DEVELOPMENT AND PERFORMANCE EVALUATION OF TWO ROW POWER OPERATED PADDY TRANSPLANTER FOR ROOT WASHED SEEDLINGS

A Thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415 712, MAHARASHTRA (INDIA)

In the partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in

FARM MACHINERY AND POWER

by

More Raviraj Yuvraj

B.Tech. (Agril. Engg.)

DEPARTMENT OF FARM MACHINERY AND POWER
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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NOVEMBER 2018

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Mr. More Raviraj Yuvraj

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NOVEMBER 2018

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2.1.2.4.1

2.1.2.4.2 LIST OF SYMBOLS

Symbols	**2.1.3** Description
%	Per cent
@	at
/	Per
±	Plus or Minus
<	Less than
>	Greater than
θ	Theta
^{0}C	Degree Celsius
=	Equal to
Δ	Delta
^{0}	Degree
₹	Rupees

LIST OF ABBREVIATIONS

Abbreviation	Meaning
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
AICRP	All India Coordinated Research Project
AWL	Acceptable Work Load
BPDS	Body Part Discomfort Score
bpm	beats per minute
CAET	College of Agricultural Engineering and Technology
CIAE	Central Institute of Agricultural Engineering
cm	centimeter
CO_2	carbon dioxide
Deptt.	Department
DAS	Days After Sowing
DBSKKV	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
EER	Energy Expenditure Rate
ESA	Ergonomics and Safety in Agriculture
et al.	and others
etc.	Etcetera
Fig	Figure
g	gram
h	hour
ha	hectare
hp	horsepower
HR	heart rate
i.e.	that is
IS	Indian Standards
ISAE	Indian Society of Agricultural Engineers
ISO	International Standard Organization
J.	Journal
kcal	Kilocalorie
kg	Kilogram
kJ	kilo joule

kW	kilowatt
RHR	Resting heart rate
l	litre
LCP	Limit of Continuous Performance
MT	Million tonnes
Ltd.	Limited
m	Meter
Mha	Million hectare
M. S.	Maharashtra State
M.S	Mild steel
M. Tech.	Master of Technology
m^2	Square meter
min	minute
mm	millimeter
No.	Number
O_2	Oxygen
OCR	Oxygen Consumption Rate
ODR	Overall Discomfort Rating
OUAT	Orissa University of Agriculture and Technology
rpm	revolutions per minute
SD	Standard deviation
Sec	Second
VO_2	Volume of oxygen consumption
VO_2 max	Maximum aerobic capacity
Vol.	Volume
W	watt
WHR	Working heart rate

CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled **"Development and Performance Evaluation of Two Row Power Operated Paddy Transplanter for Root Washed Seedlings"** or part of thereof has not been submitted for any other degree or diploma of any University nor the data have been derived from any thesis/publication of any University or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

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The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

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I offer my salutations at the feet of **God**, for bestowing me the energy and enthusiasm through ransifying path of thick and thin of my efforts.

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ABSTRACT

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Rice (*Oryza sativa*) is the major staple food for more than 70 per cent of the Indian population with its cultivation mostly concentrated in the river valleys, deltas of rivers and coastal plains. In Maharashtra, rice is grown on an area of 14.99 lakh hectares with Konkan region occupying 28 per cent of the total rice producing area of the state. The transplanting method of growing rice uses root washed seedlings grown in nursery and then uprooting it for transplanting either manually or mechanically in main field. Konkan region has small land holdings and hilly terrains which restricts the farmers to follow the conventional practices of growing rice which was time-consuming, causing musculoskeletal problems and unavailability of labours at peak period. Thus, to reduce work stress and to improve the work quality, a manually operated two row paddy transplanter was developed and evaluated for its field and ergonomic performance. It was found that physiological cost for paddy transplanting with this transplanter was higher. Hence, it was decided to incorporate some modifications in mechanisms and to make the transplanting operation power operated.

As mentioned above, the tedious operation of hand cranking was eliminated in the developed transplanter by using power of a 2 stroke, air cooled, petrol engine (1.75 hp @ 6500 rpm). Further, this power was reduced by a speed reduction unit in

ratio of 32.5:1 and transferred through chain and sprocket drive to the machine shafts. The handle of the developed machine was designed ergonomically. The throttling lever was fit with handle to control the engine speed. Several other refinements like re-designing the picking cam as well as the nursery holding and releasing cam, using springs of proper tension and replacing the G.I sheet float with wooden float were done for the effective working of the developed power operated transplanter.

The field test of existing and modified transplanter was conducted in kharif season of 2017-18 in Kumbhave village of Dapoli tehsil. The age of seedlings used was 35 (DAS). Manual and power operated paddy transplanter produced field capacities of 0.026 ha/h and 0.032 ha/h, respectively with field efficiencies of 40.62 and 49.27 per cent, respectively. Hence field capacity and field efficiency were increased by 23 % and 21.2 % respectively. The ergonomic evaluation of both the transplanter was done by selecting six male subjects. The working OCR of the subjects while operating the manual paddy transplanter was 1.15 (±0.17) l/min while that with the power operated transplanter was 0.86 (±0.13) l/min, showing decrease of 18.86 % with the developed machine. Also, the working heart rate (WHR) of subjects with manual paddy transplanter and power operated transplanter were 115.7 (±3.19) bpm and 106.4 (±3.14) bpm, respectively, depicting a reduction of 6.69 %. The work pulse (ΔHR) was 36.9 (±8.97) bpm, while operating the manual paddy transplanter which insisted rest pause to the subjects. For power operated paddy transplanter, rest pause was not required as ΔHR 25.7 (±5.41) bpm was less than the LCP limit (40 bpm). The energy expenditure rate with manual and power operated paddy transplanter were 23.95 (±3.60) kJ/min and 17.99 (±2.56) kJ/min respectively, thus categorizing the operation as “heavy” and “moderately heavy”, respectively. The average ODR with manual and power operated transplanter were 7 and 4, respectively, thus categorizing the work as “more than discomfort” and “moderate discomfort”, respectively. The average BPDS were 16.5 and 10, respectively, for manual and power operated paddy transplanter respectively. The average pulling force with manual and power operated paddy transplanter was 9.57 kg and 8.06 kg, respectively. The fuel consumed by power operated paddy transplanter was 0.417 l/h. The total cost of power operated paddy transplanter was Rs. 27,400/- with operating cost for manual and developed operated paddy transplanter as Rs. 2368/ha and Rs. 4532/ha, respectively.

Keywords: paddy transplanter, musculoskeletal, chain and sprocket, throttling lever, working heart rate, moderately heavy, operating cost

I. INTRODUCTION

Rice is the seed of grass species *Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice). As a cereal grain, it is the most widely consumed staple food for a large part of the world's human population, especially in Asia. Roughly one-half of the world's population, including virtually all of East and Southeast Asia, is totally dependent on rice as a staple food (Anonymous, 2018a). Asian countries produce 89 per cent of world's rice, while China and India alone account for 55 per cent of the total production.

The slogan "rice is life" is very much appropriate for India as this crop plays a vital role in ensuring nation's food security and is a means of livelihood for millions of rural households. Nearly 62 per cent of the estimated i.e. 142 million ha area is rain-fed. In 2016-17, the total rice production of India stood at 110 million tonnes (Anonymous, 2018b). Rice is the major staple food for more than 70 percent of the Indian population (Anonymous, 2017). It is cultivated in almost all the states of India but most of its cultivation is concentrated in the river valleys, deltas of rivers and coastal plains. The main rice producing states are Tamil Nadu, West Bengal, Andhra Pradesh, Bihar, Punjab, Orissa, Uttar Pradesh, Karnataka, Assam and Maharashtra.

Maharashtra occupies the western and central part of the country with a long coastline stretching nearly 720 kilometres along the Arabian Sea. The principal crops grown in the state include wheat, rice, jowar, bajra, wheat, tur, mung, gram and other pulses. Rice is the second important crop in Maharashtra, grown on an area of 14.990 lakh hectares. The annual rice production was 32.37 lakh tonnes and average productivity of Maharashtra was 2.01 t/ha (Bobade *et al.* 2018). Konkan region of Maharashtra which is basically a narrow strip of 40 kilometres wide and running 750 km of length from north to south, occupies 28 per cent of the total rice producing area in the state. It has about 4.01 lakh hectares area under rice with production of about 11.28 lakh tonnes and productivity of around 2.81 t/ha (Shinde, 2017).

Indian agriculture is characterized by overwhelmingly small land holdings due to higher population density and nearly two-third of its population residing in the rural areas coupled with unabated land fragmentation due to the inheritance laws of the country (Mohanty, 2016). India's overall rice yields are well below the world average, and there are wide variations in rice productivity among the various producing states in the country depending on the irrigation water availability and adoption of

technology. Consequently, there is scope for increasing productivity by expanding irrigation facilities and adopting technology (Anonymous, 2017). The western and southern states in the country have a lower level of mechanization due to the smaller land holdings prevalent in these regions as well as the land holding being more scattered. As a result, in many cases, mechanization has been uneconomical leading to the lower development. The progress in production or steady growth in output is necessary to meet the challenges posed by the present economic, political and technological environment (Torane *et al.* 2011). With declining farm labour availability and their wages, farm operations have turned expensive calling for mechanical intervention.

The various methods being practiced to grow rice are the direct seeding method also known as the broadcasting method and the widely adopted method of using a manual or mechanical rice transplanter. Farmers traditionally follow broadcasting seeds, as it is convenient. However, this practice often results in inadequate crop stand due to the surface placement of seed, whereas in the transplanting method, seedlings are first raised in a seedbed in the nursery and uprooted for transplanting either manually or mechanically. Mostly, in India and other developing countries of Asia, rice is transplanted manually which is labour intensive and requires 250-350 man-hr ha^{-1} which is 25 % of the total labour requirement of the crop (Singh *et al*. 1985). Manual uprooting and transplanting is more physically demanding activity as compared to mechanical uprooting and transplanting activity (Ojha and Kwatra, 2012). It is also considered as tedious and tiresome because the workers have to hold the bunch of seedlings in one hand and fix 1 to 2 seedlings by the other hand in the puddled field in bending posture, which affects their spinal cord. This method also fails to meet the agronomical requirements like plant population per square meter and uniform row and hill spacing, thereby limiting the use of agricultural implements and hand tools for intercultural operations (Behera *et al.* 2009). For transplanting, walking in puddled field alone consumes 72 to 87% of total energy expense of male workers whereas for female workers it varies from 83 to 89% (Karunanithi and Tajuddin, 2003). Working in puddled field condition and simultaneously providing push and pull action to the manual transplanter is not an easy task and it requires lot of human efforts (Guru *et al.* 2018). Further, due to rapid industrialization and migration to urban areas, availability of labour has reduced with

hike in the wages of labour, thereby resulting in costlier transplanting operation and leading to reduced profits to farmers.

Across South Asia, labour scarcity is a major problem and there is a need to explore establishment methods for rice that require less labour but still allow the crop to be transplanted on time. Therefore, modern agricultural machineries play a vital role. Farm mechanization implies the use of various power sources, improved farm tools and equipment, with a view to reducing the drudgery of the human beings and draught animals, thereby increasing crop production and productivity (Nagaraj *et al.* 2013). Mechanization not only changes the structure of labour in agriculture but also influences the nature of the workload. Hence, there is a need of mechanization in rice cultivation sector (Kalchuri and Shende, 2016). Past studies on efficiency of farm mechanization revealed that if the mechanization is used properly, one can save 15-20 per cent of seeds, 20-30 per cent of fertilizer, 20-30 per cent of time, 5-20 per cent of labours, he could increase the cropping intensity by 10-15 per cent, and 15-20 per cent rise in the productivity (Singh, 2008).

Manual transplanter is a useful machine for marginal and small farmers because of its higher capacity as compared to hand transplanting. Usually, timely transplanting and use of seedlings of appropriate age for transplanting are important non-cash inputs for realizing the higher productivity in rice (Pattar *et al.* 2001). Also, mechanical transplanting refers to the planting of 20-22 days old seedlings of 12-15 cm height under wet land conditions. The spacing of transplanted paddy varies with the age of the variety. For long age varieties (4 -4 ½ months) and short age varieties (3 -3 ½ months), the best spacing is 20 x 20 cm^2 and 20 x 15 cm^2, respectively (Madusanka. 2011). Transplanting helps the plant to have better start over the weeds hence results in less growth of weeds.

From mechanization point of view, Konkan is the most backward region in the state. About 71.96 % of total cultivable land is under marginal size farms, 25.41% under medium size farms and 2.61 per cent farmers are under large size farms. Due to poor economic conditions, small land holding and hilly terrains, farmers do not use big agricultural machinery. The limited tractor population (less than 2000) in the region indicated that people had not accepted the mechanization culture. Bullock-drawn traditional implements are commonly used in this region (Shahare P. U., 2012). Paddy transplanting in Konkan region is done manually which is a time-consuming activity and causing back pain. So, to reduce the health risk and to improve the work

quality, a manually operated two row paddy transplanter using root washed seedling was developed at College of Agricultural Engineering and Technology, Dapoli during 2015-16. The ergonomic evaluation of the developed transplanter was conducted where it was noticed that the mean working heart rate (WHR) and the energy expenditure rate (EER) for female workers during transplanting was 118.06 (±2.18) bpm and 10.03 (±0.36) kJ/min, respectively. Due to this reason, the work was categorized as "moderately heavy". Hence, to reduce the work stress and drudgery involved in transplanting there is a need to make the transplanter as power operated. The idea is to develop a machine which will be pulled by the operator through the puddled field and simultaneously the transplanting would take place with the help of power provided by the prime mover. Hence the study entitled, "Development and performance evaluation of two row power operated paddy transplanter for root washed seedlings" has been undertaken with the following objectives:

1. To evaluate the performance of the existing two row manually operated paddy transplanter for root washed seedlings
2. To develop two row power operated paddy transplanter for root washed seedlings.
3. To evaluate the performance of the developed power operated paddy transplanter.

II. REVIEW OF LITERATURE

A comprehensive review has been done on the past researches concerned with paddy transplanters, their development, performance evaluation etc. and other related aspects relevant to the present research. The various studies reviewed are presented as follows.

2.1 Puddling Requirement

Kirchhof *et al.* (2000) studied the effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops in field experiments conducted on three sites in Indonesia and two in Philippines over a 3-year period. The puddling treatments used in the field were, in increasing order of puddling intensity, dry cultivation prior to submergence, one and two plowing and harrowing treatments using a draught animal and associated implements, and two cultivations using a mechanical roto tiller. Rice was followed by mungbean (Vigna radiata(L.) Wilzek) on all five sites, and in addition, soybean at Ngale and peanut (Aracis hypogaea L.) at Jambegede were also grown. Rice yields were highest under the traditional puddling techniques using draught animal traction. Results suggested that puddling with a roto tiller reduced yield because of insufficient depth of puddling, while dry cultivation might have reduced yield due to increased soil strength of the puddled layer; both were thought to limit root development. Puddling had no significant effect on post-rice mungbean and peanut production. However, results showed that increasing puddling intensity tended to reduce soybean yield.

Dhiman *et al.* (2001) conducted a study at Rice Research Station in Kaul, Haryana, India, during the rainy seasons of 1998 and 1999, to find out the suitable level of puddling and sedimentation period required for the smooth working of rice transplanter. Three puddlings methods like farmer's practice (2 puddling harrow), Chinese power tiller (once) and rotavator (once) along with three sedimentation periods (2, 3 and 4 days after puddling) were tried for the smooth performance of rice transplanter. Better quality of puddling was obtained by using rotavator with a highest puddling index (61.5 and 50.4%) and puddling depth (10 and 11.7 cm) as compared with the other methods. Also, the grain yield was higher (68.15 and 66.11 q ha-1) when recorded from the field puddled with the rotavator during both years at sedimentation period of 3 and 4 days.

Behera and Varshney (2003) studied about the optimum puddled soil conditions in silty clay loam soil for self-propelled rice transplanter with three types of puddlers namely rotary puddler, peg type puddler and cultivator with two levels of puddling viz. twice and thrice at sedimentation periods of 24, 48 and 72 h respectively. It was concluded that buried hill, floating hill and hill mortality decreased with an increase in sedimentation time. The optimum sedimentation period was 48 hrs for puddling twice with peg type puddler, twice with cultivator, and puddling thrice with cultivator and 72 hrs for puddling twice with rotary puddler, puddling thrice with rotary puddler and thrice with peg type puddler.

Dave (2004) conducted a study to characterize the puddle bed for mechanized transplanting of rice using four different puddling equipment (peg type puddler, rotary type puddler, shovel cultivator and cage wheels) with one and two number of passes in vertisols at Central Institute of Agricultural Engineering, Bhopal. It was concluded that, rotary puddling equipment with two passes having higher value of puddling performance index (0.982) was found to be more suitable for self propelled mechanized transplanting of rice.

Goel *et al*. (2008) studied the effects of sedimentation period on performance of three rice transplanters namely OUAT, CRRI and Yanji rice transplanter under four levels of sedimentation period i.e. 24, 32, 48, and 56 hours with respect to float shrinkage, draft, depth of planting, floating hills, mechanical damage, buried hills, missing hills and hill mortality. The buried hills gradually decreased from 18.29 to 0.06 per cent with increase in sedimentation period from 32 to 56 hours. It was concluded that 32 h of sedimentation period was suitable for operation of manual transplanter, settlement period of 48 hrs was suitable for operation of self propelled rice transplanter. and 56 h for the operation of Yanji transplanter.

Singh (2016) studied the field performance of different tillage equipment in terms of percolation losses and puddling index and effect of the treatments on grain yield. Three different puddling treatments consisting of cultivator & planker (CP), pulverizing roller attachment to cultivator (PR) and rotavator (RT) were used to ascertain the puddling performance. Puddling was done after fields were flooded to saturation and 2 passes of cultivator & planker and pulverizing roller attachment each and one pass of rotavator were performed. Depth of puddling was 9.4, 12.4 and 11.5 cm in these treatments, respectively. Puddling index and average percolation rates were 65, 79, 84 % and 0.26, 0.13, 0.11 cm/h, respectively in CP, PR and RT

treatments. Effective field capacities of different puddlers were 1.0, 0.8 and 0.3 ha/h, respectively in CP, PR and RT treatments. The grain yield in tonnes/ha were found to be 5.97, 6.09 and 5.85, respectively for CP, PR and RT treatments.

2.2 Planting Methods

Singh *et al.* (2005) carried out field experiment in Uttar Pradesh during the 2000 kharif season to compare the effect of different rice transplanting methods on rice yield. The experiment was accomplished using split plot design having 4 sowing transplanting methods of rice viz. direct dry seeding, direct-seeding of sprouted seeds, manual transplanting and mechanical transplanting by self-propelled rice transplanter. Labour, machinery, fuel, fertilizer, seed, pesticides and irrigation were considered as inputs for the growth period of the crop. The yield was considered as output of the crop. The mechanical transplanting of rice resulted in 6.25 tonnes/ha grain and 6.94 tonnes/ha straw yields that were at par with manual transplanting but significantly higher than both direct-seeding methods. Mechanical transplanting was found to be most cost-effective and energy-efficient, requiring lowest specific energy (408 kcal/kg), specific cost (Rs 2.27/kg), providing maximum benefit-cost ratio (2.34) and energy output- input ratio (7.36).

Ehsanullah *et. al.* (2007) conducted an experiment to determine the effects of different sowing methods on plant population and yield of fine rice variety, Super Basmati. The sowing methods included direct seeding by broadcasting at field capacity (DSBFC), direct seeding by broadcasting in standing water (DSBSW), direct seeding with drill at field capacity (DSDC), transplanting at 20cm apart rows (TR-20), farmer's practice (FP), and transplanting by parachute method (TPM). Data regarding plant population, number of panicle bearing tillers, plant eight, number of grains per panicle, 1000-grain weight and grain yield was recorded. It was observed that maximum paddy yield of 3.06 t-ha was produced by TR-20 while minimum paddy yield of 2.52 t-ha was observed in case of DSBSW.

2.3 Design and Development of Transplanter

Gowda and Rudraradhya (1998) modified a six row manually operated rice transplanter developed by IRRI (Philippines), for Indian conditions at the TNAU Campus, Bangalore, India. Field trials were conducted in University of Bangalore and in farm fields. The modifications included the use of different materials to strengthen the pickers and main body of the seeding compartments, and the replacement of joint pins with hardened nuts and bolts. The machine consisted of a wooden float, metallic

main body, tray moving mechanism, mat pusher and handle. When fully loaded, the machine weighed about 25 kg. In well prepared land, with good quality seedlings, 5-6 labourers could transplant 1 ha of land, in comparison to manual transplanting which would require another 30 workers.

Syedul *et al.* (2000) conducted an experiment for the improvement of International Rice Research Institute designed six row manually operated rice transplanter to adapt in rice producing countries. After modification, a five row prototype was developed and then both IRRI and BRRI transplanters were evaluated and compared with hand transplanting.. The wooden skid of IRRI developed six row transplanter was replaced by a skid made of G.I. sheet in BRRI transplanter which made it durable, light weight and incurred less sliding resistance. As a result, the dragging force for modified transplanter was reduced by 30 per cent compared to the previous prototype. At full load the weights of IRRI and BRRI transplanter were 37 and 30 kg respectively The circular configuration of the picker finger of IRRI developed six row transplanter was modified to a semi-circular one which improved its cutting action.

Dewangan *et al.* (2005) developed a single row laboratory model rice transplanter and evaluated for both root washed and mat type seedlings, at two levels each of the size of finger slot, age of seedlings and depths of planting and three levels of speeds of operation. The developed transplanter could operate with root washed seedlings of age 35-40 days with 23.3 % missing hills and 6.4 % floating hills when set at a depth of 6 cm and operated at 35 strokes per minute. Mat type seedlings, when set at 6 cm depth and operated at 35 strokes per minute, gave 18.6 % missing hills and 6.4 % fully floating hills. A 3 mm slot size finger was found to be suitable for both types of seedlings.

Shahare and Bhat (2011) modified Korean semiautomatic manually pulled engine operated two row paddy transplanter. It consisted of a four stroke petrol operated 0.93 kW (3000 rpm) engine, 700 mm x 700 mm size float, rocker arm, power transmission unit, needle and drive wheel of 480 mm with lugs on outer periphery. Belt and pulley arrangement was done to transmit the engine power to the gearbox. From the gear box the part of power was distributed to transplanting mechanism and to drive wheel. Power given to transplanting mechanism was transmitted to operate tray and the needle of transplanting arm. The overall dimensions of the machine were 1500 x 700 x 900 mm, with planting row spacing of

300 mm. The machine weighed 50 kg. The machine worked satisfactorily in summer season in lateritic soil of Konkan region.

Desai (2012) developed self propelled two row paddy transplanter suitable for planting mat type nursery. The machine was operated with 4 stroke 1.56 kW petrol engine. The machine had two ground wheels of 400 mm diameter, float of 375 x 600 mm size. The weight of machine was 70 kg. To avoid the falling down of seedling mat at the time of field operation it was suggested that the seedling tray should be placed at minimum angle. The transplanting arm was kept horizontally to achieve the complete elliptical path of transplanting.

D. Ananda Babu (2013) conducted an experiment on development and evaluation of Yanji 8 row paddy transplanter to suit SRI cultivation over conventional method of transplanting. Tray type nursery was used to plant paddy seedling with existing machine and mat type nursery, for manual SRI and conventional methods. Instead of changing the finger mechanism in Yanji 8 row transplanter, a template with equally spaced perforations and punch consisting of equally spaced spikes were used to make holes in the prepared tray. To obtain plant to plant spacing of 23 x 23 cm, the existing Yanji 8 row transplanter was modified by changing the gear box, which is connected to the ground wheel. By replacing a new set of gears which are having more number of teeth with the existing less number of teeth, the speed ratio changed from 0.774 for existing to 1.394 for modified.

Selvan *et al.* (2014) developed a three row improved pull type transplanter capable of planting seedlings in three rows at 250 mm row to row distance. The push action for transplanting of rice seedling was eliminated and the machine was made more user friendly. The improved transplanter weighed 35 kg and was provided with two ground wheels of 500 mm diameter having 16 equally spaced lugs on the periphery of the ground wheel. The picker mechanism was designed in such a way to perform the planting operation simultaneously as the equipment is being pulled with handle. Thus the push-pull mechanism adopted in the IRRI transplanter was eliminated in the improved model, reducing drudgery of operation.

Abdrabo (2016) developed a double purpose machine prototype for rice transplanting, locally manufactured, and evaluated in order to overcome numerous problems which restrict the mechanization of rice transplanting in Egypt. The proposed transplanter was 4 rows planting machine, and propelled on three ground wheels to suit small scale farms. It suited both traditional rice seedlings method, and

in trays seedling method. To achieve the machine functions, the developed prototype included two seedling platforms: - one of them was fixed to accomplish the traditional seedlings method, while the other was movable to accomplish the in trays seedling method. The frame of the machine was made of iron rectangle with dimension of 2500, 1800 and 1900 mm length, width and height respectively. The developed rice transplanter was operated by a 6.0 hp engine.

Rajput *et al.* (2017) designed and developed a hand cranked rice transplanter. The machine aimed in eliminating the hand cranking efforts. Power from the wheels was used to operate the transplanting mechanism and to convert pulling force into torque. The necessary tasks like design of chain drive, design of wheel shaft, bending of wheel spokes and selection of bearings were all accomplished using appropriate considerations. After the testing it was found that the chain drives transmitted the motion in required speed ratio. Seedling spacing of 15-16 cm was also achieved as per the standard required seedling spacing.

2.4 Performance Evaluation of Paddy Transplanter

Garg and Sharma (1984) developed a six row riding type paddy transplanter operated by diesel engine of 4.8 hp at Punjab Agricultural University, Ludhiana. It was designed to utilize mat type seedlings. It had uniform row spacing of 22.5 cm with varying plant to plant spacing. The machine transplanted 110 ha/hr at a working speed of 1.01 km/hr & 0.150 ha/hr at a working speed of 1.26 km/hr. Average hill population was 25/m^2 when planted at plant to plant spacing of 14 cm & 20/m^2 when planted at plant spacing of 19.30 cm. Missing hills were 16.67%. Net labour & financial savings over the traditional system were 144.92 man-hr/ha & Rs. 154.32/ha respectively.

Eam-O-Pas and Goto (1990) studied that the performance of the 4-row riding type and 2-row walking type Japanese transplanter in actual paddy fields prepared by traditional method were satisfactory. When operated at half throttle setting speed, the 4-row riding type transplanter had a field capacity of 0.1485 ha/hr compared to 0.01 ha/hr that of hand transplanting, assuming 800 m²/day coukd be completed by hand transplanter. The 2-row walking type self propelled transplanter and manually operated IRRI transplanter had a field capacity of 0.1139 ha/hr and 0.058 ha/hr respectively. It was seen that the transplanter worked five times faster than hand transplanting.

Garg *et al*. (1997) carried out the field evaluation of 30 number of six-row manually operated paddy transplanters in an area of 36 ha at farmer's fields and university farm of Punjab Agricultural University, Ludhiana. Two people could easily transplant 0.4 ha per day, including uprooting and transporting from the nursery. Hill and tiller population as well as grain yield were higher than for manually transplanted fields at almost all locations. The number of hills transplanted by the machine varied from 25.2 to 28.8/m². The average hill mortality after 15 days of transplanting was 12.1 %. The average grain yield was 250 kg/ha higher than the manually transplanted fields. Transplanting by machine saved 45% cost and 60% labour as compared to manual transplanting.

Kumar (1997) evaluated the performance of eight row self propelled rice transplanter, marketed by M/S VST Agro Inputs, Bangalore which was found satisfactory during its operation in the University farm as well as farmers field. Field capacity of the machine was found to be 0.174 ha/h with field efficiency of about 54 per cent at an operating speed of 1.7 km/h. By using this transplanter, the cost of transplanting including nursery raising was Rs.1200/hectare less than the conventional system of rice transplanting. This system required about 9-10 times less labour as compared to hand transplanting.

Chaudhary *et al.* (2005) concluded that rice transplanting by self propelled transplanter ensured timely operation, saving in cost and minimum human drudgery. A detailed economics of both manual and machine transplanting was worked out based on the study done at G. B. Pant University of Agriculture and Technology, Pantnagar during 2000. The self propelled rice transplanter gave net profit of Rs.1146 and Rs.1319 per ha., when the annual use of the machine was 300 hours (one season) and 500 hour(two seasons) respectively, over the manual transplanting. The field capacity, field efficiency and fuel consumption of the transplalnter was 0.16 ha/h, 60.02 % and 2.87 l/ha respectively.

Tatugade *et al.* (2006) evaluated a two row paddy transplanter. It worked with respect to uniformity in spacing and number of plants per hill. In laboratory test of transplanter, it showed best performance at 1100 rpm of the power source with forward speed of transplanter as 1.78 km/h and 140 strokes of transplanting arm. Hill to hill spacing varied as per forward speed of machine and average hill to hill spacing was found to be 23.4 cm. Field trial reported that average forward speed of transplanter was 1.8 km/h and there

was sinkage of transplanter with power source in puddle field because of rigid hitching system and smaller size of lug wheels.

Singh and Vatsa (2006) evaluated PAU 6-rows manual transplanter to mechanize the operation of paddy sowing in hills. Field capacity of transplanter was 0.03-0.035 ha/h and labor requirement was 57-66 man-h/ha which was 2-3 times less over the traditional methods. The cost of operation was observed 73% and 54% less on use of the transplanter. Yield increase was in the range of 30-35 %. It was also observed that a transplanter with lesser width of coverage would be more useful.

Manjunatha *et al.* (2009) conducted studies at Agricultural Research Station, Gangavathi, Karnataka state during 2002 to 2004 on the feasibility of mechanizing transplanting operations in paddy crop with a view to reduce the cost of cultivation. An eight row self-propelled paddy transplanter was used for the purpose. The performance of the mechanical transplanter was quite satisfactory. The field capacity, field efficiency and fuel consumption of the transplanter were 0.19 ha/h, 78 per cent and 6.25 l/ha, respectively. Cost of mechanical transplanting was Rs.789 per ha as compared to Rs.1625 per ha in case of manual transplanting provided the machines were used for their maximum usage of 90 hectares in a year. Grain yield in both manual and mechanical transplanting remained on par with mean grain yield of 53.77 and 54.01 q/ha, respectively.

Shahare and Bhat (2011) tested semi automatic two row self propelled paddy transplanter. Various parameters like plant to plant spacing, planting depth, field capacity, field efficiency, total time of operation and speed of operation were recorded during field evaluation. The field efficiency and field capacity of the transplanter was observed to be 84.5 per cent and 0.051 ha/h respectively. The total numbers of hill/m^2 area were obtained as 23.3 and plants to plant distance, plant depth were obtained as 124.6 mm and 44.9 mm respectively.

Pateriya and Datta (2012) evaluated self propelled riding type rice transplanter using mat type seedlings. Based on the trials in the existing rice transplanter certain design deficiencies like main clutch lever spring, front tyre, side wheel beam and beam support were observed which affected the performance of the machine. Based on the performance some modifications were made and tested with mat type seedlings. Results indicated that the performance of the modified rice transplanter was better compared to the unmodified rice transplanter. The machine was capable of transplanting 2-4 seedlings per hill. The percentage of missing hills was limited to

8.06 to 9.75 per cent, plants per hill ranged from 2 to 4, planting depth was 50 to 65 mm. The hill to hill spacing was 95 to 102.5 mm at low gear and 147.7 mm at high gear, the row to row spacing varied from 230 to 235 mm. The total number of plants ranged from 35-42/m^2. The planting depth was 5.4 cm with no mechanical injury to the seedlings. The field capacity of the machine was 1.05 ha/day when operated at low gear (1.03 km/h) in the side to side method.

Pradhan and Mohanti (2014) conducted a study to compare ergo-economic analysis of different paddy transplanting methods (OUAT manually operated two row, three row, four row paddy transplanter) with local hand transplanting practice. It was revealed that more force was obtained in pulling the transplanter in forward direction by female worker which was 183 N in 4 row and lowest 104 N in 2 row paddy transplanter. Minimum (0.03 ha/day) transplanted area was recorded in manual method of transplanting and maximum 0.10 ha/day in 4 row transplanter followed by 0.08 ha/day in 3 row and 0.065 ha/day in case of 2 row transplanter. The continuous working time was recorded 17 min in 4 row transplanter, 28 min in 3 row and 32 min in 2 row transplanter.

Kavitkar (2016) compared performance of two row manually operated hand cranked paddy transplanter with traditional method of transplantinga and with existing two row manually operated paddy transplanter. The field capacity for traditional method of paddy transplanting for male and female workers was 0.0040 ha/h (40m^2) and 0.0038 ha/h (38m^2), respectively. The field capacity and field efficiency of transplanting for male workers using existing manual paddy transplanter were 0.020 ha/h (200 m^2/h) and 47.7 %, respectively, while those for female workers using refined manual paddy transplanter were 0.030 ha/h (300 m^2/h) and 60.4% respectively. The cost of hand cranked manual paddy transplanter was ₹ 2183.31/- with operating cost as ₹ 69.66 /hr and ₹ 2368.44 /ha, whereas cost of transplanting by traditional method of transplanting was ₹ 7920/ha. Hence there was 70% saving in transplanting expenditure by the using of developed hand cranked manual paddy transplanter.

. Patil *et al.* (2017) carried out field testing of power operated paddy transplanter suitable for root washed seedlings. The soil settlement period was 48 h tested with 35 days and 22 days old seedlings, transplanted in two season viz. summer and kharif respectively. Field testing was carried out on

the basis of total time required for operation, The obtained results concluded that average speed of operation and fuel consumption of the transplanter were 0.98 km/h and 1.135 l/h respectively. The average field capacity and field efficiency of the transplanter were found to be 0.0445 ha/h and 43.29 % respectively. Average seedling planted per hill, hill to hill distance, paddy hills planted per row, missing hills, floating hills, buried hills and planting efficiency were found to be 3, 117 mm, 34, 6.97 per cent, 4.35 per cent, 1.65 percent and 93.03 per cent respectively. The operating cost of newly developed paddy transplanter for one hectare of paddy was found to be Rs. 5,415/- which is Rs. 3385/- less (38.47%) than traditional method.

2.5 Ergonomic Evaluation of Rice Transplanter

Ergonomic plays a crucial role for the safe and efficient design of farm machinery and equipments. It is important to understand the different physiological parameters of workers involved in doing agricultural practices. It helps to understand the drudgery involved in the respective agricultural operations.

2.5.1 Selection of subjects

Seidal *et al.* (1980) stated that selection of subjects plays an important role in conducting the ergonomic studies. The subject should be medically fit to undergo trials. The subjects were selected on the basis of adetaoled anamnesis, a general clinical state and ECG test.

2.5.2 Calibration of subjects

Kroemer *et al.* (1997) stated that heart rate and oxygen consumption has a linear relationship. They found that the relationship may change within one person with training, and it differs from individual to another. They inferred that heart measurements could be substituted for measurement of metabolic processes, particularly for oxygen consumption, since it could be performed easily.

Tewari *et al.,* (2005) studied the ergonomic evaluation of self propelled reaper. For this study, they calibrated the subjects on bicycle ergometer. The subjects peddled 33 a standard bicycle ergometer at predetermined speed and with varying braking load. They followed standard protocol to record the data of their physiological responses at different load conditions.

2.5.3 Energy cost of work

Bimla *et al.* (2002) tested the efficiency of sickles in wheat harvesting. They found that the average heart rate expenditure for existing sickle is 110 bpm and average energy expenditure was 9.6 kJ/min.

Tiwari and Philip (2002) reported that the energy cost of different agricultural work situation of female agricultural work in west Bengal as 18.20 kJ min-1 in load carrying, 15.69 kJ min-1 in weeding, 14.88 kJ min-1 in transplanting, 14.26 kJ min-1 in threshing and 13.46 kJ min-1 in harvesting.

Rana *et al.* (2005) studied the ergonomic evaluation of the rural women while performing wheat harvesting activity. The study was undertaken in Ludas village of Hisar district of Haryana State. On an average, women spent 8 h in wheat harvesting activity and 2 h in bundling activity per day. Average heart rate of women increased from 121.5 upto 126.7 beats/min during the activity. Similarly, energy expenditure was found to be 10.5 kJ/min which increases up to11.2 kJ/min during evening hours.

Yadav *et al.* (2007) undertook a study to evaluate manually operated six-row paddy transplanter on ergonomic basis and to work out the energy expenditure rate involved in the transplanting operation. The male and female subjects randomly selected for the study ranged within the age group of 25-35 years. The average energy expenditure for male and female workers for transplanting operation by manually operated paddy transplanter was found to be 30.70 and 32.58 kJ min-1, respectively. The operation was graded as 'heavy work' on the basis of heart rate and suggested rest pause of 14.30 minutes followed by 30 minutes of work for achieving functional effectiveness during transplanting.

Ojha and Kwatra (2011) carried out an comparative study on human drudgery in rice transplanting based on experimental research design in Kalinagar village of U.S. Nagar, District of Uttarakhand. The total sample size was 40 including 20 male and 20 female farm workers. Maximum heart rate was more in case of traditional method of rice transplanting *i.e.*119.5 beats/min. as compared to improved method *i.e.* 107.47 beats/min. Average and peak energy expenditure was less in case of improved method. Energy expenditure, Total cardiac cost of work and physiological cost of work was found to be 10.28 kj/min, 840.42 beats and 55.43 beats respectively in case of traditional method and 8.36 kj/min, 572.71 beats and 36.9 beats, respectively for improved method. Respondents involved in manual method suffered from high level of human drudgery, physiological stress and higher workload whereas very low level

of fatigue and discomfort was found in farm workers performing the activity using mechanical uprooting and transplanting.

Alka (2014) studied the ergonomics of farm women during farm working by improved sickle. A technically prepared serrated sickle was tested on farm women to improve work efficiency and to reduce the drudgery of women. The results revealed that 19.5 % of working efficiency was increased by using serrated sickle as an average, one farm woman harvested 50 bundles of wheat by using serrated sickle while only 39 bundles of wheat was harvested through local sickle and also with serrated sickle average working heart rate of women was found to be 110 34 beats/min. and, energy expenditure was found to be 12 kJ/s with about 19 % saving in cardiac cost of workers per unit of output**.**

Mohanty and Ghosal (2014) ergonomically evaluated a four-row manually operated paddy transplanter developed by CRRI; Cuttack with twelve female agricultural workers in the age group of 18-45 years in Odisha, and a two-row paddy transplanter suitable for female workers and developed by OUAT, Bhubaneswar. Performance of both the transplanters was compared It was observed that the mean value of working heart rate and increased heart rate was 137.5 and 67.5 beats / min in case of four row paddy transplanter as against 127.7 and 47.1 beats/ min by two-row paddy transplanter. The oxygen consumption rate (OCR) and relative cost of work load (RCWL) of these workers were also recorded to be 1.06 l min-1 and 62.3 per cent in four row transplanter and 0.99 l min-1 and 53.5 percent in two-row paddy transplanter. The force required to operate the transplanter and field capacity were observed to be 121.6 N, and 0.11 ha/hr for four–row transplanter and 101.8 N and 0.05 ha/hr for two-row paddy transplanter respectively.

2.5.4 Maximum aerobic capacity of subjects (VO_2 max)

Astrand (1960) computed the maximum aerobic capacity (VO2 max) for the subjects by conducting sub maximal tests. Because of the risk that was involved in testing a person on a maximal energy task, various sub maximal tests were adopted. The maximum heart rate attainable by the subject was computed by the following relationship.

Maximum heart rate = 190- (age in years – 25) × 0.62

Nag (1981) stated that the maximum aerobic capacity (VO2 max) was conceived as an international reference standard of cardio-respiratory fitness.

For western population, it changes from 3 to 4 l/min. However for Indians, maximum aerobic capacity (VO2 max) was about 2.0 l/min for male workers and 1.8 l/min for female workers. Thus, there was a vast difference between the work capacity of Indian workers and western workers.

Thiyagarajan (2013) studied the ergonomic invention in sugarcane harvesting knives. Commonly used and high energy demanding tools like sugarcane harvesting knives of various models available in India were selected to assess the ergonomic suitability. Ten individuals were selected for the investigation based on the age and fitness. The maximum aerobic capacity of the selected ten individuals varied from 1.84 to 2.19 l/min. for sugarcane harvesting.

2.5.5 Grading of work

Sen (1969) classified the manual jobs based on the physiological responses of young Indian male and female workers. It was categorized physiological workload of Indian male and female workers in terms of heart rate and energy expenditure as very light, light, moderately heavy, heavy, very heavy and extremely heavy work, the corresponding heart rate values for male workers were less than 75, 75 – 100, 100 – 125, 125 – 150, 150 – 175 and above 175 bpm respectively and that of oxygen consumption rate were less than 1.75, 1.75 – 3.5, 3.5 – 5.25, 25 – 7.00, 7.00 – 8.75 and above the 8.75 kcal/min respectively. The heart rate ranges for Indian female workers for severity of work were less than 90, 91-105, 106-120, 121-135, 136 - 150 and above150 bpm and the corresponding oxygen consumption rate values below the 5.0, 5.1 to 7.5, 7.6 to 10.0, 10.1 to 12.5, 12.6 to 15.0 and above 15.0 kcal/min were graded as very light, light, moderately heavy, heavy, very heavy and extremely heavy work respectively.

Varghese *et al.* (1995) estimated energy expenditure by using following formula for Indian women:

Energy expenditure (kJ/min) = 0.159 × HR (beats/min) – 8.72

They proposed attainable heart rate for classification of workload in different occupations where women are employed. The physiological workload were classified in different categories as per attainable heart rate as follow as very light up to 90 beats/min, light 91-105, moderately heavy 106-121, heavy 121-135, very heavy 135-150 and extremely heavy above 150 bpm.

Ojha and Kwatra (2014) ergonomically analysed different paddy transplanting methods in northern India. For the ergonomical evaluation, twenty female subjects were selected in the age group of 20- 55 years. Physiological parameters like HR, energy expenditure, TCCW and PCW etc. were measured in different transplanting operations. The mean value of working heart rate was assessed to be maximum 138.32±7.67 beats/ min in manual hand transplanting and 110.12±5.79 beats/min in eight- row paddy transplanter. The energy expenditure rate was measured 18.40±0.95 kJ/min in local transplanting method and reduced to 15.17±1.68 kJ/min with paddy transplanter. TCCW was found to be 1965.5±63.66 beats for manual transplanting of paddy and 770.58±39.93 beats by the use of paddy transplanter whereas the PCW was calculated 227.98±22.17 in traditional method and 85.23±2.64 in improved method. The economic cost of mechanized transplanting was 47% less than conventional method.

Kavitkar (2016) developed a two row manual paddy transplanter and evaluated it ergonomically with seven female workers. The various physiological parameters, as mean working heart rate (WHR), energy expenditure rate (EER), work pulse (ΔHR), were 118.06 (±2.18) bpm, 10.03 (±0.36) kJ/min, and 35.80 (±3.96) bpm, respectively. The mean overall discomfort rating (ODR), and body part discomfort score were 5 and 15.53, respectively. The energy grade of work was categorized as "moderately heavy".

Aware *et al.* (2017) conducted field experiment to evaluate the physiological cost and drudgery involved in traditional method of paddy transplanting and in using a manual paddy transplanter. Eight male and seven female workers were selected for the activity. It wa found that the mean working heart rate (WHR) during traditional method of paddy transplanting for male and female subject were 105.9 (±4.01) and 106.97 (±3.39) bpm, respectively, while in case of manual paddy transplanter it was 128.44 (±12.38) bpm. The field capacity for traditional method of paddy transplanting for male and female workers was 0.0040 ha/h and 0.0038 ha/h, respectively and for manual paddy transplanter it was 0.020 ha/h with 21 (DAS) nursery.. The workload for male and female workers for traditional method of paddy transplanting was "moderately heavy" while that for the manual paddy transplanter was found to be "heavy".

2.5.6 Body part discomfort score (BPDS)

Corlett and Bishop (1976) assessed the postural discomfort at work by using the body mapping technique. In this method, the perceived discomfort has referred to part of the body. The subject body was divided into 27 regions and the subject was asked to indicate the regions, which were most painful. The subject was asked to mention all body parts with discomfort, standing with the worst, and the second worst so on. The subject was also asked to assess total discomfort on a particular body part using a five or seven point scale. The scales were graded from “no discomfort” to “maximal discomfort”.

Kumar *et al.* (2002) used Corlett and Bishop Technique to determined body discomfort scores during ergonomically evaluation of manual weeders. The body part discomfort scores were found to be 29.5, 26.22 and 23.22 for wheel hoe, crescent hoe and kasola, respectively.

Vyas (2014) conducted a study to analyze the musculoskeletal problems of agricultural workers and assess the overall discomfort and body part discomfort experienced by them while performing farm activities by using Corllet and Bishop (1976) technique . The results revealed that during land preparation, sowing and irrigation most of the males and female agricultural workers reported very severe pain in lower back and moderate pain in other body parts viz. neck, shoulder, upper arm, palm/fingers, upper back and thighs. In the activity of sowing, due to frequent changes in posture and continuous movement, 75 per cent of females and half of the male respondents reported pain. Percentage of women reporting musculoskeletal problems in plant protection activity were less but 70 per cent of males reported very severe to moderate pain in neck, shoulders and upper arms as the act of spraying required considerable strength. While weeding activity, all females experienced severe pain in lower back. In harvesting operation, male and female agricultural workers experienced severe to very severe pain in upper arms, shoulders, neck, thighs and lower back because of the repetitive motion of the body part and the heavy loads, which they carried. The data of musculoskeletal problems during the activity of threshing indicated that the respondents perceived very severe to moderate pain in upper back, shoulders, upper arms and lower back although the intensity varied. Body Part Discomfort Score (BPDS) of the male and female was highest in the operation of weeding followed by the activity of land preparation and the next in order were threshing, harvesting, irrigation and use of chemicals.

2.5.7 Overall discomfort score (ODR)

Borg (1982) developed a scale for assessing the perceived exertion during work. The ratings of scale linearly related to the heart rate expected for that level of exertion. The expected heart rate was 10 times to the rating given. The Borg-RPE scale as such follows 6-7 “no exertion” at all, 8 “extremely light”, 9 “very light”, 10-11 “light”, 12-13 “somewhat hard”, 15-16 “hard” (heavy), 17-18 “very hard”, 19 “extremely hard”, 20 “maximum exertion”.

Varghese *et al.* (1995) modified a 5-point scale and used successfully to discriminate the finer details and the difficulty experienced in a study on home and farm activities while considering general population. The 5-point scale had a rating from 1-very light discomfort to 5-very heavy discomfort. They correlated perceived exertion with energy expenditure and heart rate and developed an equation, which could be used to predict the occupational work load.

Khogare *et al.* (2012) studied most of the agriculture workers are doing weeding operation by traditional methods that and suffered from postural discomfort. At the time of weeding the postural discomfort affect on productivity of work and efficiency of workers.

2.5.8 Force measurement

Salvendy (1997) defined that the physiological acceptability of any task for the work force can be determined by several factors. The capacity of the work force includes the necessary strength, the ability to sustain that strength for the required time of effort and the ability to recover quickly from any fatigue that may accumulate before the next effort is needed. He concluded that the higher the fatigue rate the less likely people would be able to sustain the work for hours.

Dingara *et al.*, (2000) observed that the force exertion in wheel hoe with the help of load cells and reported that the minimum force required operation were 122 N, 126 N and 143 N for three subjects at handle angles of 30˚, 35˚ and 45˚ respectively.

Agrawal *et al*. (2010) studied that operation of many manually operated farm tools and equipment requires exertion of push/pull force in horizontal plane. It was found that the mean values for isometric push and pull strength in standing posture with both hands were 242.4 ± 56.4 N and 231.0 ± 42.5 N, respectively for male workers and 175.5 ± 33.9 N and 159.4 ± 42.9 N, respectively for female workers.

Lin *et al.* (2012) studied the effects of handle orientation and between-handle distance on bi-manual isometric push strength. A laboratory study was designed to examine if handle rotation in the frontal plane (0°- horizontal, 45°, and 90°-vertical), anterior tilt (0°- parallel to the frontal plane, and 15°), and distance between two handles (31 and 48.6 cm) affect pushing strength and subjective rating of handle preference. A special testing station was constructed to elicit upper limb push exertions that involved minimal contribution of the torso and legs. Within the station, four load cells were used to measure the horizontal (forward pushing) and vertical components of the pushing forces. Thirty one participants performed seated bi-manual pushing strength tests. Comparing to the reference handle configuration (horizontal, straight, and a 31-cm between-handle distance), the 45°-rotated and tilted handles with a 31-cm between-handle distance allowed 6.7% more pushing output, while the horizontal and tilted handles with a 31-cm between-handle distance resulted in 2.8% less. Tilted handles, at 45°-rotated and vertical positions received highest subjective ratings of preference among all handle configurations. Men exerted greater pushing strength with the 48.6-cm handle distance while women's capacity was greatest with the 31-cm distance. The results demonstrated that handle rotation and tilt angles affected pushing strength and should be taken into consideration when evaluating or designing pushing tasks.

Chethan and Krishnan (2017) developed a test rig to optimize the speed and force exertions to generate dynamic push–pull strength data for agricultural workers for using manual dryland weeders. Five levels of force exertion from 5 to 25 kgf with an increment of 5 kgf at each level and four levels of speed of operation from 0.5 to 2.0 km/h with an increment of 0.5 km/h at each level was selected to predict the safe limit of force exertions. The minimal values were observed at 5 kgf of push/pull exertions and higher values observed at 25 kgf of push force exertion at all speed levels. The subject's physiological responses to operational speed varies significantly at 0.5 km/h responses were very low. However, most subjects felt it difficult to operate and reported shoulder and lower back pain due to slow speed. At 2.0 km/h for 20 to 25 kgf and 1.5 km/h for 20 kgf of push forces, physiological responses were much higher (LCP was >40 beats/min).Hence, 20 to 25 kgf of force application at 1.0 km/h value speed of operation was the best design to perform work continuously for 8 h.

III. MATERIAL AND METHODS

This chapter deals with the procedures necessary to evaluate the performance of the existing two-row manually operated hand cranked paddy transplanter, steps to assess the drudgery involved in its transplanting operation, appropriate considerations and modifications to develop two row power operated paddy transplanter, its testing methodology and the steps involved in its performance evaluation.

In order to evaluate the performance of the existing manually operated paddy transplanter the step by step procedure followed is discussed below.

3.1 Nursery Preparation

The nursery used for performance evaluation of the existing manually operated paddy transplanter was prepared by adopting the following procedure.

3.1.1 Seed germination test

Paddy seeds of high yielding variety i.e. Ratnagiri-1 was selected for the study. The seed to be planted in nursery were placed for 24 hours in a bucket filled with water. After then, the seed were taken out and placed in gunny bags until they started to sprout. After the next 24 hours, the seeds sprouted well, which were then ready to plant on raised beds (Khatun, 2011). Simultaneously, three samples of 100 seeds each selected randomly from the 24 hour soaked seeds were placed and covered in piece of cloth to study the germination percentage.

The germination percentage was calculated by the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds in tray}} \times 100 \quad \ldots 3.1$$

3.1.2 Nursery plantation

In order to prepare healthy seedlings for transplanting, nursery was grown on a separate field. Three plots each of size 10m x 1m were raised as shown in Plate 3.1. The land preparation practice was carried out with the help of tractor by first ploughing and then levelling it. The height of raised bed was maintained between 15-20 cm. Trenches of 30 cm width were formed along the sides of each plot for draining out excess water. The sprouted seeds were used to plant on the bed as they could attain faster growth. The seeds were placed manually in equally spaced furrows made by hoe. Farm manure was used as fertilizer during the initial planting of seeds. Care was taken to maintain the seed density thereby planting half kg of seeds per plot.

Plate 3.1 Nursery plantation

Plate 3.2 Existing manually operated paddy transplanter

(Kavitkar, 2016) The seeds were allowed to grow for a period of 35 days which was the optimized seedling period to transplant in the summer season (Patil, 2018).

3.2 Performance Evaluation of Existing Manually Operated Paddy Transplanter

The existing machine was studied by understanding its working. The performance of the machine was evaluated by conducting its field test and then accessed for the physiological cost and drudgery involved in its use.

3.2.1 Working of existing manually operated paddy transplanter

A two row manually operated hand cranked paddy transplanter for root washed seedlings was developed at College of Agricultural Engineering and Technology, Dapoli during 2015-16. The operations performed by the machine were handled by single operator. The machine consisted of main frame, camshaft assembly, seedling tray with frame, nursery shifter cum erecter mechanism, power transmission unit (chain and sprocket drive), float of G.I sheet and handle for pulling the machine. The operator had to pull the machine with one hand and perform hand cranking activity with the other. The hand cranked power of the operator was transmitted to the camshaft of the machine through chain and sprocket drive. The seedling tray of the transplanter was set in inclined position for the seedlings to slide down easily due to vibration and gravity force. The pickers rotation on the camshaft picked 3-4 seedlings from the bottom of the tray which were transplanted in soil by the erectors. The specifications of existing manually operated paddy transplanter are shown in Table 3.1.

Table 3.1 Specifications of existing manually operated paddy transplanter

Sr. No.	Particulars	Specification
1.	Length, mm	550
2.	Width, mm	450
3.	Height, mm	930
4.	Row to row distance, mm	250
5.	Float type	GI Sheet (22 SWG)
6.	Power transmission	Chain and sprocket
7.	No. of rows	2

8.	Weight, kg	14.6 kg

The overall dimensions of the manually operated paddy transplanter were 550 x 450 x 930 mm. The transplanter performed the operation in two rows by maintaining a fixed row to row distance of 250 mm. The float used for the machine was made of G.I sheet of 22 gauge. The power transmission of the machine was completed using chain and sprocket drive. The total weight of the machine was 14.6 kg. The existing manually operated paddy transplanter is shown below in Plate 3.2.

3.2.2 Details of experimental field

The machine was operated on a plain field by considering different parameters as given below.

3.2.2.1 Experimental site

The experiment was conducted in kharif season of 2017-18 in Kumbhave village of Dapoli tehsil, which is located at 17°45'18.31"N latitude 73°16'3.80"E longitude.

3.2.2.2 Soil characteristics

The soil of the experimental field was sandy clay loam in texture. The soil pH was 5.29, which indicated that the soil was acidic in nature. The available phosphorus and potassium were observed as 14.2 and 502.99 kg/ha, respectively. The sand, silt, clay proportion of the soil was 50:4.8:45.2. The average initial soil dry bulk density was observed as 1.28 g/cc before conducting the experiment.

3.2.2.3 Field testing parameters

The parameters necessary to evaluate the field performance of the existing two row manually operated transplanter are discussed below along with their methodology.

i. Plant to plant spacing

It was the spacing between two seedlings transplanted in one row. The measurements were taken using a 30 cm steel scale. Reading from different locations of the field were taken and averaged.

ii. Number of seedlings per hill

These were the seedlings transplanted by the manual transplanter on a single hill. Through visual observations, readings from different locations of the field were noticed and averaged.

iii. Number of hills per row

The total number of transplanted hills of seedling in one row was noted when the operator completed the length of field from one end to other. Such readings of several passes was noted and averaged.

iv. Missing of hills per sq. metre

The number of missing hills was determined by observation within an area of one sq. metre. By taking several readings, the average value of missing hills per sq. metre was noted.

v. Depth of transplanting

The depth of transplanted seedling was checked by uprooting these seedlings and measuring the soil immersed length of them using a steel scale of 30 cm..

vi. Total time required for separating seedlings

It was the time which included the uprooting of seedlings from the nursery, washing their roots, separating each seedling and keeping them ready to be transplanted in the main field. The total time requirement was recorded using a stopwatch.

vii. Total time of operation

The total operation time included separation of nursery as discussed above, feeding time of seedlings in the tray, turning time, refilling of tray, adjustments and the time lost in repairing. This time was recorded using stopwatch.

viii. Speed of operation

The machine was operated for a distance of 20 m. The time required to complete this length was recorded using a stopwatch. Several readings were recorded to obtain an average value of time. The speed of transplanting was thus computed using the following equation.

$$S = \frac{D}{t} \times 3.6 \qquad \ldots 3.2$$

Where,

S = Transplanting speed, km/h;

D = Distance, m; and

t = Time required to cover the distance D, Secs.

ix. Time required for turning

It was the time required by the machine to take turn after completion of each row. Summation of the time required at every alternate end of the row gave the total turning time of the machine.

x. Actual field capacity

It is the actual area covered per unit time including the time loss in turning, feeding the seedlings on tray, repair and adjustment (Anonymous, 2010). It was calculated as,

$$AFC = \frac{A}{Tt} \quad \ldots 3.3$$

Where,

AFC = Actual field capacity, ha/h

A = Total transplanted area, ha and

Tt = Total operating time required for transplanting, h

xi. Theoretical field capacity

It is the theoretical area covered per unit time eliminating the time loss in turning, feeding the seedlings on tray, repair and adjustment. The width of operation and the speed of transplanting were considered to calculate the theoretical field capacity in ha/hr (Anonymous, 2010) and expressed by the following equation,

$$TFC = \frac{W \times S}{10} \quad \ldots 3.4$$

Where,

TFC = Theoretical field capacity, ha/h;

W = Operating width of the transplanter, m; and

S = Transplanting speed, km/h.

xii. Field efficiency

It was expressed in percentage by taking the ratio of actual field capacity and theoretical field capacity as below.

$$\text{Field efficiency (\%)} = \frac{\text{actual field capacity}}{\text{theoretical field capacity}} \times 100 \quad \ldots 3.5$$

xiii. Puddling index

Samples of freshly puddled soil were taken from the experimental field in a measuring cylinder filled up to the mark of 1000 ml volume. The puddled soil sample consisted of soil and water mixture. These samples were kept undisturbed for a period of 48 hrs to achieve complete soil settlement. The puddling index was thus determined by using the following formula (Chaudhary and Varshney, 2008).

$$(PI) = \frac{Vs}{V} \times 100 \qquad \ldots 3.6$$

Where,

PI = Puddling index, %

Vs = Volume of soil, ml;

V = Total volume of the sample, ml.

3.3 Field Testing of Manually Operated Paddy Transplanter

The test was conducted in Kumbhave village of Dapoli tehsil from 03/04/2018 to 07/04/2018. The dimensions of the field used for testing were 17 x 10 m. Initially, the field was ploughed using a rotavator. The depth of tilling ranged from 10-15 cm. Shallow tillage of 15-20 cm depth was recommended when the transplanter was used in field. Depth of puddling maximum up to 10 cm was recommended for Japanese paddy transplanter (Singh and Garg, 1976). After loosening up of soil, puddling was carried out by flooding water in the field. Use of power tiller was done to carry out the puddling operation. Thereafter, the field was left undisturbed for a period of 48 hrs for the settlement of the soil. Transplanting was done after the soil was settled in the predetermined time. All the parts were inspected for the proper working, before introducing the machine into the field. The test was then carried out by using seedlings with age of 35 (DAS). All the field testing parameters as discussed in section 3.2.2.3 were evaluated to study the performance of the machine.

3.4 Computation of Physiological Cost and Drudgery Involved in Operation with Existing Manual Paddy Transplanter

A systematic procedure was followed to access the physiological cost and drudgery involved in the operation of manual paddy transplanter. The research study was extended to detect and analyse small physiological changes during the work. The calibration of this equipment along with its operation has been explained in the following section.

3.4.1 Selection of subjects

Six male subjects were selected for the ergonomic study. Care was taken that the subjects are medically fit for the study trials and they are true representative of the user's population for the operation of paddy transplanter. For the selection of the subjects, age was the main criterion that was used. The age group of the subjects varied in the range of 25 to 35 years, because in this range maximum strength level is attained (Gite, 1997).

3.4.2 Computerized ambulatory metabolic measurement equipment (COSMED $K4b^2$)

Computerized ambulatory metabolic measurement equipment make COSMED, Italy model $K4b^2$ was a portable, light weight, battery operated equipment used to measure heart rate (HR) and oxygen consumption (VO_2) of subjects under laboratory condition (Plate 3.3).

3.4.2.1 Details of COSMED $K4b^2$

The COSMED $K4b^2$ measurement equipment had a portable unit which was fixed to the subject during the test by an anatomic harness. It contained O_2 and CO_2 analyzers, sampling pump, transmitter, barometric sensor and electronics. It was powered by rechargeable battery fixed to the back side of the harness. $K4b^2$ was provided with a small display to show real time measurements. The equipment had an inbuilt memory to save data file for downloading on computer laptop through the RS232 serial port for further analysis. The equipment also had a battery charging unit for simultaneous charging 3 Nickel-cadmium batteries and to supply power to the portable unit during warm-up time. The PC software running on Windows, allowed the user to view data in tabular and graphical form. The pulmonary function test provided the data for 22 breath by breath parameters, 10 indirect calorimetric parameters, 6 lactate threshold and 2 oxygen kinetics parameters (Goyal, 2016). Detailed specifications of $K4b^2$ metabolic system kit are given in Annexure I (A).

3.4.2.2 Calibration of COSMED $K4b^2$

The equipment was calibrated for four types of tests viz. room air calibration, reference gas calibration, delay calibration, and turbine calibration. The room air calibration forced by the equipment before every test, consisted of sampling room air. It updated the baseline of the CO_2 analyzer and gain of the oxygen analyzer, in order to match the readings with predicted atmospheric values (20.93% for oxygen and

0.03% for CO_2). The reference gas calibration, recommended to be carried out daily, consisted of sampling a gas with known composition (i.e. 16% for 0_2 and 5% for CO_2) from a calibration cylinder and updating the baseline and gain of the analyzers in order to match the readings with the predicted values. The delay calibration, recommended to be carried out at least once a week was necessary to measure accurately the time necessary for the gas sample to pass through the sampling line before being analyzed. The turbine calibration consisted in measuring the volume of a 3 litres calibration syringe and in updating the gain of the flow meter in order to match the predicted value.

3.4.3 Calibration of subjects

The subject calibration was performed using bicycle ergometer of make Monark, model Ergomedic 839E which is shown in Plate 3.4. It was used to load the

Plate 3.3 COSMED K4b^2 portable metabolic system kit

Plate 3.4 Computerized bicycle ergometer

subject. It had a digital display for real time monitoring of data. The seat and handle bar of the ergometer were adjustable as per need of the subject's requirement. The details of Monark bicycle ergometer are provided in Annexure I (B).

An initial rest of 10 minutes was given for each subject and then was asked to pedal the bicycle at a rate of 60-65 rpm. The subject calibration was conducted by loading the subject on bicycle ergometer as shown in Plate 3.5. The maximum heart rate attainable by the subject was computed by the following relationship.

HR max = 220 - age in years …3.7

The test was continued until the subject attained 75 % of maximum heart rate (HR max) or until the subject felt completely exhausted, whichever reached earlier. The pedalling speed was maintained by using metronome which indicated green indicator for required pedalling speed and red indicator for low or high pedalling speed. Arrangement for increasing the workload automatically by 15 watt at an interval of every 2 minutes was provided on the device. The heart rate and corresponding VO_2 values for the increasing load were recorded on the $K4b^2$ unit and also on the computer. The breath by breathe values recorded of each subject were averaged in duration of one minute interval. Correlation between heart rate and oxygen consumption rate at specified sub maximal workloads were developed and the regression line was extrapolated to the age predicted maximum heart rate and VO_2 max corresponding to HR max was noted.

The subject loaded on the bicycle ergometer was connected with the $K4b^2$ unit along with the following sub-accessories.

i. Heart rate monitor

The heart rate of the subject was measured using Polar RS 400Tm portable heart rate monitor. This device could also be used directly on the field to record the heart rate readings while operating the paddy transplanter. Details of Polar heart rate monitor are furnished in Annexure I (C).

ii. Transmitter

Transmitter consisted of an electrodes and connector. The transmitter detected the heart rate from the body of the subject and converted to electromagnetic signals with the help of two electrodes, which were fixed in the grooved rectangular area on the underside of the belt transmitter. For better sensing, the electrode areas of the strap were well moistened.

Plate 3.5 Subject calibration using bicycle ergometer

iii. Elastic strap

Elastic strap had a connector which was placed in a central, upright position on the chest of the subjects. The strap length was adjustable which could fit comfortably around the chest, just below the chest muscles of the subject.

iv. Receiver

This unit received the signals from the transmitter, displayed it on the screen and recorded the data in the memory.

v. Interface

The interface could transmit the recorded heart rate values to the computer. Recorded heart rate values of the subjects were transmitted to the computer, which were also displayed in graphical form.

vi. Harness

It served as a holder worn by the subject to hold the $K4b^2$ portable unit and other accessories.

vii. Exercise test mask

It is made of silicone and is connected with the flow meter assembly through which the respiration takes place.

viii. Turbine flow meter

The turbine flow meter assembly consists of a bidirectional turbine and an optoelectronic reader. The device is used to measure infrared light interruptions caused by the spinning blade inside the turbine. Its calibration should be performed regularly to assure accurate measurements.

3.4.4 Ergonomic evaluation of manually operated paddy transplanter

Along with the field performance, the existing manually operated transplanter was evaluated ergonomically to access the drudgery involved in transplanting operation. The six male subjects previously calibrated in laboratory were selected for the study. They were given all the instructions related to the test. Accordingly, the trials were conducted. Each subject was initially given sufficient rest to bring their heart rate to normal. Thereon, the trial was started. The subject was made to operate the transplanter until he felt exhausted. The heart rate data of the first resting time and also of the operation time were recorded in beats per minute (bpm) using Polar RS 400 Tm portable heart rate monitor. The recorded heart rate values were downloaded to the computer. The average heart rate from 6^{th} min up to the completion time was computed for the further calculation and analysis. The same procedure was adapted to all the selected subjects. Following were the parameters used to determine the physiological cost involved in operating manual paddy transplanter.

3.4.4.1 Heart rate (HR)

Measuring heart rate is one of the most useful ways of assessing the workload because it can be done very conveniently (Sinha, 2014). Thus, heart rate of the subjects was recorded during the operation by using the heart rate monitor. All the functions of the heart rate monitor were set as per instructions given in the manual. The subjects were given sufficient rest before starting the trial to make the heart rate normal. From the downloaded data, the values of HR were taken for calculation of working HR as the physiological response of the subjects.

3.4.4.2 Oxygen consumption rate (OCR)

The oxygen consumption of subjects during the operation was carried by indirect assessment. From the mean values of heart rate determined during the experiment, a graph representing linear relationship between heart rate (HR) and oxygen consumption rate (OCR) was plotted.

3.4.4.3 Energy expenditure rate (EER)

The oxygen consumption rate (OCR) corresponding to heart rate of the male subjects during operation with manually operated paddy transplanter were predicted from the calibration chart of each individual subject. The energy expenditure during the experiments was computed by multiplying the oxygen consumption values with the calorific value of oxygen, which is 20.88 kJ/l (Nag *et al*. 1980).

i.e. EER (kJ/min) = OCR (l/min) x 20.88 …3.8

The values of HR, OCR and EER for all the subjects were averaged to get the mean values for all the selected subjects. On the basis of the values of EER in kJ/min, the grade of work was decided.

3.4.4.4 Acceptable work load (AWL)

Work load can be expressed as percentage of the individual's maximal aerobic power (VO_2 max) *i.e.* how much of the individual's maximal aerobic power has to be taxed in order to accomplish the work in question. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of the VO_2 max (Saha *et al.* 1979). To ascertain whether the operations selected for the trails were within the acceptable workload (AWL), the oxygen uptake in terms of VO_2 max (%) for each treatment was computed.

3.4.4.5 Limit of continuous performance (LCP)

The extent to which a person may increase his work rate depends in part on how much he can increase his heart rate from resting level to his maximum level, because the increase in heart rate plays a major role in increasing the cardiac output from rest to maximal work.

To have a meaningful comparison of physiological response, the difference in the working and resting heart rate i.e. is (ΔHR) and was compared with the acceptable work pulse values of 40 bpm.

3.4.4.6 Work rest cycle

This is the actual rest that must be taken by a subject after he has undergone some strenuous farming operation. At extreme workload a person could work only for few seconds. In order to reap a better performance from the subject he must be given ample time of rest after carrying any operation. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO_2 max. Better performance can be expected from worker

only when proper attention is given for the work rest schedule in different operation. The actual rest time taken for each subjects while transplanting was found from the heart rate response curves of subjects. To determine the rest pause after the transplanting operation the following formula was used (Murrel, 1965),

$$R = \frac{T\,(K-S)}{K-1.5} \qquad \ldots 3.9$$

Where,

R = Rest required, min

T = Total working time, min

K = Average kcal per min of work

S = Average kcal per min adopted as standard

3.4.5 Subjective evaluation of discomfort caused in operating manual paddy transplanter

The subjective evaluation of discomfort was done by computing overall discomfort score and body part discomfort score of the subjects while on the field. The methodology of the same has been discussed in the subsequent sections.

3.4.5.1 Overall discomfort rating (ODR)

Overall discomfort rating is the method of accessing the overall body discomfort. A 10 point psychophysical rating scale marked 0 to 10 digits (0 - no discomfort, 10 extreme discomforts) was used to assess the overall discomfort rating (Corlett and Bishop, 1976). The numbers on the scale showed the level of discomfort experienced by subject during the experiment. The scale had a movable pointer to indicate the overall discomfort rating as shown in Fig 3.1. At the end of each experiment, each subject was asked to indicate their overall discomfort rating on this scale. The overall discomfort ratings given by each subjects was added and averaged to get the mean rating.

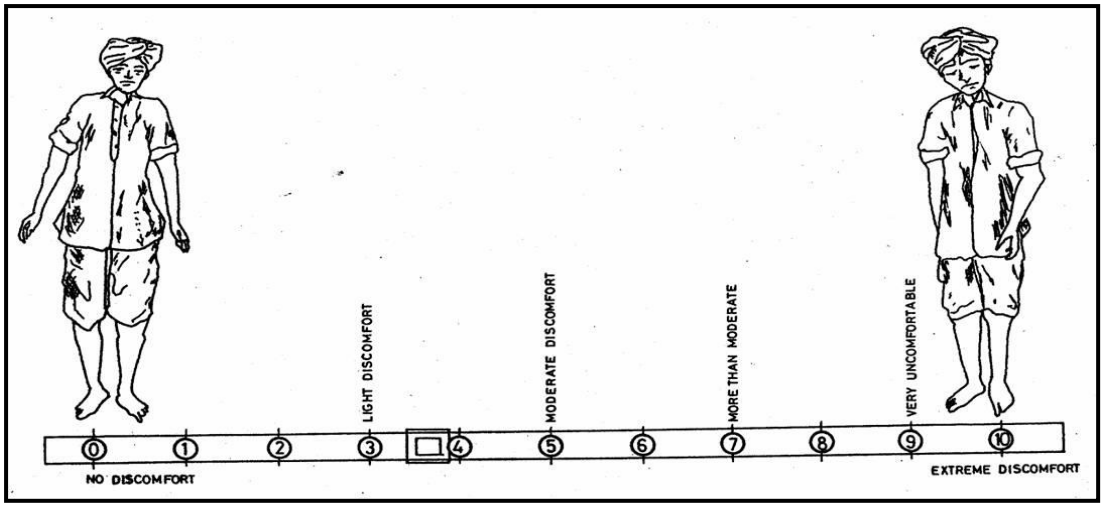


Fig 3.1 Visual discomfort scale for assessment of overall body discomfort

3.4.5.2 Body part discomfort score (BPDS)

To measure body part discomfort score (BPDS), the technique of dividing subject's body into 27 regions was used (Corlett and Bishop, 1976) as shown in Fig 3.2. After completion of the work, the subjects were asked to point out the painful regions which caused discomfort during the operation. It was meant to mention all the body parts which caused discomfort, starting with the least painful and next painful and so on until all painful body parts had been mentioned. The number of different groups of body parts, which were identified from no discomfort to extreme discomfort, represented the number of intensity levels of pain experienced by the worker. The body part discomfort score of each subject was calculated by multiplying the number of body parts corresponding to each category. The total body part score for a subject was the sum of all individual scores of the body parts assigned by the subject. The body discomfort score of all the subjects were lastly added and the average value gave the discomfort score.

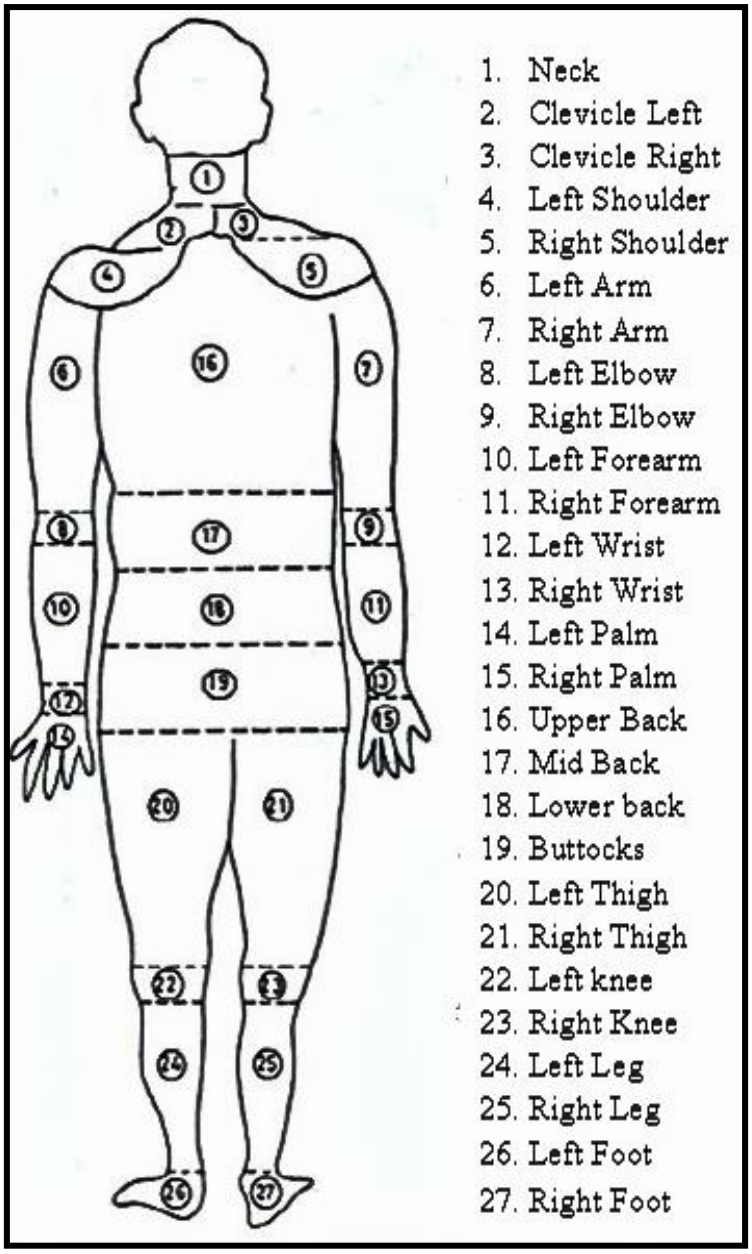


Fig 3.2 Regions for evaluating body part discomfort score

3.5 Refinement in the Existing Manually Operated Paddy Transplanter

The manually operated paddy transplanter was pulled by one hand and simultaneously the cranking operation was accomplished by other hand. It proved to be a cumbersome operation. So, for the purpose of refinement, the hand cranking mechanism was eliminated. Now, there arouse a need to design the handle to pull the developed transplanter by both hands. Thus, the handle design considerations included determining the grip length, handle length and handle height.

3.5.1 Ergonomic design features of power operated paddy transplanter

The ergonomic design feature of the following components of developed power operated paddy transplanter was finalized by using the anthropometric and strength data of Indian agricultural workers (Gite *et al.* 2009).

3.5.1.1 Design of handle

The purpose of handle is to facilitate the transmission of force from the musculoskeletal system of the user to the tool or object he is using in the performance of the task for which he is using it (Pheasant, 1986).

3.5.1.1.1 Height of handle

The height of handle was kept adjustable to make it convenient to pull by 95 per cent of the working population. The elbow height (standing) data was helpful for designing proper handle height. The desirable height of handle for continuous work should be 0.8 of 5^{th} percentile to 0.7 of 95^{th} percentile of the acromial height leading to less work stress (Gite & Yadav, 1990). As per the anthropometric data, 0.8 of 5^{th} and 0.7 of 95^{th} percentile values of acromial height for male worker under "All India" category were 1005 and 1027 mm, respectively. Hence, the handle height was finalized in between the limiting values of these two anthropometric parameters.

3.5.1.1.2 Length of handle

For maximum work efficiency, it was suggested that the elbow flexion angle should be in the range of 85 – 110° (Grandjean, 1982). Considering the elbow flexion angle as 100°, elbow height and elbow grip length values, the optimum length of handle can be found out (Tewari *et al.* 2007). Thus, the 5^{th} and 95^{th} percentile values for elbow height and elbow grip length were 938 and 1115 mm and 304 and 404 mm, respectively. So, the length of handle was decided based on this consideration.

3.5.1.1.3 Diameter of handle grip

The handle of machine should vary in size between the hand and finger size, as the maximum voluntary finger contraction force is diameter-dependent. 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. So, the 95^{th} percentile value of middle finger palm grip diameter for male workers was considered as lower limit while 5^{th} percentile of their inside grip diameter was considered as the upper limit (Dewangan *et al.* 2010).

Plate 3.6 Novatech load cell with digital indicator

3.5.1.2 Pull force measurement

The pull force was determined using Novatech load cell capable of measuring load capacity up to 40 kg with 1 g accuracy. It was attached to the handle of machine. The load was read from the readings displayed on the digital indicator. The load cell with digital indicator used for testing is shown in Plate 3.6.

3.5.2 Mechanical development of power operated paddy transplanter

There was a need to refine the existing manually operated paddy transplanter to make it more sophisticated and comfortable for the operator to work in the puddled field. The machine was pulled by directing it with one hand and operating the cranking mechanism with the other hand. So, a considerable amount of energy was consumed by the operator to perform the operation. Therefore, an alternative was found to make the cranking mechanism to be power operated. This was achieved by using a suitable petrol engine. It was also observed that the G.I float used on the existing machine could stick to the puddled soil while pulling, which imposed higher pulling force on the operator, so it was necessary to replace it. The nursery holder was found to be ineffective in holding the nursery in tray. It resulted in dropping excess

amount of nursery from the tray, so the component was modified to save the excess loss of seedlings. The picking mechanism of cam resulted in abrupt opening and closing which made the operation noisy and damaged the follower, thus the cam was to be re-designed for smooth functioning. The tension springs used in the picking mechanism which served the purpose of expansion and contraction were needed to be replaced as the tension in the spring was reduced slowly. Therefore, new springs were used to withstand the continuous tension and compression occurred during the operation. Hence, it was decided to re-fabricate the manual transplanter and make it more user-friendly. Also, being a power operated machine, focus was also given to make the machine lighter in weight by using light weight material for fabrication having good strength.

3.5.2.1 Calculation of power requirement for developed power operated paddy transplanter

The power required for refined machine was determined by computing the torque for hand-cranking and measuring the required speed (rpm). For this purpose, the machine was jacked up. A load cell was connected to the handle of the machine. As the handle was rotated, the load cell connected to the indicator displayed the load readings. The maximum load was noted at four places considered 90° apart. The

Plate 3.7 Petrol engine with speed reduction unit

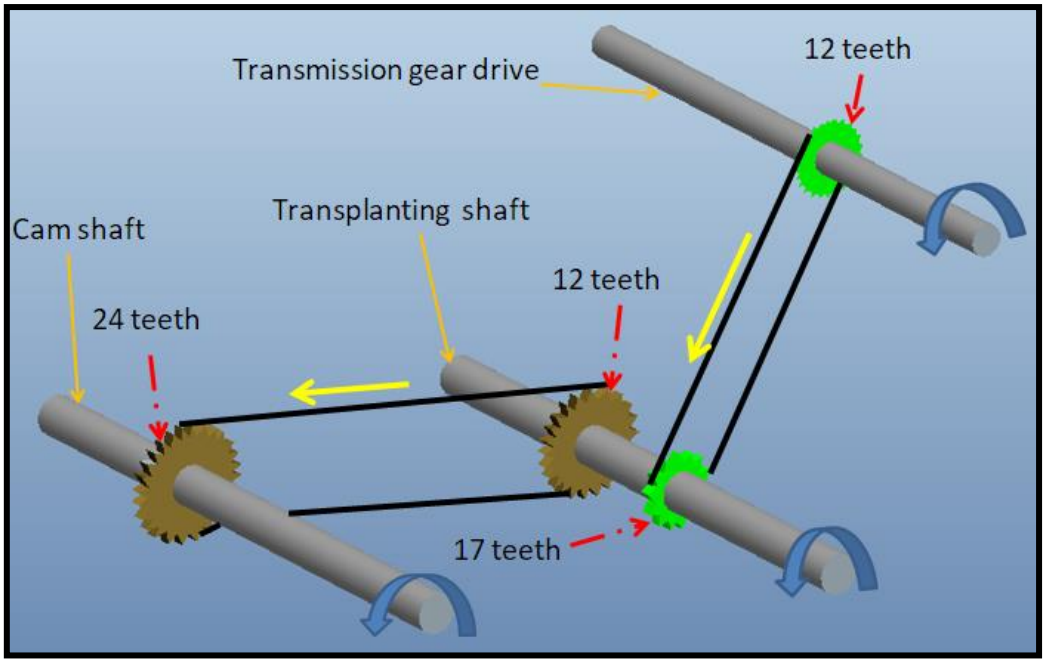


Fig 3.3 Power transmission flow diagram

operation was continued for one minute by repeating the procedure three times. The maximum average value of cranking force was 0.99 kg. The radial distance of the handle was predetermined which was 0.21 m.

During the hand cranking operation, the speed at which the camshaft assembly rotated was measured using contact-type tachometer. The average value of the camshaft revolutions was observed as 67 rpm. From the existing manually operated paddy transplanter, the following results were recorded.

Hill to hill spacing = 0.15 m

Row to row spacing = 0.25 m

Field capacity = 0.030 ha/hr = 300 m^2/h

During one revolution of the shaft, the transplanting operation occurred twice i.e. covering a length of (0.15 + 0.15) = 0.30 m.

Hence the area covered in one revolution of the shaft was,

= 0.30 m x 0.25 m = 0.075 m^2

Therefore, to complete an area of 300 m^2, the total no. of revolutions required were,

= 300 / 0.075 = 4000 rev / h

= 67 rev / min.

From the above data, the power requirement was calculated as:

$$\text{Power required (P)} = \frac{2\pi NT}{4500}$$

Where,

P = required engine power, hp

N = no. of revolutions obtained on main shaft, rpm

T = torque or cranking force, kg.m

- $P = \frac{2 \times \pi \times 67 \times 0.21}{4500}$
- Power requirement= 0.019 hp = 14.65 watt ≈ 15 watt

The shaft of the transplanting arm revolves at a speed ratio of 2:1 with the camshaft speed. Hence the speed of the transplanting arm was taken to be 134 rpm.

3.5.2.2 Power source and power transmission system

An available petrol engine of 1.28 kW (1.75 hp @ 6500 rpm) was used. It was a single cylinder, 2-stroke and air cooled engine. It weighed about 4.5 kg. The engine was equipped with a speed reduction unit having speed ratio of 32.5:1 as a result of

providing an output speed of 190 rpm. This speed was further reduced to 134 rpm as required on the transplanting arm shaft, by employing two sprockets each of 12 and 17 teeth resulting in speed ratio of 1.42:1. The engine along with speed reduction unit is shown in Plate 3.7. The flow of motion from speed reduction unit to the camshaft is shown in Fig. 3.3.

3.5.3 Mechanical components of the developed power operated paddy transplanter

The components fabricated of the power operated paddy transplanter have been described below.

1. Float

It was the main component which was in contact with the soil. The float of the machine was made of wooden plank. The edges of the float were raised 75 mm high to avoid the entry of puddled soil in it. It also helped in easy dragging of machine over the puddled field surface. The schematic view of float is shown in Fig 3.4.

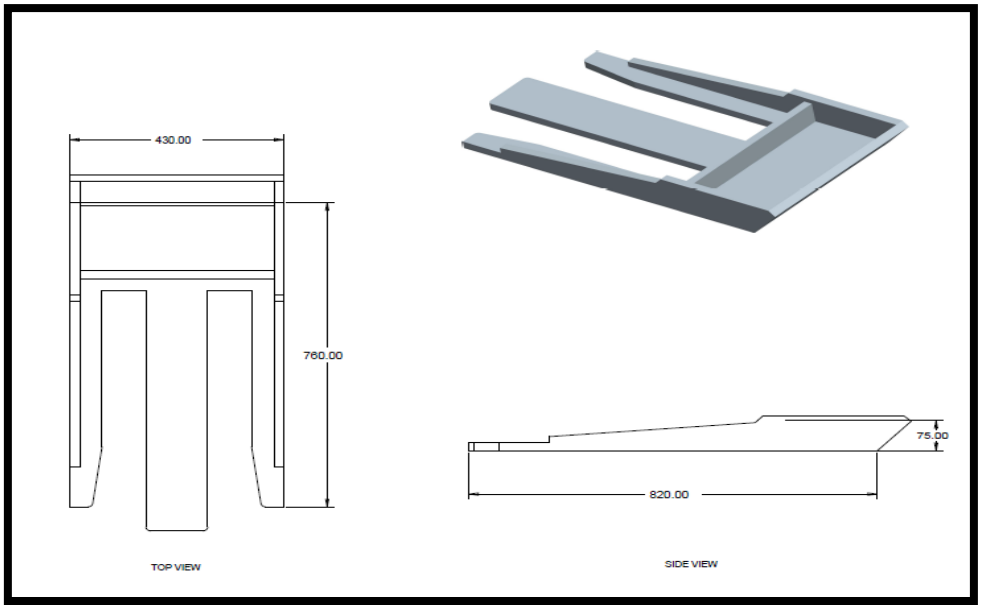


Fig 3.4 Schematic view of designed wooden float

2. Main frame

It was the important constructional component of the transplanter. All the other accessories like seedling tray, engine frame and handle were attached to the main frame. It was fabricated using galvanized iron (G.I) hollow square pipe of 20 x 20 x 3 mm which made the frame lighter in weight, rigid and achieve good strength. The developed main frame is shown in Plate 3.8.

Plate 3.8 Main frame

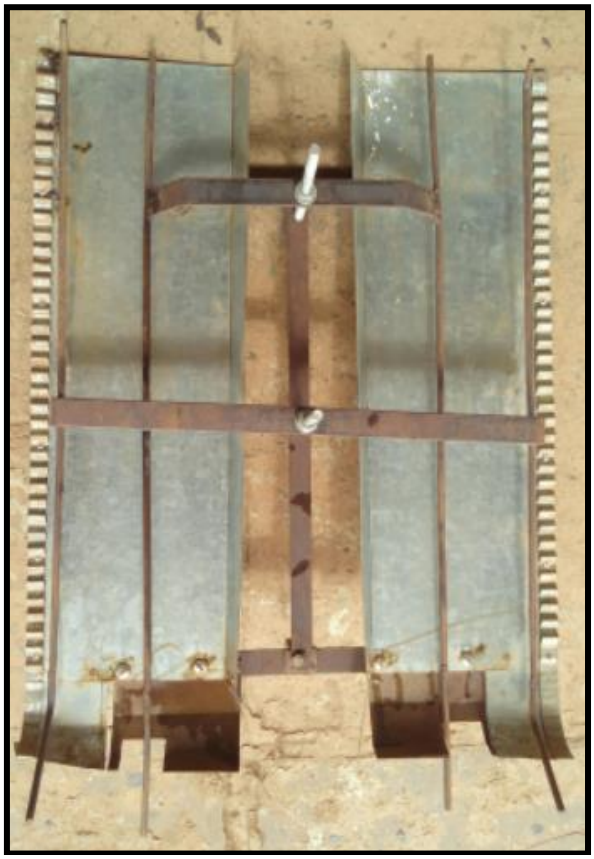


Plate 3.9 Nursery tray with frame

3 Nursery tray assembly

The function of carrying the seedlings on the transplanter was done by the nursery tray. Two compartments were made on the tray to deliver the seedlings in two rows. The length of tray was decided on the fact that the operator will have to fill the tray minimum times to complete the transplanting operation. The tray was made using 22 gauge galvanized iron (G.I) sheet. The outer edge of the tray length was stripped with undulating surface to refrain the seedlings from falling downwards and to avoid overcrowding at picking point. The fabricated seedling tray with frame is shown in Plate 3.9.

4 Camshaft assembly

Cam was the rotating machine element imparting reciprocating or oscillating motion to another element known as follower. For the developed paddy transplanter radial cam having roller type follower was considered. The initial step was to construct the displacement diagram to make the cam profile. The constructed cam profile was then marked on M.S. sheet of 3 mm thickness. The profile cutting was performed by laser cutting which gave a precise cut and finish. In the developed machine there were two cams mounted for two different reasons i.e. one for nursery planting mechanism and another for nursery holding and nursery pushing mechanism. The constructional details of displacement diagram and cam profile are explained as follows.

a) Construction of displacement diagram to nursery planting mechanism cam

i. Initially, by considering the stem diameter of seedling, the stroke length was decided. The maximum and minimum intermediate size of the cam was decided to be 120 mm and 80 mm respectively. Thus, the stroke length was taken as 40 mm.

ii. The outstroke of 20^0, dwell period 160^0, and the return stroke of 20^0 and remaining resting of 160^0 was assumed.

iii. A horizontal line AX = 360^0 was drawn with suitable scale.

iv. On this line, AS = 20^0 was marked to represent the outstroke of the follower, dwell period was marked as SR =160^0, RP = 20^0 represented the return stroke, and the resting period was represented by PX = 160^0.

v. Stroke length of the follower = 40 mm was drawn to mark a vertical line AY to complete the rectangle.

vi. The angular displacement during outstroke and return stroke was divided into six equal parts and represented by drawing six vertical lines.

vii. The follower moves with simple harmonic motion, therefore by considering AY as diameter, a semicircle was drawn which was divided into six equal parts.

viii. From points a,b,c… etc. horizontal lines intersecting the vertical lines through 1, 2, 3... etc. and 0',1', 2'... etc at B,C,D were drawn.

ix. The points A, B, C… were joined with smooth curves.

x. The complete displacement diagram is as shown in Fig 3.5.

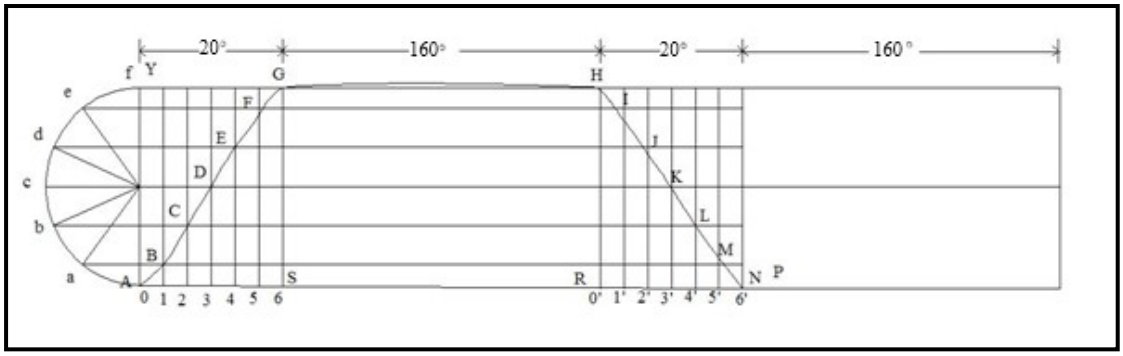


Fig 3.5 Construction of cam displacement diagram

b) Construction of cam profile for nursery planting mechanism cam

i. For constructional purpose, it was considered that the axis of follower passes through axis of camshaft.

ii. So, the base circle having radius equal to the minimum radius of cam i.e. 40 mm was drawn with the 'O' as centre.

iii. Angle AOS = 20^0, angle SOR = 160^0 and angle ROP = 20^0 was marked, which represented the outstroke, dwell and return stroke respectively.

iv. As like the displacement diagram, angle AOS and angle ROP was divided into six equal parts.

v. Taking centre as O, the points 1, 2, 3 and 0', 1', 2', 3' were joined.

vi. Now distance of 1B, 2C, 3D and 0'H, 1'J… was referred from the displacement diagram.

vii. The cam profile was completed by joining points A, G, G' and A' as shown in Fig 3.6.

viii. The fabricated nursery planting mechanism cam is shown in Plate 3.10.

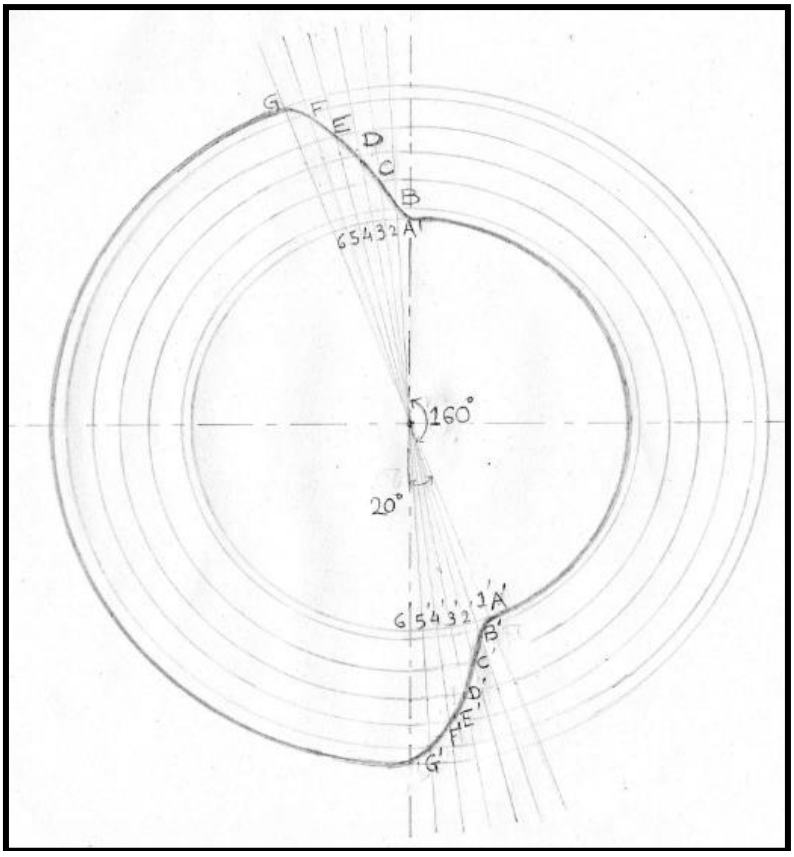


Fig 3.6 Cam profile of nursery planting mechanism cam

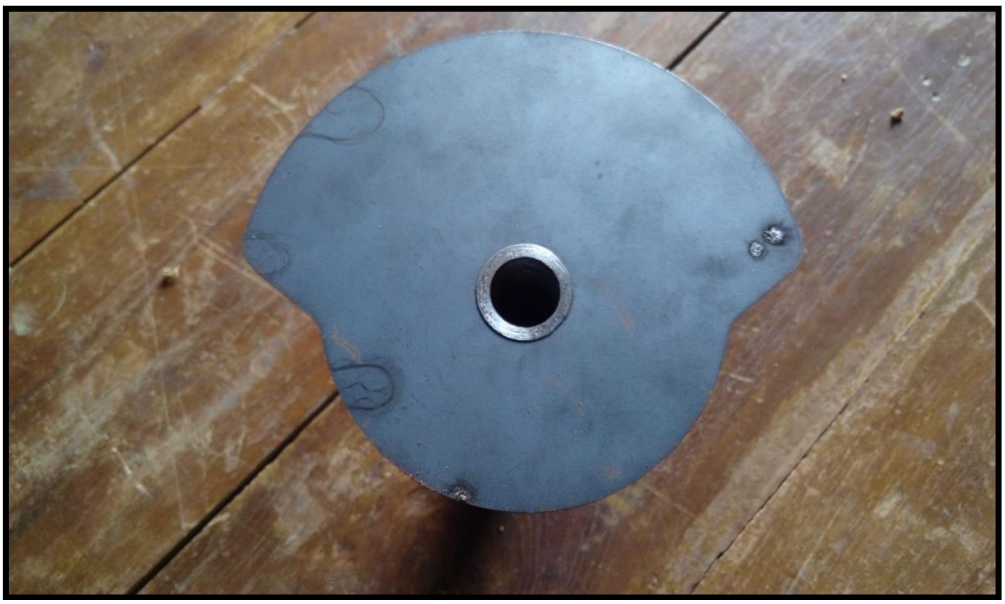


Plate 3.10 Fabricated nursery planting cam

c) Construction of displacement diagram to nursery holding and pushing mechanism cam

i. Nursery holding and pushing mechanism was completely operated by rotating cam and roller follower.

ii. The stroke length of cam was determined from the size of radial intermediate axis.

iii. The maximum intermediate size was 140 mm and minimum size was 100 mm which was measured by considering the measurements of nursery stem diameter. Thus, the stroke length considered was 20 mm.

iv. The outstroke of 15^0, dwell period 20^0, return stroke of 15^0 and remaining resting of 130^0 was assumed.

v. Horizontal line of AX = 360^0 was drawn with suitable scale, by marking AS = 15^0 to represent the outstroke of the follower, ST = 20^0 to represent the dwell and TP = 15^0 to represent the return stroke and P0 = 130^0 to represent resting period.

vi. A 20 mm vertical line AY was drawn, which is the stroke length of follower and completed the rectangle.

vii. Dividing the angular displacement during outstroke and return stroke in to six equal numbers of parts, the vertical lines were drawn.

viii. Since the follower moves with simple harmonic motion, therefore a semicircle with AY as diameter were drawn and divided into six equal parts.

ix. From points a, b, c horizontal lines intersecting the vertical lines through 1, 2, 3...etc and 0',1',2'... etc at B,C,D....M, N, P were drawn.

x. The points A, B, C....etc were joined with smooth curves as shown in Fig. 3.7

xi. Same procedure was followed for next outstroke and return stroke.

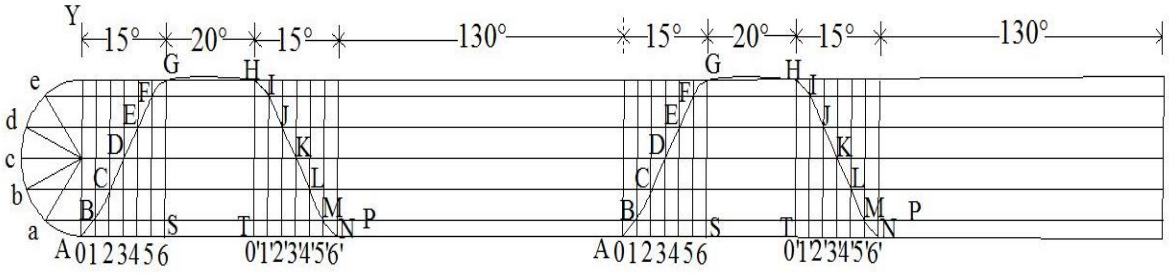


Fig 3.7 Displacement diagram for nursery holding and pushing cam

d) Construction of cam profile for nursery holding and pushing mechanism cam

1) It was considered that the axis of follower passes through axis of camshaft.
2) Base circle with the radius equal to the minimum radius of the cam such as 50 mm was drawn with the 'O' as centre.
3) Angle AOS = 20^0, angle SOT = 15^0 and angle TOR = 20^0 represented the outstroke, dwell and return stroke, respectively.
4) Angle AOS and angle TOR was divided into six equal parts as same the displacement diagram.
5) Points 1, 2, 3 and 0', 1', 2', 3' were joined with the centre O.
6) Now 1B, 2C, 3D and 0'H, 1'J, distance were set from the displacement diagram.
7) Points A, B, C… L, M, N was joined which completed the profile diagram. The curve AGHRAGHRA represented complete profile of cam.
8) The schematic view and the developed nursery holding and releasing cam are shown in Fig 3.8 and Plate 3.11, respectively**.**

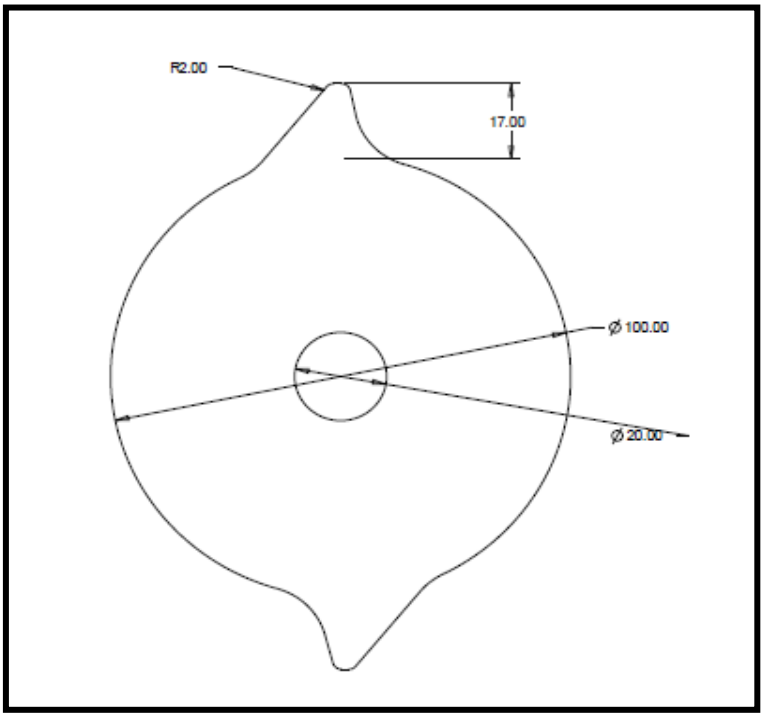


Fig 3.8 Cam profile of nursery holding and pushing cam

5. Nursery picking assembly

The picking assembly was mounted on the camshaft along with the nursery picking and nursery releasing cam. The long picking plate with forks rotated on the

Plate 3.11 Developed nursery holding and releasing cam

Plate 3.12 Picking assembly

shaft which carried the seedlings from the tray to the transplanting assembly. The follower plates two on either side assisted the seedling to be caught precisely and carry on to the bottom position from where the seedlings could be transplanted by the arm and the erector. The motion of follower plate was actuated by tension springs that expanded and contracted as the roller bearing moved along the cam profile. The picking assembly, spring and roller bearing are shown in plate 3.12, 3.13 and 3.14 respectively.

6. Transplanting arms

The transplanting arms of machine served the purpose of transplanting the seedlings carried by the picking assembly in the puddled soil. The arms were fabricated using mild steel sheet of 3 mm thickness with laser cutting. The transplanting action was actuated using four bar mechanism. The arms moved analogous to the movement of the main shaft. Both the shafts i.e. main shaft and transplanting arm shaft were connected with chain and sprocket joint. The power to the transplanting arms was supplied by the speed reduction unit run by the petrol engine. The movement of the transplanting arm shaft rotated in 2:1 ratio with the main shaft to make transplanting possible twice for each turn of the main shaft. The schematic view of transplanting arms is shown in Fig 3.9.

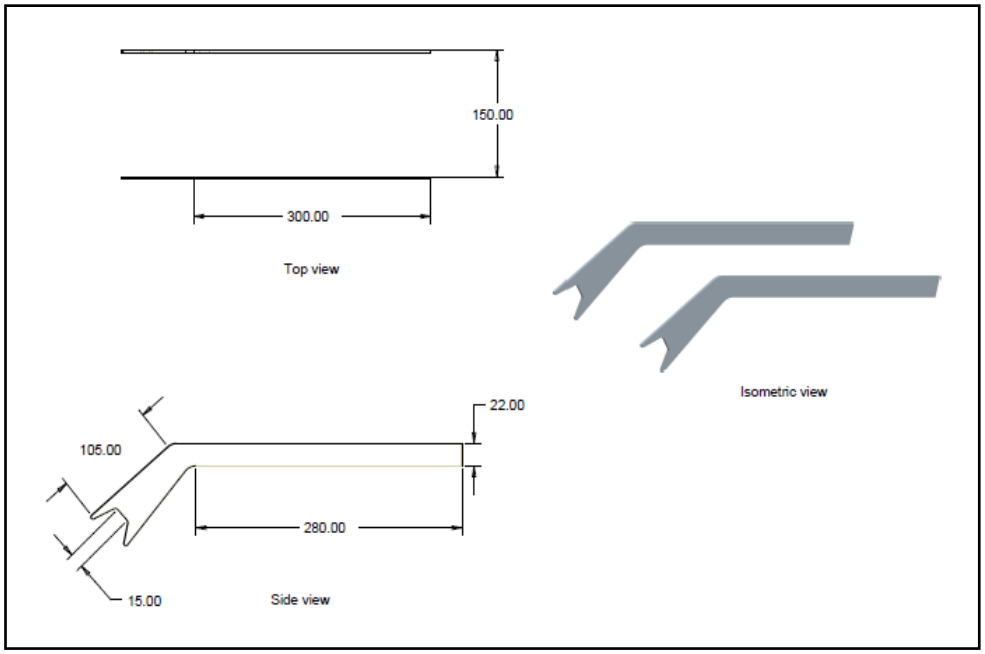


Fig 3.9 Schematic view of transplanting arms

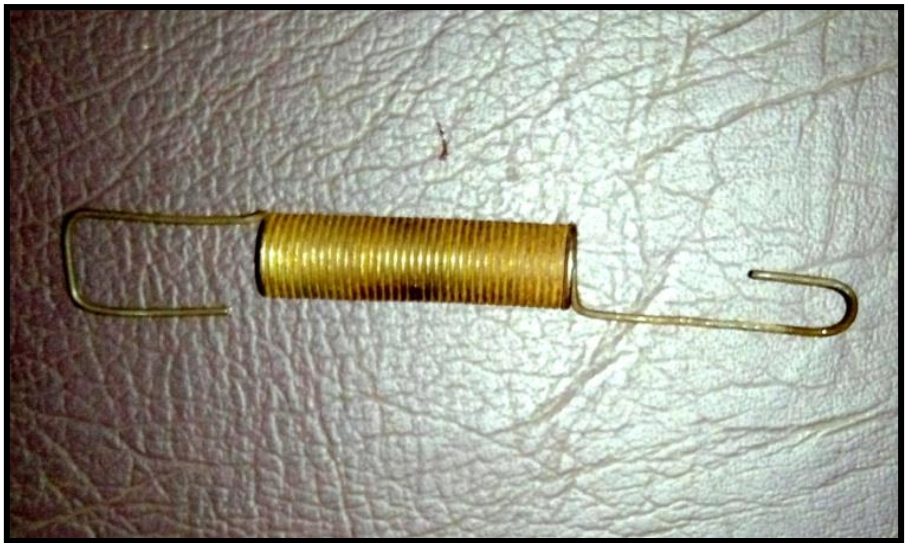


Plate 3.13 Tension Spring

Plate 3.14 Roller bearing

Plate 3.15 Seedling erector

7 Seedling erector

The main function of erecting the seedlings in puddled field was accomplished by the seedling erector. It was fixed to the bottom of the main frame. The seedlings after caught in horizontal position by the picking assembly, was dipped in standing position by the erector. The transplanting arm during its motion touched the erector almost completely as too much clearance between the both could have left the seedlings unattended resulting in increased floating of seedlings. The fabricated seedling erector has been shown in Plate 3.15

The schematic views of the developed paddy transplanter are shown in Fig. 3.10, and 3.11 respectively.

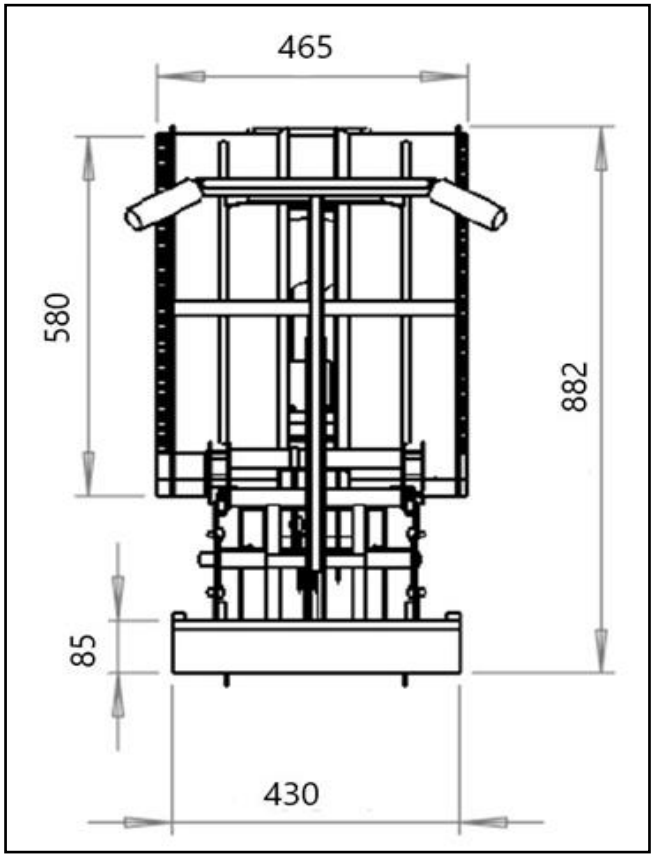


Fig 3.10a Front view of developed paddy transplanter

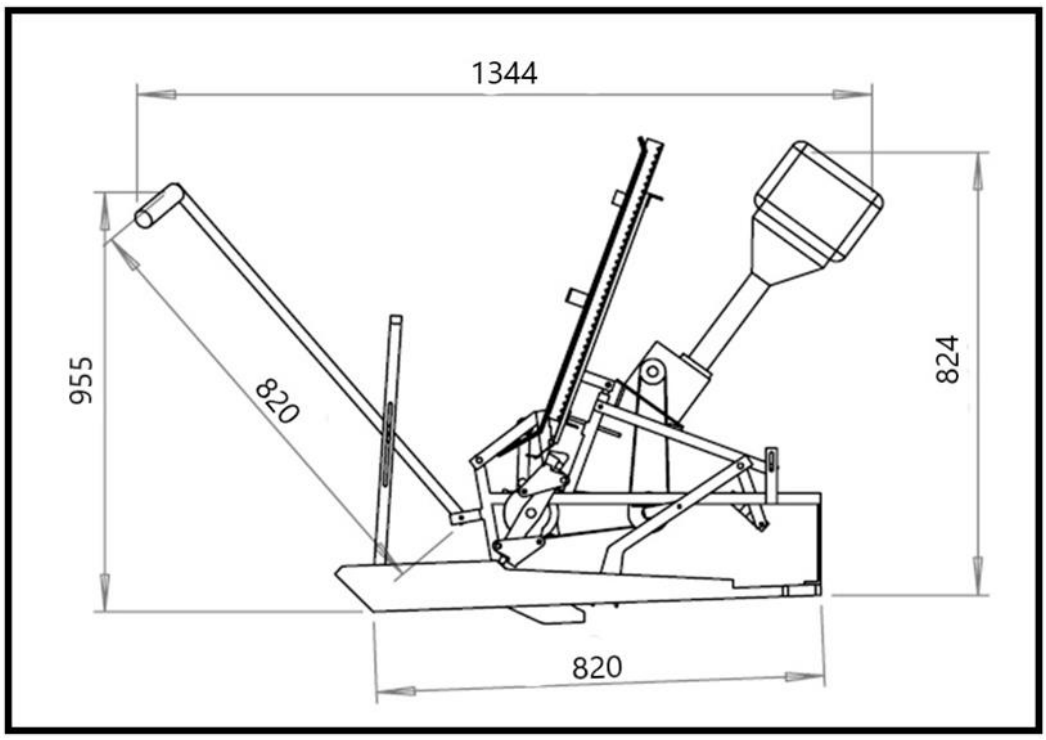


Fig 3.10b Side view of developed paddy transplanter

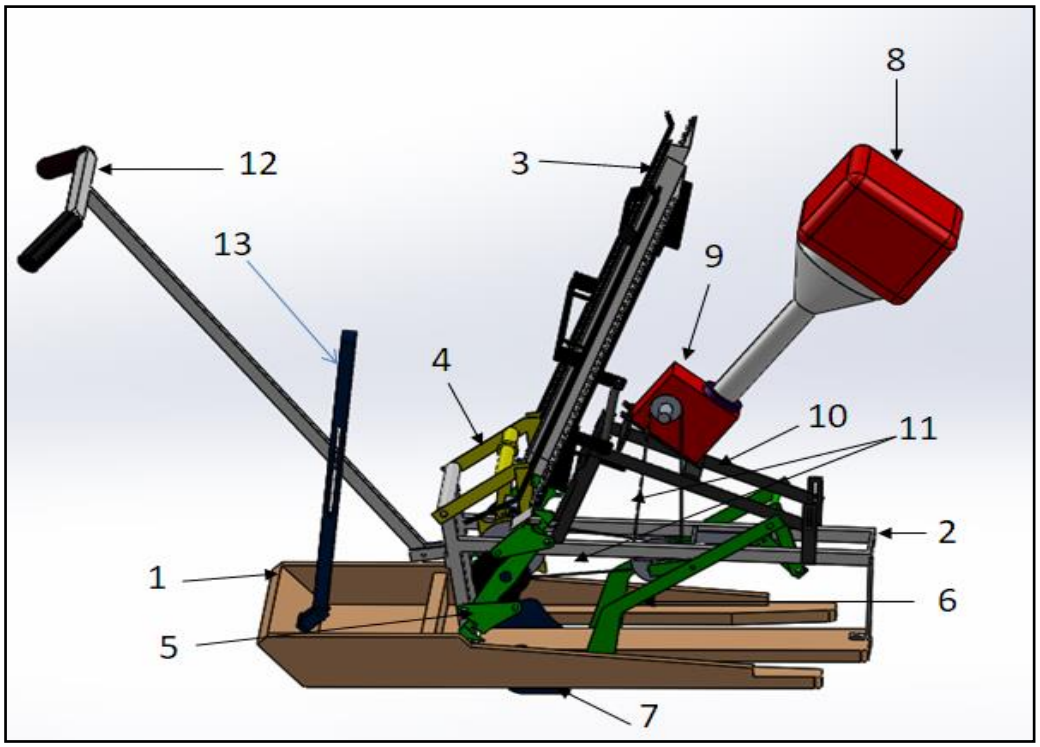


Fig 3.11 Schematic view of developed power operated paddy transplanter

1. Float
2. Main frame
3. Seedling frame with tray
4. Nursery holder
5. Picking assembly
6. Transplanting arm
7. Nursery erector
8. Engine
9. Speed reduction unit
10. Engine support
11. Chain and sprocket
12. Handle
13. Adjustment for handle height

3.5.4 Working of developed power operated paddy transplanter

The developed power operated paddy transplanter was driven by petrol engine. The power from the engine was supplied to the transmission unit which helped in reducing the engine speed and achieving the required speed for operation. This power was transferred to the transplanting arm shaft with the help of chain and sprocket. The required speed of 134 rpm (section 3.5.2.1) was achieved by using sprocket of 17 teeth and 12 teeth thus, giving speed ratio of 1.42:1. This power from the transplanting shaft was further delivered to the camshaft assembly. Here, reduction in the speed ratio of 2:1 was achieved by using another 12 teeth and 24 teeth sprockets which gave 67 rpm on the camshaft. The engine speed used for transplanting operation was controlled by using a throttle fixed on the handle of the machine. The handle was kept adjustable so as to make it convenient for any operator to pull with minimum efforts. The handle was raised from wooden float. The float was the interacting component of the machine with the puddled soil. It helped in easy pulling and causing minimum sinkage of machine during the operation.

The main frame fixed on the float served as an important component to attach all the other components. The seedling tray was supported from the frame. It was set in an inclined position for easy flow of seedlings from the tray

towards the bottom. The trays were filled with root washed seedlings. The seedlings were picked from the bottom of the tray by the picking and pushing cam assembly and transplanted in two rows by the transplanting arm. The nursery holder served the purpose of holding the nursery meanwhile in the tray. The required quantity of 2-3 seedlings were picked precisely and transplanted in the soil. The operation was carried out by pulling the machine with two hands and controlling the operation speed with the throttle when needed. The developed power operated paddy transplanter is displayed in Plate 3.16.

The detailed specifications of developed two row power operated paddy transplanter are furnished in Table 3.2.

Table 3.2 Detailed specifications of developed power operated paddy transplanter

Sr. No.	Particulars	Specification
1.	Weight, kg	28.65
2.	Length, mm	1344
3.	Width, mm	465
4.	Height, mm	882
5.	Row to row distance, mm	250
6.	Float type	Wooden
7.	Power source	2 stroke petrol engine (1.75 hp @ 6500 rpm)
8.	Power transmission	Chain and sprocket
9.	No. of rows	2

The developed paddy transplanter weighed about 29 kg. The overall dimensions of the transplanter were 1344 x 465 x 862 mm. It transplanted two rows simultaneously at a distance of 250 mm apart. The developed transplanter was operated using a 2-stroke, air cooled petrol engine of 1.75 hp @ 6500 rpm, whose power was transmitted to the other accessories using chain and sprocket drive.

3.6 Performance Evaluation of Developed Power Operated Paddy Transplanter

The performance assessment of the developed power operated paddy transplanter involved its field testing and measurement of physiological cost and drudgery involved in its operation**.**

3.6.1 Field testing parameters

The performance testing of the developed power operated two row paddy transplanter was carried out in kharif season in Kumbhave, a village in Dapoli tehsil during 2017-18. The field performance test was carried out to determine the same parameters as evaluated for the field performance testing of the manually operated

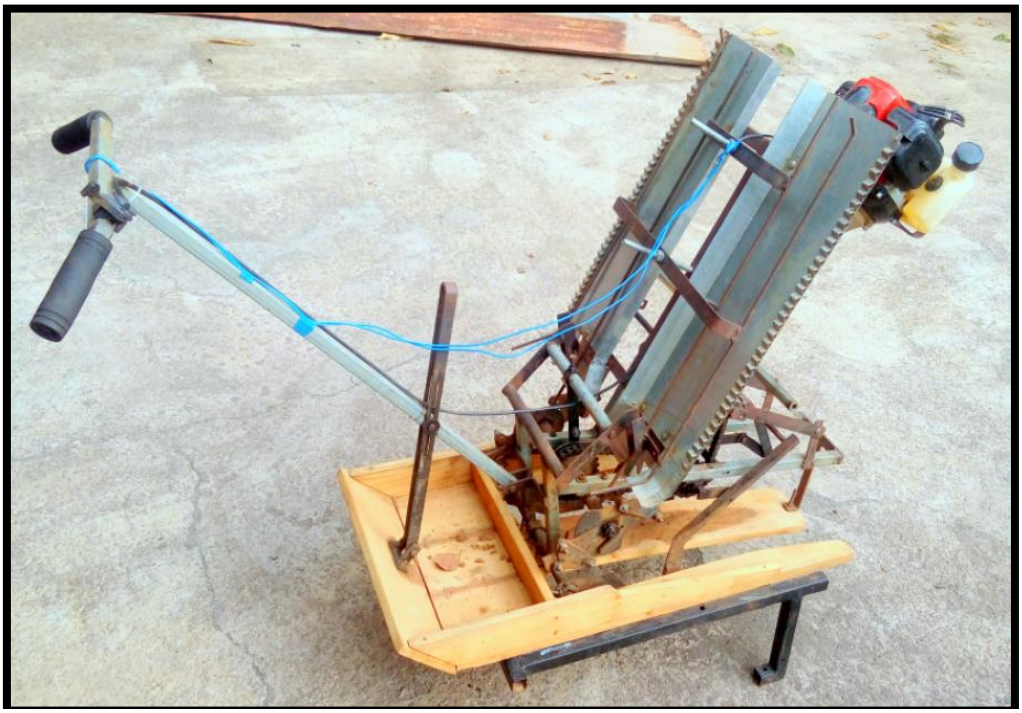


Plate 3.16 Developed power operated paddy transplanter

paddy transplanter described in section 3.2.2.3. The fuel consumed by the transplanter was also measured.

3.6.1.1 Fuel consumption

Before starting the test, the fuel tank of the transplanter was filled to full capacity. After completion of the operation, the tank was refilled to its initial level. The volume of fuel required to top up the fuel tank was the amount the fuel consumed during the operation. The fuel consumption was measured in millilitre per unit time. When filling up the tank, careful attention was paid to park the machine on horizontal floor and ensured that empty space was not left in the tank.

3.6.2 Determination of physiological cost and drudgery involved in field testing of developed paddy transplanter

The ergonomic evaluation of the developed transplanter was carried using six male subjects based on the physiological parameters like working heart rate (WHR), overall discomfort score (ODR) and body part discomfort score (BPDS). The procedure for same has been discussed earlier in section 3.2.3.4.1, 3.2.4.1 and 3.2.4.2 respectively.

3.7 Instruments used in Field Performance Testing

i. Tachometer

Tachometer was used for measuring the speed of the operation. Analogue tachometer with least count of 5 rpm and range of 1-10000 rpm was used for this purpose.

i. Measuring tape

This was used to determine the dimensions of the testing field.

ii. Stopwatch

The stopwatch was used for measuring the time, required for completing one pass, and turning time. The least count of the stopwatch was 0.1 second.

iii. Measuring cylinder

While collecting the sample for measurement of the puddling index measuring cylinder was used to measure the quantity of soil settlement in puddling. Two measuring cylinders each of 2000 ml and 1000 ml were used for taking trials.

iv. Heart rate monitor

Polar RS 400Tm portable heart rate monitor was used for measuring the heart beat of operator, for ergonomic evaluation. It measured the heart beats range between 15 to 240 heart beats per minute.

v. Vernier calliper

The use of digital vernier calliper was done to measure the diameter of seedlings and also the thickness of the material used.

3.8 Cost economics of developed power operated paddy transplanter

The cost economics of developed power operated paddy transplanter was carried out according to IS 9164:1979. It included the evaluation of fixed cost, variable cost and operating cost. The formulae for determining these costs have been given below.

1. Fixed Cost

1. Depreciation (Rs. /h) = $\frac{C-S}{L \times H}$
2. Interest @ 5% (Rs. /h) = $\frac{C+S}{2} \times \frac{I}{100 \times H}$
3. Housing (Rs. /h) = 1.5 % of Initial cost
4. Total fixed cost = 1 + 2 + 3

2. Variable Cost

1. Operators cost = Wages of operator / Working hours
2. Repair and maintenance (Rs. /h) = 10% of Initial cost
3. Total variable cost = 1 + 2

3. Operating Cost

Operating cost = Fixed cost + Variable cost

Where,

C = Initial cost or cost of machine

H = Annual use of machine

I = Interest rate

L = Total life of machine

S = Salvage value

III. MATERIAL AND METHODS

This chapter deals with the procedures necessary to evaluate the performance of the existing two-row manually operated hand cranked paddy transplanter, steps to assess the drudgery involved in its transplanting operation, appropriate considerations and modifications to develop two row power operated paddy transplanter, its testing methodology and the steps involved in its performance evaluation.

In order to evaluate the performance of the existing manually operated paddy transplanter the step by step procedure followed is discussed below.

3.1 Nursery Preparation

The nursery used for performance evaluation of the existing manually operated paddy transplanter was prepared by adopting the following procedure.

3.1.1 Seed germination test

Paddy seeds of high yielding variety i.e. Ratnagiri-1 was selected for the study. The seed to be planted in nursery were placed for 24 hours in a bucket filled with water. After then, the seed were taken out and placed in gunny bags until they started to sprout. After the next 24 hours, the seeds sprouted well, which were then ready to plant on raised beds (Khatun, 2011). Simultaneously, three samples of 100 seeds each selected randomly from the 24 hour soaked seeds were placed and covered in piece of cloth to study the germination percentage.

The germination percentage was calculated by the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds in tray}} \times 100 \quad \ldots 3.1$$

3.1.2 Nursery plantation

In order to prepare healthy seedlings for transplanting, nursery was grown on a separate field. Three plots each of size 10m x 1m were raised as shown in Plate 3.1. The land preparation practice was carried out with the help of tractor by first ploughing and then levelling it. The height of raised bed was maintained between 15-20 cm. Trenches of 30 cm width were formed along the sides of each plot for draining out excess water. The sprouted seeds were used to plant on the bed as they could attain faster growth. The seeds were placed manually in equally spaced furrows made by hoe. Farm manure was used as fertilizer during the initial planting of seeds. Care was taken to maintain the seed density thereby planting half kg of seeds per plot.

(Kavitkar, 2016) The seeds were allowed to grow for a period of 35 days which was the optimized seedling period to transplant in the summer season (Patil, 2018).

3.2 Performance Evaluation of Existing Manually Operated Paddy Transplanter

The existing machine was studied by understanding its working. The performance of the machine was evaluated by conducting its field test and then accessed for the physiological cost and drudgery involved in its use.

3.2.1 Working of existing manually operated paddy transplanter

A two row manually operated hand cranked paddy transplanter for root washed seedlings was developed at College of Agricultural Engineering and Technology, Dapoli during 2015-16. The operations performed by the machine were handled by single operator. The machine consisted of main frame, camshaft assembly, seedling tray with frame, nursery shifter cum erecter mechanism, power transmission unit (chain and sprocket drive), float of G.I sheet and handle for pulling the machine. The operator had to pull the machine with one hand and perform hand cranking activity with the other. The hand cranked power of the operator was transmitted to the camshaft of the machine through chain and sprocket drive. The seedling tray of the transplanter was set in inclined position for the seedlings to slide down easily due to vibration and gravity force. The pickers rotation on the camshaft picked 3-4 seedlings from the bottom of the tray which were transplanted in soil by the erectors. The specifications of existing manually operated paddy transplanter are shown in Table 3.1.

Table 3.1 Specifications of existing manually operated paddy transplanter

Sr. No.	Particulars	Specification
1.	Length, mm	550
2.	Width, mm	450
3.	Height, mm	930
4.	Row to row distance, mm	250
5.	Float type	GI Sheet (22 SWG)
6.	Power transmission	Chain and sprocket
7.	No. of rows	2
8.	Weight, kg	14.6 kg

The overall dimensions of the manually operated paddy transplanter were 550 x 450 x 930 mm. The transplanter performed the operation in two rows by maintaining a fixed row to row distance of 250 mm. The float used for the machine was made of G.I sheet of 22 gauge. The power transmission of the machine was completed using chain and sprocket drive. The total weight of the machine was 14.6 kg. The existing manually operated paddy transplanter is shown below in Plate 3.2.

3.2.2 Details of experimental field

The machine was operated on a plain field by considering different parameters as given below.

3.2.2.1 Experimental site

The experiment was conducted in kharif season of 2017-18 in Kumbhave village of Dapoli tehsil, which is located at 17°45'18.31"N latitude 73°16'3.80"E longitude.

3.2.2.2 Soil characteristics

The soil of the experimental field was sandy clay loam in texture. The soil pH was 5.29, which indicated that the soil was acidic in nature. The available phosphorus and potassium were observed as 14.2 and 502.99 kg/ha, respectively. The sand, silt, clay proportion of the soil was 50:4.8:45.2. The average initial soil dry bulk density was observed as 1.28 g/cc before conducting the experiment.

3.2.2.3 Field testing parameters

The parameters necessary to evaluate the field performance of the existing two row manually operated transplanter are discussed below along with their methodology.

xiv. Plant to plant spacing

It was the spacing between two seedlings transplanted in one row. The measurements were taken using a 30 cm steel scale. Reading from different locations of the field were taken and averaged.

xv. Number of seedlings per hill

These were the seedlings transplanted by the manual transplanter on a single hill. Through visual observations, readings from different locations of the field were noticed and averaged.

xvi. Number of hills per row

The total number of transplanted hills of seedling in one row was noted when the operator completed the length of field from one end to other. Such readings of several passes was noted and averaged.

xvii. Missing of hills per sq. metre

The number of missing hills was determined by observation within an area of one sq. metre. By taking several readings, the average value of missing hills per sq. metre was noted.

xviii. Depth of transplanting

The depth of transplanted seedling was checked by uprooting these seedlings and measuring the soil immersed length of them using a steel scale of 30 cm..

xix. Total time required for separating seedlings

It was the time which included the uprooting of seedlings from the nursery, washing their roots, separating each seedling and keeping them ready to be transplanted in the main field. The total time requirement was recorded using a stopwatch.

xx. Total time of operation

The total operation time included separation of nursery as discussed above, feeding time of seedlings in the tray, turning time, refilling of tray, adjustments and the time lost in repairing. This time was recorded using stopwatch.

xxi. Speed of operation

The machine was operated for a distance of 20 m. The time required to complete this length was recorded using a stopwatch. Several readings were recorded to obtain an average value of time. The speed of transplanting was thus computed using the following equation.

$$S = \frac{D}{t} \times 3.6 \qquad \ldots 3.2$$

Where,

S = Transplanting speed, km/h;

D = Distance, m; and

t = Time required to cover the distance D, Secs.

xxii. Time required for turning

It was the time required by the machine to take turn after completion of each row. Summation of the time required at every alternate end of the row gave the total turning time of the machine.

xxiii. Actual field capacity

It is the actual area covered per unit time including the time loss in turning, feeding the seedlings on tray, repair and adjustment (Anonymous, 2010). It was calculated as,

$$AFC = \frac{A}{Tt} \quad \ldots 3.3$$

Where,

AFC = Actual field capacity, ha/h

A = Total transplanted area, ha and

Tt = Total operating time required for transplanting, h

xxiv. Theoretical field capacity

It is the theoretical area covered per unit time eliminating the time loss in turning, feeding the seedlings on tray, repair and adjustment. The width of operation and the speed of transplanting were considered to calculate the theoretical field capacity in ha/hr (Anonymous, 2010) and expressed by the following equation,

$$TFC = \frac{W \times S}{10} \quad \ldots 3.4$$

Where,

TFC = Theoretical field capacity, ha/h;

W = Operating width of the transplanter, m; and

S = Transplanting speed, km/h.

xxv. Field efficiency

It was expressed in percentage by taking the ratio of actual field capacity and theoretical field capacity as below.

$$\text{Field efficiency (\%)} = \frac{\text{actual field capacity}}{\text{theoretical field capacity}} \times 100 \quad \ldots 3.5$$

xxvi. Puddling index

Samples of freshly puddled soil were taken from the experimental field in a measuring cylinder filled up to the mark of 1000 ml volume. The puddled

soil sample consisted of soil and water mixture. These samples were kept undisturbed for a period of 48 hrs to achieve complete soil settlement. The puddling index was thus determined by using the following formula (Chaudhary and Varshney, 2008).

$$(PI) = \frac{Vs}{V} \times 100 \qquad \ldots 3.6$$

Where,

PI = Puddling index, %

Vs = Volume of soil, ml;

V = Total volume of the sample, ml.

3.3 Field Testing of Manually Operated Paddy Transplanter

The test was conducted in Kumbhave village of Dapoli tehsil from 03/04/2018 to 07/04/2018. The dimensions of the field used for testing were 17 x 10 m. Initially, the field was ploughed using a rotavator. The depth of tilling ranged from 10-15 cm. Shallow tillage of 15-20 cm depth was recommended when the transplanter was used in field. Depth of puddling maximum up to 10 cm was recommended for Japanese paddy transplanter (Singh and Garg, 1976). After loosening up of soil, puddling was carried out by flooding water in the field. Use of power tiller was done to carry out the puddling operation. Thereafter, the field was left undisturbed for a period of 48 hrs for the settlement of the soil. Transplanting was done after the soil was settled in the predetermined time. All the parts were inspected for the proper working, before introducing the machine into the field. The test was then carried out by using seedlings with age of 35 (DAS). All the field testing parameters as discussed in section 3.2.2.3 were evaluated to study the performance of the machine.

3.4 Computation of Physiological Cost and Drudgery Involved in Operation with Existing Manual Paddy Transplanter

A systematic procedure was followed to access the physiological cost and drudgery involved in the operation of manual paddy transplanter. The research study was extended to detect and analyse small physiological changes during the work. The calibration of this equipment along with its operation has been explained in the following section.

3.4.1 Selection of subjects

Six male subjects were selected for the ergonomic study. Care was taken that the subjects are medically fit for the study trials and they are true representative of the

user's population for the operation of paddy transplanter. For the selection of the subjects, age was the main criterion that was used. The age group of the subjects varied in the range of 25 to 35 years, because in this range maximum strength level is attained (Gite, 1997).

3.4.2 Computerized ambulatory metabolic measurement equipment (COSMED $K4b^2$)

Computerized ambulatory metabolic measurement equipment make COSMED, Italy model $K4b^2$ was a portable, light weight, battery operated equipment used to measure heart rate (HR) and oxygen consumption (VO_2) of subjects under laboratory condition (Plate 3.3).

3.4.2.1 Details of COSMED $K4b^2$

The COSMED $K4b^2$ measurement equipment had a portable unit which was fixed to the subject during the test by an anatomic harness. It contained O_2 and CO_2 analyzers, sampling pump, transmitter, barometric sensor and electronics. It was powered by rechargeable battery fixed to the back side of the harness. $K4b^2$ was provided with a small display to show real time measurements. The equipment had an inbuilt memory to save data file for downloading on computer laptop through the RS232 serial port for further analysis. The equipment also had a battery charging unit for simultaneous charging 3 Nickel-cadmium batteries and to supply power to the portable unit during warm-up time. The PC software running on Windows, allowed the user to view data in tabular and graphical form. The pulmonary function test provided the data for 22 breath by breath parameters, 10 indirect calorimetric parameters, 6 lactate threshold and 2 oxygen kinetics parameters (Goyal, 2016). Detailed specifications of $K4b^2$ metabolic system kit are given in Annexure I (A).

3.4.2.2 Calibration of COSMED $K4b^2$

The equipment was calibrated for four types of tests viz. room air calibration, reference gas calibration, delay calibration, and turbine calibration. The room air calibration forced by the equipment before every test, consisted of sampling room air. It updated the baseline of the CO_2 analyzer and gain of the oxygen analyzer, in order to match the readings with predicted atmospheric values (20.93% for oxygen and 0.03% for CO_2). The reference gas calibration, recommended to be carried out daily, consisted of sampling a gas with known composition (i.e. 16% for 0_2 and 5% for CO_2)

from a calibration cylinder and updating the baseline and gain of the analyzers in order to match the readings with the predicted values. The delay calibration, recommended to be carried out at least once a week was necessary to measure accurately the time necessary for the gas sample to pass through the sampling line before being analyzed. The turbine calibration consisted in measuring the volume of a 3 litres calibration syringe and in updating the gain of the flow meter in order to match the predicted value.

3.4.3 Calibration of subjects

The subject calibration was performed using bicycle ergometer of make Monark, model Ergomedic 839E which is shown in Plate 3.4. It was used to load the subject. It had a digital display for real time monitoring of data. The seat and handle bar of the ergometer were adjustable as per need of the subject's requirement. The details of Monark bicycle ergometer are provided in Annexure I (B).

An initial rest of 10 minutes was given for each subject and then was asked to pedal the bicycle at a rate of 60-65 rpm. The subject calibration was conducted by loading the subject on bicycle ergometer as shown in Plate 3.5. The maximum heart rate attainable by the subject was computed by the following relationship.

HR max = 220 - age in years …3.7

The test was continued until the subject attained 75 % of maximum heart rate (HR max) or until the subject felt completely exhausted, whichever reached earlier. The pedalling speed was maintained by using metronome which indicated green indicator for required pedalling speed and red indicator for low or high pedalling speed. Arrangement for increasing the workload automatically by 15 watt at an interval of every 2 minutes was provided on the device. The heart rate and corresponding VO_2 values for the increasing load were recorded on the K4b^2 unit and also on the computer. The breath by breathe values recorded of each subject were averaged in duration of one minute interval. Correlation between heart rate and oxygen consumption rate at specified sub maximal workloads were developed and the regression line was extrapolated to the age predicted maximum heart rate and VO_2 max corresponding to HR max was noted.

The subject loaded on the bicycle ergometer was connected with the K4b^2 unit along with the following sub-accessories.

ix. Heart rate monitor

The heart rate of the subject was measured using Polar RS 400Tm portable heart rate monitor. This device could also be used directly on the field to record the heart rate readings while operating the paddy transplanter. Details of Polar heart rate monitor are furnished in Annexure I (C).

x. Transmitter

Transmitter consisted of an electrodes and connector. The transmitter detected the heart rate from the body of the subject and converted to electromagnetic signals with the help of two electrodes, which were fixed in the grooved rectangular area on the underside of the belt transmitter. For better sensing, the electrode areas of the strap were well moistened.

xi. Elastic strap

Elastic strap had a connector which was placed in a central, upright position on the chest of the subjects. The strap length was adjustable which could fit comfortably around the chest, just below the chest muscles of the subject.

xii. Receiver

This unit received the signals from the transmitter, displayed it on the screen and recorded the data in the memory.

xiii. Interface

The interface could transmit the recorded heart rate values to the computer. Recorded heart rate values of the subjects were transmitted to the computer, which were also displayed in graphical form.

xiv. Harness

It served as a holder worn by the subject to hold the $K4b^2$ portable unit and other accessories.

xv. Exercise test mask

It is made of silicone and is connected with the flow meter assembly through which the respiration takes place.

xvi. Turbine flow meter

The turbine flow meter assembly consists of a bidirectional turbine and an optoelectronic reader. The device is used to measure infrared light interruptions caused by the spinning blade inside the turbine. Its calibration should be performed regularly to assure accurate measurements.

3.4.4 Ergonomic evaluation of manually operated paddy transplanter

Along with the field performance, the existing manually operated transplanter was evaluated ergonomically to access the drudgery involved in transplanting operation. The six male subjects previously calibrated in laboratory were selected for the study. They were given all the instructions related to the test. Accordingly, the trials were conducted. Each subject was initially given sufficient rest to bring their heart rate to normal. Thereon, the trial was started. The subject was made to operate the transplanter until he felt exhausted. The heart rate data of the first resting time and also of the operation time were recorded in beats per minute (bpm) using Polar RS 400 Tm portable heart rate monitor. The recorded heart rate values were downloaded to the computer. The average heart rate from 6^{th} min up to the completion time was computed for the further calculation and analysis. The same procedure was adapted to all the selected subjects. Following were the parameters used to determine the physiological cost involved in operating manual paddy transplanter.

3.4.4.1 Heart rate (HR)

Measuring heart rate is one of the most useful ways of assessing the workload because it can be done very conveniently (Sinha, 2014). Thus, heart rate of the subjects was recorded during the operation by using the heart rate monitor. All the functions of the heart rate monitor were set as per instructions given in the manual. The subjects were given sufficient rest before starting the trial to make the heart rate normal. From the downloaded data, the values of HR were taken for calculation of working HR as the physiological response of the subjects.

3.4.4.2 Oxygen consumption rate (OCR)

The oxygen consumption of subjects during the operation was carried by indirect assessment. From the mean values of heart rate determined during the experiment, a graph representing linear relationship between heart rate (HR) and oxygen consumption rate (OCR) was plotted.

3.4.4.3 Energy expenditure rate (EER)

The oxygen consumption rate (OCR) corresponding to heart rate of the male subjects during operation with manually operated paddy transplanter were predicted from the calibration chart of each individual subject. The energy expenditure during the experiments was computed by multiplying the oxygen consumption values with the calorific value of oxygen, which is 20.88 kJ/l (Nag *et al*. 1980).

i.e. EER (kJ/min) = OCR (l/min) x 20.88 …3.8

The values of HR, OCR and EER for all the subjects were averaged to get the mean values for all the selected subjects. On the basis of the values of EER in kJ/min, the grade of work was decided.

3.4.4.4 Acceptable work load (AWL)

Work load can be expressed as percentage of the individual's maximal aerobic power (VO_2 max) *i.e.* how much of the individual's maximal aerobic power has to be taxed in order to accomplish the work in question. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of the VO_2 max (Saha *et al.* 1979). To ascertain whether the operations selected for the trails were within the acceptable workload (AWL), the oxygen uptake in terms of VO_2 max (%) for each treatment was computed.

3.4.4.5 Limit of continuous performance (LCP)

The extent to which a person may increase his work rate depends in part on how much he can increase his heart rate from resting level to his maximum level, because the increase in heart rate plays a major role in increasing the cardiac output from rest to maximal work.

To have a meaningful comparison of physiological response, the difference in the working and resting heart rate i.e. is (ΔHR) and was compared with the acceptable work pulse values of 40 bpm.

3.4.4.6 Work rest cycle

This is the actual rest that must be taken by a subject after he has undergone some strenuous farming operation. At extreme workload a person could work only for few seconds. In order to reap a better performance from the subject he must be given ample time of rest after carrying any operation. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO_2 max. Better performance can be expected from worker only when proper attention is given for the work rest schedule in different operation. The actual rest time taken for each subjects while transplanting was found from the heart rate response curves of subjects. To determine the rest pause after the transplanting operation the following formula was used (Murrel, 1965),

$$R = \frac{T\,(K-S)}{K-1.5} \qquad \ldots 3.9$$

Where,

R = Rest required, min

T = Total working time, min

K = Average kcal per min of work

S = Average kcal per min adopted as standard

3.4.5 Subjective evaluation of discomfort caused in operating manual paddy transplanter

The subjective evaluation of discomfort was done by computing overall discomfort score and body part discomfort score of the subjects while on the field. The methodology of the same has been discussed in the subsequent sections.

3.4.5.1 Overall discomfort rating (ODR)

Overall discomfort rating is the method of accessing the overall body discomfort. A 10 point psychophysical rating scale marked 0 to 10 digits (0 - no discomfort, 10 extreme discomforts) was used to assess the overall discomfort rating (Corlett and Bishop, 1976). The numbers on the scale showed the level of discomfort experienced by subject during the experiment. The scale had a movable pointer to indicate the overall discomfort rating as shown in Fig 3.1. At the end of each experiment, each subject was asked to indicate their overall discomfort rating on this scale. The overall discomfort ratings given by each subjects was added and averaged to get the mean rating.

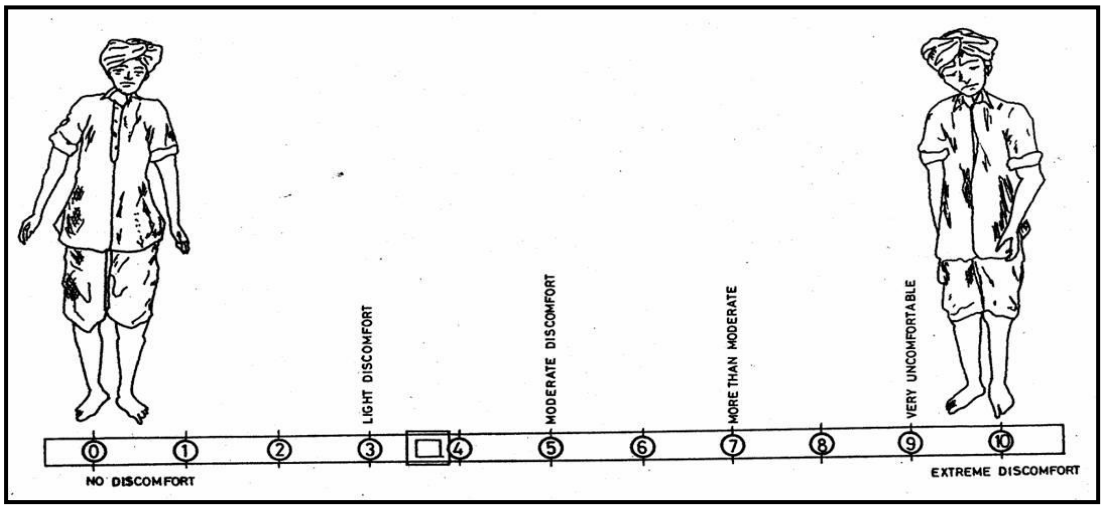


Fig 3.1 Visual discomfort scale for assessment of overall body discomfort

3.4.5.2 Body part discomfort score (BPDS)

To measure body part discomfort score (BPDS), the technique of dividing subject's body into 27 regions was used (Corlett and Bishop, 1976) as shown in Fig

3.2. After completion of the work, the subjects were asked to point out the painful regions which caused discomfort during the operation. It was meant to mention all the body parts which caused discomfort, starting with the least painful and next painful and so on until all painful body parts had been mentioned. The number of different groups of body parts, which were identified from no discomfort to extreme discomfort, represented the number of intensity levels of pain experienced by the worker. The body part discomfort score of each subject was calculated by multiplying the number of body parts corresponding to each category. The total body part score for a subject was the sum of all individual scores of the body parts assigned by the subject. The body discomfort score of all the subjects were lastly added and the average value gave the discomfort score.

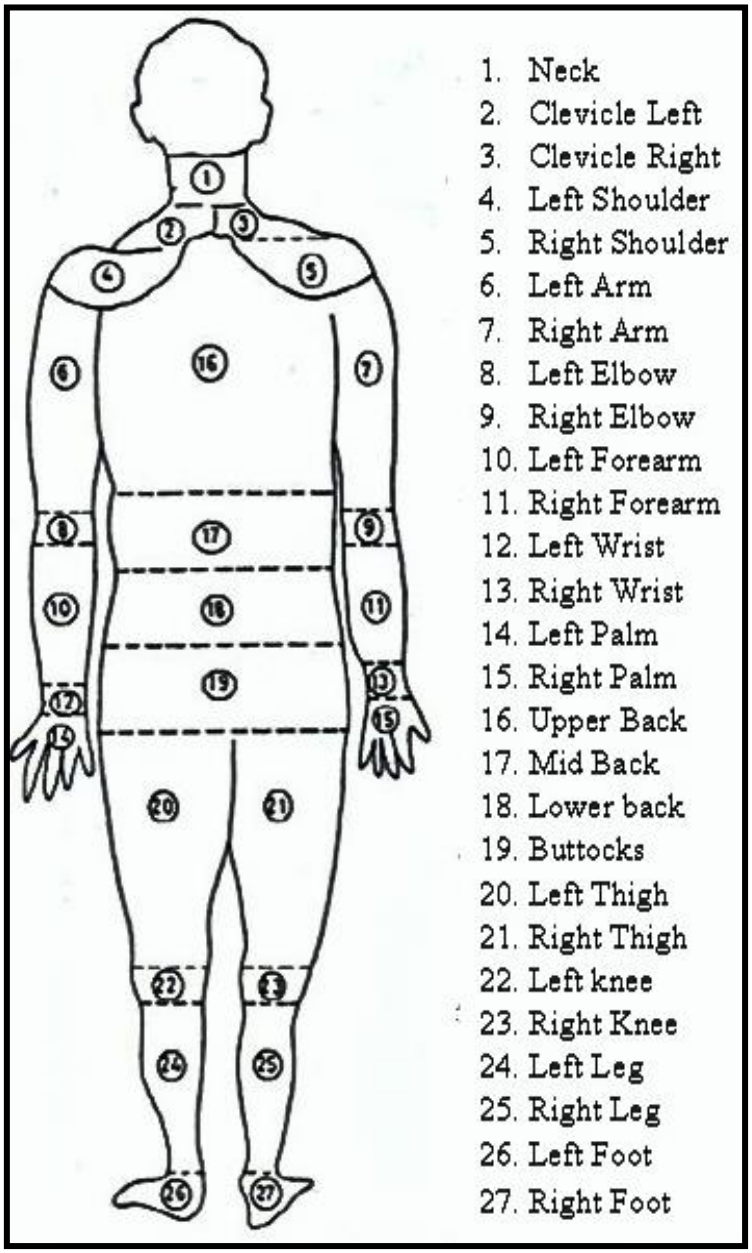


Fig 3.2 Regions for evaluating body part discomfort score

3.5 Refinement in the Existing Manually Operated Paddy Transplanter

The manually operated paddy transplanter was pulled by one hand and simultaneously the cranking operation was accomplished by other hand. It proved to be a cumbersome operation. So, for the purpose of refinement, the hand cranking mechanism was eliminated. Now, there arouse a need to design the handle to pull the developed transplanter by both hands. Thus, the handle design considerations included determining the grip length, handle length and handle height.

3.5.1 Ergonomic design features of power operated paddy transplanter

The ergonomic design feature of the following components of developed power operated paddy transplanter was finalized by using the anthropometric and strength data of Indian agricultural workers (Gite *et al.* 2009).

3.5.1.1 Design of handle

The purpose of handle is to facilitate the transmission of force from the musculoskeletal system of the user to the tool or object he is using in the performance of the task for which he is using it (Pheasant, 1986).

3.5.1.1.1 Height of handle

The height of handle was kept adjustable to make it convenient to pull by 95 per cent of the working population. The elbow height (standing) data was helpful for designing proper handle height. The desirable height of handle for continuous work should be 0.8 of 5^{th} percentile to 0.7 of 95^{th} percentile of the acromial height leading to less work stress (Gite & Yadav, 1990). As per the anthropometric data, 0.8 of 5^{th} and 0.7 of 95^{th} percentile values of acromial height for male worker under "All India" category were 1005 and 1027 mm, respectively. Hence, the handle height was finalized in between the limiting values of these two anthropometric parameters.

3.5.1.1.2 Length of handle

For maximum work efficiency, it was suggested that the elbow flexion angle should be in the range of 85 – 110° (Grandjean, 1982). Considering the elbow flexion angle as 100°, elbow height and elbow grip length values, the optimum length of handle can be found out (Tewari *et al.* 2007). Thus, the 5^{th} and 95^{th} percentile values for elbow height and elbow grip length were 938 and 1115 mm and 304 and 404 mm, respectively. So, the length of handle was decided based on this consideration.

3.5.1.1.3 Diameter of handle grip

The handle of machine should vary in size between the hand and finger size, as the maximum voluntary finger contraction force is diameter-dependent. 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. So, the 95^{th} percentile value of middle finger palm grip diameter for male workers was considered as lower limit while 5^{th} percentile of their inside grip diameter was considered as the upper limit (Dewangan *et al.* 2010).

3.5.1.2 Pull force measurement

The pull force was determined using Novatech load cell capable of measuring load capacity up to 40 kg with 1 g accuracy. It was attached to the handle of machine. The load was read from the readings displayed on the digital indicator. The load cell with digital indicator used for testing is shown in Plate 3.6.

3.5.2 Mechanical development of power operated paddy transplanter

There was a need to refine the existing manually operated paddy transplanter to make it more sophisticated and comfortable for the operator to work in the puddled field. The machine was pulled by directing it with one hand and operating the cranking mechanism with the other hand. So, a considerable amount of energy was consumed by the operator to perform the operation. Therefore, an alternative was found to make the cranking mechanism to be power operated. This was achieved by using a suitable petrol engine. It was also observed that the G.I float used on the existing machine could stick to the puddled soil while pulling, which imposed higher pulling force on the operator, so it was necessary to replace it. The nursery holder was found to be ineffective in holding the nursery in tray. It resulted in dropping excess amount of nursery from the tray, so the component was modified to save the excess loss of seedlings. The picking mechanism of cam resulted in abrupt opening and closing which made the operation noisy and damaged the follower, thus the cam was to be re-designed for smooth functioning. The tension springs used in the picking mechanism which served the purpose of expansion and contraction were needed to be replaced as the tension in the spring was reduced slowly. Therefore, new springs were used to withstand the continuous tension and compression occurred during the

operation. Hence, it was decided to re-fabricate the manual transplanter and make it more user-friendly. Also, being a power operated machine, focus was also given to make the machine lighter in weight by using light weight material for fabrication having good strength.

3.5.2.1 Calculation of power requirement for developed power operated paddy transplanter

The power required for refined machine was determined by computing the torque for hand-cranking and measuring the required speed (rpm). For this purpose, the machine was jacked up. A load cell was connected to the handle of the machine. As the handle was rotated, the load cell connected to the indicator displayed the load readings. The maximum load was noted at four places considered 90° apart. The operation was continued for one minute by repeating the procedure three times. The maximum average value of cranking force was 0.99 kg. The radial distance of the handle was predetermined which was 0.21 m.

During the hand cranking operation, the speed at which the camshaft assembly rotated was measured using contact-type tachometer. The average value of the camshaft revolutions was observed as 67 rpm. From the existing manually operated paddy transplanter, the following results were recorded.

Hill to hill spacing = 0.15 m

Row to row spacing = 0.25 m

Field capacity = 0.030 ha/hr = 300 m^2/h

During one revolution of the shaft, the transplanting operation occurred twice i.e. covering a length of (0.15 + 0.15) = 0.30 m.

Hence the area covered in one revolution of the shaft was,

= 0.30 m x 0.25 m = 0.075 m^2

Therefore, to complete an area of 300 m^2, the total no. of revolutions required were,

= 300 / 0.075 = 4000 rev / h

= 67 rev / min.

From the above data, the power requirement was calculated as:

$$\text{Power required (P)} = \frac{2\pi NT}{4500}$$

Where,

P = required engine power, hp

N = no. of revolutions obtained on main shaft, rpm

T = torque or cranking force, kg.m

- $P = \frac{2 \times \pi \times 67 \times 0.21}{4500}$
- Power requirement= 0.019 hp = 14.65 watt ≈ 15 watt

The shaft of the transplanting arm revolves at a speed ratio of 2:1 with the camshaft speed. Hence the speed of the transplanting arm was taken to be 134 rpm.

3.5.2.2 Power source and power transmission system

An available petrol engine of 1.28 kW (1.75 hp @ 6500 rpm) was used. It was a single cylinder, 2-stroke and air cooled engine. It weighed about 4.5 kg. The engine was equipped with a speed reduction unit having speed ratio of 32.5:1 as a result of providing an output speed of 190 rpm. This speed was further reduced to 134 rpm as required on the transplanting arm shaft, by employing two sprockets each of 12 and 17 teeth resulting in speed ratio of 1.42:1. The engine along with speed reduction unit is shown in Plate 3.7. The flow of motion from speed reduction unit to the camshaft is shown in Fig. 3.3.

3.5.3 Mechanical components of the developed power operated paddy transplanter

The components fabricated of the power operated paddy transplanter have been described below.

5 Float

It was the main component which was in contact with the soil. The float of the machine was made of wooden plank. The edges of the float were raised 75 mm high to avoid the entry of puddled soil in it. It also helped in easy dragging of machine over the puddled field surface. The schematic view of float is shown in Fig 3.4.

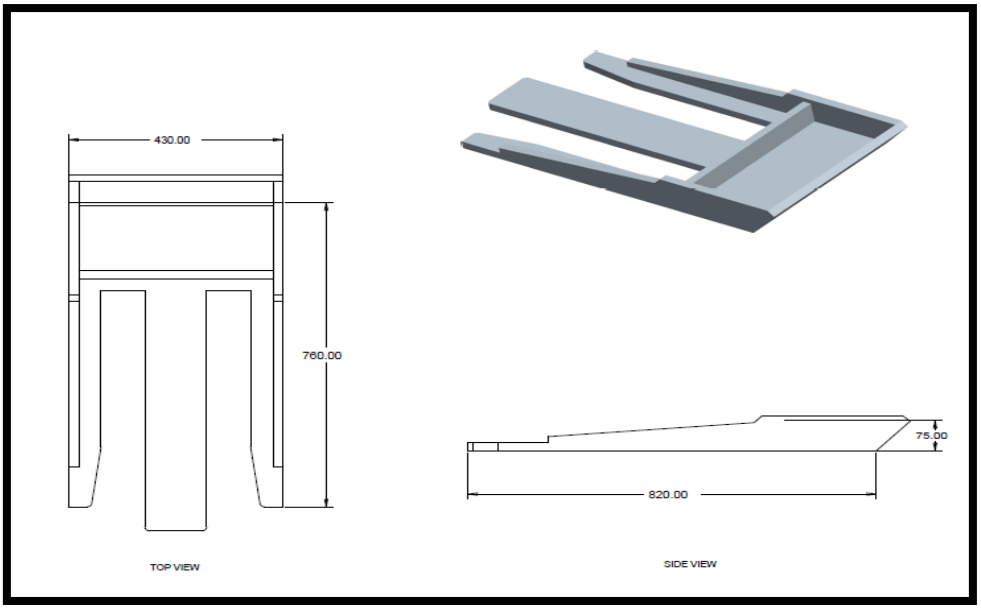


Fig 3.4 Schematic view of designed wooden float

6 Main frame

It was the important constructional component of the transplanter. All the other accessories like seedling tray, engine frame and handle were attached to the main frame. It was fabricated using galvanized iron (G.I) hollow square pipe of 20 x 20 x 3 mm which made the frame lighter in weight, rigid and achieve good strength. The developed main frame is shown in Plate 3.8.

7 Nursery tray assembly

The function of carrying the seedlings on the transplanter was done by the nursery tray. Two compartments were made on the tray to deliver the seedlings in two rows. The length of tray was decided on the fact that the operator will have to fill the tray minimum times to complete the transplanting operation. The tray was made using 22 gauge galvanized iron (G.I) sheet. The outer edge of the tray length was stripped with undulating surface to refrain the seedlings from falling downwards and to avoid overcrowding at picking point. The fabricated seedling tray with frame is shown in Plate 3.9.

8 Camshaft assembly

Cam was the rotating machine element imparting reciprocating or oscillating motion to another element known as follower. For the developed paddy transplanter radial cam having roller type follower was considered. The initial step was to construct the displacement diagram to make the cam profile. The constructed cam

profile was then marked on M.S. sheet of 3 mm thickness. The profile cutting was performed by laser cutting which gave a precise cut and finish. In the developed machine there were two cams mounted for two different reasons i.e. one for nursery planting mechanism and another for nursery holding and nursery pushing mechanism. The constructional details of displacement diagram and cam profile are explained as follows.

e) Construction of displacement diagram to nursery planting mechanism cam

xi. Initially, by considering the stem diameter of seedling, the stroke length was decided. The maximum and minimum intermediate size of the cam was decided to be 120 mm and 80 mm respectively. Thus, the stroke length was taken as 40 mm.

xii. The outstroke of 20^0, dwell period 160^0, and the return stroke of 20^0 and remaining resting of 160^0 was assumed.

xiii. A horizontal line AX = 360^0 was drawn with suitable scale.

xiv. On this line, AS = 20^0 was marked to represent the outstroke of the follower, dwell period was marked as SR =160^0, RP = 20^0 represented the return stroke, and the resting period was represented by PX = 160^0.

xv. Stroke length of the follower = 40 mm was drawn to mark a vertical line AY to complete the rectangle.

xvi. The angular displacement during outstroke and return stroke was divided into six equal parts and represented by drawing six vertical lines.

xvii. The follower moves with simple harmonic motion, therefore by considering AY as diameter, a semicircle was drawn which was divided into six equal parts.

xviii. From points a,b,c… etc. horizontal lines intersecting the vertical lines through 1, 2, 3... etc. and 0',1', 2'... etc at B,C,D were drawn.

xix. The points A, B, C… were joined with smooth curves.

xx. The complete displacement diagram is as shown in Fig 3.5.

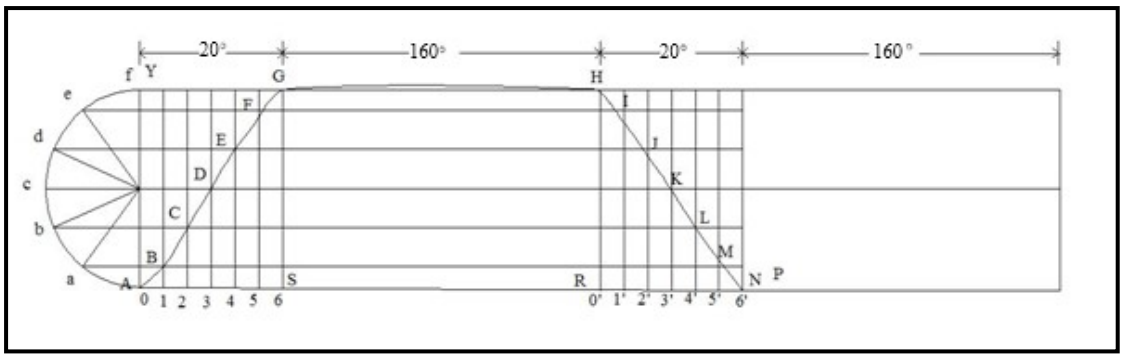


Fig 3.5 Construction of cam displacement diagram

f) Construction of cam profile for nursery planting mechanism cam

ix. For constructional purpose, it was considered that the axis of follower passes through axis of camshaft.

x. So, the base circle having radius equal to the minimum radius of cam i.e. 40 mm was drawn with the 'O' as centre.

xi. Angle AOS = 20^0, angle SOR = 160^0 and angle ROP = 20^0 was marked, which represented the outstroke, dwell and return stroke respectively.

xii. As like the displacement diagram, angle AOS and angle ROP was divided into six equal parts.

xiii. Taking centre as O, the points 1, 2, 3 and 0', 1', 2', 3' were joined.

xiv. Now distance of 1B, 2C, 3D and 0'H, 1'J… was referred from the displacement diagram.

xv. The cam profile was completed by joining points A, G, G' and A' as shown in Fig 3.6.

xvi. The fabricated nursery planting mechanism cam is shown in Plate 3.10.

g) Construction of displacement diagram to nursery holding and pushing mechanism cam

xii. Nursery holding and pushing mechanism was completely operated by rotating cam and roller follower.

xiii. The stroke length of cam was determined from the size of radial intermediate axis.

xiv. The maximum intermediate size was 140 mm and minimum size was 100 mm which was measured by considering the measurements of nursery stem diameter. Thus, the stroke length considered was 20 mm.

xv. The outstroke of 15^0, dwell period 20^0, return stroke of 15^0 and remaining resting of 130^0 was assumed.

xvi. Horizontal line of AX = 360^0 was drawn with suitable scale, by marking AS = 15^0 to represent the outstroke of the follower, ST = 20^0 to represent the dwell and TP = 15^0 to represent the return stroke and P0 = 130^0 to represent resting period.

xvii. A 20 mm vertical line AY was drawn, which is the stroke length of follower and completed the rectangle.

xviii. Dividing the angular displacement during outstroke and return stroke in to six equal numbers of parts, the vertical lines were drawn.

xix. Since the follower moves with simple harmonic motion, therefore a semicircle with AY as diameter were drawn and divided into six equal parts.

xx. From points a, b, c horizontal lines intersecting the vertical lines through 1, 2, 3...etc and 0',1',2'... etc at B,C,D....M, N, P were drawn.

xxi. The points A, B, C....etc were joined with smooth curves as shown in Fig. 3.7

xxii. Same procedure was followed for next outstroke and return stroke.

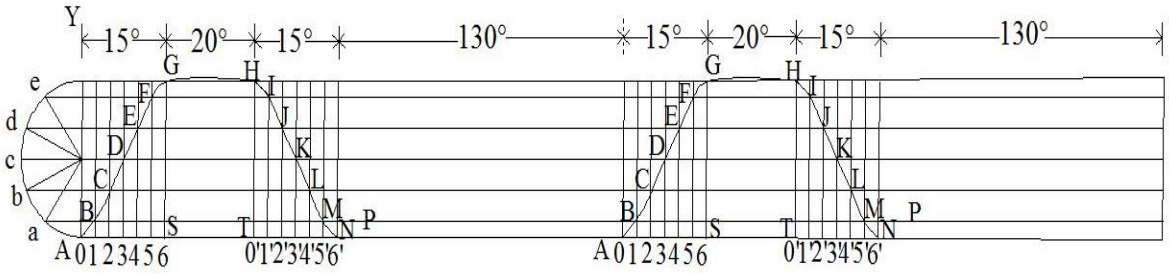


Fig 3.7 Displacement diagram for nursery holding and pushing cam

h) Construction of cam profile for nursery holding and pushing mechanism cam

9) It was considered that the axis of follower passes through axis of camshaft.

10) Base circle with the radius equal to the minimum radius of the cam such as 50 mm was drawn with the 'O' as centre.

11) Angle AOS = 20^0, angle SOT = 15^0 and angle TOR = 20^0 represented the outstroke, dwell and return stroke, respectively.

12) Angle AOS and angle TOR was divided into six equal parts as same the displacement diagram.

13) Points 1, 2, 3 and 0', 1', 2', 3' were joined with the centre O.

14) Now 1B, 2C, 3D and 0'H, 1'J, distance were set from the displacement diagram.
15) Points A, B, C… L, M, N was joined which completed the profile diagram. The curve AGHRAGHRA represented complete profile of cam.
16) The schematic view and the developed nursery holding and releasing cam are shown in Fig 3.8 and Plate 3.11, respectively**.**

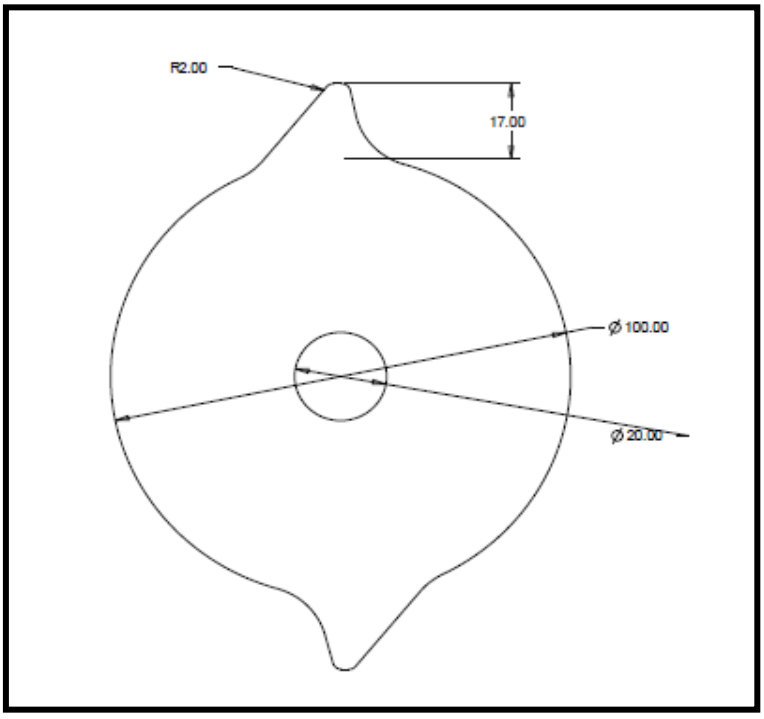


Fig 3.8 Cam profile of nursery holding and pushing cam

8 Nursery picking assembly

The picking assembly was mounted on the camshaft along with the nursery picking and nursery releasing cam. The long picking plate with forks rotated on the shaft which carried the seedlings from the tray to the transplanting assembly. The follower plates two on either side assisted the seedling to be caught precisely and carry on to the bottom position from where the seedlings could be transplanted by the arm and the erector. The motion of follower plate was actuated by tension springs that expanded and contracted as the roller bearing moved along the cam profile. The picking assembly, spring and roller bearing are shown in plate 3.12, 3.13 and 3.14 respectively.

9 Transplanting arms

The transplanting arms of machine served the purpose of transplanting the seedlings carried by the picking assembly in the puddled soil. The arms were

fabricated using mild steel sheet of 3 mm thickness with laser cutting. The transplanting action was actuated using four bar mechanism. The arms moved analogous to the movement of the main shaft. Both the shafts i.e. main shaft and transplanting arm shaft were connected with chain and sprocket joint. The power to the transplanting arms was supplied by the speed reduction unit run by the petrol engine. The movement of the transplanting arm shaft rotated in 2:1 ratio with the main shaft to make transplanting possible twice for each turn of the main shaft. The schematic view of transplanting arms is shown in Fig 3.9.

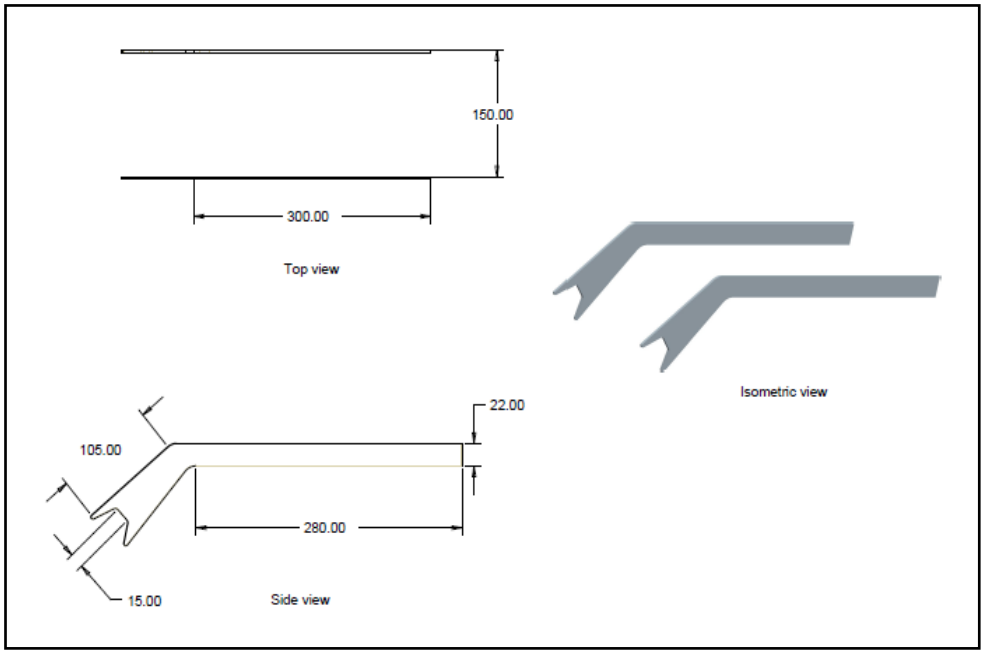


Fig 3.9 Schematic view of transplanting arms

10 Seedling erector

The main function of erecting the seedlings in puddled field was accomplished by the seedling erector. It was fixed to the bottom of the main frame. The seedlings after caught in horizontal position by the picking assembly, was dipped in standing position by the erector. The transplanting arm during its motion touched the erector almost completely as too much clearance between the both could have left the seedlings unattended resulting in increased floating of seedlings. The fabricated seedling erector has been shown in Plate 3.15

The schematic views of the developed paddy transplanter are shown in Fig. 3.10, and 3.11 respectively.

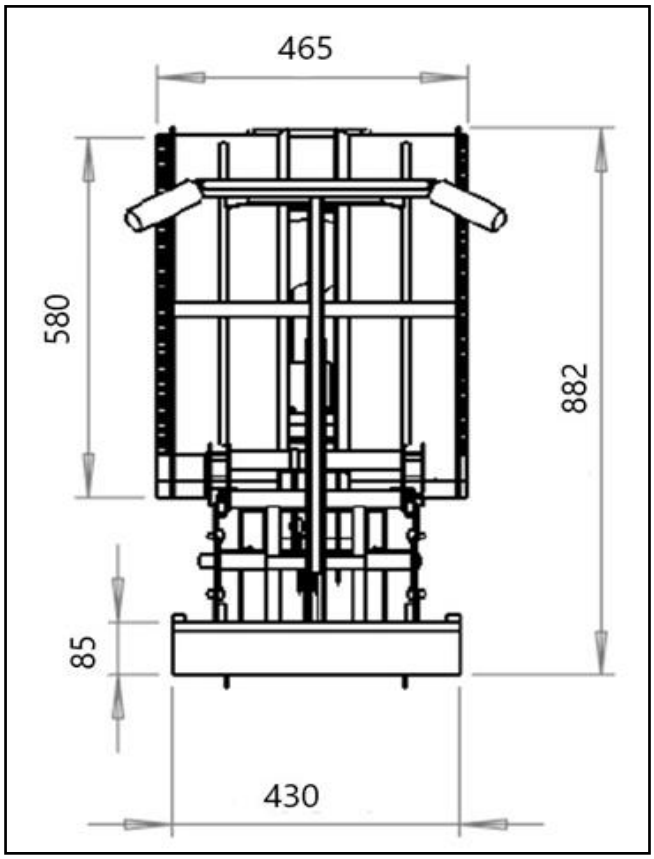


Fig 3.10a Front view of developed paddy transplanter

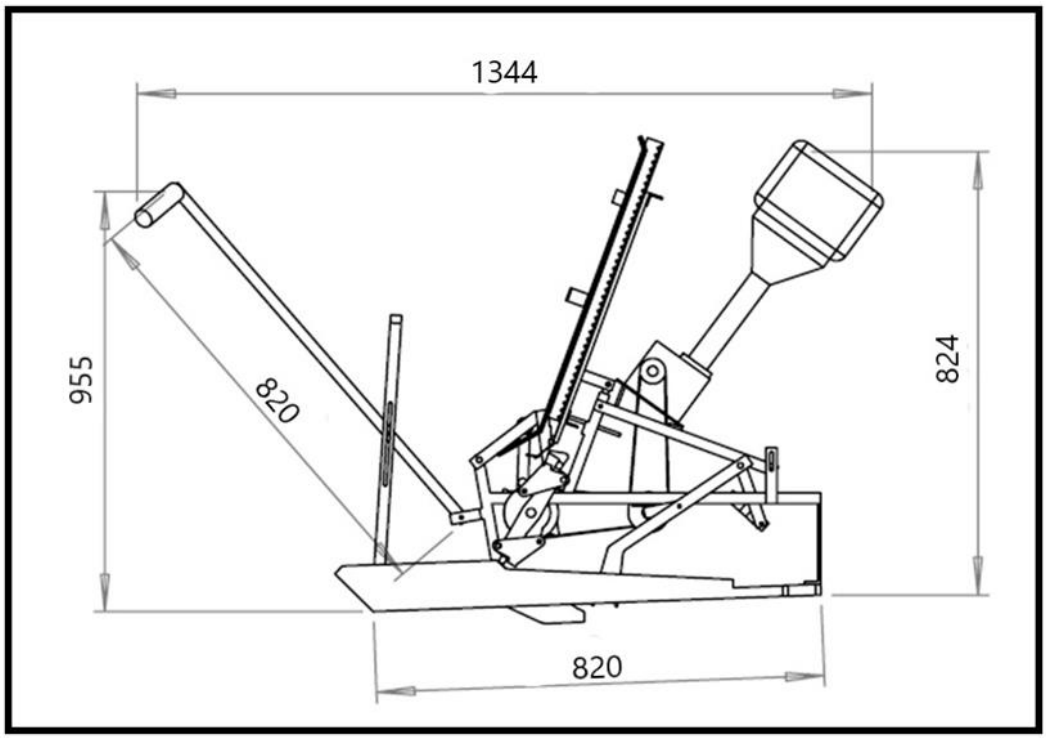


Fig 3.10b Side view of developed paddy transplanter

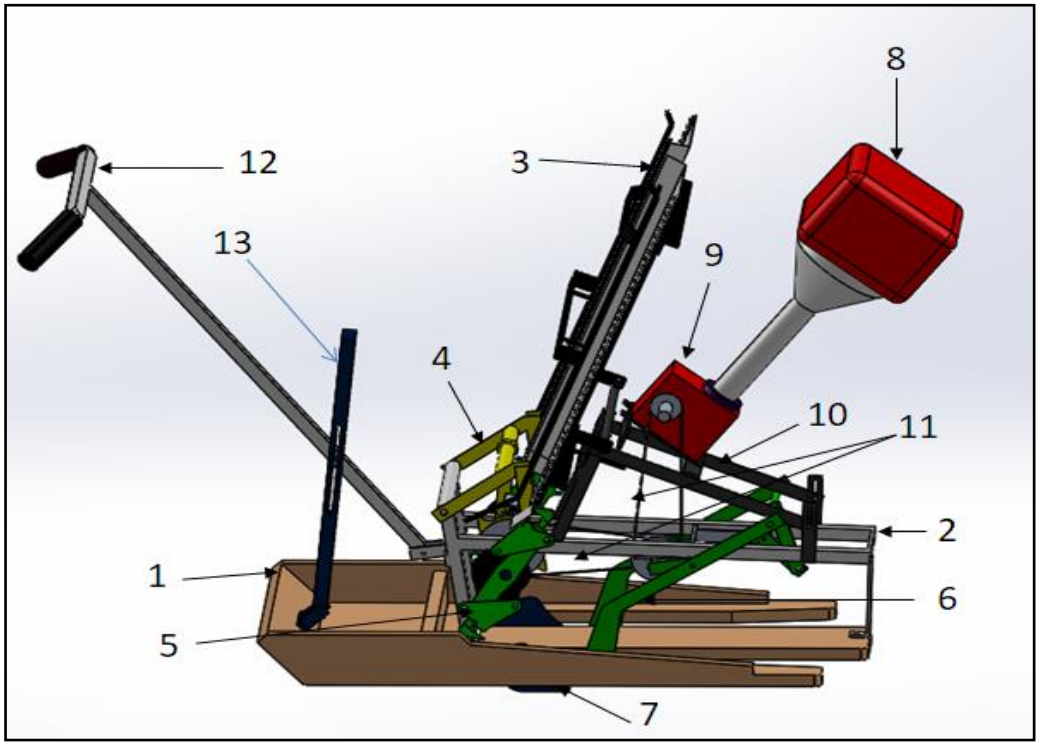


Fig 3.11 Schematic view of developed power operated paddy transplanter

14. Float
15. Main frame
16. Seedling frame with tray
17. Nursery holder
18. Picking assembly
19. Transplanting arm
20. Nursery erector
21. Engine
22. Speed reduction unit
23. Engine support
24. Chain and sprocket
25. Handle
26. Adjustment for handle height

3.5.4 Working of developed power operated paddy transplanter.

The developed power operated paddy transplanter was driven by petrol engine. The power from the engine was supplied to the transmission unit which helped in reducing the engine speed and achieving the required speed for operation. This power was transferred to the transplanting arm shaft with the help of chain and sprocket. The required speed of 134 rpm (section 3.5.2.1) was achieved by using sprocket of 17 teeth and 12 teeth thus, giving speed ratio of 1.42:1. This power from the transplanting shaft was further delivered to the camshaft assembly. Here, reduction in the speed ratio of 2:1 was achieved by using another 12 teeth and 24 teeth sprockets which gave 67 rpm on the camshaft. The engine speed used for transplanting operation was controlled by using a throttle fixed on the handle of the machine. The handle was kept adjustable so as to make it convenient for any operator to pull with minimum efforts. The handle was raised from wooden float. The float was the interacting component of the machine with the puddled soil. It helped in easy pulling and causing minimum sinkage of machine during the operation.

The main frame fixed on the float served as an important component to attach all the other components. The seedling tray was supported from the frame. It was set in an inclined position for easy flow of seedlings from the tray towards the bottom. The trays were filled with root washed seedlings. The seedlings were picked from the bottom of the tray by the picking and pushing cam assembly and transplanted in two rows by the transplanting arm. The nursery holder served the purpose of holding the nursery meanwhile in the tray. The required quantity of 2-3 seedlings were picked precisely and transplanted in the soil. The operation was carried out by pulling the machine with two hands and controlling the operation speed with the throttle when needed. The developed power operated paddy transplanter is displayed in Plate 3.16.

The detailed specifications of developed two row power operated paddy transplanter are furnished in Table 3.2.

Table 3.2 Detailed specifications of developed power operated paddy transplanter

Sr. No.	Particulars	Specification
10.	Weight, kg	28.65
11.	Length, mm	1344
12.	Width, mm	465
13.	Height, mm	882
14.	Row to row distance, mm	250
15.	Float type	Wooden
16.	Power source	2 stroke petrol engine (1.75 hp @ 6500 rpm)
17.	Power transmission	Chain and sprocket
18.	No. of rows	2

The developed paddy transplanter weighed about 29 kg. The overall dimensions of the transplanter were 1344 x 465 x 862 mm. It transplanted two rows simultaneously at a distance of 250 mm apart. The developed transplanter was operated using a 2-stroke, air cooled petrol engine of 1.75 hp @ 6500 rpm, whose power was transmitted to the other accessories using chain and sprocket drive.

3.6 Performance Evaluation of Developed Power Operated Paddy Transplanter

The performance assessment of the developed power operated paddy transplanter involved its field testing and measurement of physiological cost and drudgery involved in its operation**.**

3.6.1 Field testing parameters

The performance testing of the developed power operated two row paddy transplanter was carried out in kharif season in Kumbhave, a village in Dapoli tehsil during 2017-18. The field performance test was carried out to determine the same parameters as evaluated for the field performance testing of the manually operated paddy transplanter described in section 3.2.2.3. The fuel consumed by the transplanter was also measured.

3.6.1.1 Fuel consumption

Before starting the test, the fuel tank of the transplanter was filled to full capacity. After completion of the operation, the tank was refilled to its initial level.

The volume of fuel required to top up the fuel tank was the amount the fuel consumed during the operation. The fuel consumption was measured in millilitre per unit time. When filling up the tank, careful attention was paid to park the machine on horizontal floor and ensured that empty space was not left in the tank.

3.6.2 Determination of physiological cost and drudgery involved in field testing of developed paddy transplanter

The ergonomic evaluation of the developed transplanter was carried using six male subjects based on the physiological parameters like working heart rate (WHR), overall discomfort score (ODR) and body part discomfort score (BPDS). The procedure for same has been discussed earlier in section 3.2.3.4.1, 3.2.4.1 and 3.2.4.2 respectively.

3.7 Instruments used in Field Performance Testing

ii. Tachometer

Tachometer was used for measuring the speed of the operation. Analogue tachometer with least count of 5 rpm and range of 1-10000 rpm was used for this purpose.

vi. Measuring tape

This was used to determine the dimensions of the testing field.

vii. Stopwatch

The stopwatch was used for measuring the time, required for completing one pass, and turning time. The least count of the stopwatch was 0.1 second.

viii. Measuring cylinder

While collecting the sample for measurement of the puddling index measuring cylinder was used to measure the quantity of soil settlement in puddling. Two measuring cylinders each of 2000 ml and 1000 ml were used for taking trials.

ix. Heart rate monitor

Polar RS 400Tm portable heart rate monitor was used for measuring the heart beat of operator, for ergonomic evaluation. It measured the heart beats range between 15 to 240 heart beats per minute.

x. Vernier calliper

The use of digital vernier calliper was done to measure the diameter of seedlings and also the thickness of the material used.

3.8 Cost economics of developed power operated paddy transplanter

The cost economics of developed power operated paddy transplanter was carried out according to IS 9164:1979. It included the evaluation of fixed cost, variable cost and operating cost. The formulae for determining these costs have been given below.

1. Fixed Cost

1. Depreciation (Rs. /h) = $\frac{C-S}{L \times H}$
2. Interest @ 5% (Rs. /h) = $\frac{C+S}{2} \times \frac{I}{100 \times H}$
3. Housing (Rs. /h) = 1.5 % of Initial cost
4. Total fixed cost = 1 + 2 + 3

2. Variable Cost

1. Operators cost = Wages of operator / Working hours
2. Repair and maintenance (Rs. /h) = 10% of Initial cost
3. Total variable cost = 1 + 2

3. Operating Cost

Operating cost = Fixed cost + Variable cost

Where,

C = Initial cost or cost of machine

H = Annual use of machine

I = Interest rate

L = Total life of machine

S = Salvage value

IV. RESULTS AND DISCUSSION

The experimental findings obtained from the methodology used for the performance evaluation of the existing manually operated paddy transplanter and also of the modified two row power operated paddy transplanter have been discussed in this chapter. The findings based on the procedures have been discussed under the following sections.

4.1 Nursery seedling preparation

The procedure for conducting the seed germination test was described previously in section 3.1.1. Accordingly, the results obtained from sprouting of three samples, each consisting of 100 seeds incubated for a period of 24 hours, are presented in Table 4.1.

Table 4.1 Results of germination test

Period	**Sample 1**		**Sample 2**		**Sample 3**	
	100		100		100	
	Sprouted	Un-sprouted	Sprouted	Un-sprouted	Sprouted	Un-sprouted
After 3 days	64	36	63	37	58	42
After 4 days	25	11	15	22	31	11
After 5 days	7	4	15	7	5	6
Total	**96**		**93**		**94**	

The seed germination percentage was calculated by using formula 3.1. From the calculated results, the germination percentage for the three samples was 96%, 93% and 94% respectively. Thus, the average germination percentage of the seed samples was 94.5 %.

4.2 Performance Assessment of Manually Operated Paddy Transplanter

The testing of manually operated paddy transplanter to check its field performance as well as its suitability for agricultural workers i.e. to access the cost and drudgery involved in the transplanting operation was undertaken, the results of which are as below.

4.2.1 Plant and field parameters

The field testing was accomplished in summer season of 2017-18. The test trials were initiated with six male subjects as selected from the criteria discussed in section 3.2.3.3. The different plant parameters evaluated during the test are given in Table 4.2.

Table 4.2 Plant parameters for field testing with manual paddy transplanter

Sr. No.	Particular	Results
1.	Variety of paddy	Ratnagiri – I
2.	Type of seedlings	Root washed
3.	Age of seedling (DAS)	35
4.	Date of sowing of the nursery	26/02/2018
5.	Date of transplanting in the field	02/04/2018
6.	Number of leaves per seedling	5-7
7.	Height of seedlings (cm)	27-32 (30.5)
8.	Stem diameter (cm)	2.8-4.0

The seedlings were grown on an area of 30m^2. The age of seedlings used for transplanting was 35 (DAS). Height of these seedlings ranged in between 27 to 32 cm. The stem diameter of these seedlings measured with vernier calliper varied from 2.8 to 4.0 cm. The leaves on each seedling were observed as 5-7 in number. The field performance of the manual transplanter also included the consideration of field parameters as represented in Table 4.3.

Table 4.3 Field parameters for transplanting with manual paddy transplanter

Sr. No.	Particular	Results
1.	Length of field, m	17
2.	Width of field, m	10
3.	Area of field, m^2	170
4.	Type of soil	Sandy clay loam
5.	Puddling index, %	84
6.	Interval between puddling and transplanting, h	24
7.	Depth of water at the time of transplanting, cm	4-6

The field selected for the testing of existing manually operated paddy transplanter was 170 m^2 in area. The soil type was sandy clay loam. The settling period of soil was 24 hours. The puddling index determined after the settling period was 84 per cent. The depth of water at the time of transplanting ranged in between 4 to 6 cm.

4.2.2 Field testing of manual paddy transplanter

The manually operated paddy transplanter was tested for its field performance by considering the above discussed parameters. The testing was accomplished by six male subjects selected randomly. The results obtained from the field test are illustrated in Table 4.4.

Table 4.4 Field test performance of manually operated paddy transplanter

Sr. No.	Parameters	Subject Code						
		AR	**SS**	**SR**	**PH**	**MS**	**JK**	**Avg.**
1	No. of missing hills/m^2	7	6	8	6	8	7	**7**
2	Hill to hill spacing, cm	16	16	15	15	15	15	**15.33**
3	No. of seedlings/ hill	3-4	4-5	3-5	3-5	2-4	4-5	**3-4**
4	Planting depth, cm	5	6	6	5	6	7	**6**
5	Speed of operation, km/h	1.15	1.08	1.07	1.05	1.09	1.06	**1.09**
6	Time loss in operation, h	0.05	0.06	0.08	0.07	0.09	0.08	**0.07**
7	Total time required, h	0.17	0.16	0.20	0.16	0.17	0.18	**0.17**
8	Area covered, ha	0.0042	0.0040	0.0043	0.0045	0.0040	0.0047	**0.0044**
9	Actual field capacity, ha/h	0.025	0.025	0.022	0.028	0.024	0.026	**0.026**
10	Theoretical field capacity, ha/h	0.064	0.062	0.063	0.066	0.061	0.065	**0.064**
11	Field efficiency, %	40.62	41.93	34.92	42.42	39.34	40.17	**40.62**

Results obtained from the field testing revealed that, the average hill to hill spacing was 15.33 cm at an average operating speed of 1.09 km/h. The total missing hills observed in per square metre area during the operation were 7 hills/m^2. The average planting depth measured was 6 cm. The average time required to transplant an area of 0.0044 ha was 0.17 h, thereby providing an actual field capacity of 0.026 ha/h. Thus, the field efficiency calculated was 40.62 per cent with theoretical field capacity as 0.064 ha/h.

4.2.3 Assessment of physiological cost and drudgery involved in operating manual paddy transplanter

The performance of the manually operated paddy transplanter was evaluated ergonomically to examine its suitability. The results obtained from the test are presented in the following sub sections.

4.2.3.1 Details of subjects

The ergonomic evaluation of six male subjects was conducted. The average age, weight and stature of the subjects measured were 27 (±5.51) years, 59 (±8.36) kg and 172 (±7.89) cm, respectively. Details of the subjects are furnished in Appendix II (A).

4.2.3.2 Calibration of subjects

The selected subjects were calibrated in the ergonomics laboratory by following the procedures as discussed in section 3.2.3.4. The subjects were loaded on bicycle ergometer at sub maximal loads and by using the energy measurement system ($K4b^2$) kit, to get the relationship between the heart rate (HR) and corresponding oxygen consumption rate (OCR) of the subjects. Calibration chart was prepared with heart rate as the abscissa and the oxygen uptake as the ordinate for the selected six subjects. The calibration chart of the subjects is shown in Fig 4.1.

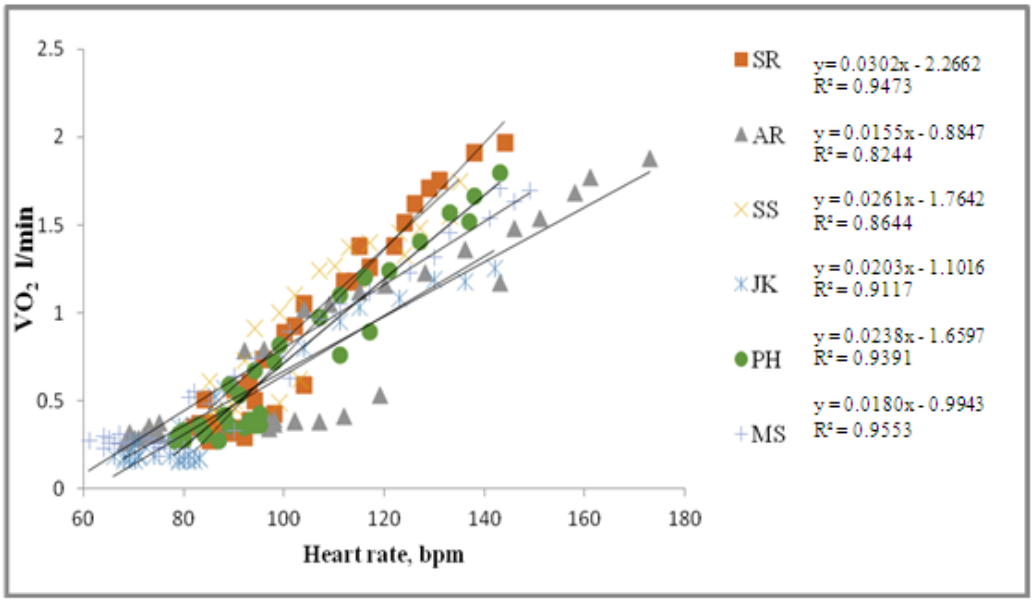


Fig 4.1 Subject calibration chart

It was observed that the relationship between the heart rate and oxygen consumption of the subjects was found almost linear for all subjects. Thus, a relationship between the two parameters of the subjects i.e. oxygen consumption (Y) and heart rate (X) was expressed by the following linear equations,

For subject SR, $y = 0.0302x - 2.266$ ($R^2 = 0.9473$) …(4.1)

For subject AR, $y = 0.0155x - 0.8847$ ($R^2 = 0.8244$) …(4.2)

For subject SS, $y = 0.0261x - 1.7642$ ($R^2 = 0.9575$) …(4.3)

For subject JK, $y = 0.0203x - 1.1016$ ($R^2 = 0.9117$) …(4.4)

For subject PH, $y = 0.0238x - 1.6597$ ($R^2 = 0.9391$) …(4.5)

For subject MS, $y = 0.0180x - 0.9943$ ($R^2 = 0.9553$) …(4.6)

Where,

y = Oxygen consumption, l/min

x = Heart rate, beats/min

The above equations were further used to predict maximum aerobic capacity (VO_2 max) values of each subject.

4.2.3.3 Maximum aerobic capacity (VO_2 max) of subjects

The maximum heart rate (HR max) of selected subjects was calculated by using equation 3.7. The maximum aerobic capacity (VO_2 max) was predicted as described in the above section. It was the maximum uptake of oxygen at maximum heart rate. The details about maximum heart rate (HR max) and maximum aerobic

capacity (VO_2 max) calculated of the subjects is given in Appendix II (B). The mean values of HR max and VO_2 max are furnished in Table 4.5.

Table 4.5 Subject details and mean results of HR max and VO_2 max

Sr. No.	Particulars	Results
1.	Number of subjects	6
2.	Mean age, years	27 (±5.51)
3.	Mean stature, cm	172 (±7.89)
4.	Mean weight, kg	59 (±8.36)
5.	Range of HR max, bpm	182 to 196
6.	Mean HR max, bpm	193 (±5.51)
7.	Range of VO_2 max, l/min	2.14 to 3.01
8.	Mean VO_2 max, l/min	2.61 (±0.57)

The average age of the selected subjects was 27 (±5.51) years. The mean stature value of the six subjects was 172 (±7.89) cm. Maximum heart rate (HR max) of the group was in the range of 182 to 196 bpm with corresponding maximum aerobic capacity in the range of 2.138 to 3.007 l/min. The mean HR max and mean VO_2 max values for the male subjects were 193 (±5.51) bpm and 2.61 (±0.57) l/min, respectively.

4.2.3.4 Determination of working heart rate (WHR), oxygen consumption rate (OCR) and energy expenditure rate (EER) for manually operated paddy transplanter

During the test, all the subjects were considered individually to check their work performance in operating the transplanter. The heart rate response was recorded using heart rate monitor and by following the procedures as described in section 3.2.4. The downloaded heart rate values during the operation of manual paddy transplanter are furnished in Appendix III (A). The combined graphical representation of heart rate response of subjects during the field testing is given in Appendix III (B). The physiological parameters measured during the operation of manual paddy transplanter are represented in Table 4.6.

As per the results obtained from the ergonomic tests of the manually operated paddy transplanter, average WHR values of the subjects ranged between 114.7 to 120.6 bpm with mean 115.7 (±3.19) bpm. The work pulse (ΔHR) was in the range of 27.1 to 48.8 with average as 36.9 (±8.97) bpm. It was observed that, ΔHR values for

couple of subjects went above limit of continuous performance (LCP) value i.e. above 40 bpm, indicating rest pause to those subjects.

From the results, it was also observed that average working OCR of the subjects was between 0.73 to 1.37 l/min, with mean 1.15 (±0.17) l/min. The energy expenditure rate (EER) for all subjects was calculated using equation 3.6. It varied from 18.83 to 28.73 kJ/min with 23.95 (±3.60) kJ/min as mean EER. Thus, the energy grade of work was classified under "heavy" category (Sen, 1969).

Table 4.6 Physiological parameters (WHR, OCR, EER, ΔHR etc.) recorded after operating manual paddy transplanter

Sr.No.	Subject code	Resting HR (bpm)	WHR (bpm)	ΔHR, bpm	LCP, 40 beats/min	Working OCR, (l/min)	EER (kJ/min)	Energy grade of work
1	AR	83.2	115.3	32.1	<LCP	0.90	18.83	Moderately heavy
2	SR	77.3	120.6	42.7	>LCP	1.37	28.73	Heavy
3	PH	74.8	117.5	42.6	>LCP	1.14	23.72	Heavy
4	MS	83.8	110.9	27.1	<LCP	1.01	20.92	Moderately heavy
5	JK	87.1	115.3	28.2	<LCP	1.24	25.88	Heavy
6	SS	65.9	114.7	48.8	>LCP	1.23	25.64	Heavy
Mean		**80.4**	**115.7**	**36.9**	**>LCP**	**1.15**	**23.95**	**Heavy**
SD		**(±4.50)**	**(±3.19)**	**(±8.97)**		**(±0.17)**	**(±3.60)**	

The work pulse (ΔHR) of subjects while operating the manual paddy transplanter is shown in Fig 4.2.

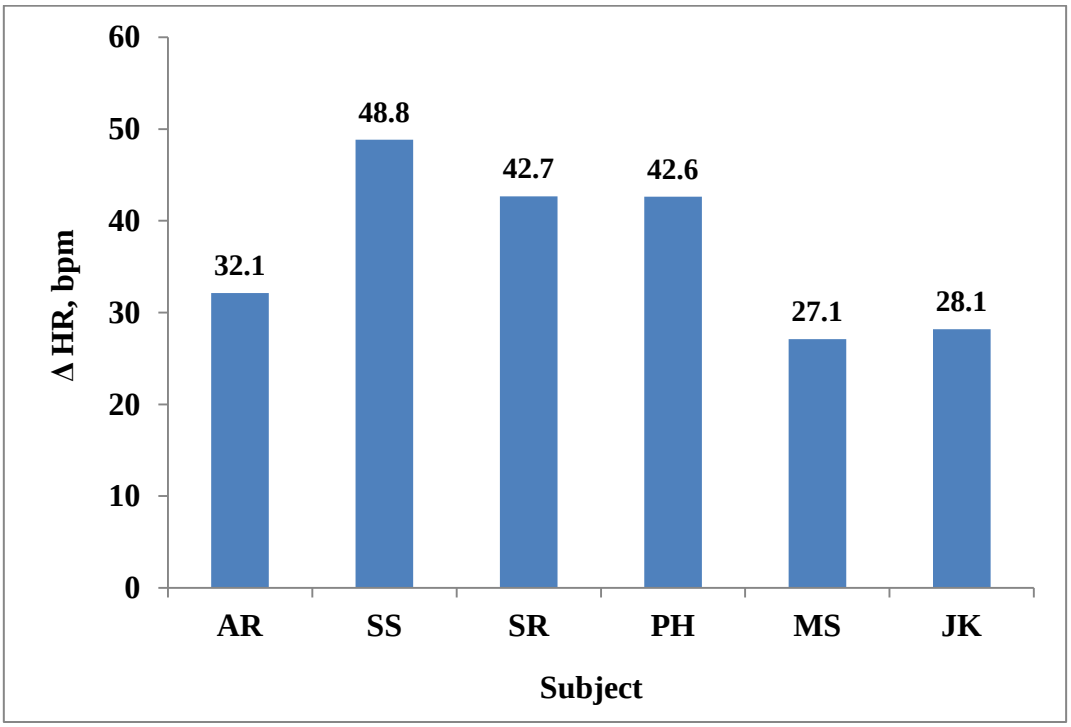


Fig 4.2 Work pulse of subjects with manually operated paddy transplanter

The above graph depicted that, three subjects with ΔHR values above 40, were required to be given rest pause of specific time after transplanting operation to maintain their work rate. It was calculated as explained below.

4.2.4 Work rest cycle

As mentioned in Table 4.6, the mean EER was 22.19 kJ/min (5.31 kcal/min). So, the work rest in minutes was calculated from equation 3.9 as follows.

$$R = \frac{T\,(K-S)}{K-1.5}$$

$$R = \frac{30\,(5.73-3)}{5.73-1.5}$$

$$R = 19.36 \approx 19.40 \text{ minutes}$$

Hence, it was recommended to give rest pause of about 20 minutes after each 30 minutes of continuous operation with the manually operated paddy transplanter.

4.2.5 Overall discomfort rating (ODR) and Body parts discomfort rating (BPDS)

The procedure for computing (ODR) and (BPDS) of each subject while transplanting with manually operated paddy transplanter was explained in the section 3.2.4.1. The individual responses of subjects of ODR are furnished in Appendix III (C). Table 4.7 states

the average ODR and BPDS values obtained from the subjects during the field test of manually operated paddy transplanter.

Table 4.7 Details of mean ODR and BPDS for manually operated paddy transplanter

Sr. No.	Particulars	Results
1.	Body parts discomfort found in	left and right leg, left palm, shoulders, left and right forearm, right wrist
2.	Range of ODR	5 to 7
3.	Mean ODR	7
4.	Range BPDS	12 to 19.5
5	Mean BPDS	16.5

The ODR values were found in the range of 5 to 7 with mean as 6. Hence, the work intensity for the subjects operating the manual paddy transplanter was classified as "moderate discomfort ". The details of BPDS calculated are furnished at Appendix III (D). The range of body part discomfort score was 12 to 19.5 with mean BPDS value as 16.50. Body parts viz. left and right leg, right palm, left palm and shoulder were found with severe discomfort, while left palm, right wrist, left wrist were found with moderate discomfort and right shoulder was found with light discomfort.

4.2.6 Pull force measurement

The pull force was determined by attaching a load cell to the handle of the transplanter. One hand was used for pulling the machine while the other was used to initiate the hand cranking operation. The average force required to pull the machine was 9.57 kg.

Also, the draft requirement for the transplanter was 6.90 kg at handle angle of 43.85˚. Details of the force measured are illustrated in Appendix III (E).

4.3 Development of Two Row Power Operated Paddy Transplanter

After the due considerations discussed in section 3.5, the power operated paddy transplanter was developed. The results of ergonomic and mechanical developments are discussed in the sections below.

4.3.1 Ergonomic design considerations in developed power operated paddy transplanter

The handle of power operated paddy transplanter was replaced so that the machine could be comfortably pulled by both hands. The handle design parameters along with their anthropometric consideration are represented in Table 4.8.

Table 4.8 Anthropometric dimensions in developed power operated paddy transplanter

Sr. No.	Design parameters	Anthropometric consideration	Dimensions (mm)
1.	Height of handle	Between 5^{th} percentile value of elbow height (standing) (938 mm) and 0.7 of 95^{th} percentile acromial height (1028 mm)	Between 945 -980
2.	Length of handle	Between 95^{th} percentile of elbow grip length (404 mm) and 5^{th} percentile value of elbow height (938 mm)	820
3.	Diameter of handle grip	Between 5^{th} percentile inside grip diameter (39 mm) to 95^{th} percentile middle finger palm grip diameter (38 mm)	38
4.	Shape of grip		Cylindrical

4.3.2 Mechanical design considerations in developed power operated paddy transplanter

The fabrication of power operated paddy transplanter was accomplished in Farm Machinery and Power workshop, DBSKKV, Dapoli. The mechanical features of the components are discussed in the following sub headings.

1. Float

The weight of the wooden float was 2.5 kg. The overall dimensions of the float were 820 mm x 430 mm with wooden plank of 20 mm thickness.

2. Main frame

The material used for fabrication was square pipe of galvanized iron. The dimensions of the pipe were 20 x 20 x 3 mm. The overall length and width of the main frame was 634 and 290 mm respectively. The overall weight of the main frame was 1.87 kg.

3. Nursery tray assembly

The seedling tray was made in two compartments from 22 gauge G.I sheet. The length of each compartment was 600 mm and width was 180 mm. The tray together weighed 0.78 kg. The material used for the fabrication of seedling tray frame included M.S flat of 20 x 3 mm, M.S angle of 20 x 20 x 3 mm, M.S rod of Φ 6 mm and M.S rod of Φ 8 mm. The weight

of the seedling tray frame was computed to be 2.3 kg thereby composing an overall weight of seedling tray assembly as 3.08 kg.

4. Camshaft assembly

The cam shaft was made from solid M.S shaft with Φ 25 mm. The length of the shaft was 290 mm. The mountings on the shaft included the nursery picking assembly, nursery holding cam, and a sprocket with 24 teeth. All the mounted components were made from M.S plate having 3 mm thickness. The overall cam shaft assembly weighed 4.5 kg.

5. Nursery holder

The fabrication material of this mechanism consisted of M.S flat with 3 mm thickness. It was supported by hollow M.S shaft having Φ 20 mm. The component weighed 0.45 kg.

6. Transplanting assembly

It consisted of transplanting shaft made of M.S having Φ 20 mm. The shaft was mounted with two sprockets each of 12 teeth and 17 teeth. The transplanting arm was fabricated in M.S material having 3 mm thickness. The assembly weighed 3.3 kg. The detailed specifications of power operated paddy transplanter are furnished in Table 4.9.

Table 4.9 Detailed specifications of power operated paddy transplanter

Sr. No.	Particular	Material	Specification
1.	Main frame	Square G.I pipe	20 x 20 x 3 mm
2.	Camshaft assembly	M.S sheet	3 mm thick
		Solid M.S shaft	Φ 25 mm
3.	Nursery holder	M.S flat	20 x 3 mm thick
		M.S hollow pipe	Φ 20 mm
4.	Transplanting assembly	M.S sheet	3 mm thick
		Solid M.S shaft	Φ 20 mm
		M.S flat	20 x 5 mm thick
5.	Seedling tray	G.I sheet	22 gauge

6.	Tray frame	M.S flat	20 x 5 mm thick
			20 x 3 mm thick
		M.S angle	20 x 20 x 3 mm
		M.S bar	Φ 8 mm
			Φ 6 mm
7.	Engine support	M.S flat	40 x 5 mm thick
			25 x 5 mm thick
			20 x 3 mm thick
8.	Engine		2 stroke, petrol, 1.75 hp @ 6500 rpm
9.	Speed reduction unit		Gear ratio 32.5 : 1
10.	Handle	Square G.I pipe	20 x 20 x 3 mm
11.	Handle support	M.S flat plate	25 x 5 mm thick
12.	Float	Wooden	820 x 430 mm
13.	Sprockets	M.S	12 teeth
			17 teeth
			24 teeth
14.	Chain		½ inch, simplex
15.	Ball bearing		Φ 4 mm

4.4 Performance Evaluation of Developed Power Operated Paddy Transplanter

The performance of the developed paddy transplanter was evaluated by conducting field test and ergonomic test. The results of these performance tests are furnished in the following sub sections.

4.4.1 Plant and field parameters

The field testing was accomplished in summer season of 2017-18 by the six subjects. The various plant parameters recorded during the test trials are given in Table 4.10.

Table 4.10 Plant parameters for field testing with power operated paddy transplanter

Sr. No.	Particulars	Results
1.	Variety of paddy	Ratnagiri – I
2.	Type of nursery	Root washed
3.	Age of seedling (DAS)	35
4.	Type of soil	Sandy clay loam
5.	Date of sowing of the nursery	26/02/2018
6.	Date of transplanting in the field	02/04/2018
7.	Number of leaves per seedling	5 to 7
8.	Height of seedlings (cm)	27-32 (30.5)
9.	Stem diameter (cm)	2.8 to 4.0

The paddy seeds used for the study was of variety Ratnagiri–I. The age of nursery seedlings used for transplanting was 35 (DAS). The height of these seedlings ranged from 27 to 32 cm. The average height was 30.5 cm. Stem diameter of the seedlings varied from 2.8 to 4.0 cm. Also, the leaves on each seedling were observed to be 5 to 7. The different field parameters as represented in Table 4.11 were also recorded before initiating the transplanting operation.

Table 4.11 Field parameters for the testing with power operated paddy transplanter

Sr. No.	Particulars	Results
1.	Length of field, m	17
2.	Width of field, m	10
3.	Area of field, m^2	170
4.	Puddling index, %	78
5.	Interval between puddling and transplanting, h	24
6.	Depth of water at the time of transplanting, cm	4 to 6

The field selected for the testing was 170 m^2. After the soil settling period of 24 h, the puddling index was 78 per cent. The depth of water at the time of transplanting was in the range of 4 to 6 cm.

4.4.2 Field performance of the developed power operated paddy transplanter

The data obtained from the field performance of power operated paddy transplanter from six subjects has been represented in Table 4.12.

Table 4.12 Field performance of developed power operated paddy transplanter

Sr. No.	Parameter	Subject Code						
		AR	SS	SR	PH	MS	JK	Avg.
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	Missing hills/m^2	5	6	4	5	7	4	**5**
2	Operating speed, km/h	1.12	1.08	1.13	1.05	1.09	1.10	**1.10**
3	Hill to hill spacing, cm	16	15	17	15	15	16	**15.66**
4	Planting depth, cm	7	7	8	7	8	7	**7.33**
5	No. of seedlings/ hill	2-3	2-3	3-4	1-2	2-4	3-4	**2-3**
6	Time loss in operation, h	0.07	0.10	0.09	0.06	0.11	0.08	**0.09**
7	Total time required, h	0.15	0.17	0.13	0.14	0.15	0.16	**0.15**
8	Area covered ha	0.0042	0.0049	0.0052	0.0049	0.0047	0.0046	**0.0045**

9	Actual field capacity, ha/h	0.028	0.029	0.040	0.035	0.031	0.029	**0.032**
10	Theoretical field capacity, ha/h	0.065	0.063	0.066	0.068	0.064	0.063	**0.065**
11	Field efficiency, %	43.1	46.03	60.60	51.47	48.43	46.03	**49.27**
12	Fuel consumption, l/h	0.408	0.425	0.417	0.410	0.421	0.420	**0.417**

From the field testing, it was concluded that the transplanter was operated at an average speed of 1.10 km/h. During this speed, the total missing hills observed per square metre area were 5 hills/m^2. The average planting depth was measured to be 7.33 cm. The total time required to complete the transplanting operation was 0.15 h for an area of 0.0045 ha. The actual field capacity was 0.032 ha/h. The field efficiency was 49.27 per cent. The fuel consumption of the engine driven paddy transplanter was 0.417 l/h.

4.4.3 Assessment of physiological cost and drudgery involved in operating power operated paddy transplanter

The performance of the developed paddy transplanter was also evaluated ergonomically by using the same subjects as used for evaluating the performance of manually operated transplanter. The heart rate data recorded during the field testing are tabulated in Appendix IV (A). The combined graphical representation of subject heart rate response is depicted in Appendix IV (B). The cost of drudgery for every subject was calculated individually based on the heart rate and VO_2 max values. Table 4.13 represents the average data of physiological parameters of each subject and with their corresponding results.

Table 4.13 Determination of working heart rate (WHR), oxygen consumption rate (OCR) and energy expenditure rate (EER)

Sr. No.	Subject code	Resting HR (bpm)	WHR (bpm)	∆ HR, bpm	LCP, 40 bpm	Working OCR, (l/min)	EER (kJ/min)	Energy grade of work
1	AR	78.2	102.7	24.5	<LCP	0.71	14.76	Moderately heavy
2	SR	79.8	109.7	29.8	<LCP	0.98	20.60	Moderately heavy
3	PH	76.8	104.3	27.5	<LCP	0.82	17.20	Moderately heavy
4	MS	88.7	104.1	15.5	<LCP	0.82	17.89	Moderately heavy
5	JK	80.8	107.7	26.9	<LCP	0.77	16.12	Moderately heavy
6	SS	80.2	110.1	29.9	<LCP	1.02	21.36	Moderately heavy
Mean		**80.8**	**106.4**	**25.7**	**<LCP**	**0.86**	**17.99**	**Moderately heavy**
SD		**(±4.14)**	**(±3.14)**	**(±5.41)**		**(±0.13)**	**(±2.56)**	

The results obtained from the ergonomic test of the power operated paddy transplanter for the six male subjects concluded that the mean value of WHR was in the range 102.7 to 110.1 bpm with mean as 106.4 (±3.14) bpm. The corresponding OCR was in the range of 0.71 to 1.02 l/min with average 0.86 (±0.13) l/min. The work pulse (ΔHR) was in the range of 15.5 to 29.9 bpm with mean 25.693 (±5.41) bpm. As the ΔHR values were below the LCP limit i.e. below 40, there was no rest required for the subjects to work continuously even after 30 minutes of transplanting operation. The values of EER ranged between 14.76 to 21.36 kJ/min. Mean of these values was 17.99 (±2.56) kJ/min. The energy grade of work was thus categorised as "moderately heavy" (Sen, 1969). The work pulse (ΔHR) for operation of developed paddy transplanter is shown in Fig 4.3.

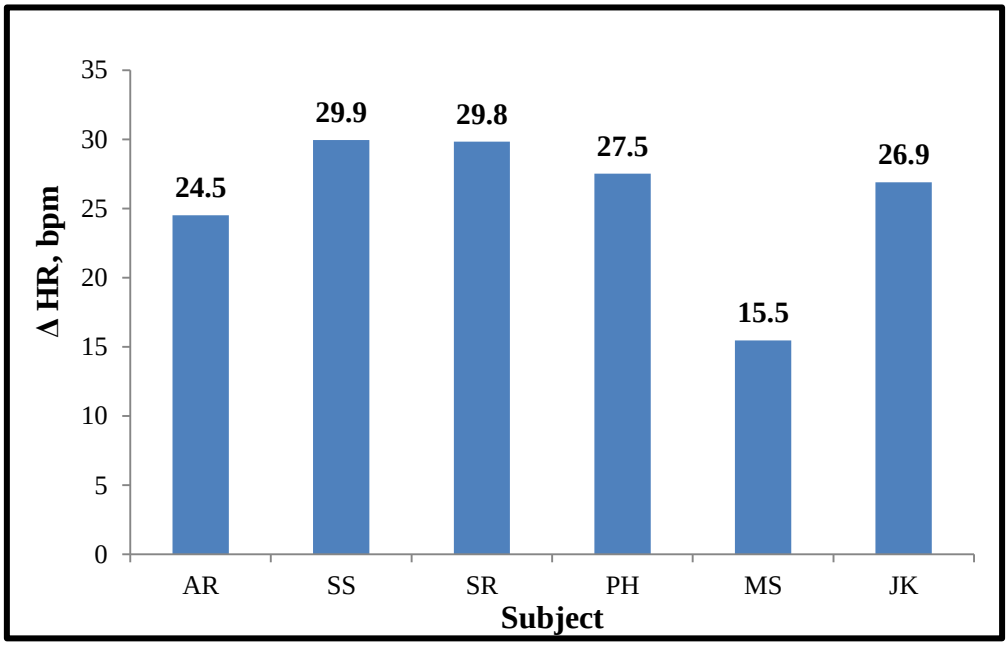


Fig 4.3 Work pulse of subjects while operating developed paddy transplanter

The above bar graph states that, as the value of ΔHR was below 40 bpm, the subjects didn't require any rest even after 30 minutes of continuous transplanting operation.

4.4.3.1 Overall Discomfort Rating (ODR) and Body Parts Discomfort Score (BPDS)

The average results of overall discomfort score and Body Parts Discomfort Score (BPDS) of each male subject while transplanting with power operated paddy transplanter is given in Table 4.14. The procedure for determining both these subjective parameters were described in section 3.4.5.1 and 3.4.5.2, respectively. The

ODR and BPDS responses of each subject while transplanting with developed paddy transplanter are presented in Appendix IV (C) and (D) respectively.

Table 4.14 Mean values of ODR and BPDS for power operated paddy transplanter

Sr. No.	Particulars	Results
1.	Body parts discomfort found in	left and right leg, left and right shoulder, left and right arm
2.	Range of ODR	3 to 5
3.	Mean ODR	4
4.	Range BPDS	5 to 17.50
5	Mean BPDS	10

The results stated that the field work for the selected subjects was less than moderate as the average ODR score was 4. The range of body part discomfort score was 5 to 17.50, with 10 being the average BPDS. Body parts like left and right leg, left and right shoulder, left and right arm of the subjects felt discomfort during the transplanting operation with developed power operated paddy transplanter.

4.4.3.2 Pull force measurement

The pull force was determined by attaching a load cell to the handle of the transplanter. The operation was started and the readings were noticed. The average force required to pull the machine was recorded as 8.06 kg. Also, the draft requirement of developed power operated paddy transplanter was calculated at handle angle of 45°. The mean draft value obtained was 5.72 kg. Appendix IV (E) represents the pulling force and draft results of power operated paddy transplanter.

4.5 Operational Cost of Developed Power Operated Paddy Transplanter

The details of operating cost are furnished in Appendix (V) and its procedure is described in section 3.7. From the data, it was inferred that, total cost of developed machine was Rs. 27,400/- which included material cost (Rs.18,267/-) as well as the fabrication cost (Rs. 9,134/-). The cost of operation was determined by evaluating the fixed and variable cost. Thus, the cost of operation was Rs. 145/h. The actual field capacity of developed transplanter was 0.032 ha/h. Therefore, the cost of operation calculated per hectare was Rs. 4,532/- whereas the cost of transplanting using manual transplanter was Rs. 2368.44/ha and that with traditional method it was Rs. 7,920/ha.

4.6 Comparative Performance of Manual and Power Operated Paddy Transplanter

The performance of manual and power operated paddy transplanter was analysed and the results are presented briefly in Table 4.15.

Table 4.15 Comparison between manual and power operated paddy transplanter

Sr. No.	Parameter	Manual paddy transplanter	Developed power operated paddy transplanter
A	**Field performance parameter**		
1	Field capacity, ha/h	0.026	0.032
2	Field efficiency, %	40.62	49.27
3	Cost of machine, Rs.	2,183/-	27,400/-
4	Cost of operation, Rs. /h	70	145
5	Cost of operation, Rs. /ha	2,368/-	4,532/-
B	**Subject details**		
1	No. of subjects	6 (Male)	
2	Age, years	27 (±5.51)	
3	Weight, kg	59 (±8.36)	
4	Stature, cm	172 (±7.89)	
5	HR max , bpm	193 (±5.51)	
6	VO_2 max, l/min	2.61 (±0.57)	
C	**Physiological parameters**		
1	Resting heart rate (RHR), bpm	80.4 (±4.50)	80.8 (±4.14)
2	Working heart rate (WHR), bpm	115.7 (±3.19)	106.4 (±3.14)
3	Work pulse (ΔHR), bpm	36.9 (±8.97)	25.7 (±5.41)
4	Working OCR, l/min	1.15 (±0.17)	0.86 (±0.13)
5	Energy expenditure rate (EER), kJ/min	23.95 (±3.60)	17.99 (±2.56)
6	Energy grade of work	Heavy	Moderately heavy
7	Limit of continuous performance (LCP)	>LCP	<LCP
8	Work rest pause	20 min. for 30 min operation	No rest pause required

9	Pull force requirement, kg	9.57	8.06
10	Overall discomfort rating (ODR)	7	4
11	Body part discomfort score, (BPDS)	16.5	10
12	Discomfort level	More than discomfort	Moderate discomfort
13	Areas of discomfort	left and right leg, left palm, shoulders, left and right forearm, right wrist	left and right leg, left and right palm, left and right foot

The comparative analysis on field performance concluded that manual and power operated paddy transplanter could produce field capacity of 0.026 ha/h and 0.032 ha/h respectively with field efficiency of 40.62 and 49.27 per cent respectively. The operational cost calculated for manual and developed power operated paddy transplanter was Rs. 2368/ha and Rs. 4532/ha, respectively. The cost of operation in Rs./h of power operated paddy transplanter was twice as that of the manual paddy transplanter. This cost of power operated transplanter could be compromised through the observed results that there was no rest pause required in using the developed transplanter. The physiological cost and drudgery associated with the work was minimized. The results of subjective discomfort evaluation i.e. of ODR and BPDS of both the transplanter revealed that the work with developed transplanter witnessed minimum discomfort than the existing ones.

Ergonomic evaluation of both the transplanter was done by selecting six male subjects. The average age of these subjects was 27 (±5.51) years. Their mean weight and height (stature) were 59 (±8.36) kg and 172 (±7.89) cm, respectively. The average of maximum heart rate HR max calculated of the subjects was 193 (±5.51), also the mean value of maximum aerobic capacity (VO_2 max) of the subjects determined from the calibration data was 2.61 (±0.57) l/min.

The successful trials of both the transplanters concluded that, working oxygen consumption rate of the subjects while operating the manual paddy transplanter was 1.15 (±0.17) l/min while that with the power operated transplanter it was 0.86 (±0.13) l/min. Working heart rate (WHR) of the subjects with manual paddy transplanter was 115.7 (±3.19) bpm and that with the power operated transplanter was 106.4 (±3.14) bpm. This variation in WHR was seen because the operator had to just pull the developed power operated paddy transplanter as the hand cranking action was

eliminated. The difference in heart rate (ΔHR) was 36.9 (±8.97) bpm while operating the manual paddy transplanter which insisted in giving a rest of 20 minutes to the subjects after each 30 minutes of continuous operation. While in the case of power operated paddy transplanter, rest pause was not required as ΔHR 25.7 (±5.41) bpm was less than the LCP limit of 40 bpm.

The energy expenditure rate (EER) resulted in categorising the operation with manual paddy transplanter as “heavy” and that with the power operated paddy transplanter as “moderately heavy” as the respective EER were 23.95 (±3.60) kJ/min and 17.99 (±2.56) kJ/min. The results of pull force measured stated that, the manual paddy transplanter required an average pulling force of 9.57 kg, while in case of developed power paddy transplanter, the pulling force required was 8.06 kg.

V. SUMMARY AND CONCLUSION

Rice is the most widely consumed staple food in the world as well as in the Asian continent with India being one of the leading consumers and producers of rice. Rice is grown in several states of India with Maharashtra holding a prominent position in rice production. The methods implemented for growing rice include direct seeding of rice or broadcasting method and transplanting method using root washed nursery. Broadcasting method often results in inadequate crop stand due to surface placement of seed, whereas transplanting method involves raising of seedlings in a nursery and then uprooting it for transplanting either manually or mechanically in main field. Manual transplanting is more physically demanding activity as compared to uprooting and mechanical transplanting activity. With declining farm labor availability and their wages, farm operations have turned expensive calling for mechanical intervention. Mechanical transplanting refers to planting of 20-22 days old seedlings of 12-15 cm height under wet land conditions. After the predetermined period, these seedlings are then transplanted in the main fields using manual transplanter, power operated or self propelled transplanter. Konkan region of a Maharashtra leads in rice production but has small land holdings and hilly terrains which restrict the farmers to follow the conventional practices of growing rice which is time-consuming and causes musculoskeletal problems.

The developed power operated paddy transplanter was driven with petrol engine. The power from engine was transmitted for transplanting operation through the gear box which reduced the power to the required gear ratio. The design features of the developed transplanter involved a wooden float in place of G.I sheet float. The handle of the developed transplanter was pulled by both hands as the hand cranking mechanism was eliminated. Some critical components of the power operated machine were laser cut. The suitability of the developed transplanter was decided based on its comparative performance with the manually operated paddy transplanter.

The field test of the manually operated paddy transplanter was initiated using root washed seedlings grown in the nursery for a period of 35 days. Germination test of the seedlings was done to understand the viability of seeds. Soil settlement period in the field of 24 hours was selected by referring to the past studies. Several plant parameters like height of seedling, number of leaves on each seedling, diameter of stem and field parameters like dimensions of field, puddling index and type of soil

were taken in consideration for conducting the field test. To evaluate the field performance, six male subjects were selected randomly. Suitability of the machine was decided based on results of field parameters like plant to plant spacing, operating speed of machine, number of missing hills per square metre, total time required for completing the operation, area covered by each subject etc. From these results the field capacity of the machine was determined along with the field efficiency. Also, the heart rate of the subjects was recorded using heart rate monitor during the field operation. By using load cell, the pull force requirement was measured. To assess the physiological cost and drudgery involved in the operation, the manual transplanter was evaluated ergonomically by calibrating the selected subjects in the laboratory using the $K4b^2$ portable metabolic system kit and bicycle ergometer. Physiological parameters like working heart rate, resting heart rate, oxygen consumption rate and energy expenditure rate were determined to classify the workload category. The subjective discomfort i.e. overall discomfort rating (ODR) and body part discomfort score (BPDS) associated with manual paddy transplanter was also determined.

The performance of power operated paddy transplanter was also evaluated similarly like the manually operated paddy transplanter using 35 days old seedlings. In addition to the field testing parameters adopted to evaluate the performance, fuel consumption of the power operated transplanter was also measured. Ergonomic evaluation of the developed paddy transplanter was accomplished using the same subjects to determine the physiological cost and drudgery involved in the operation. The conclusions drawn are mentioned below.

1. The results of germination test with three selected samples gave germination percentage as 96 %, 93 % and 94 % respectively with average germination percentage as 94.5 %..
2. The age of seedlings used to evaluate the field performance of both i.e. manual and power operated transplanter was 35 days after sowing (DAS).
3. Field testing parameters like operating speed, total operation time and total area covered with manual paddy transplanter were 1.09 km/h, 0.17 h and 0.0044 ha respectively.
4. Actual field capacity and field efficiency obtained with the manual paddy transplanter was 0.026 ha/h and 40.62 % respectively.

5. The average age of six male subjects selected for the study was 27 (±5.51) years, with average stature as 172 (±7.89) cm and mean of their weight as 59 (±8.36) kg.
6. Average values of maximum heart rate (HR max) and maximum aerobic capacity values (VO_2 max) calculated of the subjects from the calibration data were 193 (±5.51) bpm and 2.61 (±0.57) respectively.
7. Physiological drudgery cost associated with the manual paddy transplanter concluded that average working heart rate (WHR), working oxygen consumption rate (OCR) and energy expenditure rate (EER) were 114.04 (±4.87) bpm, 1.06 (±0.23) l/min and 22.19 (±4.85) kJ/min, respectively.
8. The workload experienced with the manual paddy transplanter was therefore classified under "heavy" category.
9. Subjects working with the manual paddy transplanter were thus recommended to have rest pause of 20 minutes for 30 minutes operation.
10. Subjective evaluation i.e. body part discomfort score (BPDS) and overall discomfort rating (ODR) in operating manual paddy transplanter was 16.5 and 7, respectively.
11. The cost of manual paddy transplanter was Rs. 2,183/- with operational cost as Rs. 70/h and Rs. 2,368/ha.
12. The power source used for developed paddy transplanter was 2 stroke, 1.75 hp @ 6500 rpm, air cooled petrol engine attached with transmission box producing a gear ratio of 32.5:1.
13. Field testing results obtained from the power operated paddy transplanter gave operating speed as 1.1 km/h, total time required for operation as 0.09 h and total area covered was 0.0045 ha.
14. The actual field capacity and field efficiency with the developed transplanter was 0.032 ha/h and 49.27%, respectively, which was 23 % and 21.29 % more as compared to that of manual paddy transplanter.
15. Fuel consumption calculated for the power operated paddy transplanter was 0.417 l/h.
16. The average working heart rate (WHR), working OCR and energy expenditure rate (EER) with power operated paddy transplanter were 106.4 (±3.14) bpm, 0.86 (±0.13) l/min and 17.99 (±2.56) kJ/min, respectively, which was 7.18 %, 18.86 % and 18.93 % less as compared to manual paddy transplanter.

17. The workload associated with power operated paddy transplanter was classified as “moderately heavy”.
18. Subjective discomfort i.e. overall discomfort rating (ODR) of 4 and body part discomfort score (BPDS) of 10 was recorded while working with power operated paddy transplanter.
19. The respective weights of manual and power operated paddy transplanter were 14.60 kg and 28.65 kg.

VI. BIBLIOGRAPHY

Abdrabo A. F. A. 2016. Developing a double purpose machine prototype for rice transplanting. *Journal of Soil Science and Agricultural Engineering*, 7(9): 635–644.

Agrawal K. N, P. S. Tiwari, L. P. Gite and V. Bhushanababu, 2010. Isometric push/pull strength of agricultural workers of Central India. *Agricultural Engineering International: The CIGR Ejournal*. Vol. 12(1): 115-124.

Alka, 2014. Ergonomic study of farm women during wheat harvesting by improved sickle. *Asian Journal of Agricultural Research.* 9(18): 1386-1390.

Anonymous. 2017. Global agricultural information network report, USDA Foreign Agriculture Services. IN7031, pp.14. Accessed 24 February 2017.

Anonymous. 2018a. https://www.britannica.com/plant/rice. Accessed 27 February, 2018.

Anonymous. 2018b. http://www.ibef.org/agriculture and allied industries. Accessed 21 June, 2018,

Anonymous. 2010. Philippine Agricultural Engineering Standard (PAES) 152:2010 Agricultural Machinery-Mechanical rice transplanter-Method of test.

Astrand, I. 1960. Aerobic work capacity in men and women. *Acta Physiological Scandinavica.* 4: 169.

Aware V. V., C. R. Kavitkar, M. R. Patil, P. U. Shahare, S. V. Aware, and N. A. Shirsat.

2017. Physiological cost and drudgery in paddy transplanting. *International Journal of Agricultural Engineering.* 10(1): 103-108.

Babu D. Ananda. 2013. Modification and evaluation of self propelled8 row paddy transplanter (Yanji) to suit SRI cultivation over manual SRI transplanting. *Unpublished M. Tech. thesis.*, Acharya N. G. Ranga Agricultural University, Bapatla, Andhra Pradesh.

Behera B. K. and B. P. Varshney. 2003. Studies on optimization of puddled soil characteristics for self-propelled rice transplanters. *Agricultural Mechanization in Asia, Africa and Latin America*. 34(3): 12-16.

Behera B. K., B. P. Varshney and A. K. Goel. 2009. Effect of puddling on puddled soil characteristics and performance of self-propelled transplanter in rice crop. *Agricultural Engineering International: The CIGR Ejournal.* 10: 1-18.

Bimla S., Gandhi and M. Dilbaghi. 2002. Efficiency testing of sickles in wheat harvesting. An ergonomic study. Department of Family Resource, Management, *College of Home Science*, CCSHAU, Hissar.

Bobade Akib, A. Desai, S. Dharvat, P. Gamare, S. K. Raut. 2018. Design and manufacturing of manually operated multipurpose rice transplanter. *Int. Journal of Innovations in Engineering Research and Technology [IJIERT]*. 5(2), 39-41.

Borg, G. 1982. Psychological basis of physical exertion. *Medical and Science in Sports,*

Chaudhary V. P., B. P. Varshney and M. S. Karla. 2005. Self propelled rice transplanter-better alternative than manual transplanting. *Agricultural Engineering Today*, 29(5-6): 32-45.

Chaudhary Y. P. and B. P. Varshney. 2008. Studies on influence of rotary blade and peg type puddlers on soil physical and dynamic properties and rice yield. *Journal of Agricultural Engineering.* 45(2): 74-80.

Chethan C. R. and D. Anantha Krishnan. 2017. Dynamic push–pull strength data generation for agricultural workers to develop manual dryland weeders. *Current Science,* Vol. 113(8): 1601-1605.

Corlett E. N. and R. P. Bishop. 1976. A technique for assessing postural discomfort. *Ergonomics*, 19: 175-182.

Dave A. K. 2004. Soil puddle characterization for mechanized transplanting of rice in vertisols. *Unpublished Ph.D. (Agril. Engg.) thesis.* Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan.

Desai K.S. 2012. Development and performance testing of two row paddy transplanter. *Unpublished M. Tech. (Agril. Engg.) Thesis.* College of Agricultural Engineering and Technology, DBSKKV, Dapoli.

Dewangan K. N., C. Owary and R. K. Datta. 2008. Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region *International Journal of Industrial Ergonomics*, 38(1): 90-100.

Dewangan, K. N., E. V. Thomas and B. C. Ghosh. 2005. Performance Evaluation of a Laboratory Model Rice Transplanter. *Agricultural Engineering Today.* 29(5): 38-45.

Dhiman S. D., D. P Nandal, T. R Sharma and V Rani. 2001. Performance of puddling equipment and self-propelled rice transplanter in crop establishment and grain yield of rice *Indian Journal of Agronomy*. 46(1): 64-67.

Dingara H. S., H. M. Khurana, and S. Singh. 2000. Studies on force exertion in operating wheel hand hoe. A paper presented in 35th ISAE convention held at OUAT, Bhubaneshwar, January 22-24.

Eam-o-pas K., Goto Y. 1990 Comparative performance of the rice transplanters in Thailand's field conditions. *Kasetsart Journal (National Science Suplementary.* 24: 64-68.

Ehsanullah A., J. Nadeem, Khawar and H. Tahir. 2007. Comparison of different planting methods for optimization of plant population of fine rice (*Oryza sativa* l.) in Punjab. ***Pakistan Journal of Agricultural Sciences***. 44(4): 597-599.

Garg, I. K. and V. K. Sharma. 1984. Design, development and evaluation of PAU riding type engine operated paddy transplanter using mat type seedlings. *Proceedings of ISAE. SJC,* 1(2): 57-63.

Garg, I. K., V. K. Sharma and J. S. Mahal. 1997. Development and field evaluation of manually-operated six-row paddy transplanter. *Agricultural Mechanization in Asia, Africa and Latin America.* 28(4): 21-24.

Gite L. P. and B. G. Yadav. 1990. Optimum handle height for a push-pull type manually operated dryland weeder. *Ergonomics*. 33(12): 1487–1494.

Gite L. P. and G. Singh. 1997. *Ergonomics in agricultural and allied activities in India.* Central Institute of Agricultural Engineering, Bhopal.

Gite L.P., J. Majumder, C. R. Mehta and A. Khadatkar. 2009. *Anthropometric and strength data of Indian agricultural workers for farm equipment design.* Central Institute of Agricultural Engineering, Bhopal.

Goel, A.K., D. Behera and S. Swain. 2008. Effect of Sedimentation Period on Performance of Rice Transplanter. *Agricultural Engineering International: The CIGR E-journal.* 10: 43-46.

Gowda M. C. and M. Rudraradhya. 1998. Performance evaluation of manually operated paddy transplanter. University of Agricultural Sciences Bangalore. 27(5): 95-97.

Goyal Gagandeep. 2016. Ergonomic evaluation of walk behind type self propelled paddy transplanter. *Unpublished M.Tech thesis.* Punjab Agricultural University, Ludhiana.

Grandjean E. 1982. Fitting the task to the man. *An Ergonomic Approach*. Taylor & Francis Ltd, London: 77-81.

Guru Prabhat Kumar, N K Chhuneja, A Dixit, P Tiwari and A Kumar 2018. Mechanical transplanting of rice in India: status, technological gaps and future thrust. *Oryza*, 55(1): 100-106.

Indian Standards Institution. 1979. IS-9164-1979. *Guide for estimating cost of farm machinery operation,* New Delhi.

Lin Jia-Hua, Raymond W. McGorry, Chien-Chi Chang. 2012. Effects of handle orientation and between-handle distance on bi-manual isometric push strength. *Applied Ergonomics.* Vol. 43(4): 664-670.

Kalchuri Dushyant and P. N Shende. 2016. An overview on rice transplanting machine: *A review: Discovery*, 52(246): 1222-1230.

Karunanithi R. and A. Tajuddin. 2003. Physiological response of agricultural workers in rice farming operations. *Journal of Agricultural Engineering.* 40(1): 33-40.

Kavitkar C. R. 2016. Ergonomic evaluation and refinement of manually operated paddy transplanter for women workers of Konkan region. *Unpublished M.Tech. thesis.* Dr. BSKKV, Dapoli.

Khatun Asma. 2011. Development of entrepreneurship for custom hire service of rice transplanter in Bangladesh. *Unpublished M.Sc thesis.* Bangladesh Agricultural University, Bangladesh.

Khogare, D.T. and Borkar, S. 2012. Development and evaluation of scale for measurement of postural discomfort and satisfaction of agriculture workers after weeding operation. *Indian Streams Research Journal*. 2(6).

Kirchhof G., S. Priyono, W.H. Utomo, T. Adisarwanto, E.V. Dacanay, H.B. So 2000. The effect of soil puddling on the soil physical properties and the growth of rice and post- rice crops. *Soil & Tillage Research*, 56: 37-50.

Kroemer, K .H .E., H. J. Kroemer, and K.E. Kroemer-Elbert. 1997. *Engineering physiology*. Van Nostrand Reinhold. New York, 193-228.

Kumar U. 1997. Performance evaluation of eight row self propelled rice transplanter. Agricultural Engineering Today. Vol. 12(1): 35-39.

Kumar, A., Tandon, S.K. and Saxena, J.P. 2002. Ergonomic evaluation of weeders. *Journal of Agricultural Engineering*, Vol. 39(4): 17-22.

Madusanka H.K.S, 2011. Design and development of paddy seedling transplanting mechanism. *B.Sc. Thesis*, Department of Agricultural Engineering, University of Peradeniya, Sri Lanka.

Manjunatha, M. V., B. G. Masthana Reddy, S. D. Shashidhar and V. R. Joshi. 2009. Studies on the performance of self propelled rice transplanter and its effect on crop yield. *Karnataka Journal of Agricultural Sciences*, 22(2): 385-387.

Mohanty S. K. and M. K. Ghosal 2014. Ergonomical evaluation of manually operated paddy transpalnter for female agricultural workers in the state of Orissa. *International Journal of Tropical Agriculture*. 32(3-4): 731-735.

Mohanty T. 2016. An economic analysis of adoption and spread of mechanical rice transplanter in Odisha. *Master of Business Administration Thesis.* Department of Agribusiness Management, Orissa University of Agriculture and Technology Bhubaneswar.

Murrell K. F. H. 1965. *Human Performance in Industry.* Reinhold Publishing Corporation, New York, USA.

Nag P. K., N. C. Sebastian and M. G. Malvanker. 1980. Occupational workload of Indian Agricultural workers. *Ergonomics*. 23(2): 91-102.

Nag, P.K. 1981. Predicting maximal oxygen uptake of workers engaged in agricultural tasks. *Human Ergology*, 10: 25-33.

Nagaraj P.S., D. Swamy, A. Madhushree and B. Vidyadhara 2013. A study on knowledge and adoption of farm mechanization by paddy grower in Tungabhadra project area, Karnataka. *International Journal of Agriculture and Food Science Technology*, 4(4): 385-390.

Ojha Pragya and S. Kwatra. 2011. A comparative study on human drudgery by rice transplanting: An ergonomic Approach. *Advance Research Journal of Social Science,* 2(2): 227-230.

Ojha Pragya and S. Kwatra. 2012. An ergonomic study on human drudgery and musculoskeletal disorders by rice transplanting. *Home Science and Community*. 6(1); 15-20.

Ojha Pragya and S. Kwatra. 2014. Analysis of different paddy transplanting methods in northern India: Ergo - economical study. *Journal of Allied and Natural Science.* 6(2): 654-658.

Pateriya R. N. and R.K. Datta. 2012. Design modifications of mat type rice transplanter *International Journal of Advanced Technology and Engineering Research.* 2(6): 87- 91.

Patil S. B, P. U. Shahare and V. V. Aware 2017 Field testing of power operated paddy transplanter suitable for root washed seedlings. *International . Journal of. Pure and Allied Bioscience.*5(6): 1146-1152.

Patil S. B. 2018. Design, development and testing of power operated paddy transplanter suitable for root washed seedlings. *Unpublished Ph.D. thesis.* DBSKKV, Dapoli.

Pattar P.S., B.G.M Reddy and P H Kuchanur 2001.Yield and yield parameters of rice (Oryza sativa L.) as influenced by date of planting and age of seedlings. *Indian Journal of Agricultural Sciences,* 71: pp. 521-522.

Pheasant S. 1986. *Body space: Anthropometry, Ergonomics and Design*. Taylor and Francis, London.

Pradhan S. and S. K. Mohanty, 2014. Ergo-economical analysis of different paddy transplanting operations in eastern India, *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS),* 6(6): 23-27.

Rajput Kuntesh D. A P. Bhide, G. R. Kandan, M. D. Shukla, R. V. Bhaskar 2017. Modification and Manufacturing of Hand Cranked Rice Transplanter. *International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE).* 4(6): 1–6.

Rana K. Jyotsna, K. Singh and M. Mehta. 2005. Ergonomic evaluation of the rural women while performing wheat harvesting activity. *Journal of Human Ecology*. 18(4): 309- 311.

Saha, P. N., S. R., Datta, P. K. Banerjee, and G. G. Narayane. 1979. An acceptable workload for Indian workers. *Ergonomics.* 22(9): 1059-1071.

Salvendry G 1997 *Handbook of human factors and ergonomics* 2nd Edition. A Wiley Interscience Publication, New York.

Seidal, H., R. Bastek., D. Brauer., C.H. Buchholz., A. Meister., A.M. Metz and R. Rothe. 1980. On human response to prolonged repeated whole body vibration. *Ergonomics*, 23(30): 191-211.

Selvan, M Muthamil, S J K Annamalai, N Thavaprakash and D Ananathakrishnan. 2014. Design and development of three-row improved pull-type rice transplanter for small farmers. *Indian Journal of Agricultural Sciences.* Vol. 84 (11): 1422–1427.

Sen, R. N. 1969. Tentative classification of strains in different types of jobs according to the physiological responses of young Indian workers in comfortable climate. ICMR report, New Delhi.

Shahare P. U. and M. R. Bhat. 2011. Development and performance evaluation of two row paddy transplanter. *International Journal of Agricultural Engineering.* 4(1): 103-105.

Shahare P.U. 2012. Agricultural Mechanization in Konkan Region of Maharashtra. *Agricultural Engineering Today.* 36 (2), 6-9.

Shinde Archana, 2017. Rice production in konkan region- An economic analysis. *Ph.D thesis, (Agriculture),* Department of Agricultural Economics,Faculty of Agriculture, DBSKKV, Dapoli.

Singh K.K, A.S. Jat, and S.K. Sharma. 2005. Improving productivity and profitability of rice through tillage and planting management. *Indian Journal of Agricultural Sciences.* 75(7): 396-399.

Singh C. P. and I. K. Garg. 1976. Field evaluation of Japanese paddy transplanter. *Journal of Agricultural Engineering*. 13(1): 1-4.

Singh G, Sharma T. R. and Bockhop C. W. 1985. Field performance evaluation of a manual rice transplanter. *Journal of Agricultural Engineering Research* 32: 259-268.

Singh S. and D. K Vatsa. (2006). Performance of evaluation of PAU manual transplanter in hills of Himachal Pradesh. *Agricultural Engineering Today* 30(3): 43-46.

Singh Saimbhi. 2016. Effect of puddling equipment on puddling characteristics under paddy cultivation in Punjab. *International Journal of Agriculture and Environmental Research,* 2(03): 332-338.

Singh Surendra. 2008. Farm mechanization Scenario in India, *First machinery manufactures meet Karnataka.* 25-28.

Sinha Jaya. 2014. Ergonomic design modification in intercultural hand tools to make female worker friendly. *Unpublished M.Tech thesis.* Indian Agricultural Research Institute, New Delhi.

Syedul, M. D. Ahmad and M.A. Baqui. 2000. Modification, test and evaluation of manually operated transplanters for lowland paddy. *Agricultural Mechanization in Asia, Africa & Latin America*. 31(2): 33-38.

Tatugade D.P. and S.D. Valvi 2006. Development of two row rice transplanter. *Unpublished B.Tech. thesis,* Dr. BSKKV, Dapoli.

Tewari V, R. Ailavadi, K. Dewangan and S. Sharangi. 2007. Rationalized Database of Indian Agricultural Workers for Equipment Design. *Agricultural Engineering International: The CIGR Ejournal*. 9: 1-12.

Tewari, V. K., K. N. Dewangan and B. Sarkar. 2005. Ergonomic evaluation of self propelled vertical conveyor reaper. *Power Machinery Systems and Ergonomics, Safety and Health,* 278-285.

Thiyagarajan R, Kathirvel K, Jayashree G. C. 2013. Ergonomic invention in sugarcane harvesting knives. *African Journal of Agricultural Research.* 8(6), 574-581.

Tiwari, V.K. and Philip, G.S. 2002. Occupational stress on Indian female agricultural workers. Paper presented at 37th annual convention of ISAE held at Udaipur.

Torane S. P, B. K. Naik, V. S. Kulkarni and J. M. Talathi. 2011. Farming systems diversification in north Konkan region of Maharashtra - An economic analysis. *Agricultural Economics Research Review.* 24. 91-98.

Varghese, M.A., P.N. Saha and N. Atreya. 1995. Aerobic capacity of urban women homemakers in Bombay, *Ergonomics.* Vol. 38(9): 1877-1883.

Vyas Rekha. (2014). Ergonomic assessment of prevalence of musculoskeletal disorders among indian agricultural workers. *Journal of Ergonomics.* ISSN: 2165-7556. S4: 005: 1-4.

Yadav Rajvir, M. Patel, S.P. Shukla and S. Pund 2007. Ergonomic evaluation of manually operated six-row paddy transplanter. *International Agricultural Engineering Journal*. 16(3-4): 147-157.

APPENDIX- I

A) Specifications of energy measurement system (K4b2) (COSMED, Italy)

Sr. No.	Particulars	Specifications
A)	**Portable Unit**	
1.	Memory, breaths	16,000
2.	Display LCD	2 lines x 16 characters
3.	Serial Port	RS 232C
4.	Power supply	Ni-MH rechargeable batteries
5.	Thermometer	0-500°C
6.	Barometer, Kpa	53-106
7.	Dimensions portable unit, mm	170 ×55 × 100
8.	Dimensions battery, mm	120 × 20 × 80
9.	Weight, g	400
B)	**Receiver Unit**	
1.	Battery, v (AC)	4 × 1.5
2.	Dimensions, mm	170 × 48 ×90
3.	Weight, g	550
4.	PC interface	RS 232
C)	**Battery charger Unit**	
1.	Power supply, v	120 – 240
2.	Power consumption, kWh	25
D)	**Flow meter**	
1.	Type	Bidirectional digital turbine Φ 28 mm
2.	Flow Range, l/sec	0,03 – 20
3.	Accuracy, %	± 2
E)	**Oxygen Sensor (O_2)**	
1.	Response time, milliseconds	< 150
2.	Range, % O_2	7 – 24
3.	Accuracy, % O_2	± 0.02
F)	**Carbon Dioxide Sensor (CO_2)**	
1.	Response time, milliseconds	< 150
2.	Range, %	0 – 8
3.	Accuracy, %	± 0.01
G)	**Power Supply**	
1.	Voltage, v	100 – 240

B) Specifications of bicycle ergometer (Monark 839E)

Sr. No.	Particulars	Specifications
A)	**Dimensions**	
1.	Length, mm	1120
2.	Width, mm	530
3.	Height at handlebar, mm	650-1135
4.	Height at saddle, mm	800-1120
5.	Weight, kg	55
B)	**Electrical**	

1.	Voltage (AC), v.	18
2.	Brake power @ 200 rpm, W	0-1400
C)	**Measured quantities**	
1.	Distance: meters, miles	
2.	Energy: kcal	
3.	Heart rate: (bpm)	
4.	Force: (N)	
5.	Power: (W)	
6.	Time: min, sec	
D)	**Pre-programmed protocols**	
1.	Åstrand	
2.	YMCA	
3.	Bruce	
4.	Naughton	
E)	**Computer**	
1.	Computer system 8MHz	
2.	Multi-colour rpm pacing bar graph display	
3.	Visual metronome or heart rate	
4.	Heart rate maximum limit alarm	

C) Specifications of computerized polar heart rate monitor (Polar RS 400Tm) (China)

Sr. No.	Particulars	Specifications
A)	**Transmitter**	
1.	Battery life of wear link	Avg. 2 years (3h/day, 7 days/week)
2.	Battery type	CR 2025
3.	Operating temperature, °C	-10 to + 40
4.	Connector material	Polyamide
5.	Strap material	Polyurethane/ Polyamide
B)	**Wrist unit (class one laser product) (Polar 331)**	
1.	Battery life	Avg.1 year (1h/day, 7 days/week)
2.	Battery type	CR 2032
3.	Operating temperature, °C	-10 to + 50
4.	Watch accuracy	Better than ± 0.5 sec/day at 250C
5.	Accuracy of heart rate	± 1% or 1 bpm, whichever larger
6.	Heart rate measuring range, bpm	15-240

APPENDIX- II

A) Details of male subjects

Sr. No.	Name	Code	Age (years)	Weight (kg)	Stature (cm)	HR max (bpm)
1	Ajinkya Rangbhal	AR	25	60	178	195
2	Sandip Rupnar	SR	24	60	165	196
3	Prasad Holkar	PH	24	44	164	196
4	Mahesh Shinde	MS	27	60	180	193
5	Jagdish Khurdal	JK	24	60	178	196
6	Sachin Sable	SS	38	70	164	182
Avg.			**27**	**59**	**172**	**193**
SD			**(±5.51)**	**(±8.36)**	**(±7.89)**	**(±5.51)**

B) Maximum aerobic capacity (VO_2 max) of male subjects

Subject	Subject code	Max. heart rate, bpm	Maximum aerobic capacity (VO_2 max), l/min
1	AR	195	2.14
2	SR	196	2.77
3	PH	196	3.01
4	MS	193	2.48
5	JK	196	2.26
6	SS	182	2.99
Average		**193**	**2.61**
SD		**(±5.51)**	**(±0.57)**

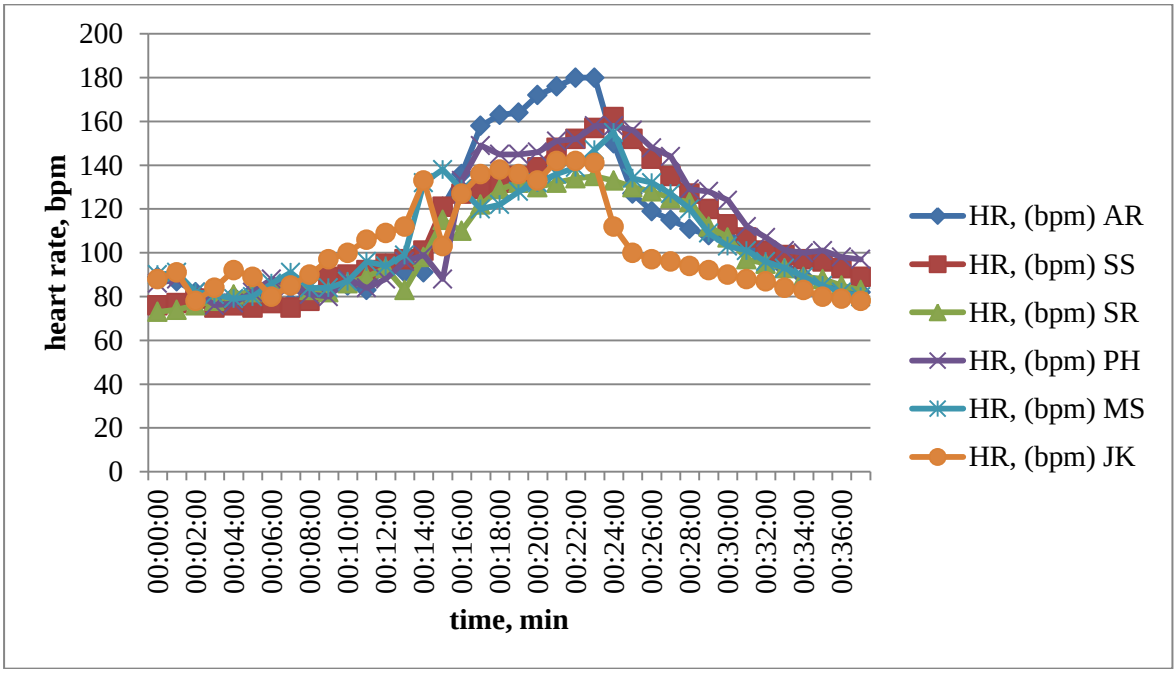
APPENDIX- III

A. Subject's heart rate data records while operating manual paddy transplanter

Sr. No.	Time	AR	SS	SR	PH	MS	JK
1	0:00:00	89	76	73	86	90	88
2	0:01:00	87	77	74	88	91	91
3	0:02:00	82	79	76	82	82	78
4	0:03:00	79	75	78	76	81	84
5	0:04:00	80	76	81	77	79	96
6	0:05:00	82	75	82	82	80	89
7	0:06:00	80	77	84	88	86	80
8	0:07:00	77	75	86	85	91	85
9	0:08:00	82	78	83	81	84	90
10	0:09:00	83	89	82	80	84	97
11	0:10:00	85	90	86	88	87	103
12	0:11:00	83	92	89	84	96	106
13	0:12:00	95	95	93	88	94	109
14	0:13:00	91	97	83	96	99	112
15	0:14:00	91	101	98	99	132	133
16	0:15:00	121	121	115	88	138	103
17	0:16:00	136	127	110	133	129	127
18	0:17:00	158	129	122	149	120	136
19	0:18:00	163	132	129	145	122	138
20	0:19:00	164	135	132	145	128	136
21	0:20:00	172	139	135	146	132	133
22	0:21:00	176	148	137	151	136	142
23	0:22:00	180	152	139	152	139	142
24	0:23:00	180	157	136	158	147	141
25	0:24:00	150	162	133	158	155	112
26	0:25:00	127	152	130	156	134	100
27	0:26:00	119	143	128	148	132	97
28	0:27:00	115	135	125	144	127	96
29	0:28:00	111	127	123	129	120	94
30	0:29:00	108	120	112	128	109	92
31	0:30:00	107	113	107	124	103	90
32	0:31:00	103	107	97	112	101	88
33	0:32:00	99	101	95	107	96	87
34	0:33:00	93	99	93	101	93	84
35	0:34:00	89	97	89	100	89	83
36	0:35:00	86	96	88	101	85	80
37	0:36:00	83	93	85	98	82	79
38	0:37:00	82	89	83	97	80	78

Resting HR	**83.2**	**76.3**	**77.3**	**74.8**	**83.8**	**87.1**
Working HR	**115.3**	**114.7**	**120.6**	**117.5**	**110.9**	**115.3**
ΔHR	**32.1**	**48.8**	**42.7**	**42.6**	**27.1**	**28.2**

B. Heart rate response of subjects during the operation of manually operated paddy transplanter



C. Overall discomfort rating of subjects for manual paddy transplanter

Subject	Subject code	ODR	Scale
1	AR	7	>Moderate discomfort
2	SS	6	>Moderate discomfort
3	SR	7	>Moderate discomfort
4	PH	6	>Moderate discomfort
5	MS	7	>Moderate discomfort
6	JK	5	Moderate discomfort
Mean		**7**	**>Moderate discomfort**

D. Body part discomfort score of subjects for manually operated paddy transplanter

Cat.	Weig htage	Body part experiencing pain						Body Score					
		AR	**SS**	**SR**	**PH**	**MS**	**JK**	**AR**	**SS**	**SR**	**PH**	**MS**	**JK**
I	6.0	-	1	10	-	4, 9	-	-	6	6	-	12	-
II	4.5	8,9	9	-	5,8,9	-	9,10	9	4.5	-	13.5	-	9
III	3.0	10,11	13	5,2,425	24,25	24,25	-	6	3	9	6	6	-
IV	1.5	13,26	24,25		-	-	24,25	3	3	-	-	-	3
							Total	18	16.5	15	19.5	18	12
							Mean	**16.5**					

E. Pull force measurement for manually operated paddy transplanter

Sr. No.	Pull, kg	Angle of inclination	Draft= P cos θ, kg
1	8.27	**43.85°**	5.96
2	9.03		6.51
3	9.67		6.97
4	8.85		6.38
5	10.02		7.23
6	10.35		7.46
7	11.03		7.95
8	9.87		7.12
9	8.90		6.42
10	9.75		7.03
Average	**9.57**		**6.90**

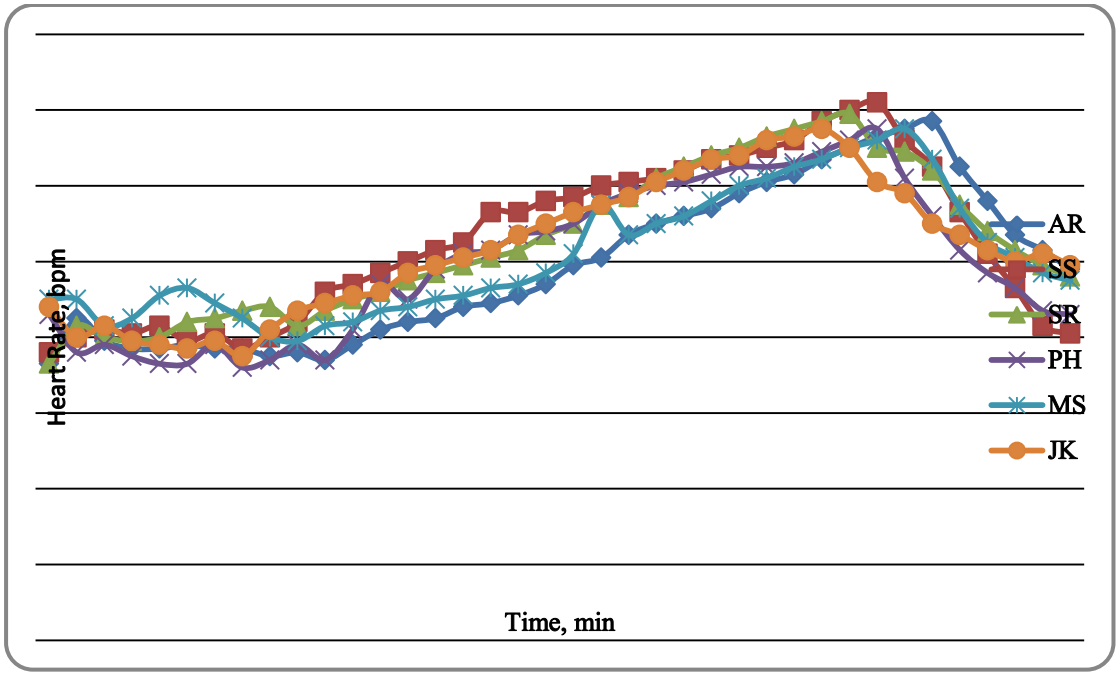
APPENDIX- IV

A. Subject's heart rate while operating power operated paddy transplanter

Sr. No.	Time	AR	SS	SR	PH	MS	JK
1	0:00:00	73	76	73	86	90	88
2	0:01:00	85	80	83	76	90	80
3	0:02:00	79	82	80	78	83	83
4	0:03:00	77	81	79	75	85	79
5	0:04:00	77	83	80	73	91	78
6	0:05:00	78	79	84	73	93	77
7	0:06:00	77	81	85	78	89	79
8	0:07:00	77	77	87	72	85	75
9	0:08:00	75	80	88	74	80	82
10	0:09:00	76	84	83	78	79	87
11	0:10:00	74	92	87	74	83	89
12	0:11:00	78	94	90	82	84	91
13	0:12:00	82	97	92	94	87	92
14	0:13:00	84	100	95	90	88	97
15	0:14:00	85	103	97	98	90	99
16	0:15:00	88	105	99	102	91	101
17	0:16:00	89	113	101	103	93	103
18	0:17:00	91	113	103	107	94	107
19	0:18:00	94	116	107	108	97	110
20	0:19:00	99	117	110	110	102	113
21	0:20:00	101	120	115	115	115	115
22	0:21:00	107	121	117	118	107	117
23	0:22:00	110	122	122	120	110	121
24	0:23:00	112	124	125	121	112	124
25	0:24:00	114	127	128	123	116	127
26	0:25:00	118	128	130	125	120	128
27	0:26:00	121	130	133	125	122	132
28	0:27:00	123	132	135	126	125	133
29	0:28:00	127	137	137	129	127	135
30	0:29:00	130	140	139	132	130	130
31	0:30:00	133	142	130	135	132	121
32	0:31:00	135	132	129	122	135	118
33	0:32:00	137	125	124	112	127	110
34	0:33:00	125	113	115	103	114	107
35	0:34:00	116	102	108	97	105	103
36	0:35:00	107	93	103	93	101	100

37	0:36:00	103	83	99	87	97	102
38	0:37:00	98	81	96	86	95	99
Resting HR		**78.2**	**80.2**	**79.8**	**76.8**	**88.7**	**80.8**
Working HR		**102.7**	**110.1**	**109.7**	**104.3**	**104.1**	**107.7**
Δ HR		**24.5**	**29.9**	**29.8**	**27.5**	**15.5**	**26.9**

B. Heart rate response of subjects for developed paddy transplanter



C. Overall discomforts rating of subjects with developed paddy transplanter

Subject	Subject code	ODR	Scale
1	AR	4	<Moderate discomfort
2	SS	4	<Moderate discomfort
3	SR	5	Moderate discomfort
4	PH	3	<Moderate discomfort
5	MS	4	<Moderate discomfort
6	JK	5	Moderate discomfort
Total		**4**	**<Moderate discomfort**

D. Body part discomfort score of subjects with developed power operated paddy transplanter

Category	Weightage	Body part experiencing pain						Body Score					
		AR	SS	SR	PH	MS	JK	AR	SS	SR	PH	MS	JK
I	5.0	16	-	-	-	-	-	5	-	-	-	-	-
II	3.75	4,5	-	-	5,9	24,25	-	7.50	-	-	7.5	7.5	-
III	2.5	26,27	24,25	-	24,25	-	24,25	5	5	-	5	-	5
IV	1.25	-	-	24,25	-	-	-	-	-	2.5	-	-	-
Total								17.5	5	2.5	12.5	7.5	5
Average								**10**					

E. Pull force measured for developed power operated paddy transplanter

Sr. No.	Pull (kg)	Angle of inclination	Draft = P cos θ (kg)
1	6.08	45˚	4.29
2	8.18		5.78
3	9.39		6.64
4	9.78		6.92
5	8.63		6.10
6	6.12		4.33
7	5.94		4.20
8	7.72		5.46
9	10.79		7.63
10	8.01		5.66
Average	**8.06**		**5.70**

APPENDIX- V

1. Cost of material required for fabrication

Sr. No.	Particular	Material	Specification	Weight (kg)	Rate / Kg	Amount
1.	Main frame	G.I sq. pipe	20 x 20 x 3 mm	1.87	Rs.15/ft	120
2.	Camshaft assembly	M.S flat plate	3 mm thick	1.5	53	80
		M.S solid pipe	← 25 mm	1.2	53	64
3.	Nursery holder	M.S flat	20 x 3 mm thick	0.250	53	14
		M.S hollow pipe	← 20 mm	0.200	53	10
4.	Transplanting assembly	M.S flat plate	3 mm thick	0.650	53	35
		M.S solid pipe	← 20 mm	0.800	50	40
		M.S flat	20 x 5 mm thick	0.300	53	15
5.	Seedling tray	G.I sheet	22 gauge	0.780	-	120
6.	Tray frame	M.S flat	20 x 5 mm thick	0.400	53	20
			20 x 3 mm thick	0.400		20
		M.S angle	20 x 20 x 3 mm	0.800	53	42
		M.S bar	← 8 mm	0.800	40	32
			← 6 mm	0.400	40	16
7.	Engine support	M.S flat	40 x 5 mm thick	0.300	53	16
			25 x 5 mm thick	0.400		20
			20 x 3 mm thick	0.300		16
8.	Engine	-	2 stroke, petrol 1.75 hp @ 6500 rpm	5.25	-	10,000
9.	Gear box		Gear ratio 32.5:1	5.50		4,000
10	Handle	G.I sq. pipe	20 x 20 x 3 mm	0.600	Rs.15/ft	80
11	Handle support	M.S flat plate	25 x 5 mm thick	1.02	53	54
12	Float	Wooden	820 x 430 mm	2.5	-	750
13	Sprocket	M.S	12 teeth	-	-	115
			17 (2) teeth			370
			24 teeth			300
14	Chain	-	½ inch Simplex	10 ft	-	660
15	Ball bearing	-	← 4 mm	-	Rs.30 /piece	354
16	Nut and bolts	-	-	-	-	500
17	Springs	M.S	Helical			420
Total material cost (Rs.)						**18267**
Fabrication cost (Rs.) = 50 % of initial cost						**9,134**
Total cost of machine (Rs.)						**27,400**

2. Operational cost of power operated paddy transplanter

1. Fixed Cost:

1. Cost of machine (C) = Rs. 27,400/-
2. Salvage value (S) = 10 % of initial cost

   = 0.10 x 27,400

   = Rs. 2,740/-

3. Interest rate (I) = 5 %
4. Life of the machine , years (L) = 6
5. Annual working hours, h (H) = 240
6. Depreciation (Rs. /h)

$$= \frac{C - S}{L \times H}$$

$$= \frac{27400 - 2740}{6 \times 240}$$

= Rs. 17.13/-

7. Interest (Rs. /h)

$$= \frac{C + S}{2} \times \frac{I}{100 \times H}$$

$$= \frac{27400 + 2740}{2} \times \frac{5}{100 \times 240}$$

= Rs. 3.13/-

8. Housing (Rs. /h) = 1.5 % of initial cost (C)

$$= \frac{1.5 \times 27400}{100 \times 240}$$

= Rs. 1.72/-

- Total fixed cost (Rs. /h) = 6 + 7 + 8

  = 17.13 + 3.13 +1.72

Total fixed cost (Rs. /h) = 21.98/- ≈ **Rs. 22/-**

2. Variable Cost

1. Fuel cost (Rs. /h)

= Fuel consumed (lit/h) X Fuel Charge (Rs. /lit)

= 0.417 × 86.20

= Rs. 35.94/-

2. Operators cost (Rs. /h)

= Wage of operator / Working Hours

Considering two operators each working @ Rs. 300/ day

$$= \frac{300+300}{8}$$

= Rs. 75/-

3. Repair and maintenance (Rs /h) = 10 % of initial cost

$$= \frac{10 \text{ x } 27400}{100 \text{ x } 240}$$

= 11.42/-

Total Variable cost (Rs. /h) = 1 + 2 + 3

= 35.94 + 75 + 11.42

 Total variable cost (Rs. /h) = **Rs. 122.35/-**

3. Operating Cost

= Fixed Cost + Variable Cost

= 22 + 122.35

 Operating cost of machine (Rs. /h) = 144.35 ≈ **Rs. 145 /-**

The actual field capacity of developed transplanter (ha/h) = 0.032

And, total hours required to complete the transplanting operation (h) = $\frac{1}{0.032}$ = 31.25

Total cost of operation (Rs/ha) = 145 ×31.25

 Total cost of operation (Rs/ha) = 4531.25 ≈ **Rs. 4,532/-**

Plate 3.1 Nursery plantation

Plate 3.2 Existing manually operated paddy transplanter

Plate 3.3 COSMED K4b^2 portable metabolic system kit

Plate 3.4 Computerized bicycle ergometer

Plate 3.5 Subject calibration using bicycle ergometer

Plate 3.6 Novatech load cell with digital indicator

Plate 3.7 Petrol engine with speed reduction unit

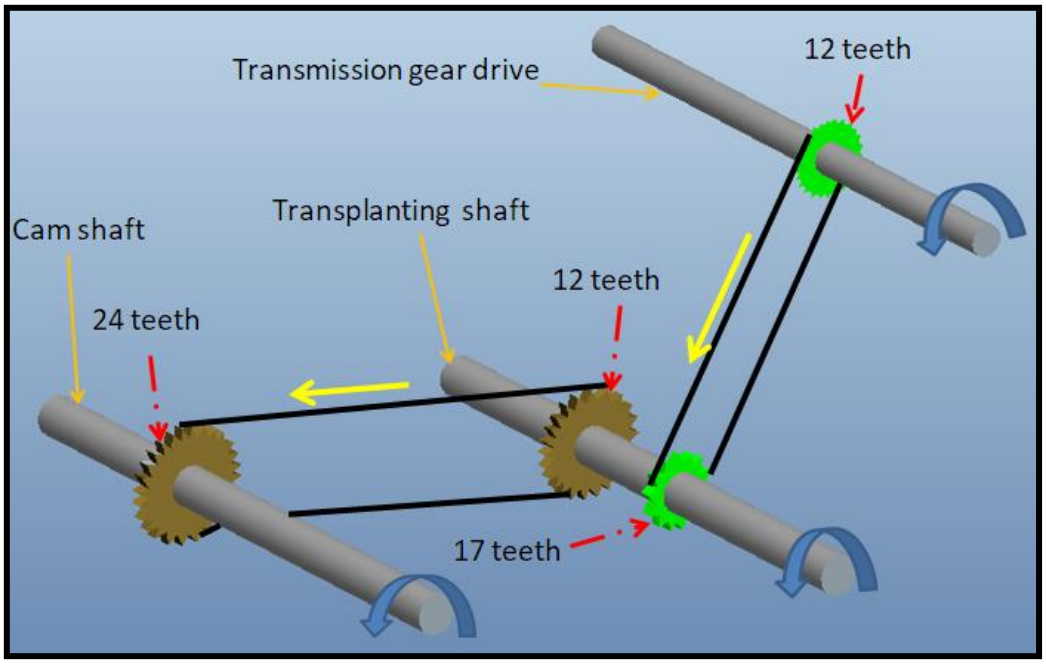


Fig 3.3 Power transmission flow diagram

Plate 3.8 Main frame

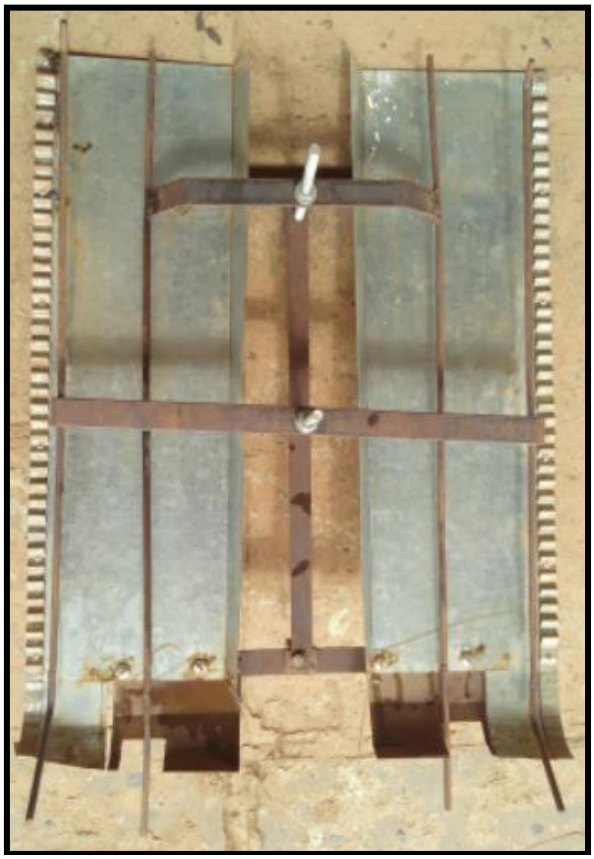


Plate 3.9 Nursery tray with frame

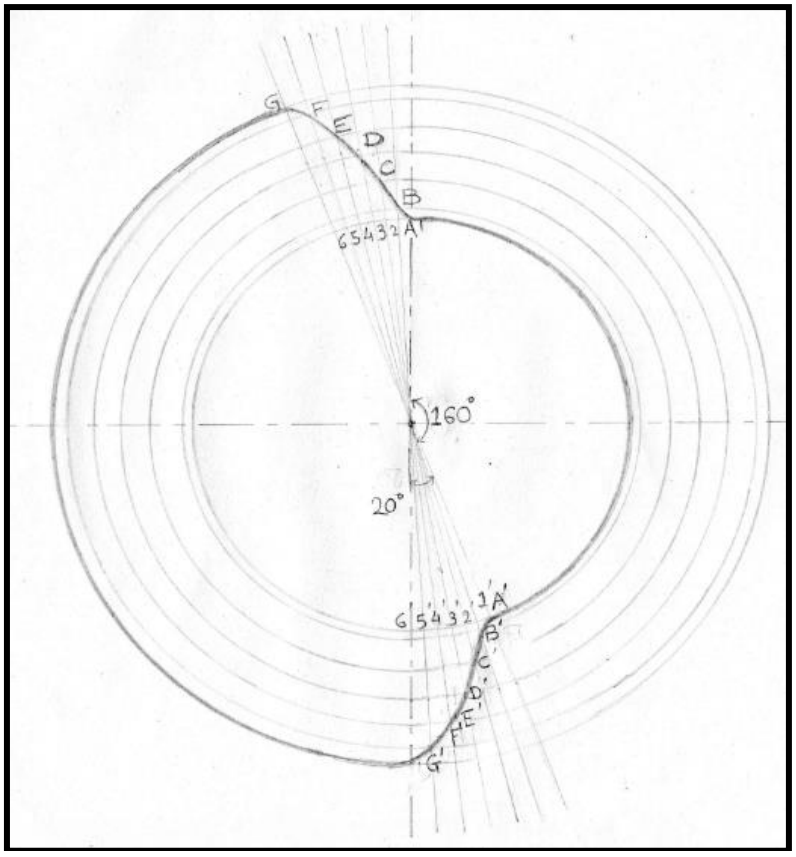


Fig 3.6 Cam profile of nursery planting mechanism cam

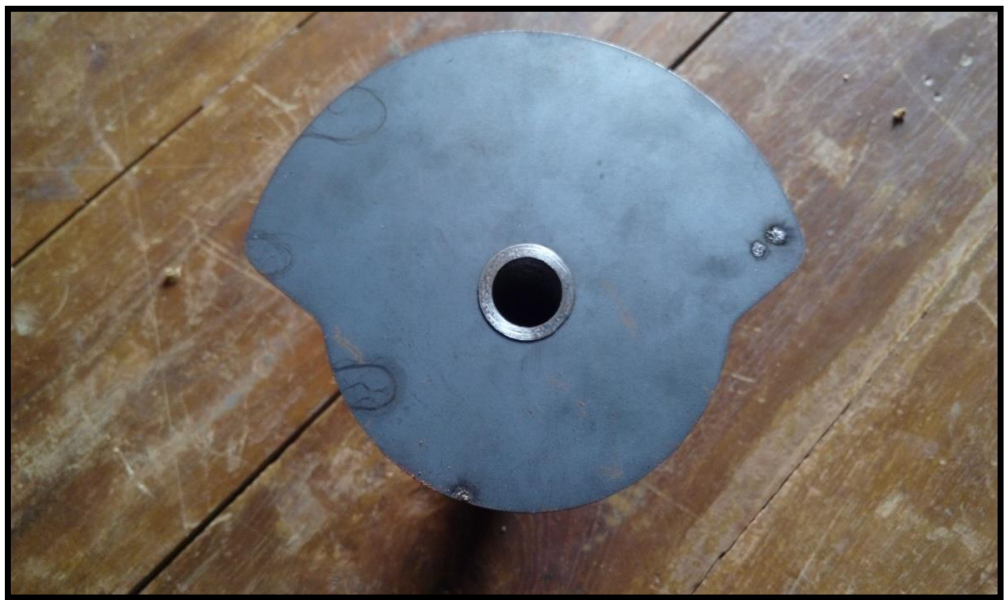


Plate 3.10 Fabricated nursery planting cam

Plate 3.11 Developed nursery holding and releasing cam

Plate 3.12 Picking assembly

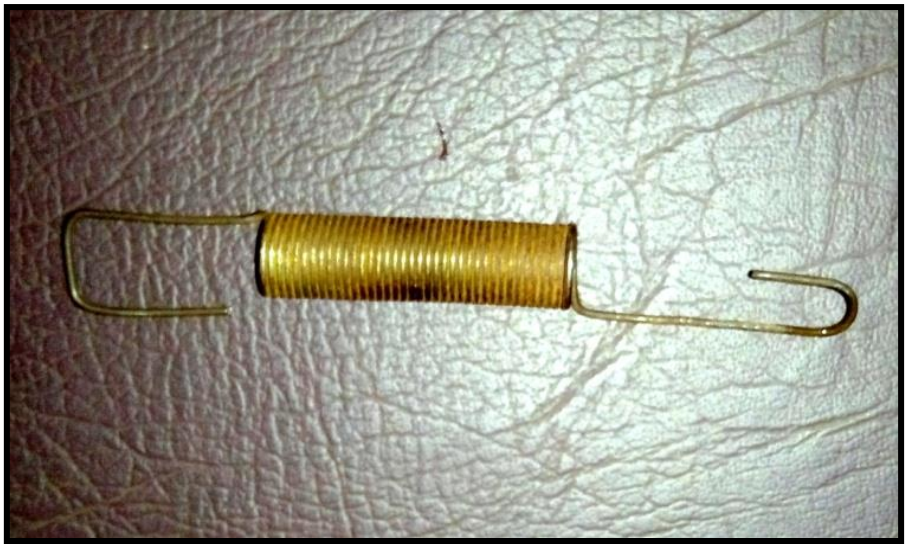


Plate 3.13 Tension Spring

Plate 3.14 Roller bearing

Plate 3.15 Seedling erector

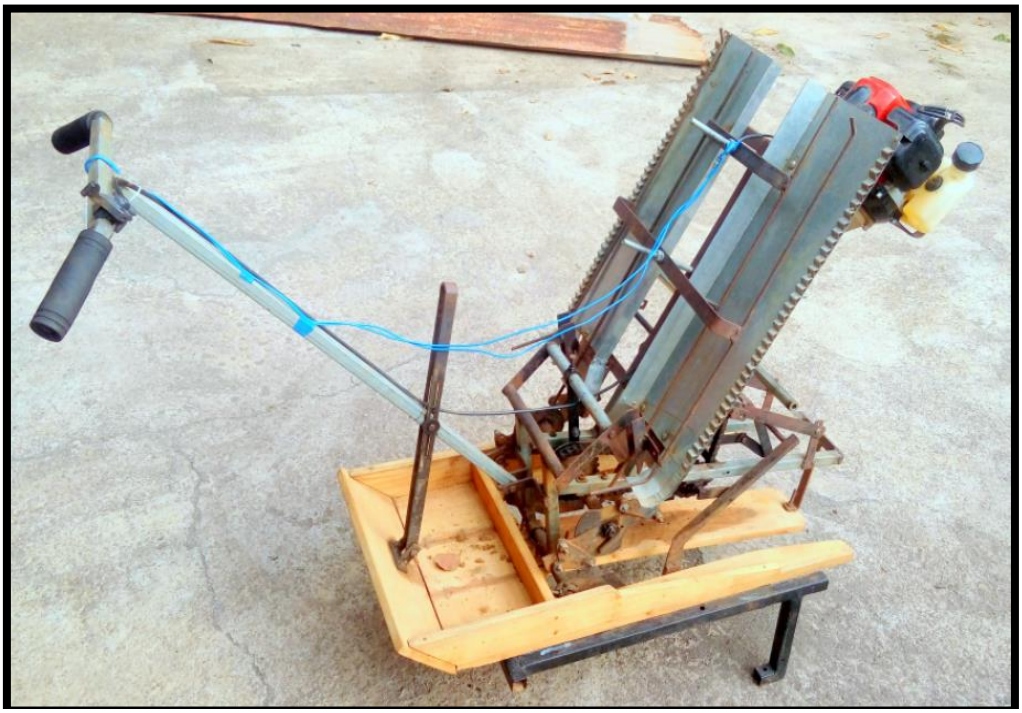


Plate 3.16 Developed power operated paddy transplanter