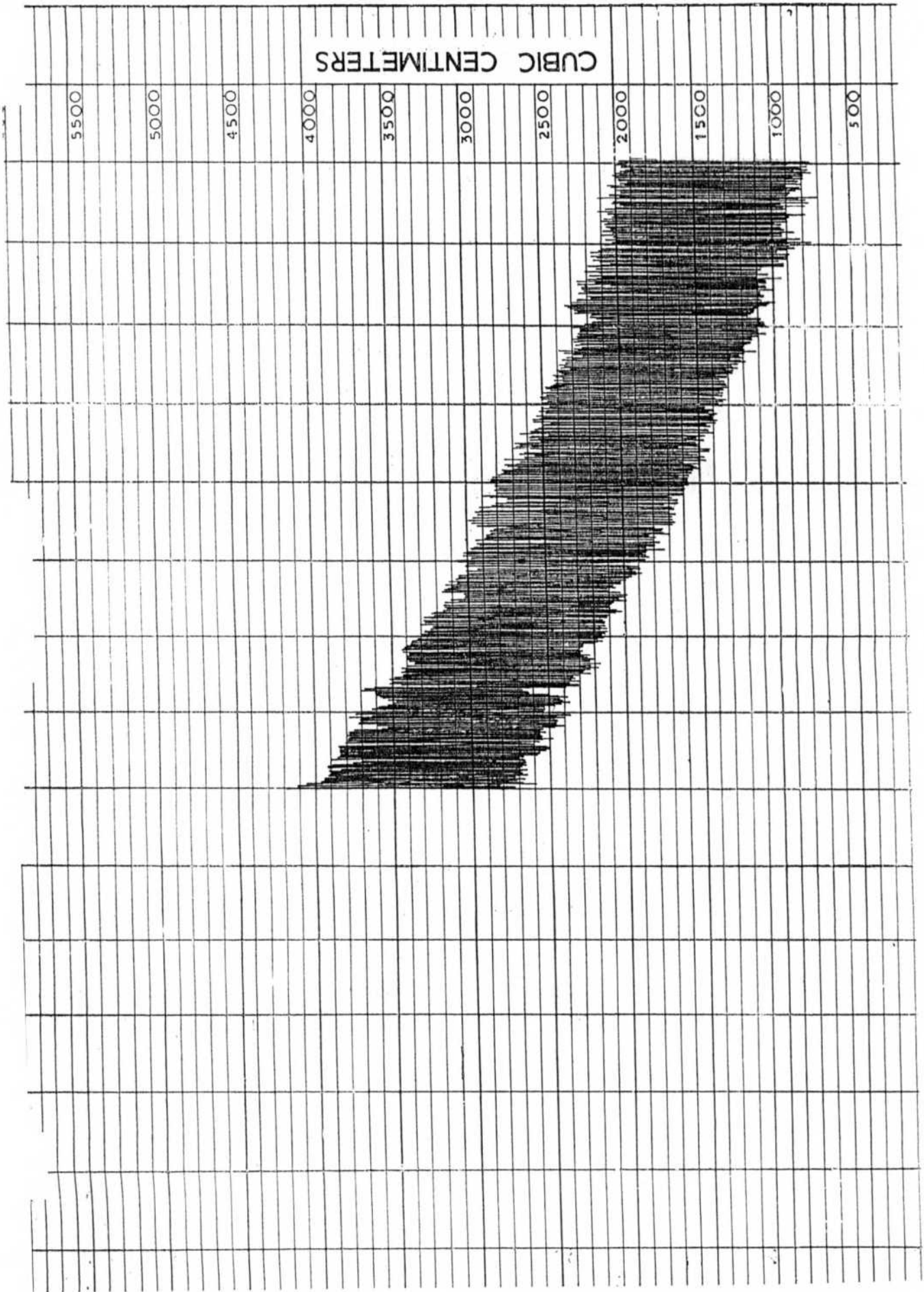
The BMR of selected 8 subjects (4 male and 4 female) were presented in the Table 4.5.

4.4. Calibration of the subject

For the calibration of the subject Tread mill, Benedict Roth apparatus and Telemetry system were used to record the oxygen consumption at different work load and the variation in heart beat rate. The oxygen consumption was recorded on the strip charts (Fig 4.5b). The strip charts obtained during the calibration of the subjects were analysed. The oxygen consumed for specific uninterrupted time interval was derived and converted

Table 4.5 : Basal Metabolic Rate (BMR) of subjects

S.No		Oxygen consumption, l/min	BMR, k cal
I Male			
	A ₁	0.217	1334.10
	A ₂	0.233	1436.65
	B ₁	0.250	1522.35
	B ₂	0.240	1480.00
II Female			
	FA ₁	0.175	1077.48
	FA ₂	0.170	1046.70
	FB ₁	0.180	1108.27
	FB ₂	0.192	1182.15



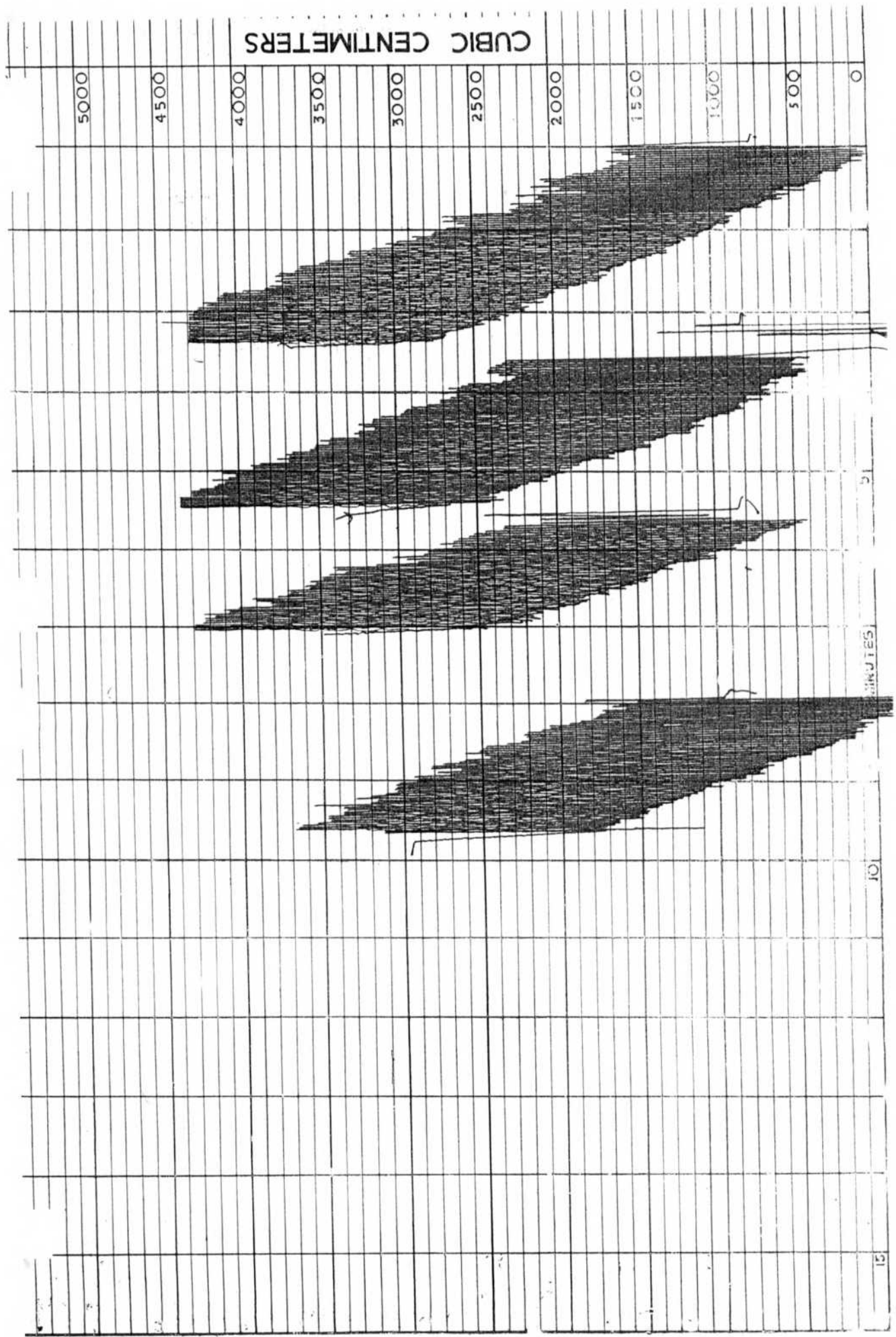


Fig.4.5.(b). OXYGEN CONSUMPTION OF SUBJECT DURING EXERTION

into energy units for each subject. A graph was drawn between heart beat rate and the corresponding oxygen uptake of different time. The results revealed the linear relationship between heart beat rate and energy expenditure for all the subjects (Fig4.6). It is concluded that heart beat rate predicts energy expenditure of the subjects. These findings were in confirmation with the results of Suggs and Splinter (1958), Mookerjee (1979) and Brockway (1978).

4.5. Heart beat rate and oxygen consumption

The heart beat rate of the subjects under this study was recorded with Polar Pacer Heart rate Monitor at different operating time. The average heart beat rates were given in the respective tables and the variations of the heart beat rates were also shown. The oxygen uptake by the subjects during the different experiments were estimated with the help of Oxylog-2. The mean values of oxygen uptake for different works by different subjects were analysed and presented in the respective tables.

4.6. Work and Physiological measurements

Evaluation of hand tools selected for the study were done for different design parameters, for the selected subjects by operating in a measured piece of land. The details were discussed under the respective headings.

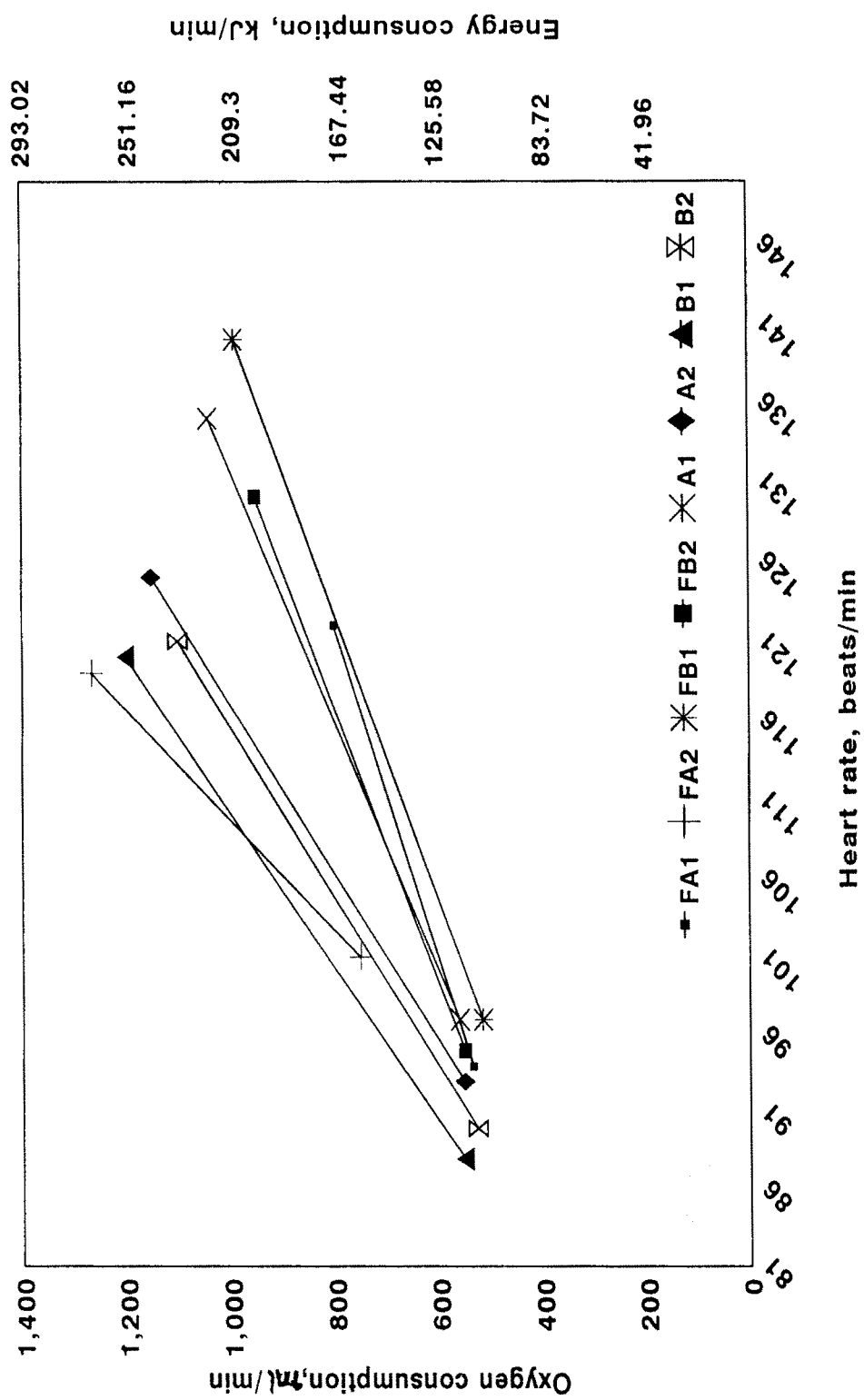


Fig.4.6. Calibration curves of subjects selected for study

4.6.1. Spade

The three design parameters in spade namely blade angle with handle, weight of the tool and girth of handle were altered and the effect of change in these design parameters on the oxygen consumption, heart beat rate and work measurements were calculated and presented.

a. Effect of weight

The work measurement and the physiological responses with respect to weight of tool were shown in Table 4.6. From the table, it is evident that operational rate was decreased as the weight of the tool was increased. The maximum value was 45.1 ± 4.7 strokes/min and the minimum value was 39.2 ± 3.9 strokes/min for 'A' type subjects. For 'B' type subjects, it was 47.7 ± 2.3 strokes/min and 40.1 ± 5.1 strokes/min respectively.

The area dug was found to be decreased as the weight of the tool increased. Minimal and maximal values were 2.35 ± 1.2 m²/min with 1.75 kg spade and 1.85 ± 1.0 m²/min with 2.5 kg spade respectively.

From the Fig 4.7 and Table 4.6, it is evident that the oxygen consumption significantly increased with the increase in weight of the tool from 1.34 ± 0.22 l/min or 7.37 ± 0.13 l/m³ to 1.71 ± 0.42 l/min or 11.75 ± 1 l/m³ for the 'A' type subjects and for 'B' type subjects it was from 1.27 ± 0.35 l/min or 6.62 ± 0.14 l/m³ to 1.63 ± 0.6 l/min or 11.02 ± 0.82 l/m³ for the increase in weight from 1.75 kg to 2.5 kg.

Table 4.6. Effect of spade weight on the physiological response

Description	Subject type	Weight, kg									
		1.75		2.00		2.25		2.50			
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	45.123	4.73	41.71	3.131	42.83	2.179	39.23		39.23	3.96
	B	47.71	2.36	44.82	4.713	44.27	6.116	40.18		40.18	5.13
Heart rate, beats/min	A	132	16	140	9	147	16	158		158	12
	B	128	7	133	4	139	7	148		148	11
Respiration, breath/min	A	39	6	40	4	41	9	43		43	8
	B	40	8	41	7	41	6	41		41	11
O ₂ uptake, l/min	A	1.343	0.226	1.415	0.205	1.514	0.090	1.71		1.71	0.424
	B	1.275	0.353	1.402	0.091	1.482	0.459	1.630		1.630	0.607
O ₂ uptake, l/m ³ of soil	A	7.375	0.131	7.581	0.446	9.114	0.404	11.75		11.75	0.950
	B	6.625	0.145	7.472	0.264	8.99	0.313	11.018		11.018	0.253
Area dug, m ² /min	A	2.277	1.124	2.334	0.134	2.052	0.115	1.822		1.822	0.563
	B	2.406	1.040	2.340	0.2117	2.0629	0.6616	1.852		1.852	0.9108

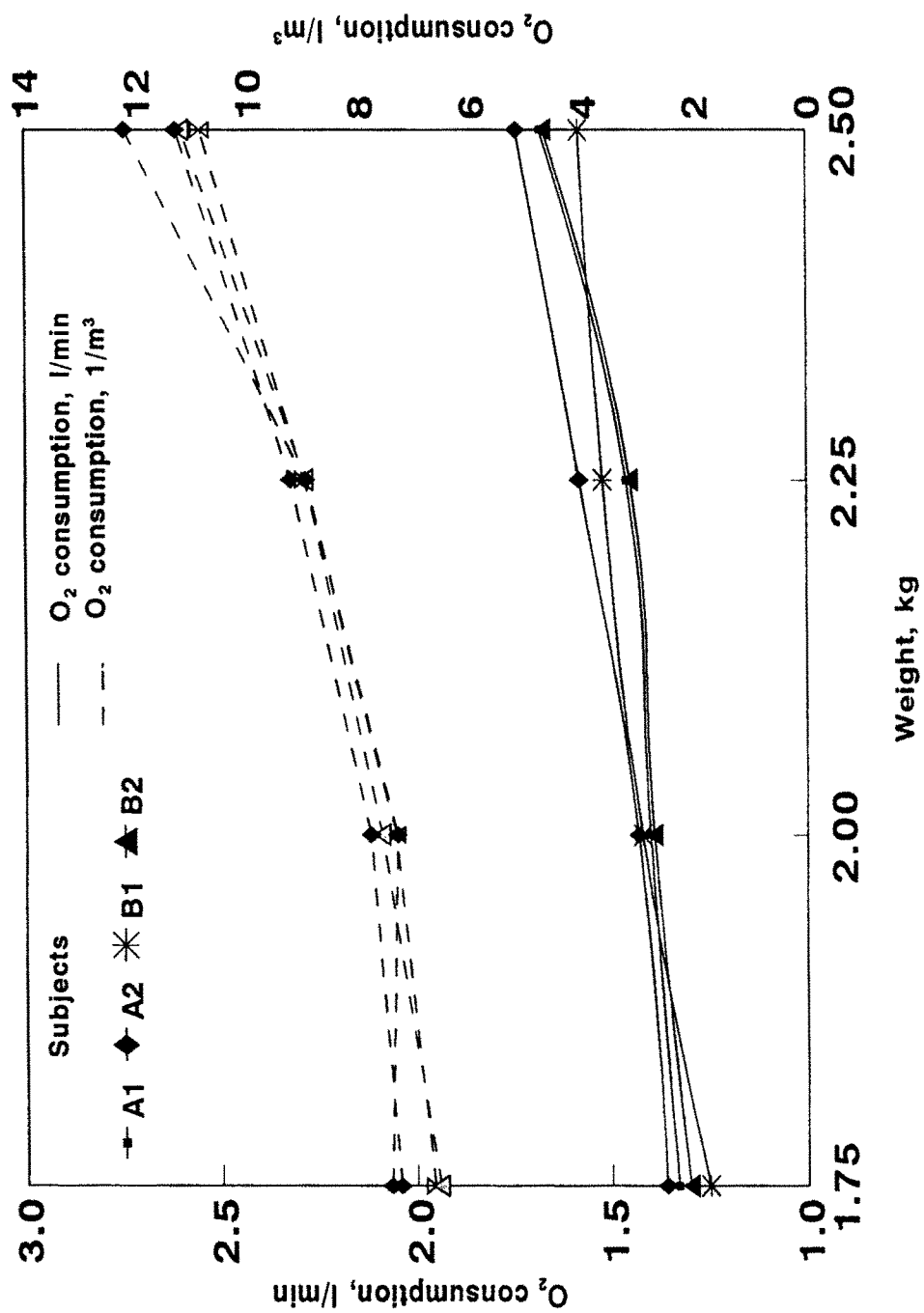


Fig. 4.7. Effect of spade weight on physiological response of male subjects

The cardio vascular load, as reflected in heart beat rates had an increasing trend from 132 ± 16 beats/min to 158 ± 12 beats/min for 'A' type subjects and for 'B' type subjects, it ranged from 128 ± 7 beats/min to 148 ± 11 beats/min with increasing weight of spades from 1.75 to 2.5 kg.

The mean energy spent with minimum weight 1.75 kg spade was 6.31 k cal./min or 33.77 k cal./m³ and was 8.06 k cal./min or 54.93 k cal./m³ with spade of 2.5 kg. in the increase i.e., energy spent was found with increase in the weight of working tool. This was coincided with report that the weight of hand tools directly influence the human energy requirements (Nwuba and Kaul, 1987) and also confirmed by Gill and Choudary (1987).

The fig 4.8 showed the effect of spade weight on the Fatigue factor (H/R). From the figure it is certain that the subjects got fatigued more with heavy tools and less with light tools. The minimum Fatigue factor of 3.38, 3.2 and maximum of 3.67, 3.60 for A, 'B' type subjects with 1.75 and 2.5 kg spades respectively. It was also observed from the above figure, that the Fatigue factor was increased at lower pace while working with the light tools and increased sharply with the heavier tools. Hence for better comfort the suggested spade weight is 1.75kg.

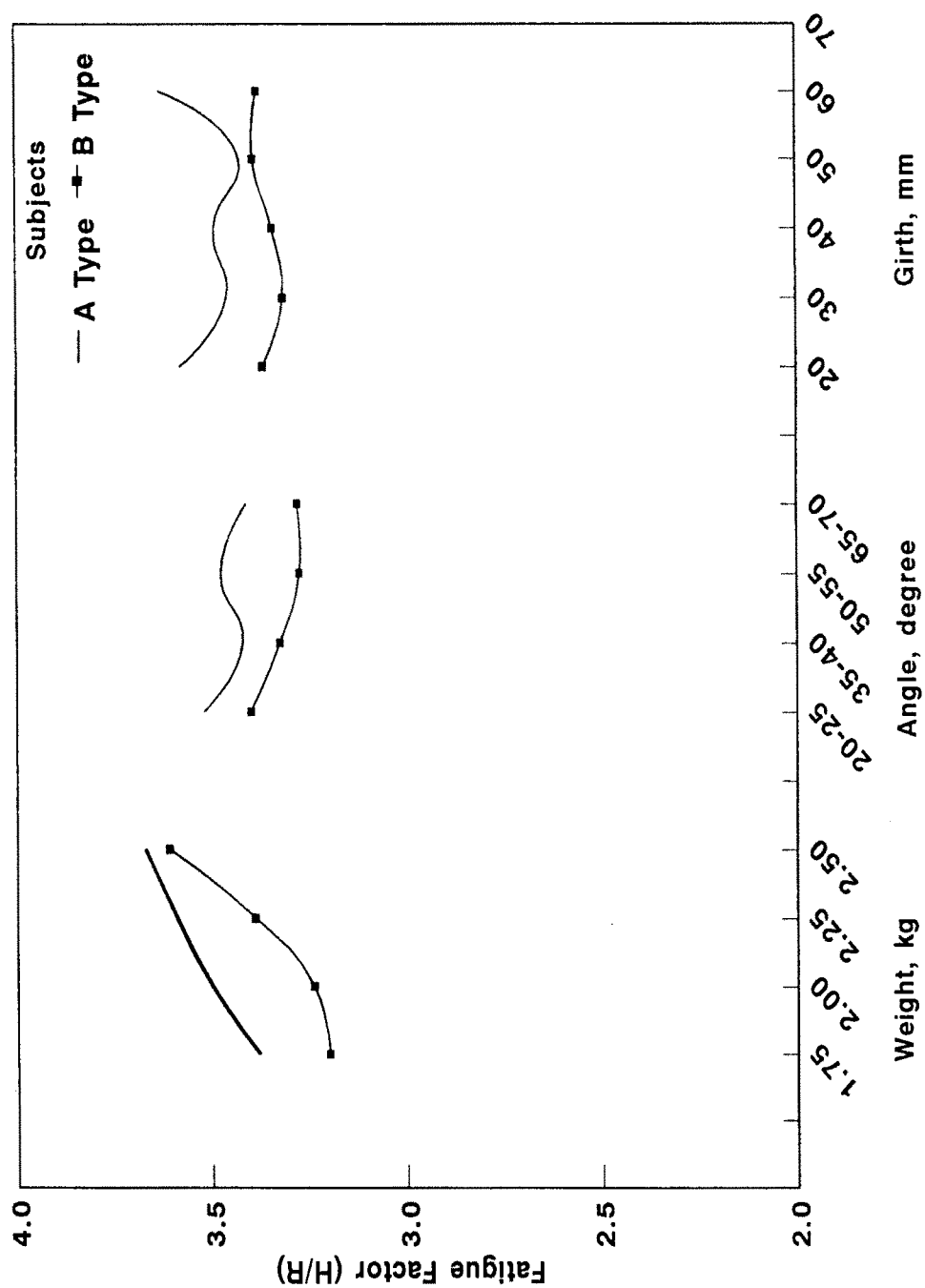


Fig.4.8. Effect of spade weight, angle and handle girth on
Fatigue factor (H/R)

b. Effect of blade angle

The work measurement and physiological responses with respect to angle was presented in Table 4.7. The work measurement i.e., the area dug increased as the angle of the blade with handle was increased. The minimum area dug was 1.93 m²/min, 2.00 m²/min with an angle of 20-25° and maximum area dug was 2.287 m²/min; 2.292 m²/min with an angle of 65-70° by the 'A' and 'B' type subjects respectively. Physiological responses, (fig 4.9) the heart beat rate of subjects 'A' and 'B' types were lowered from 148, 136 beats/min to 133, 128 beats/min respectively as the angle increased from 20-25° to 65-70°.

Oxygen uptake of subjects reduced as the angle was increased. The maximal value be 1.52, 1.72 l/min with 20-25° angle and minimum being 1.32 l/min, 1.38 l/min with 65-70° angle by A and B subjects respectively. Similarly the oxygen consumption per cubic metre of soil dug decreased by 2.65 l and 2.92 l for the increase in angle from 20-25° to 65-70°.

This was mainly because of the subject posture, as the angle was low the subject was forced to bend much to reach the handle awkward posture and work with tool which caused strain in the spinal muscle and the lumbosacral joint reaction which led to discomfort within short time. This conferred with the findings of Nag and Dutt (1980) and Nwuba and Kaul (1986).



Table 4.7. Effect of spade blade angle on physiological response

Description	Subject type	Angle, degree									
		20-25		35-40		50-55		65-70			
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	40.54	3.75	42.14	40.24	43.71	3.23	45.12	4.14		
	B	41.46	6.83	41.19	5.13	42.16	2.79	43.46	7.1		
Heart rate, beats/min	A	148	11	144	12	139	6	133	10		
	B	136	7	133	9	131	8	128	11		
Respiration, breath/min	A	42	8	42	11	40	12	39	10		
	B	41	12	40	6	40	7	39	9		
O ₂ uptake, l/min	A	1.52	1.113	1.475	1.148	1.42	0.905	1.32	0.042		
	B	1.727	0.103	1.46	0.501	1.475	0.702	1.395	1.049		
O ₂ uptake, l/m ³ of soil	A	9.89	1.101	8.45	0.115	9.407	1.054	7.24	0.215		
	B	11.33	0.829	8.66	0.37	8.366	0.23	8.402	0.876		
Area dug, m ² /min	A	1.930	0.065	2.162	0.523	2.202	0.077	2.287	0.562		
	B	2.001	0.06	2.115	0.091	2.216	0.617	2.292	0.131		

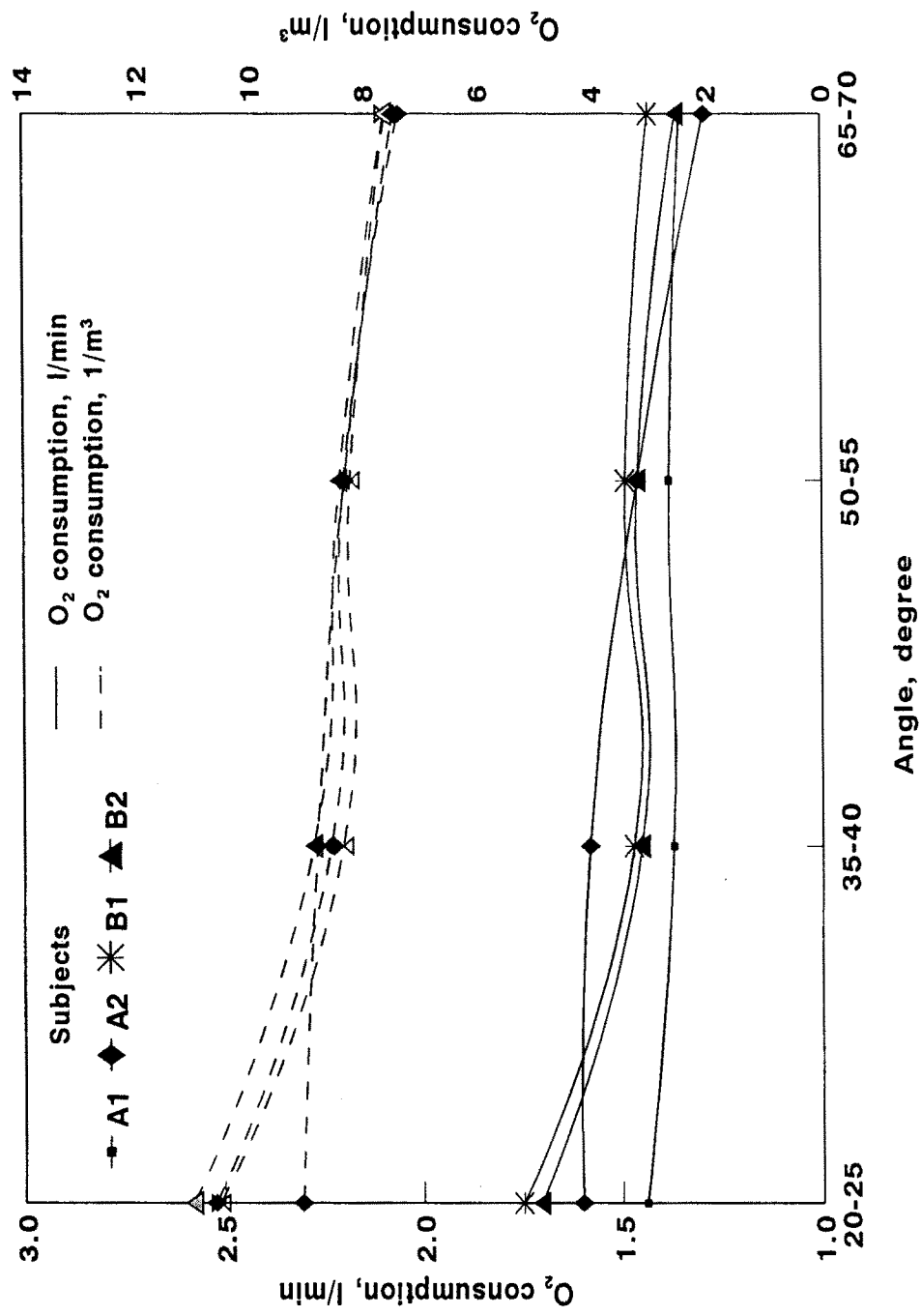


Fig.4.9. Effect of spade angle on physiological response of male subjects

The Fig 4.10 shows the mean clod size distribution for various angles of spade selected for the study. The clod size increased as the angle of blade with handle increased. This variation in clod size distribution was due to the difference in soil and blade (metal) interaction, i.e., in the case of least angle, 20-30°, the soil dug rised along the blade and the enhanced scouring action was resulted. Hence the mean clod size is reduced i.e., 18.4 mm. Whereas in the case of maximum angle, the effect/action was in contrast with the less angle, since the more angle spade was just cut the soil slice and pushed rear by hoeing action. Hence scope for soil and metal interaction was curtailed. This resulted in poor pulverisation and enhanced mean clod size i.e., 29.93mm. This opinion was confirmed by Nag and Pradhan (1992).

The effect of blade angle with handle was also caused considerable change in the Fatigue factor (H/R) as depicted in Fig 4.8. The Fatigue factor decreased as the increase in blade angle. The maximum being 3.5, 3.4 at 20-35° angle and minimum 3.4, 3.2 at 60-75° for 'A' and 'B' type subjects respectively.

Since the angle of blade played major role in the clod size formation, it was suggested that depending on the necessity or job to be carried out, the angle of blade for a spade must be selected. Spade with less angle 20-40° would give better results for works like seed bed preparation, ridge making, civil construction works (mixing work), etc., in which more soil and metal interaction is required. The works like bund trimming and clearing irrigation

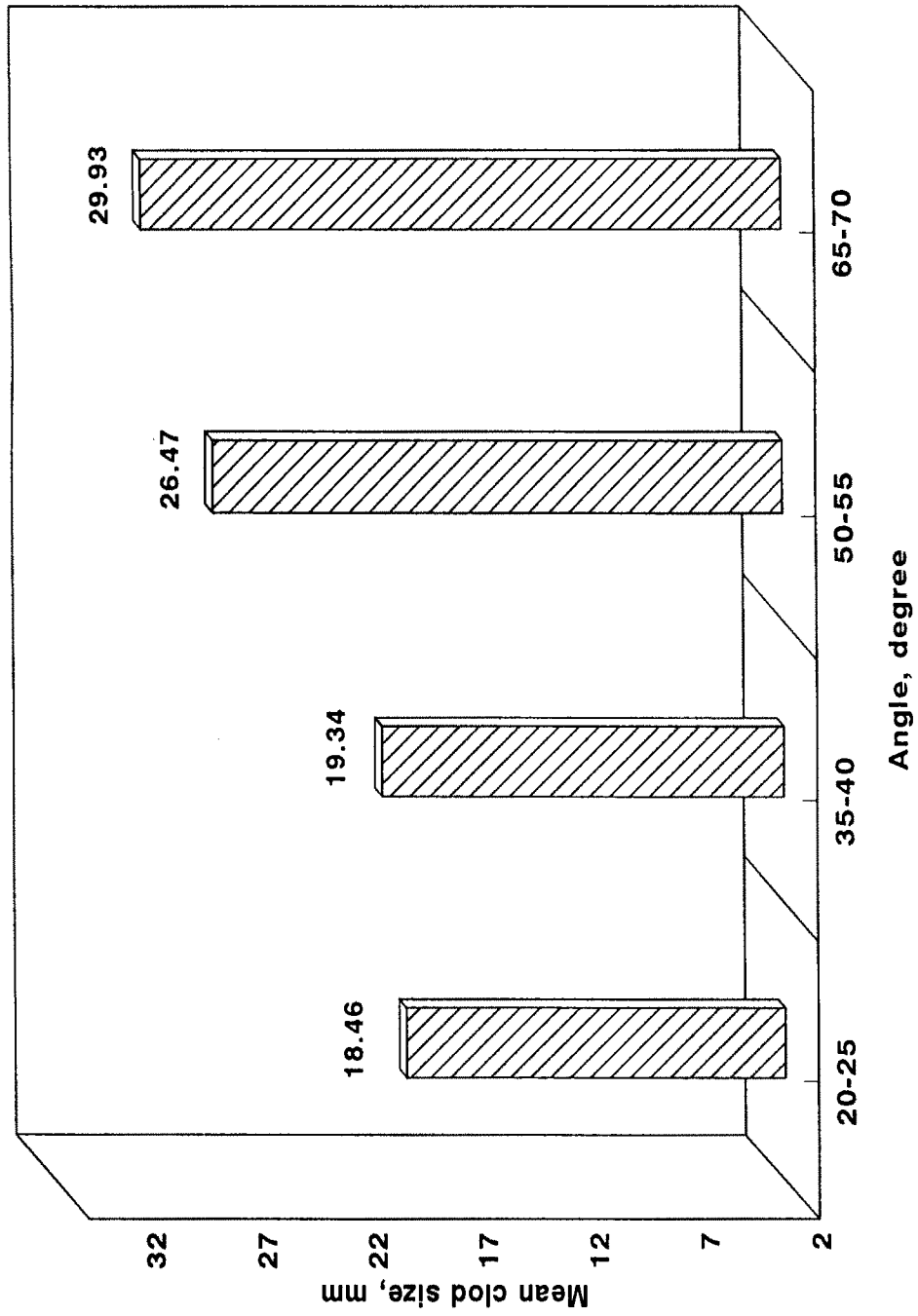


Fig.4.10. Clod size distribution for different spade angle

channels, etc., where the only cutting action is sufficient could be efficiently (with less physiological cost) carried out with more angle 65-70° spades. This is in confirmation with the findings of Pradhan et al. (1986) and Parikh (1980).

c. Effect of handle girth

Table 4.8 shows the effect of change in handle girth on different work measurements and physiological responses.

Area dug by both the type of subjects was more or less same i.e., $2.208 \pm 0.23 \text{ m}^2/\text{min}$ for the varied hand grip diameters from 20mm to 50 mm. But suddenly it dropped to $2.04 \pm 0.09 \text{ m}^2/\text{min}$ when the grip diameter raised to 60mm.

The oxygen uptake was same (Fig 4.11) with little variance of $1.32 \pm 0.29 \text{ l/min}$ or $7.61 \pm 0.3 \text{ l/m}^3$ and minimum 1.27 l/min or $7.25 \pm 0.211 \text{ l/m}^3$ at 40 mm for type 'A' subjects. For subjects 'B' type the oxygen uptake was maximum i.e., 1.42 l/min or $8.23 \pm 0.75 \text{ l/m}^3$ for both the 20 mm and 60 mm handle grip diameter and was minimum i.e., $1.7 \pm 0.05 \text{ l/min}$ or $7.36 \pm 0.10 \text{ l/m}^3$ for 40 mm diameter handle.

This was due to the hand grip diameter. Hand grip diameter of A and 'B' type subjects ranged from $3.05 \pm 0.1 \text{ cm}$ to $3.5 \pm 0.1 \text{ cm}$. Hence the subjects could hold a handle of diameter 3-4 cm. If it exceeded, then the

Table 4.8. Effect of spade handle girth on physiological response

Description	Subject type	Hand grip diameter, mm											
		20 mm		30 mm		40 mm		50 mm		60 mm		Mean	sd
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd		
Stroke rate/min	A	42.33	4.21	43.12	2.41	42.71	1.713	40.34	6.121	34.231	8.351		
	B	39.19	3.04	41.72	2.74	42.85	24.17	38.44	5.36	37.313	6.812		
Heart rate, beats/min	A	136	6	138	8	133	14	137	6	138	6		
	B	128	9	126	12	127	9	129	6	132	15		
Respiration, breath/min	A	38	7	40	5	36	14	40	13	38	10		
	B	38	11	38	9	38	8	38	8	37	13		
O ₂ uptake, l/min	A	1.323	0.021	1.344	0.041	1.27	0.055	1.331	0.042	1.34	0.141		
	B	1.42	0.141	1.325	0.071	1.285	0.355	1.33	0.289	1.42	0.565		
O ₂ uptake, l/m ³ of soil	A	7.556	0.038	7.503	0.249	7.258	0.211	7.539	0.3676	8.210	0.366		
	B	7.702	0.202	7.737	0.365	7.362	0.109	7.712	0.259	8.758	0.531		
Area dug, m ² /min	A	2.189	0.1749	2.239	0.33	2.192	0.108	2.212	0.400	2.048	0.045		
	B	2.309	0.273	2.144	0.82	2.183	0.04	2.166	0.042	2.024	0.094		

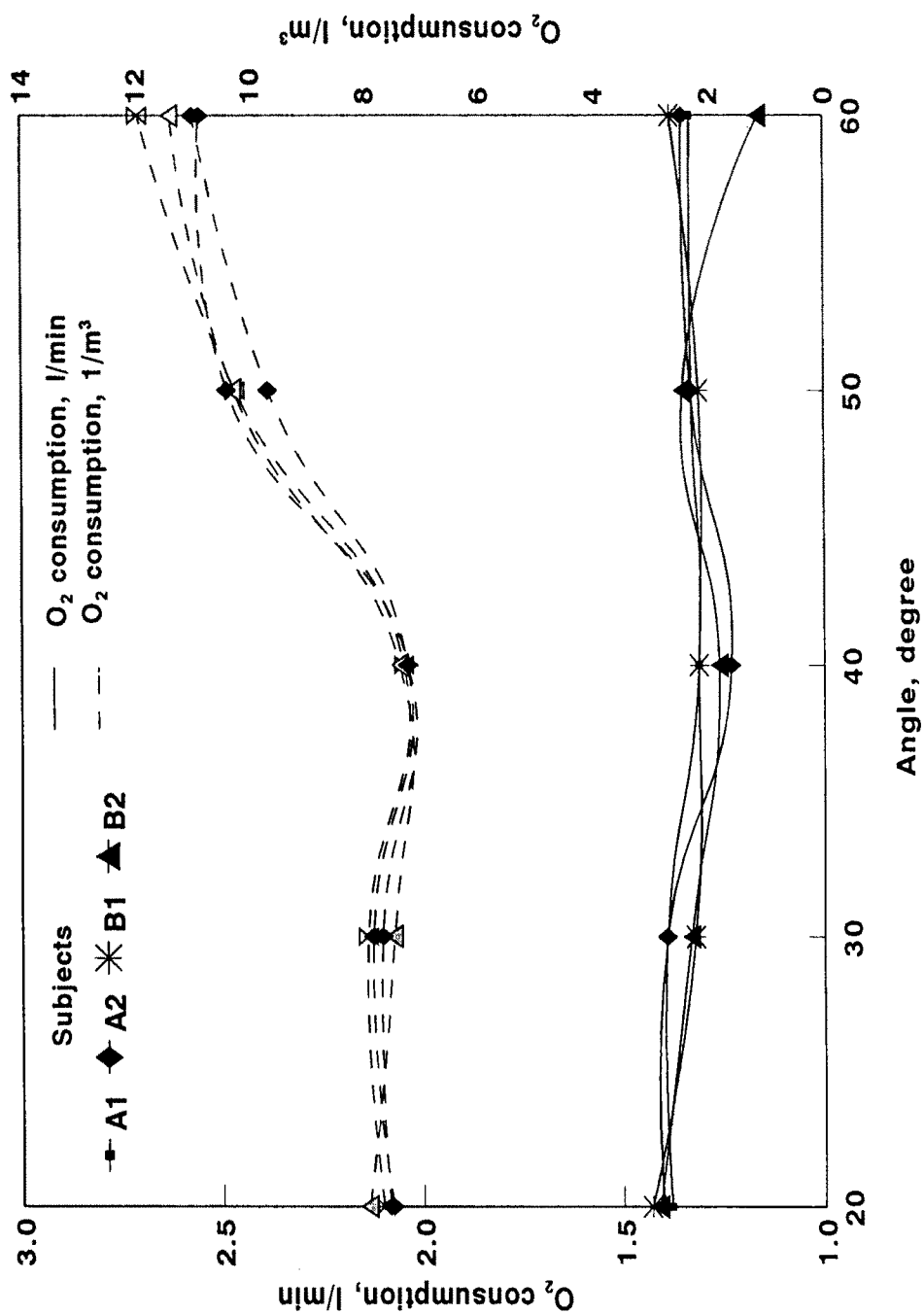


Fig.4.11. Effect of spade handle girth on physiological response of male subjects

subject had to strain much to hold the handle and work. Hence the 3-4 cm handle diameter is suggested for better comfort.

The above results were supported by minimum values (Table 4.9) of respective mean physiological cost i.e., oxygen uptake ml/min/kg of body weight, Oxygen uptake/min/cm of stature and Oxygen uptake ml/min/cm hand grip diameter.

4.6.2. Hand hoe

To optimise the basic design parameters, namely weight, angle of blade with handle, handle girth, the changes were made in design parameters and the effect of the changes on the work and physiological measurements were discussed.

a. Effect of weight

From the table 4.10 it was evident that the operational strokes/min decreased as the weight of the hoe increased irrespective of the type of subject. The area covered by 'A' and 'B' type subjects were decreased from 1.84 m²/min, 1.83 m²/min to 1.56 m²/min, 1.53 m²/min respectively, as the weight of the tool was increased from 0.55 kg to 0.85 kg.

In contrast, the cardiovascular stress was increased from 93, 91 beats/min to 106, 109 beats/min of 'A' and 'B' type subjects respectively as the weight of tool increased from 0.55 kg to 0.85 kg.

Table 4.9. Spade - mean physiological cost per body dimensions of subject

Variables	O ₂ Consumption, ml/min / kg of body weight					
	A ₁ (48)*	A ₂ (50)*	B ₁ (76)*	B ₂ (79)*	Mean	CV
1.75	27.70	27.216.44	16.44	16.46	21.95	0.2892
2.00	29.40	28.6	18.68	17.59	23.56	0.2671
2.25	30.41	31.6	20.00	18.35	25.09	0.2742
2.50	35.00	34.8	20.78	21.13	27.927	0.2883
O ₂ Consumption, ml/min / kg of stature						
Angle	152.6**	154.9**	172.1**	173.0**	Mean	CV
20-24	9.44	10.33	10.168	9.85	9.947	0.039
35-40	8.98	10.20	8.54	8.38	9.791	0.058
50-55	9.04	9.42	8.65	8.44	8.887	0.0487
65-70	8.85	8.32	8.30	7.86	8.332	0.0486
O ₂ Consumption ml/min / kg of hand grip diameter						
Girth	3.0***	3.1***	3.6***	3.4***	Mean	CV
20	460.0	451.6	397.2	414.7	430.875	0.069
30	463.3	448.3	366.6	391.1	417.325	0.1101
40	436.6	396.7	363.8	370.5	391.90	0.0842
50	442.6	429.0	363.8	397.0	408.1	0.0862
60	443.3	435.48	383.3	429.4	422.87	0.06381

* Body weight of respective subject, kg.

** Stature of respective subject, cm.

*** Hand grip diameter of subject, cm.

Table 4.10. Effect of hand hoe weight on physiological response

Description	Subject type	Weight, kg									
		0.550		0.650		0.750		0.850			
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	59.13	5.365	57.93	6.009	55.03	4.876	53.17	4.773		
	B	60.76	4.387	60.27	3.789	58.21	4.697	55.39	5.328		
Heart rate, beats/min	A	93	4	94	7	99	5	106	7		
	B	91	8	93	3	96	10	109	6		
Respiration, breath/min	A	38	8	38	10	39	6	41	10		
	B	36	14	38	7	38	11	40	5		
O ₂ uptake, l/min	A	0.905	0.21	0.908	0.113	1.053	0.169	1.20	0.0219		
	B	0.861	0.021	0.98	0.424	0.985	0.07	1.145	0.021		
O ₂ uptake, l/m ³ of soil	A	12.340	0.794	12.590	0.406	14.131	0.451	19.208	0.198		
	B	11.756	0.324	13.958	1.464	13.104	0.367	18.631	0.470		
Area dug, m ² /min	A	1.8414	0.585	1.809	0.760	1.872	0.319	1.563	0.130		
	B	1.830	0.223	1.768	0.196	1.885	0.362	1.533	0.571		

Oxygen consumption (Fig 4.12) of 'A' and 'B' type subjects were increased from 0.905 l/min, 0.86 l/min to 1.2 l/min, 1.14 l/min respectively for the above increase of weight. The oxygen uptake was also significantly increased from 11.75 l/m³ of soil to 19.20 l/m³ of soil, with the increase in weight of tool. This is confirmed with the results of Nwuba and Kaul (1987) and Gill Choudary (1987).

Fig 4.12 explains the Fatigue factor (H/R) variation during hoeing (weeding) operation with the various changes in design parameters. Fatigue factor increased as the weight of tool increased from 2.40, 2.5 to 2.5, 2.72 for 'A' and 'B' type subjects with weight 0.55 kg and 0.85 kg respectively.

b. Effect of blade angle

The effect of angle on the work and physiological aspects were shown in Table 4.11. The operational strokes decreased as the angle of blade handle increased i.e., from 55.5 ± 4.3 strokes/min to 58.8 ± 5.7 strokes/min.

Cardiovascular load, the heart beat rate lowered as the angle of the blade increased from 98 beats/min to 92 beats/min and from 100 beats/min to 90 beats/min for 'A' type and 'B' type subjects respectively. Oxygen uptake (Fig. 4.14) lowered from 1.08 l/min, 1.07 l/min to 0.95 l/min; 0.90 l/min by the 'A' and 'B' type subjects respectively. Similarly Oxygen uptake per cubic metre of soil handled by the 'A' and 'B' type subjects were reduced from 17.0 l to 16.6 l and from 16.9 l to 15.5 l respectively.

Table 4.1.1. Effect of hand hoe blade angle on physiological response

Description	Subject type	Blade angle with handle, degree									
		20-25		30-35		40-45		50-55		Bent handle* (30 & 60)	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	54.3	4.215	55.2	5.362	56.23	6.171	57.31	4.773	58.213	4.731
	B	56.7	3.171	54.3	4.721	59.71	5.114	58.74	3.376	59.34	6.127
Heart rate, beats/min	A	98	7	96	9	96	3	94	5	92	3
	B	100	6	99	4	93	11	93	9	90	6
Respiration, breath/min	A	39	8	39	16	39	10	38	6	38	6
	B	40	11	40	9	38	6	39	4	36	8
O ₂ uptake, l/min	A	1.085	0.212	1.085	0.049	0.9615	0.1202	0.955	0.073	0.825	0.070
	B	1.0745	0.360	1.095	0.353	0.935	0.353	0.956	0.049	0.865	0.070
O ₂ uptake, l/m ³ of soil	A	17.0	0.369	16.437	0.088	15.674	0.111	16.618	0.761	11.673	0.192
	B	16.986	0.259	16.638	0.406	15.131	0.636	15.548	0.452	12.375	0.179
Area dug, m ² /min	A	1.601	0.195	1.638	0.442	1.537	0.098	1.446	0.082	1.77	0.103
	B	1.584	0.355	1.633	0.509	1.547	0.169	1.540	0.130	1.757	0.048

* The Bent handle possess blade angle 30° at blade joining part and 60° at hand grip.

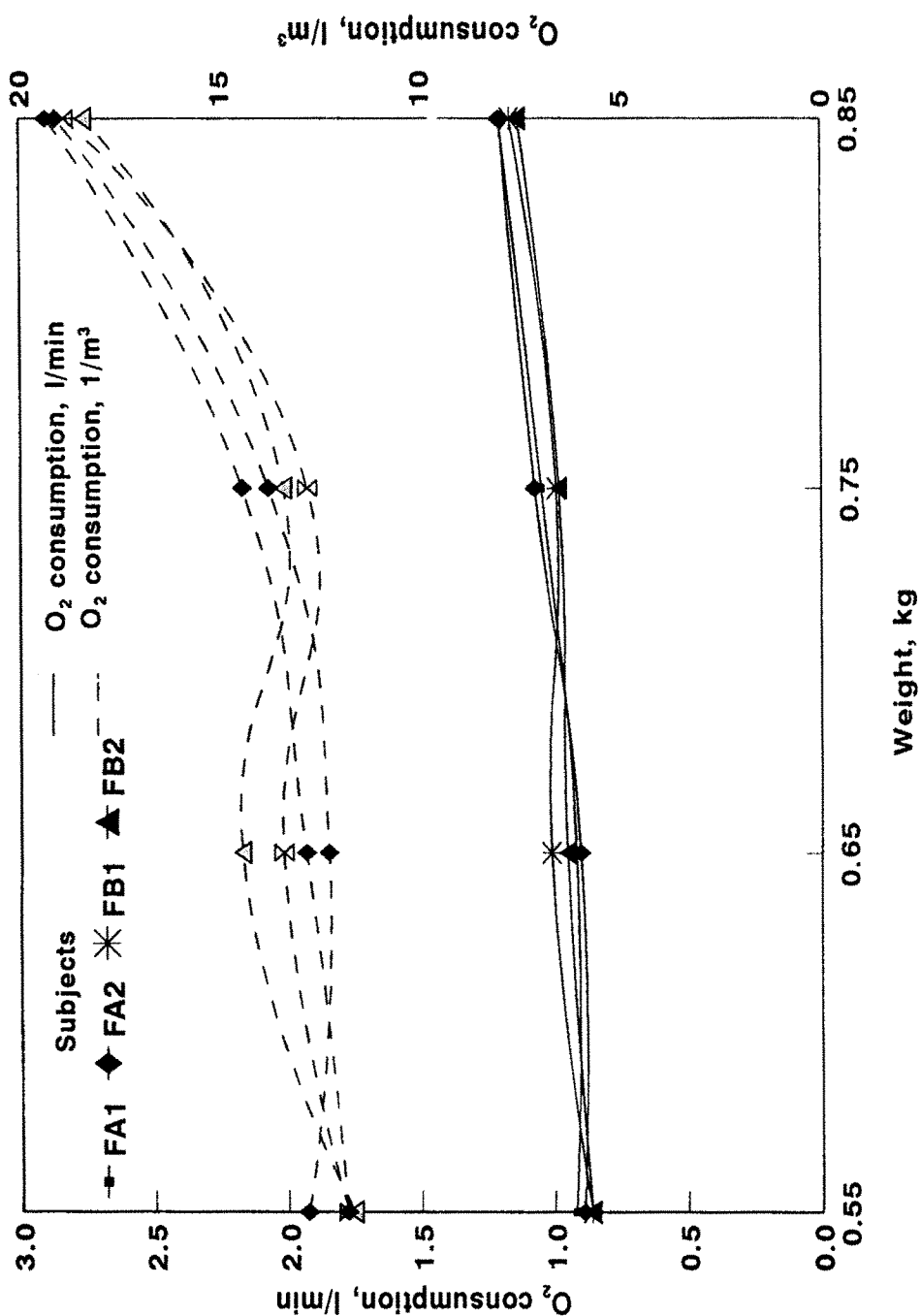


Fig.4.12. Effect of hand hoe weight on physiological response of female subjects

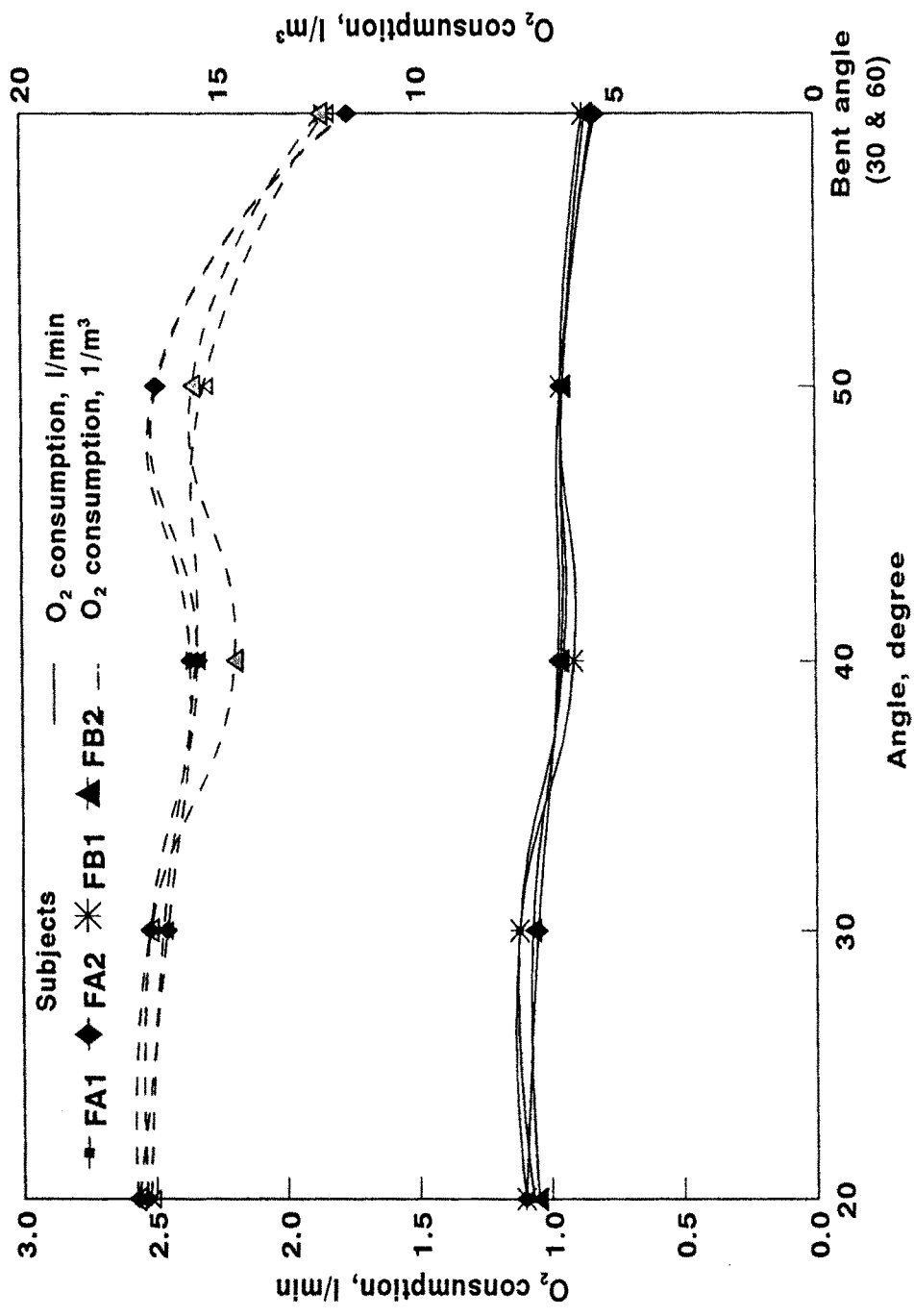


Fig.4.14. Effect of hand hoe angle on physiological response of female subjects

Fig.4.15 shows the weeding efficiency (in percentage) by different angle of blade with handle which confirmed the minimum efficiency of 55.83 per cent at 50-55° angle and the maximum being 76.85 per cent at 20-25° angle. This could be due to more weed and blade interaction in lower angles i.e., 20-25°

To incorporate this advantage in maximum angle (60-65°), the bent handle was designed as shown in Fig 4.2, in which the angle at blade joining part of handle measures 30° and 60° at the hand grip of handle. Since the blade was inclined 30° with handle, the weed and blade interaction was not hampered or similar to that of 30° straight handle. Hence the weeding efficiency was 73.29 per cent. At the same time oxygen consumption was 0.82 l/min or 11.67 l/m³ by 'A' type and 'B' type subjects consumed around 0.86 l/min or 12.375 l/m³. This was due to the bent angle provided in the handle which facilitates the subjects to work without much bending i.e., more upright (Fig 4.16), intern reduced the strain in the spinal muscle force, lumbosacral joint reaction (Nwuba and Kaul 1986). This was also confirmed by Nag and Dutt (1980).

Fig 4.17 showed the influence of angle on Fatigue factor. From the figure the Fatigue factor reduced as the angle of blade with handle increased. For the 'A' and 'B' type subjects maximum value was 2.5, 2.5 at 20° angle and minimum of 2.42, 2.44 at 60° angle respectively.

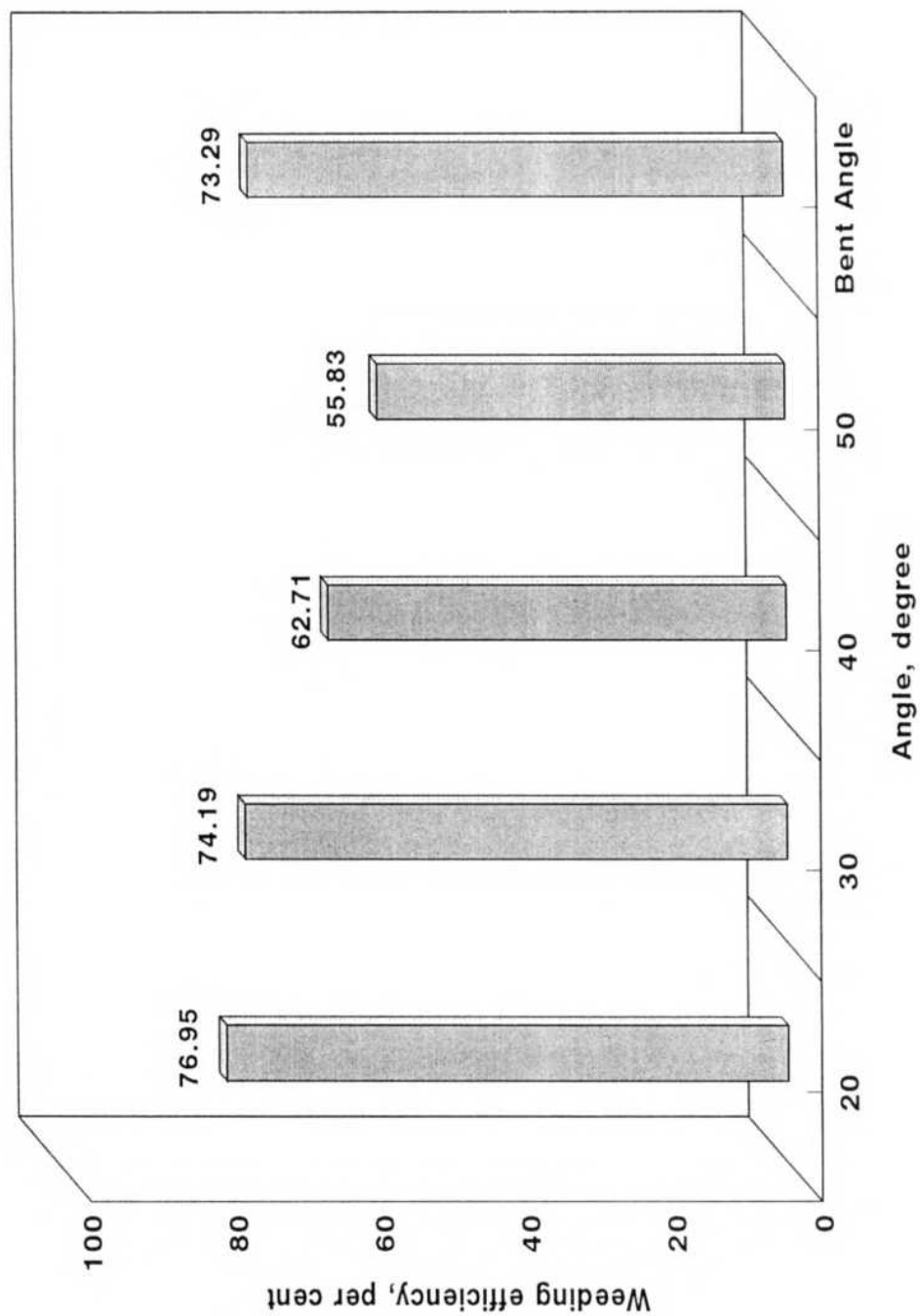
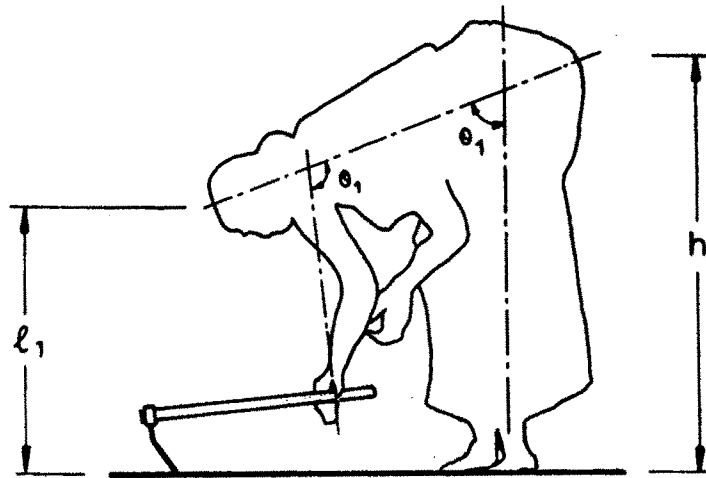
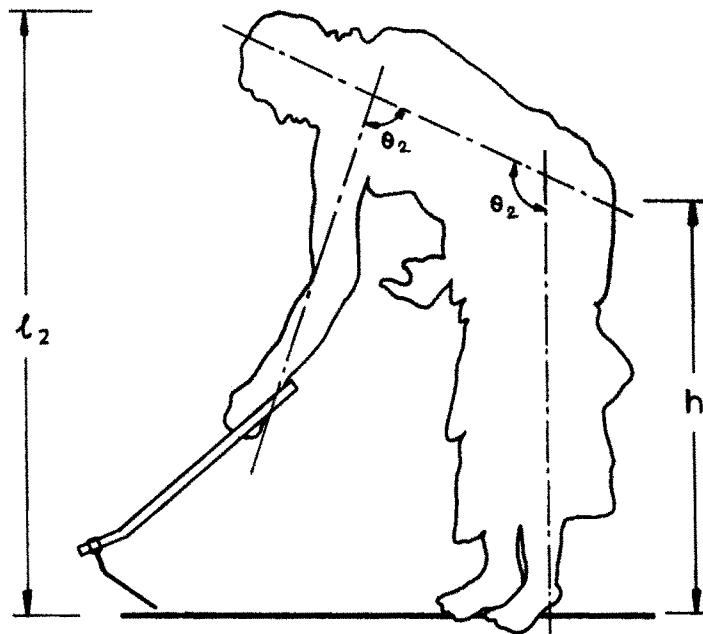


Fig.4.15. Weeding efficiency of hand hoe



(a)



(b)

Fig.4.16.WORKING POSTURE

- a) HAND HOE WITH STRAIGHT HANDLE
- b) HAND HOE WITH BENT HANDLE

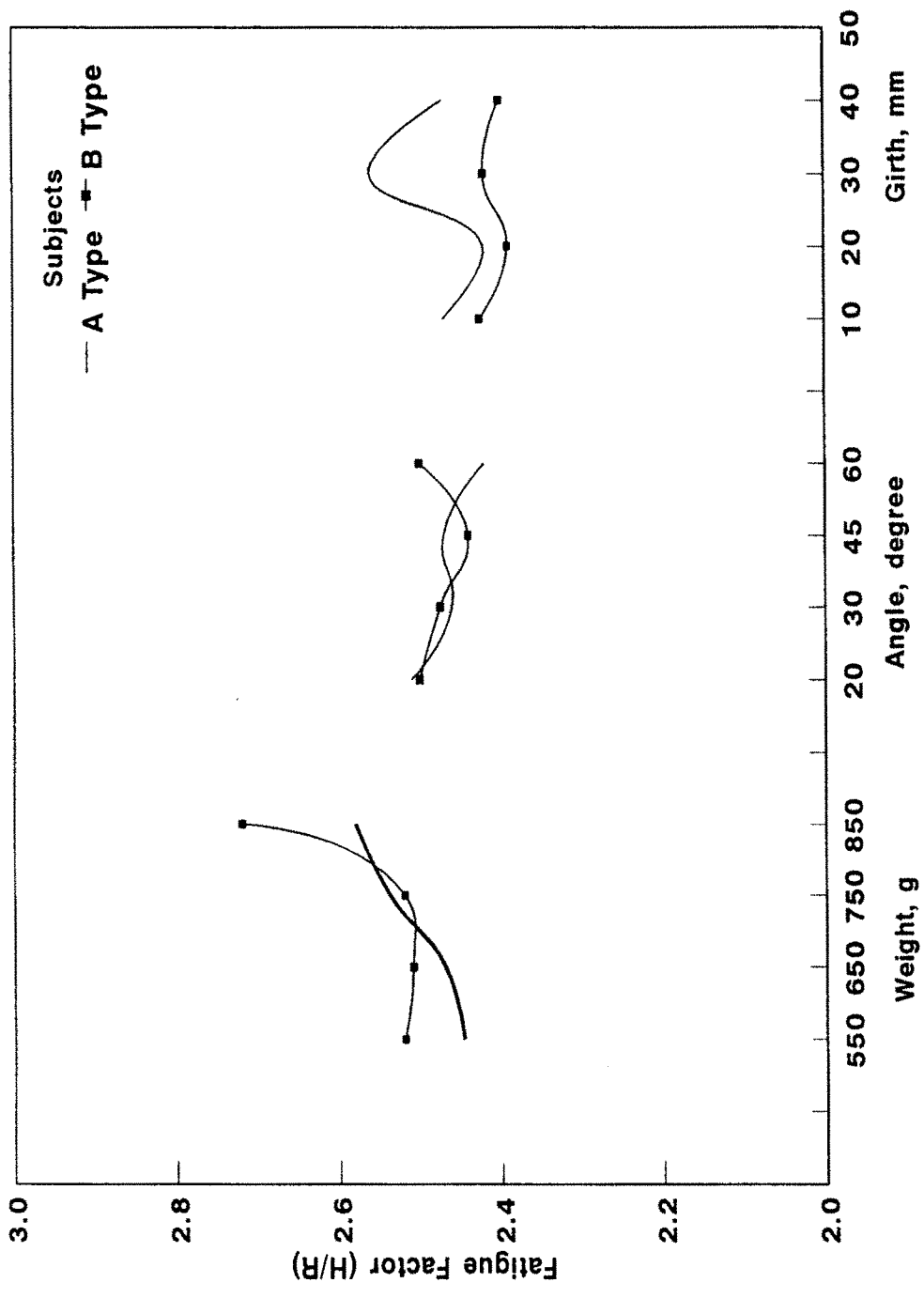


Fig.4.17. Effect of hand hoe weight, angle and handle girth on Fatigue factor (H/R)

c. Effect of handle girth

Table 4.12 shows the effect of handle girth on work and physiological responses. From the table it is clear that operational stroke rate was slightly affected by the change in handle girth in between 53.2 ± 5.1 strokes/min and 54.92 ± 3.7 strokes/min. The area covered was meagerly reduced from $1.69 \text{ m}^2/\text{min}$ to $1.60 \text{ m}^2/\text{min}$ by the increase of handle grip diameter from 10 mm to 40 mm.

The oxygen uptake (Fig 4.18) by the both type of subjects were more or less same i.e., $1.01 \pm 0.04 \text{ l/min}$ and $15.47 \pm 0.7 \text{ l/m}^3$ of soil handled. The minimum Oxygen consumption of $0.98 \pm 0.02 \text{ l/min}$ and $14.95 \pm 0.29 \text{ l/m}^3$ of soil with 20 mm handle grip diameter .

Fatigue factor (Fig 4.17) lowered with the increase of handle grip diameter upto 20 mm and after that increased Fatigue factor was found with increased hand grip diameter. The minimum Fatigue factor 2.42 and 2.39 was estimated with 20 mm diameter of handle for 'A' and 'B' type subjects respectively. Hence the 20 mm diameter handle is suggested for the better comfort and with less physiological cost.

The above results were supported by minimum values (Table 4.13) of respective mean physiological cost i.e oxygen uptake ml/min/kg of body weight, Oxygen uptake ml/min/cm of stature and Oxygen uptake ml/min/cm hand grip diameter.

Table 4.12. Effect of hand hoe handle girth on physiological response

Description	Subject type	Diameter of handle, mm							
		10		20		30		40	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	53.24	5.126	55.77	3.261	54.33	2.173	54.92	3.732
	B	55.82	4.712	55.62	6.772	53.29	3.623	54.88	4.516
Heart rate, beats/min	A	94	3	92	8	93	9	94	7
	B	97	6	91	8	92	3	96	11
Respiration, breath/min	A	38	7	35	11	36	10	38	6
	B	40	9	38	6	38	9	40	5
O ₂ uptake, l/min	A	1.069	0.296	0.966	0.516	1.02	0.1414	1.06	0.239
	B	0.95	0.989	1.005	0.212	0.997	0.608	1.048	0.028
O ₂ uptake, l/m ³ of soil	A	15.819	0.507	14.75	0.749	15.027	0.849	16.630	0.789
	B	14.709	1.079	15.166	0.813	14.909	0.615	16.125	1.0123
Area dug, m ² /min	A	1.698	0.875	1.641	0.531	1.704	0.091	1.600	0.384
	B	1.698	0.637	1.668	0.173	1.613	0.449	1.629	0.229

Table 4.13. Hand hoe - mean physiological cost per body dimensions of female subject

Variables	O ₂ Consumption, ml/min / kg of body weight						
Weight, kg	A ₁ (41)*	A ₂ (46)*	B ₁ (55)*	B ₂ (52)*	Mean	sd	CV
0.550	18.775	19.34	15.69	16.538	17.588	1.751	0.0996
0.650	18.693	19.565	18.36	18.269	18.724	0.589	0.0314
0.750	21.34	23.26	18.00	18.946	20.363	2.397	0.117
0.850	24.48	26.086	21.090	21.73	23.349	2.346	0.100
	O ₂ Consumption, ml/min/cm of stature						
Angle, degree	154.2**	156.7	144.1	142.3	Mean	sd	CV
20	6.939	7.019	7.63	7.371	7.240	0.322	0.044
30	7.26	6.700	7.772	7.519	7.3127	0.458	0.062
40	6.180	6.190	6.135	6.746	6.357	0.266	0.0418
50	6.160	6.126	6.662	6.697	6.4115	0.310	0.048
Bent handle	5.382	5.232	6.037	6.064	5.679	0.433	0.0763
	O ₂ Consumption, ml/min/cm of hand grip diameter						
Hand grip diameter, mm	3.1***	2.9	2.7	2.8	Mean	sd	CV
15	338.06	375.86	377.77	314.28	356.96	26.72	0.074
20	30.00	345.86	377.7	353.57	322.93	32.42	0.100
30	332.25	348.27	385.18	340.71	351.608	23.321	351.60
40	341.93	365.51	388.89	373.57	365.44	23.476	0.064

* Body weight of respective subject, kg

** Stature of respective subject, cm

*** Hand grip diameter of subject, cm

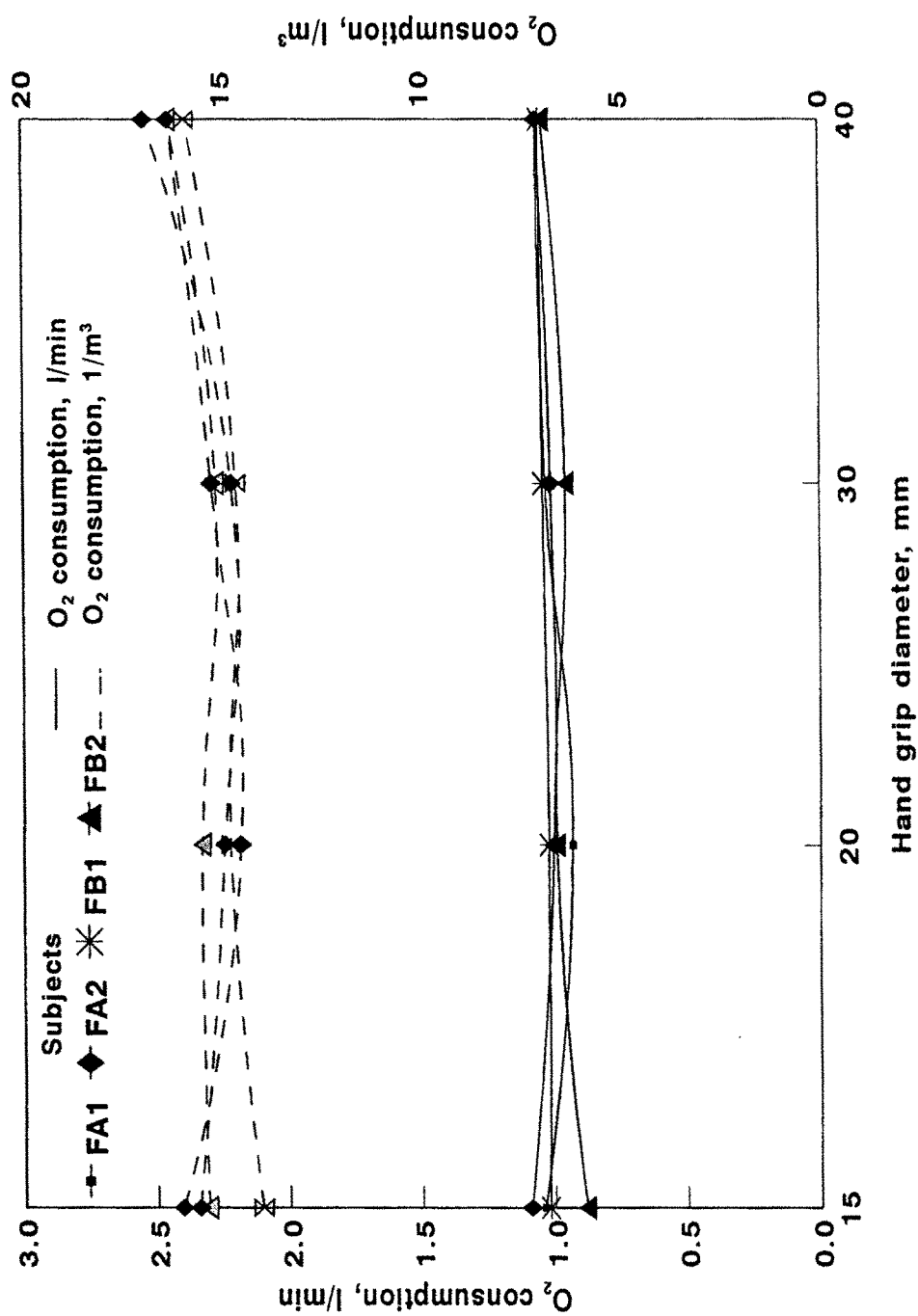


Fig.4.18. Effect of hand hoe handle girth on physiological response of female subjects

4.6.3. Shovel

The variables considered for the shovel study were weight of the implements, angle of blade with handle axis. Experiments were conducted with the above altered design parameter tools to form field bunds and channels in measured piece of land.

a. Effect of weight

The work measurement and physiological responses were analysed and shown in Table 4.14. From the table, it is observed that the operational stroke rate was meagerly lowered from 32.7 ± 4.3 strokes/min to 30.1 ± 2.9 strokes/min for 'A' type subject and for 'B' type subjects it was from 36.8 ± 3.2 strokes/min to 31.3 ± 4.7 strokes/min with the increase in weight of tool from 2 kg to 3 kg. And also the area covered 2.02 ± 0.08 m²/min was scantily affected by the weight of shovel.

Physiological response, oxygen uptake (Fig 4.19) by 'A' type subject increased from 1.16 ± 0.35 l/min or 9.30 ± 0.58 l/m³ of soil handled to 1.22 ± 0.98 l/min or 10.38 ± 0.13 l/m³ of soil handled for the 1 kg increase in the shovel weight (i.e., from 2 kg to 3 kg). For 'B' type subject the same weight change of 1 kg, increased the oxygen uptake from 1.14 ± 0.07 l/min or 8.86 ± 0.19 l/m³ of soil handled to 1.23 ± 0.07 l/min or 10.26 ± 0.11 l/m³ of soil handled. This was obvious that the increased weight caused increased physiological stress.

Table 4.14. Effect of shovel weight and angle on physiological response

Description	Subject type	Weight, kg						Angle, degree					
		2		2.5		3.0		10		15		20	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	32.71	4.32	32.02	3.78	30.18	2.91	34.16	5.267	32.22	5.71	32.00	3.13
	B	36.88	3.21	33.61	4.17	31.36	4.73	33.77	4.021	32.92	3.49	30.63	5.21
Heart rate, beats/min	A	108	7	112	10	121	8	122	11	110	5	110	8
	B	103	12	111	9	119	6	120	9	110	15	108	6
Respiration, breath/min	A	38	8	37	11	40	6	40	11	37	6	36	8
	B	37	15	39	9	41	9	42	8	39	6	38	4
O ₂ uptake, l/min	A	1.165	0.353	1.14	0.424	1.223	0.098	1.035	0.212	1.14	0.424	1.195	0.07
	B	1.145	0.0707	1.055	0.212	1.230	0.71	1.088	0.028	1.055	0.712	1.251	0.268
O ₂ uptake, l/m ³ of soil	A	9.308	0.587	9.652	0.268	10.383	0.130	9.627	0.329	9.652	0.268	10.111	0.084
	B	8.869	0.196	8.82	0.219	10.263	0.118	10.208	0.170	8.82	0.219	10.286	0.200
Area dug, m ² /min	A	2.093	0.743	1.961	0.331	1.930	0.105	1.794	1.007	1.9614	0.33	1.972	0.018
	B	2.149	0.391	2.034	0.292	2.008	0.266	1.784	0.105	2.034	0.29	2.030	0.029

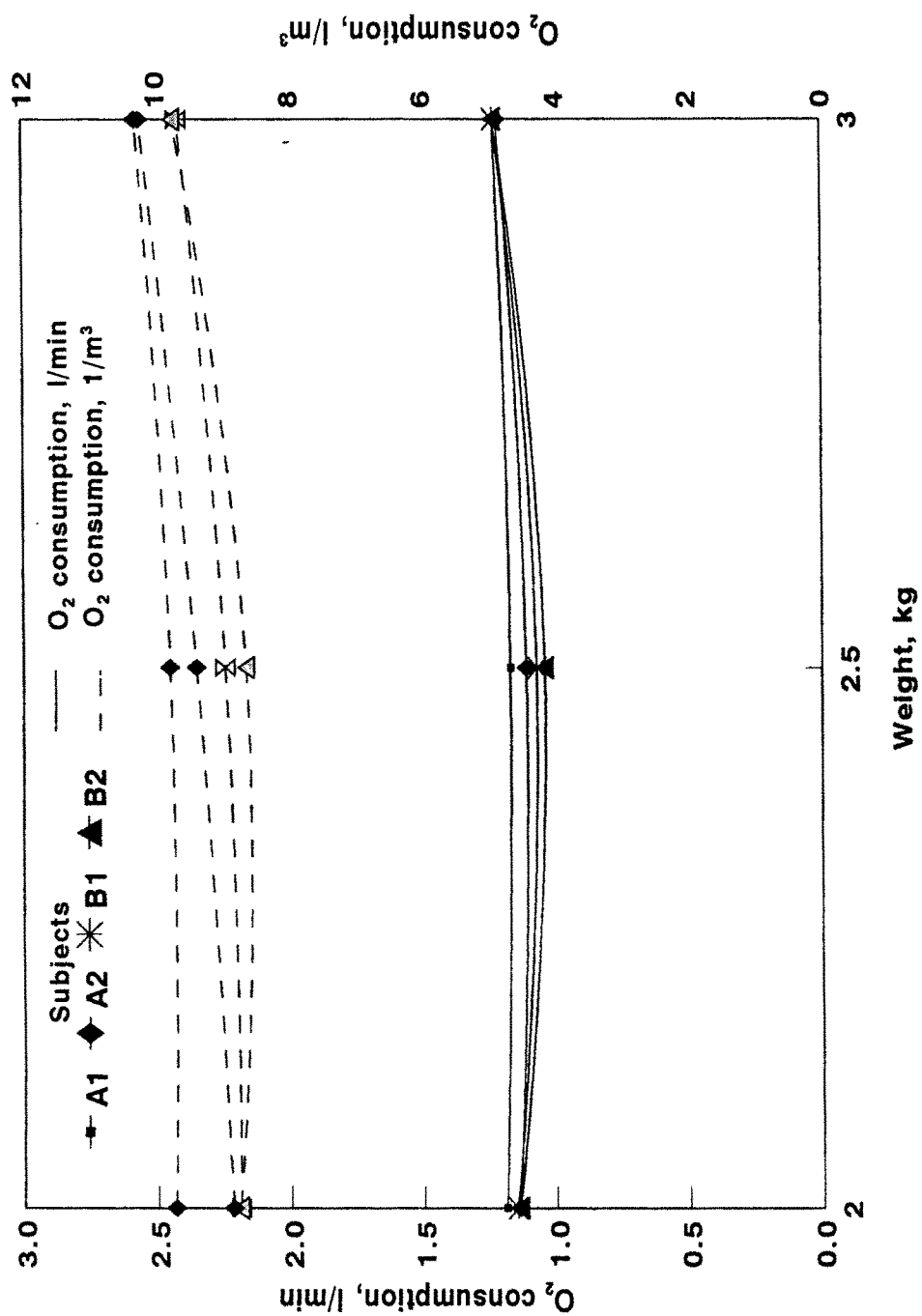


Fig.4.19. Effect of shovel weight on physiological response of male subjects

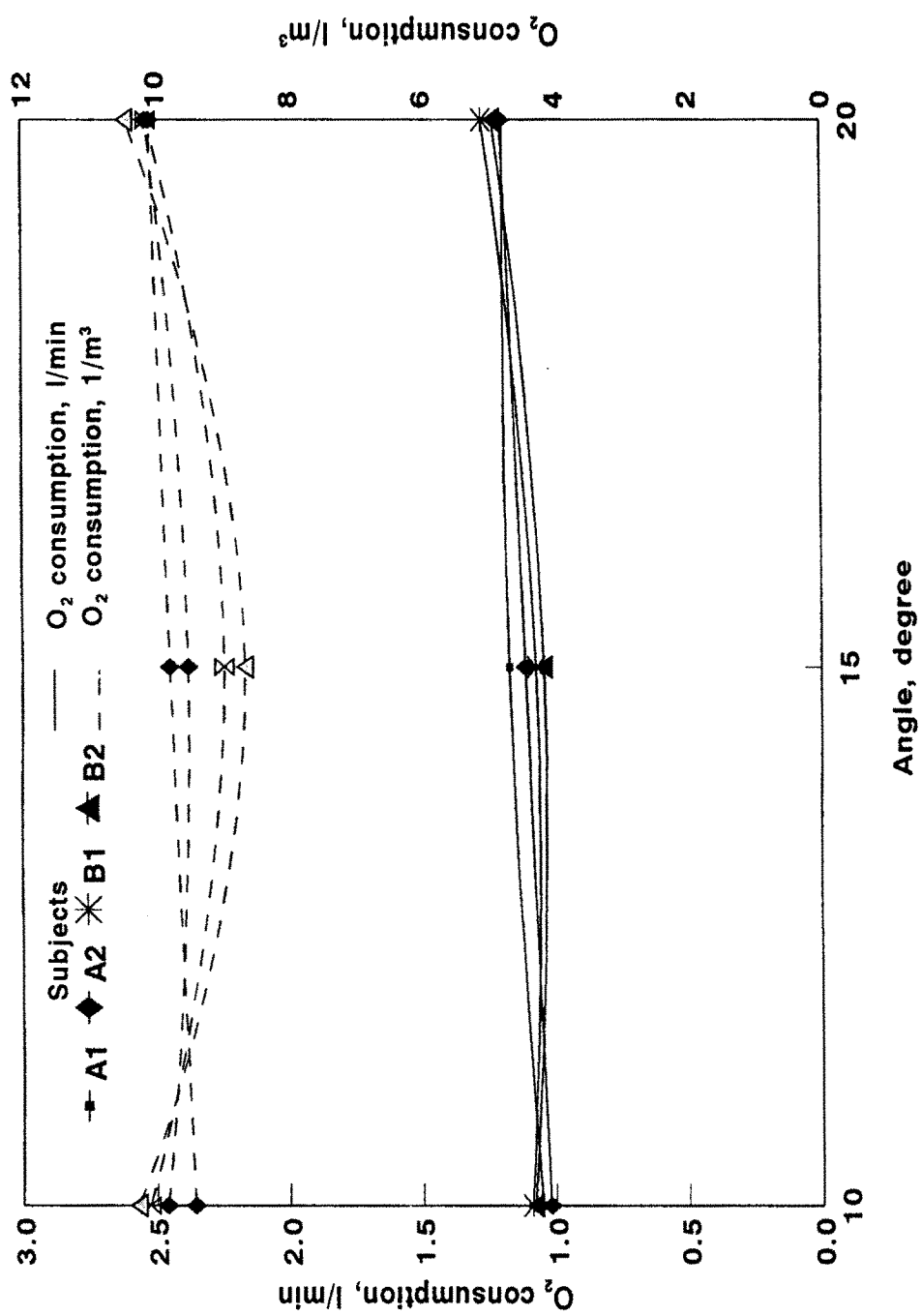


Fig.4.20. Effect of shovel angle on Physiological response of male subjects

b. Effect of blade angle

From the table 4.14 it is evident that the slight increase in area covered from $1.78 \pm 0.01 \text{ m}^2/\text{min}$ to $1.99 \pm 0.05 \text{ m}^2/\text{min}$ for varied angle from 10° to 15° and the change in area covered was negligible with change in angle from 15° to 20° . The oxygen consumed was more or less same, i.e., $1.07 \pm 0.04 \text{ l/min}$ for the both angles of 10° and 15° . This was increased to $1.22 \pm 0.03 \text{ l/min}$ for 20° angle of blade. This oxygen consumption (Fig 4.20) per cubic metre volume of soil handled was more or less same i.e., $9.78 \pm 0.5 \text{ l}$ and minimum was $9.23 \pm 0.58 \text{ l}$ with 15° blade angle.

Area covered increased with the increase in blade angle upto 15° with handle axis was due to the convenient posture of a subject. The less angle made the subjects to repeat the action more times to scoop out the same quantity of soil. But in the greater angle the subject could work in standing or more upright posture. This was confirmed by the Hansson and Oberg (1996). Hence the suggested blade angle with handle axis is 15° and weight of the shovel is 2.5 kg.

The effect of the weight and angle on the Fatigue factor is depicted in Fig 4.21. From the figure the increase in Fatigue factor with the increase in weight of tool was observed. The minimum value 3.00 and 2.78 with 2 kg weight shovel and maximum of 3.02 and 2.9 with 3 kg shovel for 'A' and 'B' type subjects respectively.

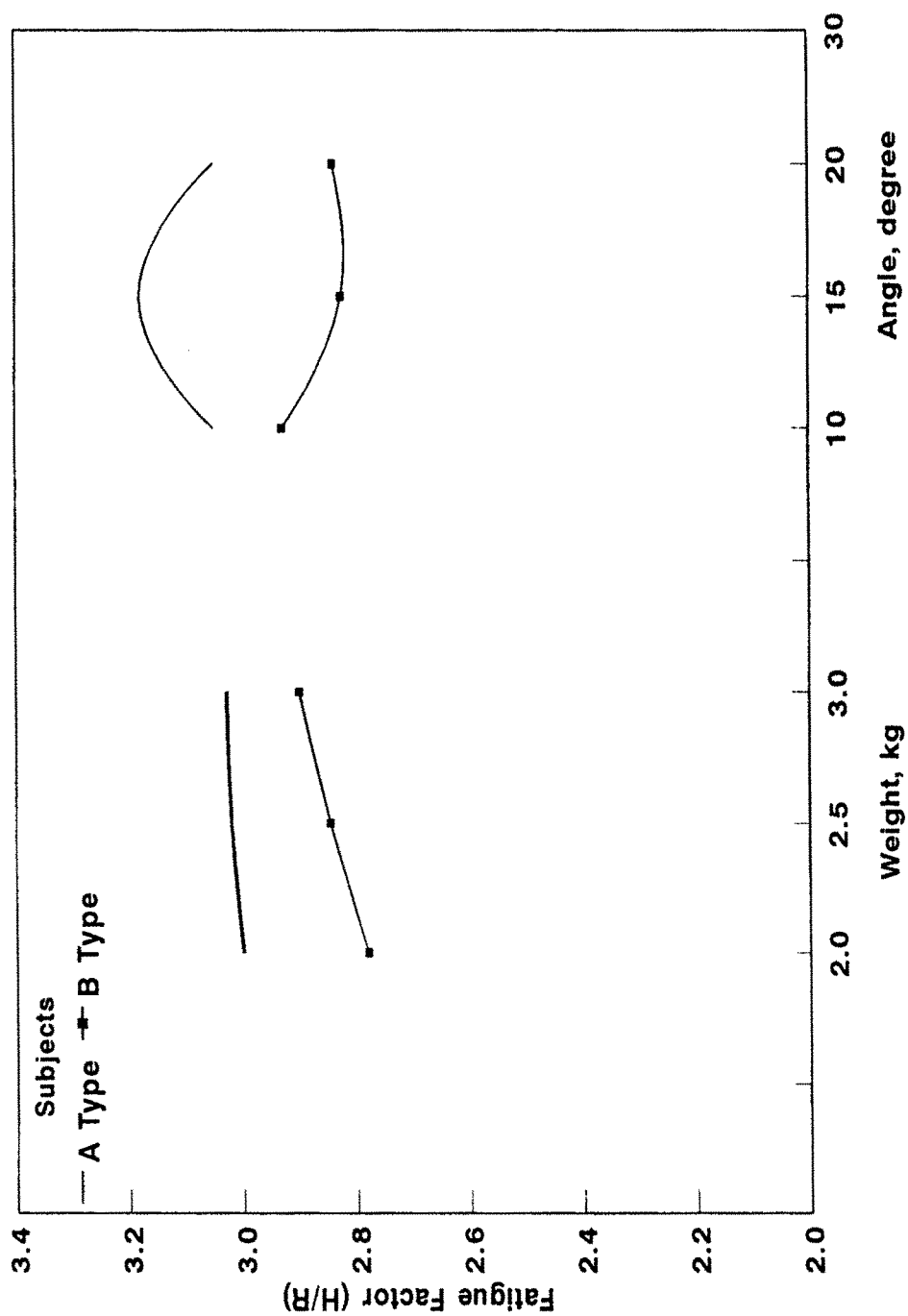


Fig.4.21. Effect of shovel weight and angle on
 Fatigue factor (H/R)

The change in angle of shovel had not caused much impact on the Fatigue factor. From Fig. 4.20, it can be read that minimum Fatigue factor 3.05 was at 10° and 20° and maximum 3.2 at 15° for 'A' type subjects and for 'B' type subjects the maximum Fatigue factor 2.93 at 10° and least 2.82 at 15° angle.

The above results were supported by minimum values (Table 4.15) of respective mean physiological cost i.e., oxygen uptake ml/min/kg of body weight, Oxygen uptake ml/min/cm of stature and Oxygen uptake ml/min/cm hand grip diameter.

4.6.4. Digger fork

The variables taken for the study was weight of the digger and angle of fork with the handle axis (The angle in fork was attained by giving curvature in the tine portion and not at the neck of the fork). The physiological responses and work measurements during the digging operation with selected variables were furnished in Table 4.13.

a. Effect of weight

The change in weight from 1.75 kg to 2.35 kg was done and observed that the operational strokes decreased as weight of tool increased. It varied from 20.6 ± 2.1 strokes/min to 13.6 ± 1.7 strokes/min for 'A' type subjects and for 'B' type subjects, it varied from 22.3 ± 1.8 strokes/min to 14.2 ± 1.6 strokes/min. The decrease in area dug was noted as the weight of the tool

Table 4.15. Shovel - mean physiological cost per body dimensions of male subject

Weight, kg	O ₂ Consumption, ml/min/kg of body weight						
	A ₁ (48)*	A ₂ (50)*	B ₁ (76)*	B ₂ (79)*	Mean	sd	CV
2.0	24.79	22.8	15.13	14.430	19.288	5.275	0.272
2.5	24.375	21.8	13.94	12.67	18.44	1.460	0.295
3.0	24.583	24.0	15.13	14.556	21.046	5.627	0.267
Angle, degree	O ₂ Consumption, ml/min/cm of stature						
	152.6**	154.9**	172.1**	173.0**	Mean	sd	CV
10	6.880	6.584	6.333	6.273	6.518	0.276	0.042
15	7.667	7.165	6.217	6.008	6.764	0.784	0.116
20	7.798	7.746	7.379	7.117	7.51	0.3215	0.042

* Weight of respective subject, kg

** Stature of respective subject, cm

increased, from 0.32, 0.43 m²/min to 0.27, 0.34 m²/min by the 'A' and 'B' type subjects respectively.

The oxygen uptake (Fig 4.22) was increased from 1.05 ± 0.14 l/min, 0.98 ± 0.27 l/min to 1.20 ± 0.5 l/min, 1.22 ± 0.06 l/min as the weight increased for 'A' and 'B' type subjects respectively. Oxygen consumption for cubic metre of soil dug varied from 30.12 ± 0.64 l to 26.59 ± 1.01 l for the varied weights from 1.75 kg to 3.25 kg by the 'A' type subjects and minimum 23.7 ± 0.67 l was for 2.5 kg digger. 'A' and 'B' type subjects consumed more or less same Oxygen (20.55 ± 1.2 l) and was minimum 19.14 ± 1.6 l with 2.5 kg tool. This variation i.e., minimum oxygen consumption was with 2.5 kg tool instead of being with 1.75 kg is because, more force was required to insert the light digger (1.75 kg) than the heavy digger (2.5 kg) to penetrate into the deeper depth of 17 cm (operational depth).

b. Effect of fork angle

The physiological responses and work measurement with different fork angle was presented in Table 4.16. The area dug was marginally differs from 0.25 ± 13 m²/min, 0.36 ± 22 m²/min to 0.27 ± 0.5 m²/min, 0.35 ± 0.01 m²/min by 'A' and 'B' type subjects respectively.

The oxygen consumption (Fig 4.23) was reduced from 1.15 ± 0.35 l/min to 1.05 ± 0.77 l/min with change in the angle from 10° to 15° by 'A' type subject and 'B' type subjects, consumption varied from 1.23 ± 0.56 l/min to

Table 4.16. Effect of digger fork weight and angle on physiological response

Description	Subject type	Weight, kg						Angle, degree					
		1.75		2.5		3.25		10		12.5		15	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Stroke rate/min	A	20.6	2.135	16.7	2.456	13.64	1.747	15.4	2.316	16.2	3.172	17.4	2.63
	B	22.3	1.892	17.3	1.725	14.2	1.609	16.7	1.479	16.9	2.790	16.9	4.03
Heart rate, beats/min	A	120	4	127	12	136	9	132	4	128	13	120	10
	B	110	16	118	8	128	11	122	14	118	9	113	7
Respiration, breath/min	A	30	12	31	4	32	6	36	4	36	12	30	6
	B	30	6	32	8	33	11	38	9	37	3	34	9
O ₂ uptake, l/min	A	1.049	0.135	1.098	0.452	1.208	0.537	1.155	0.353	1.095	0.494	1.055	0.770
	B	0.981	0.268	1.195	0.070	1.215	0.059	1.23	0.565	1.195	0.070	1.081	0.297
O ₂ uptake, l/m ³ of soil	A	30.12	0.641	23.72	0.674	26.57	1.019	26.38	2.17	23.72	0.674	22.279	0.353
	B	21.25	0.482	19.14	1.627	21.28	0.422	19.94	0.272	19.14	1.627	18.64	0.332
Area dug, m ² /min	A	0.317	0.074	0.272	0.106	0.267	0.094	0.257	0.137	0.272	0.106	0.278	0.158
	B	0.428	0.0831	0.368	0.138	0.336	0.081	0.362	0.221	0.368	0.138	0.352	0.012

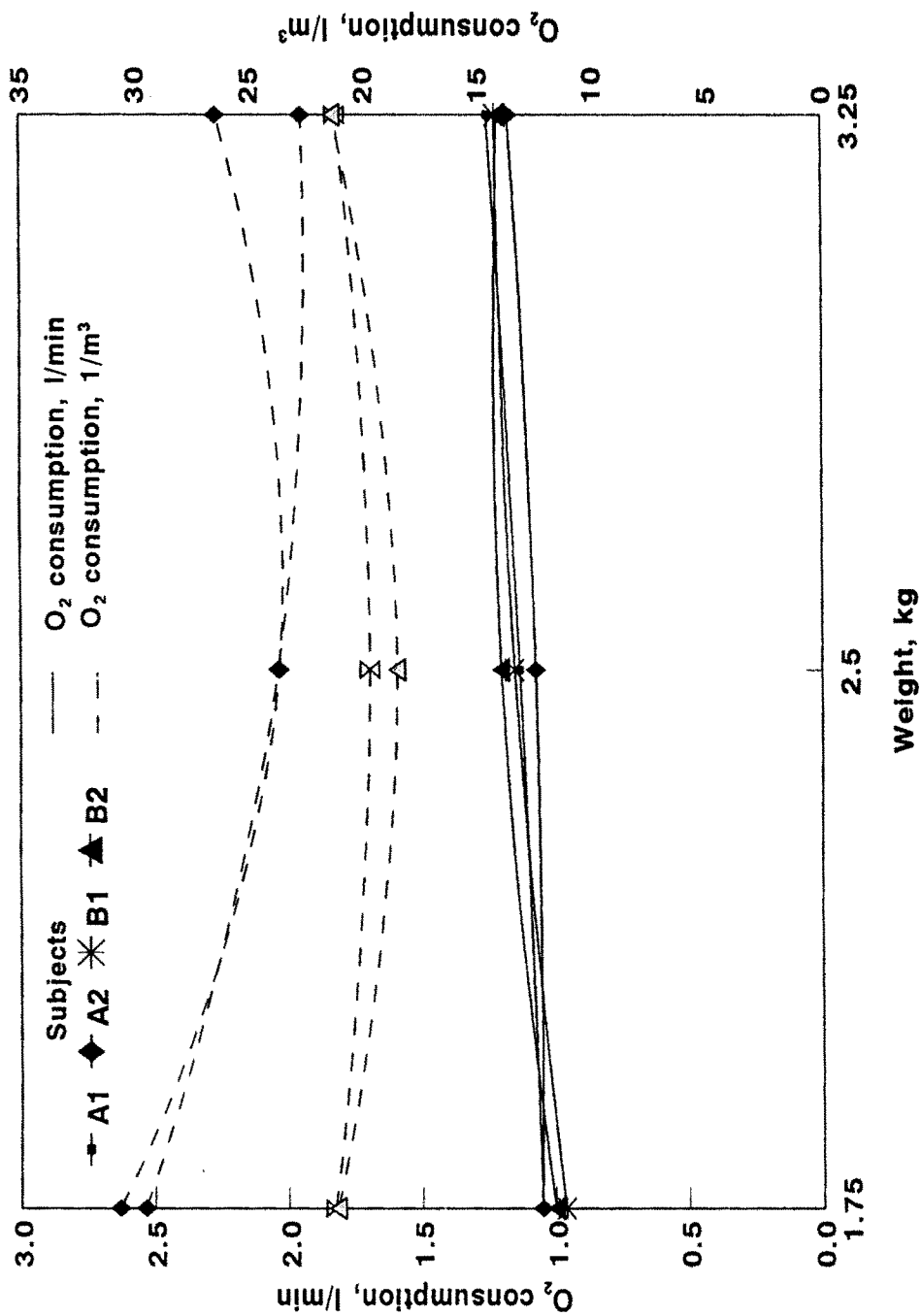


Fig.4.22. Effect of digger fork weight on physiological response of male subjects

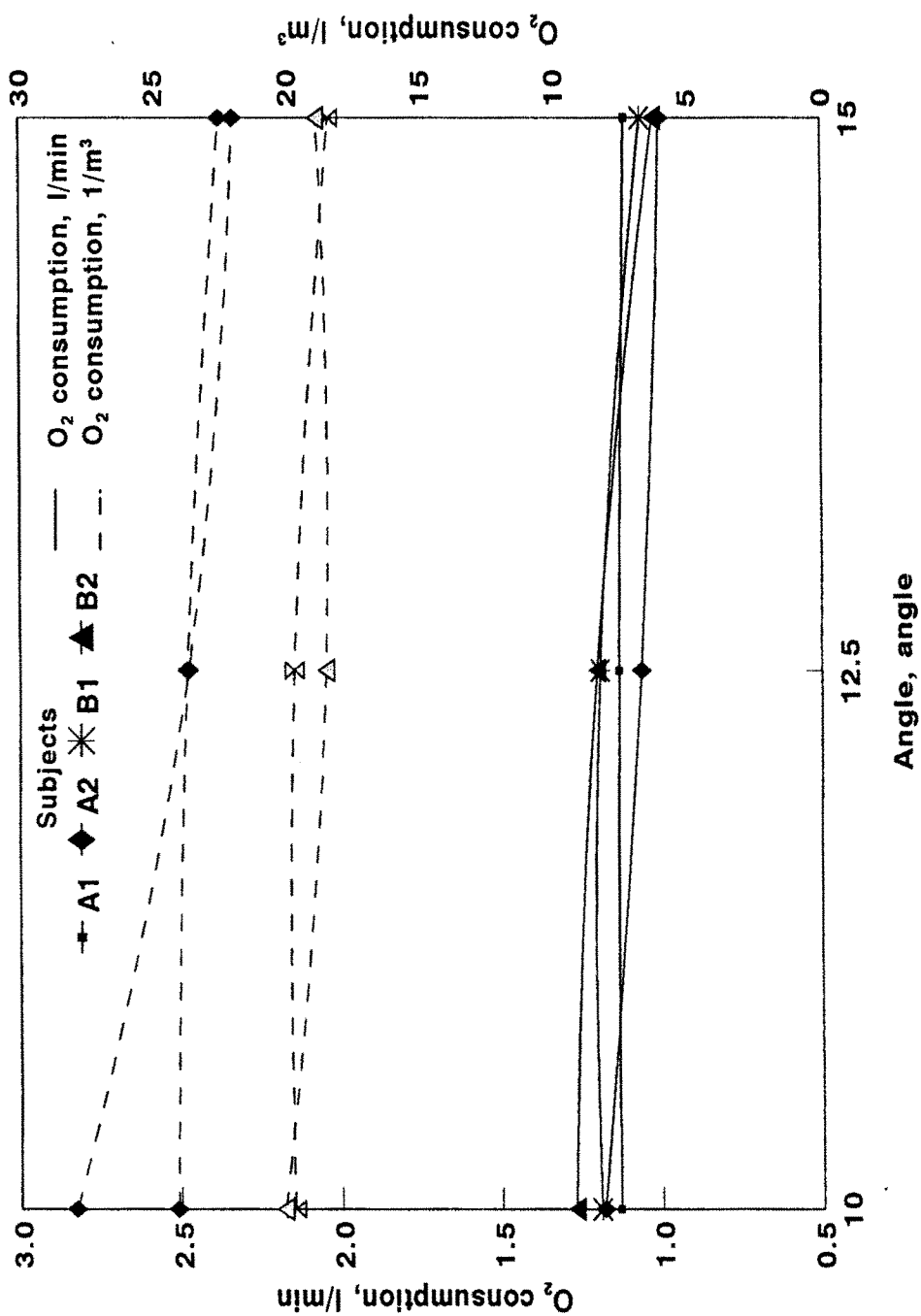


Fig.4.23. Effect of digger fork angle on physiological response of male subjects

1.08 ± 0.29 l/min. The oxygen consumption was reduced from 26.38 ± 2.17 l/m³ of soil dug to 22.27 ± 0.35 l/m³ by 'A' type subject and for 'B' type subjects, it was from 19.94 ± 1.62 l/m³ to 18.64 ± 0.33 l/m³ of soil dug for the angle variation from 10 to 15°. This reduced oxygen consumption with the increase of fork angle may be due to the enhanced leverage action, with the higher values of fork angle i.e., 15° when compared to 10° angle. At the sametime the angle could not be increased further, since the fork angle was attributed by giving some curvature in the fork tines. If this curvature is further increased the penetration cannot be attributed. At the sametime the angle cannot be given at neck of the fork and handle (as in the case of shovel), it will fail at neck since the depth of operation is too high i.e., 17 cm.

The effect of digger fork weight and fork angle with handle axis on Fatigue factor (H/R) was shown in Fig 4.24.

The Fatigue factor increased from 4.00, 3.60 to 4.250, 3.88 with the increased in the weight from 1.75 kg to 3.25 kg for 'A' and 'B' type subjects respectively.

The Fatigue factor was maximum 3.66 with 10° fork angle and reduced to 3.52 as the angle increased to 15° for 'A' type subjects. The Fatigue factor of 'B' type subjects was decreased from 3.2 to 3.18 as the angle increased from 10° to 12.5° and again increased to 3.3 at 15° angle. Hence

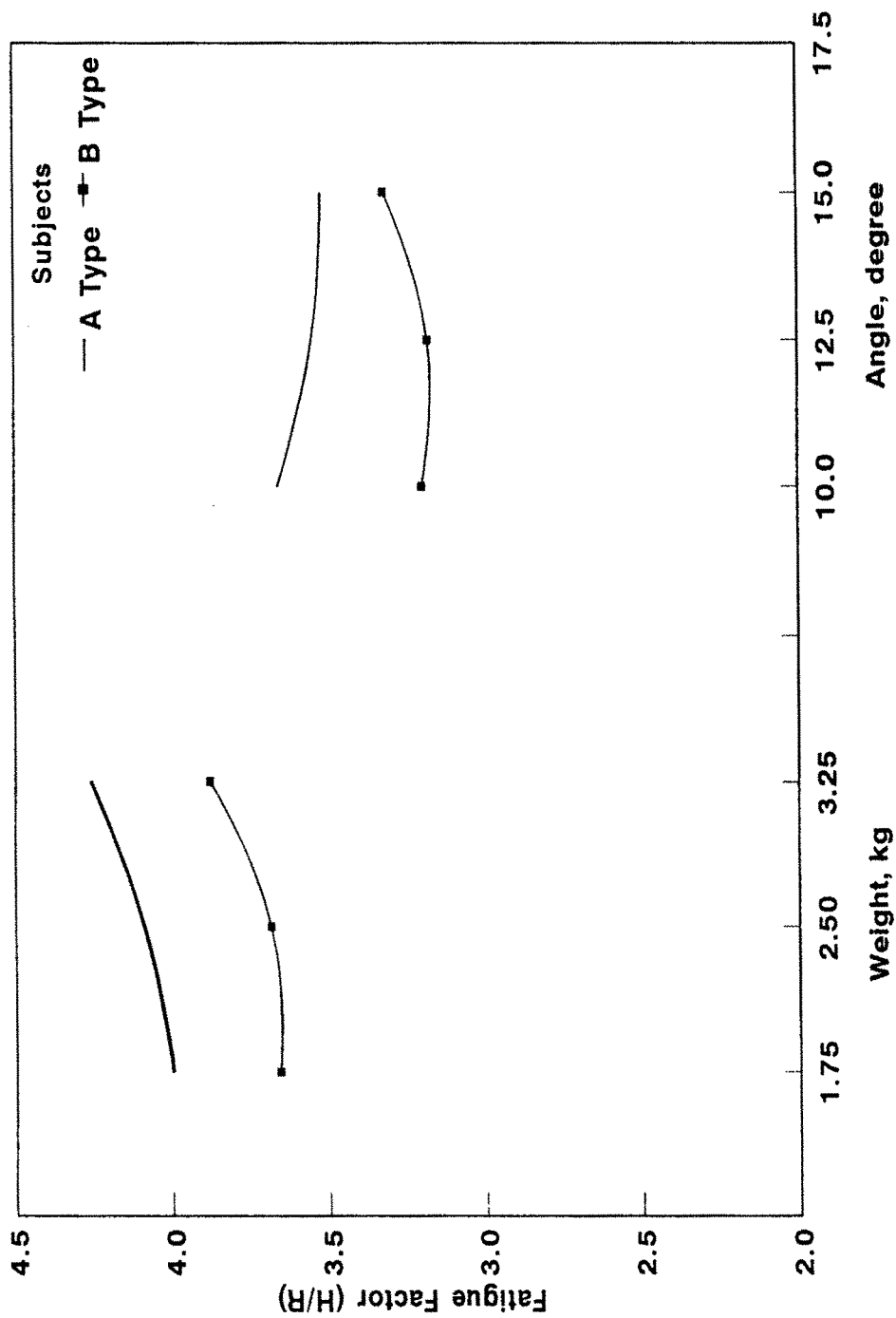


Fig.4.24. Effect of digger fork weight and angle on
Fatigue factor (H/R)

the suggested angle is 12.5° and weight of the tool is 2.5 kg for better human comfort and less physiological stress.

The above results were supported by minimum values of respective mean physiological cost (Table 4.17) i.e., oxygen uptake ml/min/kg of body weight, oxygen uptake ml/min/cm of stature and oxygen uptake ml/min/cm hand grip diameter.

4.6.5. Development of prototype

The prototype of four selected tools were fabricated, using the optimised design parameters as shown in table which were demanding least physiological cost without sacrificing work measurement.

Name of tool	Optimised design parameters		
	Weight, kg	Angle, degrees	Handle diameter, mm
Spade	1.75	35-40	40
	1.75	65-70	40
Digger fork	2.5	12.5	-
Shovel	2.5	15	-
Hand hoe	0.55	Bent handle (30 & 60)	20

Table 4.17. Digger fork - mean physiological cost per body dimensions of male subject

Weight, kg	O ₂ consumption ml/min/kg of body weight						
	A ₁ (48) *	A ₂ (50) *	B ₁ (76) *	B ₂ (79)*	Mean	sd	CV
1.75	21.854	21.0	12.657	12.658	17.042	5.074	0.297
2.5	23.541	21.32	15.657	15.189	18.927	4.150	0.219
3.25	25.95	23.4	16.052	15.316	20.18	5.305	0.262
Angle, degree	O ₂ Consumption, ml/min/cm of stature						
	152.6**	154.9**	172.1**	173.0**	Mean	sd	CV.
71.5	7.404	7.617	6.914	7.336	7.318	0.294	0.040
10	7.405	6.88	6.914	6.932	7.067	0.293	0.041 6
12.5	7.273	6.462	6.159	6.366	6.565	0.488	0.074 4

* Weight of respective subject, kg

** Stature of respective subject, cm

4.6.6. Field evaluation of prototype

The prototype developed as per the optimised design parameters were evaluated in the field for this energy expenditure and work measurement tabulated below.

Effect of optimised design parameters on the physiological cost

Name of tool	Physiological cost				Reduction in energy, Per cent
	With existing parameters		With optimised parameters		
	Oxygen uptake, l/min.	Energy, kJ/min.	Oxygen uptake, l/min.	Energy, kJ/min.	
Spade	1.42	29.74	1.36	28.46	4.1
	1.42	29.74	1.32	27.62	7.1
Digger fork	1.23	25.64	1.15	24.07	6.1
Shovel	1.14	23.93	1.09	22.81	4.7
Hand hoe	1.01	20.96	0.85	17.79	17.5

From the table and Fig 25, it is evident that the more energy demanding tool among the selected hand tools was spade where energy consumption was 28.46 kJ/min with 35°-40° angle and 27.62 kJ/min with 65-70° angle. The next energy demanding tool was digger fork which required 24.07 kJ/min energy, followed by shovel demanding 22.81 kJ/min and Hand hoe demanding the least energy of 17.79 kJ/min.

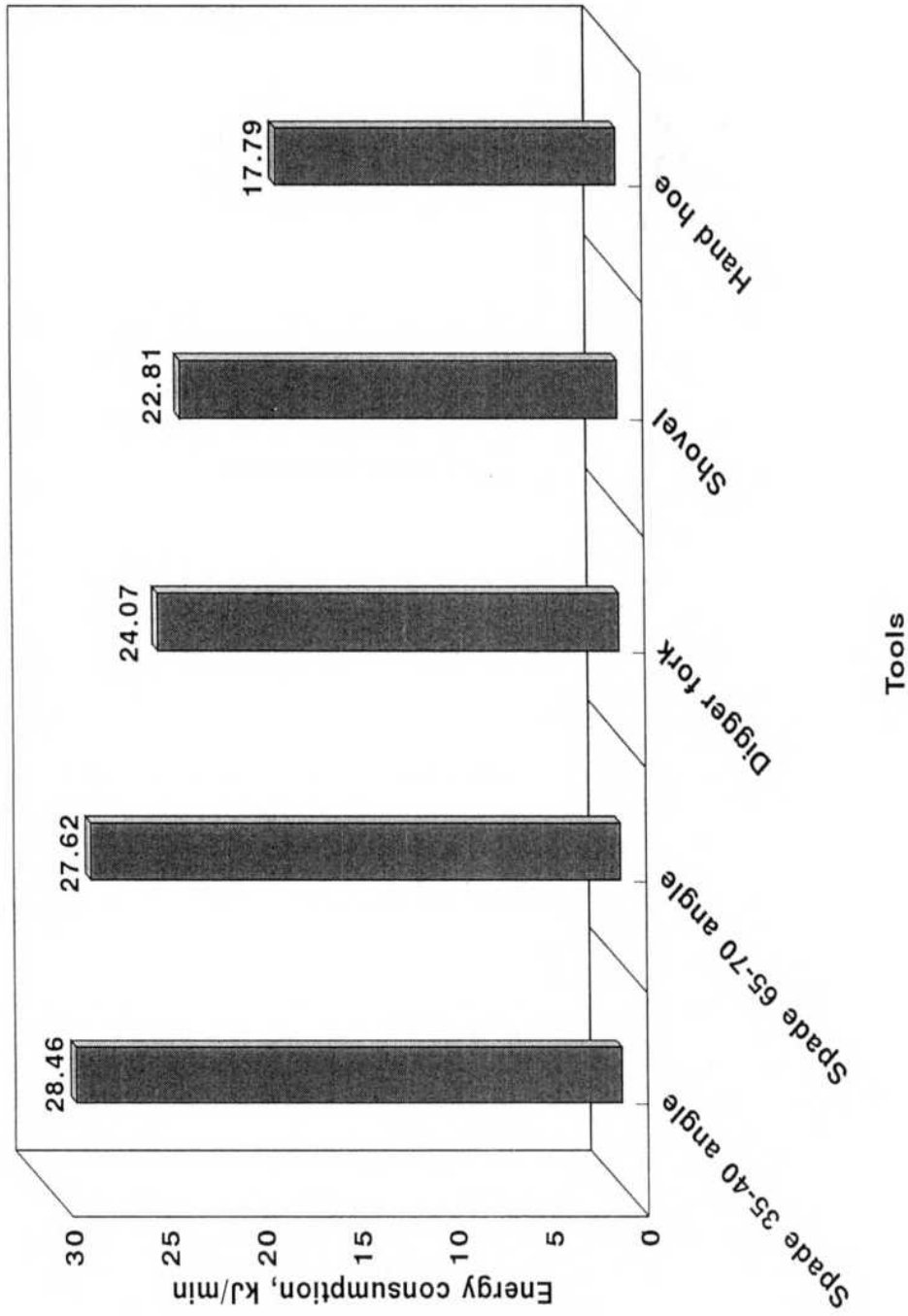


Fig.4.25. Energy demands of different modified tools

Summary and Conclusion

CHAPTER - V

SUMMARY AND CONCLUSION

In developing countries, the use of hand tools in farm operations are inevitable and farm tools in use in India is estimated as 800 millions. Though there are number of improved tools emerged from the various research activities for their better output, none of them had given due importance to the operational comfort.

Hence, this study was undertaken to optimise the design parameters of majorly used and more energy demanding soil working tools (i.e., spade, hand hoe, shovel and digger fork) by giving due consideration to operational comfort. Experiments were designed in the following manner.

1. Four tools, mostly used and energy demanding were selected for evaluation
2. Eight subjects, four male and four female subjects were selected from the anthropometric survey data analysis.
3. All the subjects selected for the study were tested for their medical fitness by doing necessary blood pressure and ECG tests.

4. Bio-clinical analysis were performed for all the blood and urine samples of the subjects to assess physiological and pathological disorders of subjects.
5. Basal metabolic rates (BMR) of subjects were estimated using Benedict - Roth apparatus.
6. Subjects were calibrated to determine the heart beat rate and energy expenditure relationship.
7. Preliminary trials were conducted with the selected hand tools and with different variables of weight, angle and handle girth. The range of weight varied for different tools were 1.75, 2.00, 2.25 and 2.50 kg for Spade, 0.55, 0.65, 0.75 and 0.85 kg for Hand hoe, 2.00, 2.50 and 3.00 kg for Shovel and for Digger fork it was 1.75, 2.50 and 3.25 kg.

The range of angle varied were 20-25, 35-40, 50-55 and 65-70 degree for Spade; 20-25, 30-35, 40-45, 50-55 and bent handle of 30 and 60 degree for Hand hoe; 10, 15 and 20 degree for Shovel and for Digger fork it was 10, 12.5 and 15 degree.

The range of handle girth varied were 20,30,40,50 and 60 mm for Spade and 15,20,30 and 40 mm for Hand hoe.

The following conclusions are drawn from the analysis of results obtained from the study.

1. The Basal metabolic rate is 1334.10, 1436.65, 1522.35, 1480.0, 1077.48, 1046.7, 1108.27 and 1182.15 kcal for subject A₁, A₂, A₃, A₄, AF₁, AF₂, AF₃ and AF₄ respectively.
2. The relationship between heart beat rate and oxygen consumption is linear for all eight subjects.
3. The work measurement increased as the weight of the tool reduced, for the selected range of weights : With spade it is increased from $1.84 \pm 0.74 \text{ m}^2/\text{min}$ to $2.34 \pm 1.08 \text{ m}^2/\text{min}$; with hand hoe it is from $1.54 \pm 0.34 \text{ m}^2/\text{min}$ to $1.84 \pm 0.32 \text{ m}^2/\text{min}$; with shovel it is from $1.96 \pm 0.15 \text{ m}^2/\text{min}$ to $2.11 \pm 0.53 \text{ m}^2/\text{min}$ and from $0.30 \pm 0.08 \text{ m}^2/\text{min}$ to $0.37 \pm 0.08 \text{ m}^2/\text{min}$ with digger fork.
4. The cardio vascular load, increased as the weight of the tool increased. For spade it was increased from $130 \pm 12 \text{ beats/min}$ to $153 \pm 12 \text{ beats/min}$; hand hoe it is from $92 \pm 6 \text{ beats/min}$ to $108 \pm 7 \text{ beats/min}$; for shovel it is $106 \pm 9 \text{ beats/min}$ to $120 \pm 7 \text{ beats/min}$ and for digger fork it is from $115 \pm 10 \text{ beats/min}$ to $132 \pm 10 \text{ beats/min}$.
5. Oxygen uptake also increased as the weight of the tool increased. For spade oxygen consumption increased from $1.31 \pm 0.28 \text{ l/min}$ to $1.67 \pm 0.51 \text{ l/min}$; for hand hoe, from $0.88 \pm 0.12 \text{ l/min}$ to $1.17 \pm 0.02 \text{ l/min}$; for shovel, from $1.15 \pm 0.17 \text{ l/min}$ to $1.22 \pm 0.12 \text{ l/min}$ and for digger fork it was $1.05 \pm 0.85 \text{ l/min}$ to $1.25 \pm 0.29 \text{ l/min}$.

6. Work measurement increased as the angle of blade with handle increased for the range of angles selected. With spade it is increased from $1.97 \pm 0.06 \text{ m}^2/\text{min}$ to $2.29 \pm 0.39 \text{ m}^2/\text{min}$; with hand hoe, from $1.59 \pm 0.25 \text{ m}^2/\text{min}$ to $1.76 \pm 0.08 \text{ m}^2/\text{min}$; with shovel, from $1.78 \pm 0.56 \text{ m}^2/\text{min}$ to $1.98 \pm 0.02 \text{ m}^2/\text{min}$ and with digger fork it was from $0.30 \pm 0.18 \text{ m}^2/\text{min}$ to $0.32 \pm 0.09 \text{ m}^2/\text{min}$.
7. Cardio vascular load reduced as the angle of the tool increased. For spade it is reduced from $142 \pm 9 \text{ beats/min}$ to $130 \pm 11 \text{ beats/min}$; hand hoe, from $99 \pm 7 \text{ beats/min}$ to $91 \pm 5 \text{ beats/min}$; shovel, from $121 \pm 10 \text{ beats/min}$ to $109 \pm 7 \text{ beats/min}$ and with digger fork it is from $127 \pm 9 \text{ beats/min}$ to $117 \pm 9 \text{ beats/min}$.
8. Physiological cost reduced as the angle of the tool is increased in spade, hand hoe and digger fork, but it is decreased in shovel, For spade it is reduced from $1.62 \pm 0.62 \text{ l/min}$ to $1.36 \pm 0.51 \text{ l/min}$; for hand hoe, from $1.08 \pm 0.27 \text{ l/min}$ to $0.82 \pm 0.07 \text{ l/min}$, for shovel, from $1.05 \pm 0.15 \text{ l/min}$ to $1.22 \pm 0.17 \text{ l/min}$ and for digger fork it is from $1.18 \pm 0.47 \text{ l/min}$ to $1.07 \pm 0.50 \text{ l/min}$.
9. The bent handle for hand hoe is developed which forms an angle of 30° and 60° with blade, to facilitate the workers to work with more upright posture for the same weeding efficiency that of 30° angle.
10. Area dug is not showing any trend with the increase of handle girth and it is staggered.

11. The heart beat rate meagerly increased with the increase in the size of handle girth, for spade handle, it is increased from 132 ± 8 beats/min to 135 ± 11 beats/min and for hand hoe handle, from 92 ± 6 beats/min to 107 ± 7 beats/min.
12. Oxygen consumption increased as the size of handle girth increased, For spade handle, oxygen consumption is increased from 1.37 ± 0.62 l/min to 1.38 ± 0.37 l/min and for hand hoe handle, it is from 0.88 ± 0.11 l/min to 1.17 ± 0.02 l/min.
13. The reduction in energy consumption is found 7.1, 6.1, 4.7 and 17.5 per cent for spade, digger fork, shovel and hand hoe respectively with optimised design parameters.
14. The design parameters suggested are ~~as~~ given below:
 - i. Spade : weight 1.70 kg; handle diameter 3 to 4 cm angle of blade 35-40 degree for seed bed preparation and 65-70 degree for bund trimming and root cutting works.
 - ii. Hand hoe : Weight 0.55 kg; handle diameter 2 cm; bent handle which forms 30° and 60° with blade.
 - iii. Shovel : Weight 2.5 kg; blade angle 15 degree with handle.
 - iv. Digger fork : Weight 2.50 kg; fork angle 12.5 degree with handle.
15. Fatigue factor (H/R) is calculated to quantify the cardio respiratory stress. This Fatigue factor (H/R) for spade is 3.35 ± 0.1 , hand hoe 2.48 ± 0.05 , shovel 2.95 ± 0.12 and for digger fork it is 3.66 ± 0.34 .

References

REFERENCES

- Abdul Kareem, A. 1996. Versatile spade-V.C. Key note. Tamil Nadu Agril. University, Coimbatore.
- Abdulbaqui and Lantin, R.M. 1982. Human expenditure in manually operated rice transplanter. *Agricultural Mechanization in Asia, Africa and Latin America*, 14(1): 14-16.
- Anonymous. 1987. Instruction manual of Oxylog. M/s. P.K. Morgan Ltd., U.K.
- Bansal, A.K., Mittal, V.K., Sharma, V.K. and Gupta, P.K. 1987. *Journal Punjab Agricultural University*. 24(2): 296-303.
- Boehlemann, Juergen; Kluth, Karsten; Kotzbaur, Knut; Strasser, Helmut. 1994. Ergonomics assignment of handle design by means of electromyography and subjective rating. *Applied Ergonomics*, V. 25.n. p. 346-354.
- Broackway, J.W. 1978. Escape from the champer, alternate method for large animal catorionetry *Proc. Nut. Soc.* 31(1): 13-18.
- Central Institute of Agricultural Engineering (CIAE), Bhopal, 1987. Working group meeting on agricultural hand tools, September.
- Chatizwa, I. 1997. Mechanical weed control-the case of hand weeders. Brighton Crop Protection International Conference - proceedings - Brighton, UK, Vol 1. 203-208.
- Christinson, E.H. 1953. Physiological valuation of work in the NYKROPPIA irons works in W.F.Floyd and A.T.Welfood. *Ergonomics Soc. Sympm. on Fatigue*, London. 93-108 p.



- Clarke, H.D. and H.H. Clarke. 1965. Energy required for various exercises. Research process in physical education, Recreation and Health, p.282.
- Crolla, D.A. 1976. Effect of cultivation implements on tractor ride vibration and implications for implement control - Journal of Agric. Engg. Research. 21: 247-261.
- Curteon, T.K. 1947. Physical fitness appraisal and guidance. The C.V. Mosby Co., St Louis.
- Das, H. and Bhattacharya, S. 1984. Optimum design and location of a hand operated rotary device. J. Agric. Engg., 21(3):29-36.
- Davis, C.T.M. and E.A. Harris. 1964. 'Heart rate during transition from rest to exercise in relation to exercise tolerance'. J. Appl. Physiol., 19(5): 857-862.
- De.A., and Sen, R. 1986. Ergonomic evaluation of ploughing process of paddy cultivation in India. J. Human Ergology, 1:103-112.
- Degani, A., Asfour, S.S., Waly, S.M. and Koshy, J.G. 1993. Comparative study of two shovel designs. Applied Ergonomics, V.24. (5) Oct. 1993. p. 303-312.
- Drillis, R., Schneck, D. and Gage, H., 1963. The Theory of striking tools. Human factors, 5: 467-478.
- Durnin, J.C.G.A. 1978. Indirect calorimetry in Man. A critique on practical problems. Proc. Nut. Soc., 37(1):5-11.
- Edholm, O.G. 1967. The biology of work. World University Library, McGraw-Hill Book Company, New York.
- Fraser, T.M. 1980. Ergonomic principles in the design of hand tools, occupational safety and health series. No. 44. (Geneva: International Labour Office.

- Ghadge, B. 1977. Studied on various modes of working with rotary device for optimum human performance. Unpublished M.Tech. Thesis. Agricultural Engineering Department, Indian Institute of Technology, Kharagpur.
- Ghugare, B.D., Adhanoo, S.H., Gite, L.P., Pandey, A.C. and Patel, A.L. 1991. Ergonomic evaluation of a lever operated knapsack sprayer. *Appl. Ergonomics*, 22: 241-250.
- Gill, H.S. and Choudhary, A. 1987. Ergonomic evaluation of a few manually operated dryland weeders. unpublished B. Tech. Thesis. College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur.
- Gite, L.P. and Singh, G. 1997. Ergonomics in agricultural and allied activities in India - Technical Bulletin. No. CIAE/97/70.
- Gite, L.P. 1991. Optimum handle height for animal drawn mould board plough. *Applied Ergonomics*, 22, 21-28.
- Gite, L.P. and Yadav, B.G. 1989. Anthropometric survey for agricultural machinery design - *Applied Ergonomics*, 1989. 20(3): 191-196.
- Gite, L.P. and Yadav, B.G. 1990. Optimum handle height for a push-pull type manually operated dryland weeder. *Ergonomics*, 33:1487-1494.
- Gohlich, H. 1984. The development of tractors and other agricultural vehicles - *J. Agric. Engg. Res.* 29: 3-16.
- Gour, G. Ray, 1998. - Workshop on methodology in Ergonomics - May 18-22- Industrial design centre - I.I.T., Bombay.
- Grandjean, E. 1982. Fitting the task to the man - An Ergonomic Approach. Taylor and Francis Ltd., London.
- Gupta, P.K. and Sharma, V.K. 1979. Anthropometry and its applications. In report of faculty programme in Human Engineering, Punjab Agricultural University, Ludhiana.

- Gupta, P.K., Sharma, A.P. and Gupta, M.L. 1983. Anthropometric survey of Indian farm workers. *Agricultural Mechanization in Asia, Africa and Latin America*, 14(1): 27-30.
- Hansson, P.A., Oberg K.E.T. 1996. Analysis of biomechanical load when shoveling. *Journal of Agricultural Safety and Health*. No. 2 & 3: 127-142.
- Harinder Singh and Kaul, R.N. 1972. Human energy requirements of selected farm operation. *Journal of Agril. Engineering*. Vol. IX. No. 3. p. 44-52.
- Huzayyin, S., Sallam, M. and Hafez, A. 1980. Evaluation of human effort during hoeing. *Proc. First Conf. Theoretical and Application Mechanics (Cairo)* pp. 361-370.
- Intaranont, K. and Srithongchai, S. 1993. Study of work strain of sugarcane cutters. *Agricultural Engineering Journal*. 2(1&2): 49-57.
- Jeanbogert, L.J. 1966. *Nutrition and physical fitness*. Saunders Company Philadelphia. p.60.
- Karunanithi, R. 1997. Some investigations on Ergonomics of selected Rice farming operations and Equipments. Unpublished Ph.D., Thesis, Department of Farm machinery, Tamil Nadu Agricultural University, Coimbatore.
- Karunanithi, R., Tajuddin, A., Kathirvel, K. and Duraisamy, V.M. 1998. Anthropometric survey for agricultural machinery design. XIII National convention of Agricultural Engineers.
- Kath, F.L. and McArdle, S.D. 1977. *Nutrition, weight control and exercise*. Houghton Mifflin.

- Kathirvel,K. 1986. Influence of dynamics of power tiller on operator's performance. Unpublished M.E. (Ag.) thesis, Department of Farm Machinery, Tamil Nadu Agricultural University, Coimbatore.
- Kathirvel,K. and Manian, R. 1998. Energy cost of power tiller operation. XIII National convention of Agril. Engineers.
- Kaul,R.M. and Splinter, W.E. 1964. The man-machine concept as a guideline to the introduction and the development of small implements in India. Paper presented at the Annual Meeting of ASARE held at Colorado.
- Kim,Jae Young, Yun, Myung Hwan, Lee, Myun, W. 1996. "Design of optimum grip and control area for one hundred manual control devices". Computers and Industrial Engineering v.31n (3-4): 661-664.
- Kinoshita, H. 1985. Effect of different loads and carrying systems on selected biomechanical parameters describing walking gait - Ergonomics 28(9): 1347-1362.
- Leblanc,J.S. 1957. Use of heart beat rate as an index of work output. J.Appl. Phy., 10: 257-280.
- Lehman,G. 1958. Physiological measurements as a basis for work organisation in industry. Ergonomics Vol. I. 226-233.
- Lucienbrouha. 1960. Physiologoy in Industry, Pergamon Press, New York, p. 87.
- Mani, V.S., Malla, M.L., Gautam, K.C and Bhargwandas (1973) weed-Killing chamicals in potato cultivation - Indian farming. November : 17-18.
- Margaria,R. 1965. "The kinematics of the oxygen consumption at the onset of muscular exercise in man". Ergonomics, 8(1): 49-54.

- Moitra, P.K., Rao, V.K. and Yadav, B.G. 1974. Studies on water pumping modes for operation comfort - Journal of Agricultural Engineering - Vol. XII. No. 2: 13-18.
- Mookeryjee, S. 1979. Assessment of work load and energy metabolism and fatigue. A report on faculty programme in human engineering. P.A.U. Ludhiana.
- Nag, P.K. 1987. Maximal Oxygen uptake of agricultural men and women in India. Amer. J. Phys. Anthropol. 74: 149-153.
- Nag, P.K., and Pradhan, C.K. 1992. Ergonomics in the hoeing operation International Journal of Industrial Ergonomics, 10: 341-350.
- Nag, P.K. and Chatterjee, S.K. 1981. Physiological reactions of female workers in Indian agricultural workers. Ergonomics, 23:91-102.
- Nag, P.K. and Dutt, P. 1980. Cardio respiratory efficiency in some agricultural work. Appl. Ergonomics, 11: 81-84.
- Nag, P.K., Subastian, N.C. and Malvankar, M.G. 1980. Effective heat load on agricultural workers during summer season - Indian Med. Res. 72. September: 408-415.
- Nag, P.K. 1981. Predicting maximal oxygen uptake of workers engaged in agricultural tasks. Human Ergology, 10:25-33.
- Nag, P.K. and Dutt, P. 1979. Effectiveness of some simple agriculture weeders with reference to physiological responses. J. Human Ergology, 8: 13-21.
- Narasingh Rao, S. 1997. Ergonomic analysis of man-machine system on sprayers. Unpublished M.E. (Ag.) Thesis, Department of Farm Machinery, Tamil Nadu Agricultural University, Coimbatore.

- Nwuba,E.I.U. 1989. Ergonomic study of shadoof of Irrigation in Northern Nigeria. J. Agric. Engg. Res. 43: 137-147.
- Nwuba,E.I.U. and Kaul, R.N. 1987. Energy requirements of hand tools for wood cutting. J.Agric. Engng. Res., 36: 207-250.
- Nwuba.E. I.U. and Kaul. R.N. 1986. The effect of working posture on Nigerian Hoe Farmer. Journal of Agricultural Engineering Research. 33: 179-185.
- Parikh,M. 1980. Hand tools for small and marginal farmers. Paper presented at XVII Annual Convention of Indian Society of Agricultural Engineers held at New Delhi.
- Parvathi, S., Anantha Krishnan, D. and Swaminathan, K.R. 1998. The effect of working posture of rural women for selected farm operation. XIII National convention of Agricultural Engineers-Coimbatore.
- Passmore, R. and Durnin, J.V.G.A. 1955. Human energy expenditure, Physiology Reviews, 35:801-815.
- Pawar, J.G. 1978. Investigation on human energy requirements for power tiller operation. Unpublished M.Tech. Thesis. Punjab Agrl. University, Ludhiana.
- Pradhan, S.K., Goswami, A., Ghosh,S.L. and Nag, P.K. 1986. Evaluation of working with spade in agriculture. Indian J. Med. Res. 84: 424-429.
- Rao,M.N. and Saha, P.N. 1965. The Indian Agriculturist. J. of Occupational Medicine, 1: 447-451.
- Robinson,C.H. 1967. Fundamentals of normal nutrition; McMillan Publishing Co., Inc., New York.
- Robinson,C.H. 1978. Fundamentals of normal nutrition; McMillan Publishing Co., Inc., New York.
- Saha,P.H., Datta, S.R.Banerjee, P.K. and Narayane G.G. 1979. An acceptable work load for Indian workers. Ergonomics, 22(9): 1059-1071.

- Saraswathy Eswaran, Swaminathan, K.R. Kathivel, K. and Pushpa, G. 1987. Energy expenditure pattern by rural womenfolk in Tamil Nadu. *Energy Management*, 11(3): 211-217.
- Schertz.C.E. 1967. Human energy expenditure for picking oranges - *Journal of Agric. Engg. Research* (1967) 12(4): 281-284.
- Sen, R.N. and Bhattacharya, S. 1976. Development of an ergonomic design of a shovel from the view point of increasing productivity in manual material handling in India. M.Sc. project No.23, University of Calcutta.
- Sen,R.N., Nag P.K. and Ray, G.G. 1977. Some anthropometry of the people of eastern India. *J.Indian Anthropological Soc.*, 12: 201-208.
- Sharma,V.K. and Gupta, P.K. 1979. Assessment of different forms of fatigue. In report of faculty programme in human engineering. P.A.U.,Ludhiana.
- Shathish Verma and Prathap Singh. 1994. Needs and prospects of mechanizing Indian Agriculture. *Agricultural mechanization in Asia, Africa and Latin America*. 25 (1): 16-19.
- Srivastava,R.K. Johnson C.V. and Zabradinik, J.W. 1962. Paper presented at the Annual Meeting of ASAE held at Washington DC. Ad Contribution No.40.
- Suggs, C.W., Splinter, W.E. 1961. Effect of environment on the allowable work load of man. *Transactions of the American society Agricultural Engineers*. 4(1):48-51.
- Suggs.C.W., Splinter, W.E. 1958. Time and energy analysis of agricultural tasks. *Trans. A. S.A.E.* Vol. 1. p.50.
- Swift, R.W., Fisher, K.H., 1964. *Energy metabolism* Academic Press. pp. 237-257.

- Tandon, S.K., Saxena, J.P. and Adarsh Kumar. 1995. Development and Ergonomic Evaluation of sheet hand hoes. Presented during XXX ISAE Annual convention, TNAU, Coimbatore.
- Tewari, V.K. and Datta, R.K. 1983. Development of wetland seeder from mechanical and ergonomical considerations. AMA. Vol. 14 (3): 11-15.
- Tuttle, W.W. and Schottelius, B.A. 1969. Text book of physiology 16th Ed., The C.V. Mosby Company, St. Louis.
- Vasudha Atreya and Gaur G. Ray (1998) - Anthropometric measurement technique in design - Workshop on methodology in Ergonomics.
- Verma, S.R., Rawal G.S and Bhatia, B.S. 1979. A study of human accidents in wheat threshers. J. Agric. Engg., 15(1): 19-23.
- Wilfried Hammer, 1991. Safe Access to Farm Tractors and Trailers. Journal of Agril. Engg. Res., 50: 219-237.
- Yadav, B.G. Panigrahi, B.K. and Jena, D., 1976. Comparative study of hand hoes for operators' comfort - Journal of Agricultural Engineering, 13(2): 91-93.
- Yadav, R.N.S. and Srivastava, N.S.L. 1984. Sugarcane harvesting knives used in India. The Indian sugar Crops Journal. July-Sept. 5-8.
- Yakou, Takao, Yamamoto Keijiro, Kayama, Masahiro, Hyodo. Kazuhito. 1996. Sensory evaluation of grip using cylindrical objects. Transactions of the Japan Society of Mechanical Engineers. Part C. V62. n602 3999-4004.