Rationalized Database of Indian Agricultural Workers for Equipment Design

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ABSTRACT

Anthropometric data of agricultural workers is very essential for the safe and efficient design of farm machinery. The anthropometric data of about 2000 male and female agricultural workers was collected throughout the state of West Bengal, India. For making the data comprehensive and more useful, a set of 21 body dimensions, which are found to be relevant in the design of various machines were selected. The data was analyzed and the application of several important parameters have been done for the design of agricultural equipment.

Keywords: Anthropometric, agricultural workers, farm equipment design, standardization, India

1. INTRODUCTION

More and more hand tools, implements and machines are developed, manufactured and used for various agricultural operations in Indian agriculture. The size, design and dimensions of these tools and implements have a great bearing on the size and physical built of the users. Therefore compatibility between the two is essential. The only way to fulfil this objective is to create a database of anthropometric dimensions of the user population and to customize or rationalize the same for the target groups. Majority of the earlier studies involving anthropometric data survey are case studies and, generally, male workers have been included (Sen et al., 1977; Gupta et al., 1983; Gite and Yadav, 1989; Fernandez and Uppugonduri, 1992; Yadav et al., 1997; Dewangan et al., 2005). In Indian agriculture about 88% of rural women are absorbed in the agricultural sector, constituting 50.2% of the total agricultural labour force (Reddy et al., 19994). Therefore, anthropometric data of female agricultural workers are also important for the rationalization of the design of agricultural hand tools and equipment. An anthropometric study of female agricultural workers was conducted at southern and eastern India (Philip and Tewari, 2000; Tewari and Ailavadi, 2002).

The real value of database lies in its applications. According to previous experiences and a survey among the professional designers and engineers, not many of those professionals exactly knew how the anthropometric data could be used (Wang et al., 1999). Gite (1999) pointed out that there is large variation in handle height in various models of manually drawn weeders. At the same time, it is not feasible to design equipment for an individual user. The design or size must be rationalized to accommodate majority of these workers.

In view of the above discussion the present study was conducted to create a database for male and female agricultural workers of West Bengal, and compare if with other data available in Eastern region and rationalizing the same for design of different farm tools and equipment.

2. MATERIALS AND METHODS

The whole state was divided into five major zones viz., East, West, Central, North, and South zone covering all the districts. Care was taken to involve both male (70%) and female (30%) agricultural workers, depending on their population in the given village. The effort has been made to include most of the tribe/community involved in agricultural occupation. The data of 2000 male and female subjects was collected throughout the state of West Bengal.

An integrated composite anthropometer (ICA) was used to measure the anthropometeric dimensions (Fig. 1). The ICA was designed, fabricated and tested at the Ergonomics Laboratory of the Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal, India. The ICA is patented (No. 205834) and now sold to different research organizations for collecting similar anthropometric database. The ICA facilitates the measurement of vertical, transverse and circumferential body dimensions in standing and as well as sitting posture to a good degree of accuracy. The least count of the equipment in length measurements is 1 mm. The ICA consists of base platform, backrest, seat pan, telescopic supports, rope and pulley arrangement and arrangement for force measurement. The base platform forms reference surface for vertical dimensions. The lower part of long backrest is separate and can be converted to seat pan by folding it at an angle of 90^o to the backrest, then the seat pan is supported by a telescopic square cross section pipe. A pin arrangement is provided to adjust the height of the seat pan, which becomes the reference frame for measuring body dimensions in seated posture. Vertical measurements are measured on a steel tape. One end of the tape is fixed at an appropriate location on the base platform while the body of the tape is hinged at top of square pipe attached to frame of a long backrest. A transverse scale with a pointer running on vertical scale is provided to observe the data accurately and precisely. This scale is used to measure the dimensions in the horizontal plane. The seat pan and long backrest are adjustable by means of a rope and pulley arrangement for different body dimensions.

Prior to collecting anthropometric data, staff members were given adequate training on the identification of the landmarks and measurement procedure by ICA for accurate and precise measurement of identified body dimensions. The trained staff members collected anthropometric dimensions of the selected subjects in each village. Subjects were screened so that those in normal health without any serious disease or physical handicapped were selected. The sequence of measurement was from standing to sitting postures. For measuring body dimensions in standing posture, subjects were asked to stand on base platform of ICA with their feet closed and their body vertically erected, while heels, buttocks and shoulders touched the same vertical plane. ICA was adjusted for height of the subject. Similarly, in the sitting posture, subjects were asked to sit with their body vertically erect, while their shoulders and head touched the same vertical plane. In sitting posture, feet of the subject completely touched the base platform. Subjects were bare footed with light cloths during measurement to minimize errors. During the measurement of body dimensions, care was taken to avoid any excessive compression of underlying tissues and to record the measurement in correctly. Data were collected during morning hours only. Primary data colleted in the study were used to compute minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV), 5th and 95th percentile values for each anthropometric dimension using the Microsoft Excel (USA) software package.

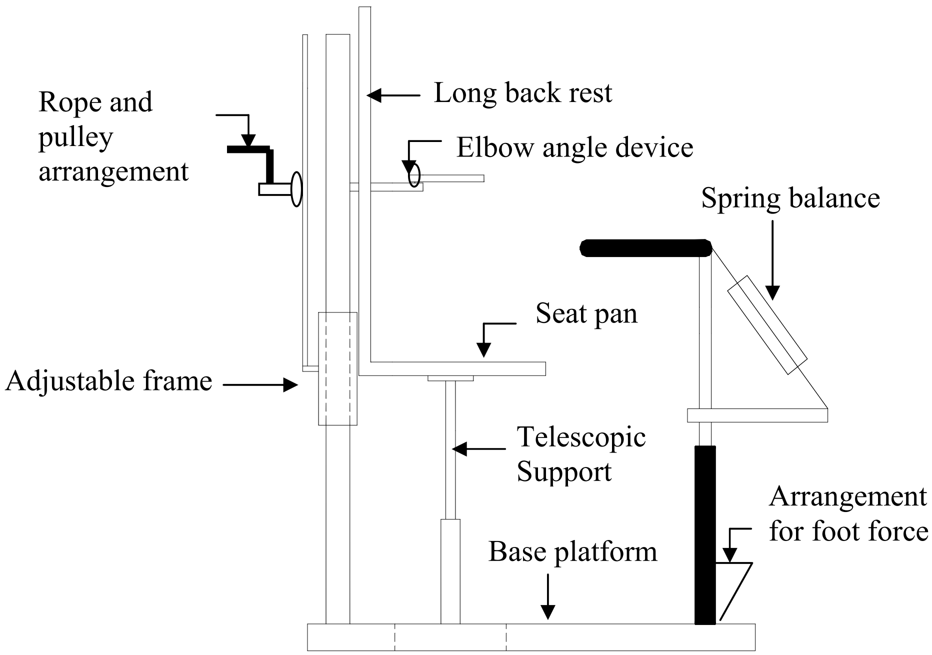


Figure 1. Integrated composite anthropometer

3. RESULTS

Table 1 shows the minimum, maximum, mean, standard deviation, coefficient of variation and 5th and 95th percentile values of the anthropometric data including strength parameters for male and female agricultural workers. The anthropometric dimensions of male subjects of the present study is compared with those of other regions of India, i.e., northern, central, eastern, southern and western region and presented in Table 2.

3.1 Design of Handle Grip for Hand Tools and Manually Operated Equipment

The 5th, 95th and 50th percentile values of inside grip diameter of male and female Indian agricultural workers have been found to be 34, 54 and 44 mm; 32, 52 and 42 mm respectively. Furthermore, the 5th, 95th and 50th percentile values of middle finger palm grip diameter of male and female Indian agricultural workers have been found to be 27, 34 and 28 mm; 20, 30 and 25 mm respectively. Thus, the handle diameter will be 34 and 32 mm for the male and female respectively, i.e. 5th percentile value of the inside grip diameter.
The 5th, 95th and 50th percentile values of hand breadth at metacarpal III of male and female have been found to be 76, 85 and 77 mm; 61, 77 and 69 mm respectively. The optimum value for the grip length should be such that his widest palm should accommodate in the handle.

Therefore, the length of the handle grip will be 85 and 77 mm for male and female respectively, 85 mm being the 95th percentile value of the handbreadth at metacarpal III of male and 77 mm being the 95th percentile value of the handbreadth at metacarpal III of female. Furthermore, to accommodate for longitudinal fidgeting space for the handgrip of the subjects, it is observed that the values may be increased by 10 to 15%.

3.2 Design of Handle Height for Manually Operated Equipment

The 5th, 95th and 50th percentile values of Metacarpal III height of male and female Indian agricultural workers have been found to be 680, 740 and 675 mm; 572, 686 and 629 mm respectively. Furthermore, the 5th, 95th and 50th percentile values of elbow grip length of male and female Indian agricultural workers have been found to be 290, 360 and 325 mm; 220, 320 and 267 mm respectively. For maximum work efficiency, it is suggested that the elbow flexion angle should be in the range of 85 – 110^{o} (Grandjean, 1988). Tewari (1985) showed that for the push and pull operation of a machine the elbow flexion angle would be 90^{o}.

Considering the elbow flexion angle as 100^{o}, and 5th and 95th percentile value of elbow height and elbow grip length from the anthropometric data one can easily find out the optimum length (Fig. 2) of the handle from the geometry adopted by the operator. The optimum holding height for male and female population ranges from 630 to 677 mm and 534 to 630 mm respectively.

3.3 Strap Design for a Knapsack Sprayer

The anthropometric values of scapula to waist back length and waist circumference determine the design of the strap. The 5th, 95th and 50th percentile values of scapula to waist back length of male and female Indian agricultural workers have been found to be 420, 630 and 508 mm; 337, 580 and 439 mm respectively. Therefore, the optimum value of the strap length (Fig. 3) could be taken as the mean value for the male and females and it should be adjustable for 5th and 95th percentile values of the operator. The value of strap length for males should be 508 mm and adjustable within 420 and 630 mm. The value of strap length for females may be 439 mm and adjustable within 337 and 580 mm.
The 5th, 95th and 50th percentile values of waist circumference of male and female Indian agricultural workers have been found to be 650, 927 and 760 mm; 610, 875 and 726 mm respectively. The optimum value of the waist belt length should be the 50th percentile value of waist circumference for the male and females and it should be adjustable within 5th and 95th percentile value. Therefore, the value of waist belt length for males may be taken as 760 mm and adjustable within 650 and 927 mm. The value of waist belt length for females should be 726 mm and adjustable within 610 and 875 mm.

Table 1. Anthropometric dimensions of male and (female) agricultural workers of West Bengal

Sl No	Dimensions	Minimum value	Maximum value	Average	Standard Deviation	Coefficient of Variation, %	95th percentile	5th percentile
1	Weight, kg	31.0(26.0)	94.0(73.0)	51.4(42.8)	7.9(6.7)	15.5(15.8)	65.0(55.0)	50.0 (34.0)
2	Stature	1396(1316)	1800(1745)	1627(1499)	65(57)	4.0(3.8)	1732(1590)	1625(1405)
3	Illiocrystale height	820(780)	1101(1015)	942(894)	47(41)	5.0(4.6)	1022(970)	940(830)
4	Metacarpal III height	520(510)	840(830)	675(629)	40(38)	5.9(6.0)	740(686)	680(572)
5	Waist circumference	540(540)	1020(995)	760(726)	83(80)	10.9(11.1)	927(875)	650(610)
6	Arm reach from wall	634(612)	995(890)	795(766)	58(45)	7.3(5.9)	890(840)	795(692)
7	Scapula to waist back length	345(280)	690(630)	508(439)	84(75)	16.5(17.0)	630(580)	420(337)
8	Sitting height	670(618)	964(870)	842(764)	38(34)	4.6(4.5)	900(822)	844(713)
9	Sitting eye height	585(566)	908(775)	731(657)	44(33)	6.0(5.1)	794(716)	732(601)
10	Sitting shoulder height	447(405)	670(635)	561(511)	31(31)	5.5(6.0)	611(559)	561(465)
11	Sitting popliteal height	350(260)	490(495)	402(384)	22(21)	5.4(5.3)	440(414)	401(354)
12	Elbow rest height	104(130)	310(315)	215(211)	29(27)	13.6(12.7)	265(255)	215(170)
13	Buttock popliteal length	300(300)	551(530)	414(411)	32(28)	7.7(6.8)	470(455)	410(370)
14	Buttock knee length	351(655)	655(614)	539(524)	34(33)	6.3(6.3)	590(580)	541(470)
15	Fore arm hand length	305(237)	524(492)	443(406)	26(24)	5.9(6.0)	483(442)	445(370)
16	Elbow grip length	257(200)	395(380)	325(267)	22(23)	6.8(6.5)	360(320)	290(220)
17	Hip breadth (sitting)	231(232)	380(390)	316(310)	23(26)	7.3(8.5)	350(350)	320(261)
18	Hand length	150(140)	205(190)	176(162)	10(9)	5.4(5.5)	190(177)	175(150)
19	Hand breadth at metacarpal III	60(57)	99(80)	77(69)	77(69)	6.7(6.9)	85(77)	76(61)
20	Inside grip diameter	25(30)	60(58)	44(42)	6(6)	13.7(13.8)	54(52)	34(32)
21	Middle finger palm grip diameter	14(13)	43(35)	28(25)	4(4)	13.9(14.9)	34(30)	27(20)
22	Hand force, N	98(69)	205(160)	154.5(122.7)	8.4(4.7)	25.4(23.8)	175.8(139.8)	137.2(106.2)
23	Leg force, N	168(100)	220(160)	197(129)	7.2(6.5)	23.6(25.1)	211.4 (143.4)	182.6(114.6)

Note: all the dimensions are in mm until otherwise specified

Table 2. Comparison of mean (SD) of anthropometric data of male agricultural workers of West Bengal, India with those from different regions of India

Body dimension	North Eastern India (n = 2000)	Southern India[a] (n = 128)	Central India[b] (n = 39)	Northern India[c] (n = 40)	Western India[d] (n = 40)	Eastern India[e] (n = 134)
Stature	1627(±65)	1607(±60)	1620(±50)	1685(±69)	1644	1621(±58)
Sitting height	842(±38)	791(±40)	838(±25)	-	862	809(±22)
Eye height (Sitting)	731(±44)	701(±46)	739(±26)	-	-	714(±20)
Shoulder height (Sitting)	561(±31)	529(±39)	557(±21)	-	-	534(±21)
Popliteal height	402(±22)	471(±35)	416(±21)	-	420	420(±17)
Buttock popliteal length	414(±32)	447(±23)	466(±18)	-	456	462(±23)
Fore arm hand length	443(±26)	401(±25)	459(±20)	-	-	446(±20)
Hand length	176(±10)	164(±14)	183(±8)	-	191	178(±16)

All dimensions are in mm
n = number of subjects
[a]Fernandez and Uppugonduri (1992)
[b]Gite and Yadav (1989)
[c]Gupta et al. (1983)
[d]Sen (1964)
[e]Yadav et al. (1997)

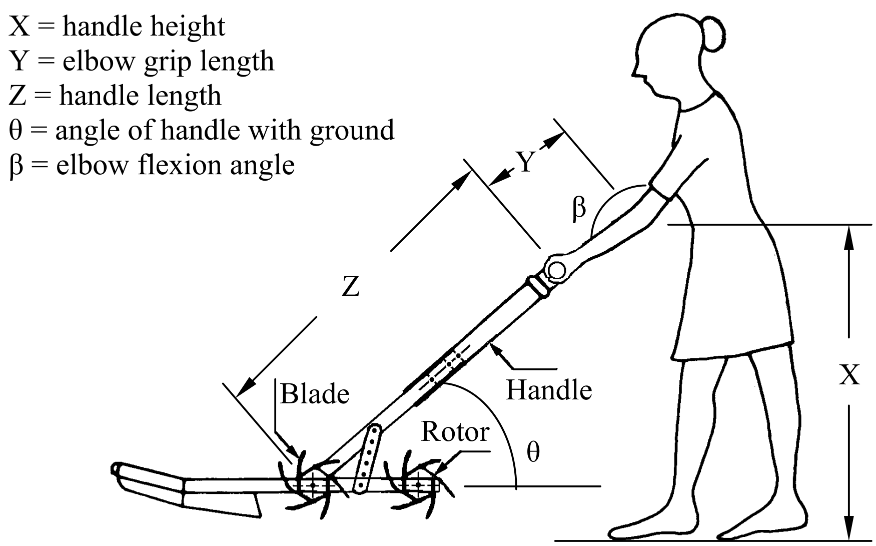


Figure 2. Grip and holding height of cono-weeder

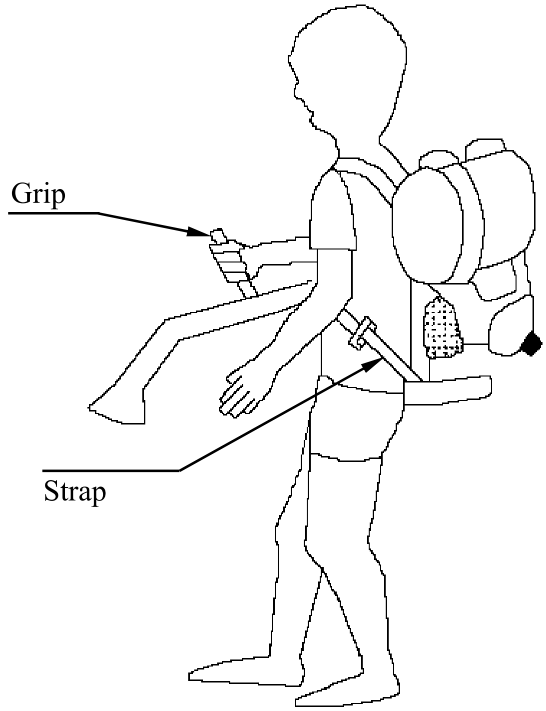


Figure 3. Grip and strap for knapsack sprayer

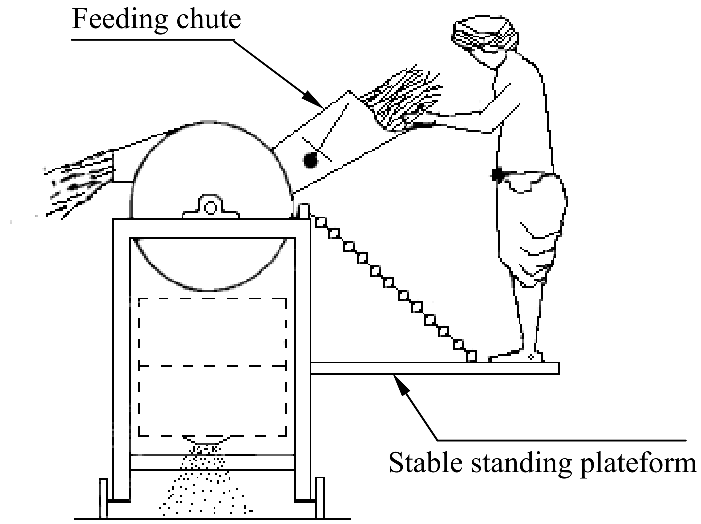


Figure 4. Threshing operation

3.4 Design of Feeding Chute of a Thresher

The 5^{th}, 95^{th} and 50^{th} percentile values of illiocrystale height of male and female have been found to be 940, 1022 and 942 mm; 830, 970 and 894 mm respectively. The maximum permissible height for the feeding chute (Fig. 4) should be decided from illiocrystale height

(Kumar et al., 2002). Considering this the feeding chute of a thresher should be 940 and 830 for male and female respectively, being the 5th percentile value of illiocrystale height.

3.5 Load Carrying

The 5th, 95th and 50th percentile values of weight of male and female Indian agricultural workers have been found to be 50, 65 and 51.4 kg; 34, 55 and 42.8 kg respectively. For continuous load carrying, it has recommended 40% body weight as permissible limit. Since, the agricultural workers of lowest body weight should able to carry the load, the maximum permissible limit for male and female Indian workers would be 20 and 13.6 kg.

3.6 Layout of Tractor Workplace Design

Figure 5 shows the tractor operator work place optimized on the basis of mean, 95th, and 5th percentile data.

3.7 Application of Strength Data

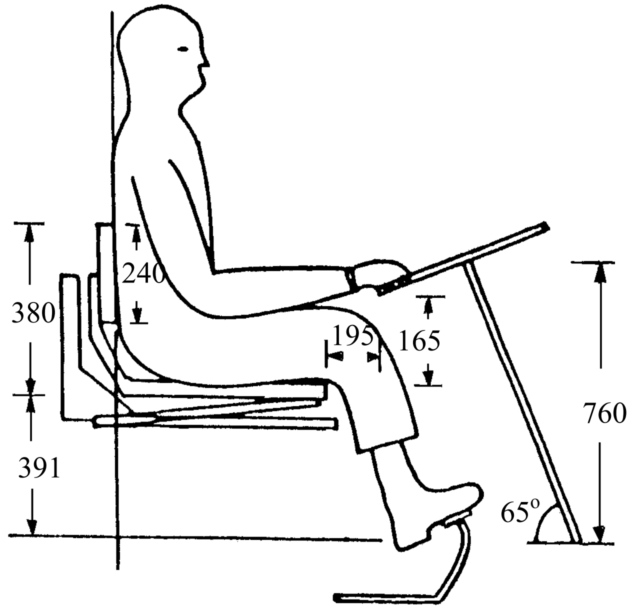
The 5th, 95th, and 50th percentile values for the average hand force for the male agricultural workers have been found to be 103.5 N, 313.8 N and 154.5 N respectively. Here the average hand force, means the average of push and pull force in sitting as well as standing posture. The corresponding values of hand force for female workers are 55.3 N, 209.2 N and 122.7 N respectively. The optimum value of the hand strength for the male and female population could be taken as 154.5 N and 122.7 N respectively.

The 5th, 95th, and 50th percentile values for the average leg force applied by the male agricultural workers have been found to be 123.1 N, 315.0 N and 197.0 N respectively. The corresponding values of foot force for female workers are 61.5 N, 234.7 N and 128.3 N respectively. The optimum value of the foot force for effective control of foot controls for the male and female population therefore should be 197.0 N and 128.3 N respectively.

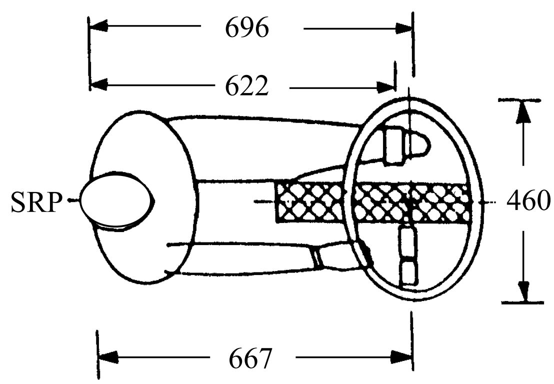
4. DISCUSSION

In the application of anthropometric data to specific design problems, there can be no nicely honed set of procedures to follow, because of the variations in the circumstances and the types of individuals for whom the facilities would be designed. However, there are three general principles for applying anthropometric data to specific problems. These are design for extreme individuals, design for adjustable range, and design for the average. The use of these principles varies depending on type of equipment design. For application of anthropometry in design of farm equipment and machines, it is essential to categories them at different levels of mechanization. These levels include manually operated, animal drawn, self-propelled and tractor or power tiller operated machines.

Hand tools and manually operated equipment are extensively used in digging, weeding and harvesting operations. The operator grasps the handle in such a way that fingers and thumb flex around the handle. Anthropometrically, the diameter of the handle should be such that while an operator grips the handle, his longest finger should not touch the palm. At the same time, it should not exceed the internal grip diameter. There is large variation in the size of the hand of the agricultural workers. So contour shape handle grip, such as ridges and valleys for fingers, fluting, indention, etc. is undesirable (Nag et al., 1988).



Side View



Top View

Figure 5. Tractor operator workplace (all dimensions in mm)

Handle height is one of the important components of manually operated tools, animal drawn implements and self propelled equipment. These tools, implements and equipment are controlled and guided by the operator. The body posture of the operator is dictated by the height of the handle. A misfit in the length of handle and the operator will cause undue early fatigue and therefore less work output per unit time. The telescopic handle should be designed such that the length of the handle can be changed to suit the small and the large size of the operator. The provision should also be made to change the angle of inclination of the handle.

For increasing human comfort and for minimizing stress during spraying operation, proper strap design is necessary (Ghugare et al., 1991). In spraying operation, the sprayer load is carried in rucksack mode. The weight of the sprayer load is supported by the shoulder of the operator. The excess pressure in small area results in pain or numbness. Therefore strap should be enveloped with a cushion material.

During the threshing operation, a worker lifts the crop material and puts it in the feeding chute (Fig. 4). The feeding chute should be at waist level (illiocrystale height) however, above this height causes circulatory stress and undue early fatigue in the hand arm system (Gite and Yadav, 1989). But due to constructional and functional problems, it is not possible to keep the thresher feeding chute at such a low height. Therefore, a stable standing plateform should be provided in the thresher for operator to feed the crop in standing posture without bending.

It is felt that the seat should be designed so that, in both the forward and backward sitting postures, it provides support to the upper edge of the pelvis. Dhingra et al. (2003) has reviewed the seat design considerations and observed that several claims and counter claims are available for best seat design. Furthermore, to accommodate the physiology of tractors ranging from 5^{th} to 95^{th} percentile it is easier to adjust the seat, particularly the horizontal adjustment, than to adjust the controls (Yadav and Tewari, 1998). Depending on the frequency of use, importance of use and sequence of use, the location of control may be designed.

The tractor seat height should be designed such that the foot of the short legged person rests on the foot rest. The seat height is generally chosen 10 mm less than the sitting popliteal height. The seat depth should ensure that the buttocks are supported and it should be such that it can accommodate shorter people. For the seat depth, three-forth of the buttock knee length is used as general guide. Therefore, for seat height and seat depth design, a 5^{th} percentile value has to be considered. The seat width should be greater than buttock width of 95^{th} percentile operator. The slight inclination of the seat pan at the front helps to prevent the gradual slippage out of the seat. Therefore 3 to 5^{o} seat pan angle should be provided for tractor seat. The back rest is provided to support the lumber region of the body. A high back rest prevent full mobility of the arms and shoulders in rear viewing and hydraulic control lever operation. Therefore small back rest which supports the 5^{th} lumber vertebra is suitable. Provision should be made for forward and backward movement of the seat so that operator of different body sizes can be accommodated.

The various controls should be located within the reach of the operator. While operating control levers the operators should not bend forward or side ways. The forward or side ways bending causes strain to the spinal column. The operation of the controls must also be within the strength capability of the weakest male driver but must not be so low as to make control difficult for heavy footed man. The optimum location of the controls is a function of the type of control, the mode of operation, frequency of operation, sequence of operation and the appropriate criterion of performance.

Steering wheel and clutch pedal are very commonly used controls in tractor. Steering wheel location should be based on physiological aspects, where it requires minimum energy in operation. The design for the inclination of the steering wheel is compromised between force required and turning velocity. The maximum force is needed on an almost horizontal steering wheel whereas vertical steering wheel is turned with the greatest velocity but the energy consumption is very high. Furthermore, for better comfort to the operator, they should hold the wheel in such a posture that the arm is bent at the elbow by 87^o. For the clutch pedal, the position, angle of the fulcrum and the maximum force required to operate are important parameters. As it is not possible to notice the movement when the clutch is actually engaged or relaxed. So it is necessary to fit the tractor with an upward curved bottom plate in such a way that it provides a comfortable footrest.

5. CONCLUSIONS

A rationalized anthropometric database (including strength parameters) of male and female agricultural workers of Eastern region of India is generated. These data would be useful in the design of small farm tools, implements and farm machines. The data could also be used for the design of house appliances, clothing, work place etc. The anthropometric designed of workplaces, location of controls, size of control panel, design of safety belt, seat size, and orientation of foot pedal etc. would reduce occupational injury and enhance operator safety.

6. ACKNOWLEDGEMENT

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