

**DEVELOPMENT OF GRASS CUTTER CUM PADDY
HARVESTER**

A THESIS SUBMITTED TO THE

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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

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B. Tech.(Agril. Engg.)



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OCTOBER, 2021

CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled **“Development of Grass Cutter Cum Paddy Harvester”** 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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LIST OF SYMBOLS

Symbols	Description
%	Per cent
@	at
/	per
±	Plus or minus
<	Less than
>	Greater than
=	Equal to
Δ	Delta
°	Degree
₹	Rupees
°C	Degree Centigrade

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
Co ₂	Carbon dioxide
Deptt.	Department
DBSKKV	Dr.BalasahebSawant Konkan KrushiVidyapeeth
DBT	Dry Bulb Temperature
EER	Energy Expenditure Rate
Engg.	Engineering
Er.	Engineer
ESA	Ergonomics and Safety in Agriculture
et al.	and others
etc.	Etcetera
Fig.	Figure
g	gram
GCCPH	Grass Cutter Cum Paddy Harvester
GI	Galvanized iron
h	hour
ha	Hectare
ha/h	Hector per hour
hp	Horsepower
HR	Heart Rate
i.e.	That is
I. D	Internal Diameter
Abbreviation	Meaning
kcal	Kilocalorie
kcal/min	Kilocalorie per minute
kg/ha	Kilogram per hector

kJ/min	Kilo joule per minute
kW	Kilowatt
km/h	Kilometre per hour
l	litre
LCP	Limit of Continuous Performance
l/min	Litre per minute
m	Meter
m ²	Square meter
man-h/ha	Man hour per hector
Mha	Mega hector
min	minute
mm	millimeter
mm ²	Square millimeter
MPa	megapascal
M.S.	Mild Steel
m/s	Meter per second
M. Tech.	Master of Technology
N	newton
No.	Number
N mm ⁻²	Newton per square millimeter
OCR	Oxygen Consumption Rate
O.D.	Outer Diameter
ODR	Overall Discomfort Rating
rad	Radian
PH	Paddy harvesting
RHR	Resting Heart Rate
RH	Relative Humidity
rpm	revolutions per minute
SD	Standard Deviation
Abbreviation	Meaning
Sec	Second
SMBC	Shoulder mounted brush cutter
t/ha	Tonn per hector
VCo ₂	Volume of carbon dioxide
Viz.	As follows
VO ₂	Volume of oxygen consumption

VO ₂ max	Maximum aerobic capacity
Vol.	Volume
W	Watt
WHR	Working Heart Rate
WBT	Wet Bulb Temperature
WRC	Work Rest Cycle

ABSTRACT

DEVELOPMENT OF GRASS CUTTER CUM PADDY HARVESTER

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Agriculture is the backbone of Indian economy. India is the world's second-largest producer of wheat, rice and pulses (Anonymous, 2014; Khatkaret *al.*, 2016). Paddy (*Oryza Sativa*) is the most important cereal crop and dietary staple food for 65% of the population of India (Ghoseet *al.*, 2013). In Maharashtra paddy is grown in different regions. Harvesting of paddy is one of the major field operation in rice production. Different methods are adopted for paddy harvesting viz. conventional method and mechanical methods. Because of the unavailability of roads, skilled labour requirement and high initial cost the farmers in Konkan region are harvested paddy by conventional method. It requires 185-340 man-h/ha which is time consuming and drudgeries (Michel and Ojha, 1987). The another method adopted for paddy harvesting is by shoulder mounted brush cutter. It is also used for grass cutting as well as paddy harvesting. With the shoulder mounted brush cutter the forces and vibrations are directly transmitted to the operator's body. It is reported that the use of these machines may lead to musculoskeletal disorders in the long term (Viveket *al.*, 2020)

To reduce the drudgery in existing shoulder mounted brush cutter a grass cutter cum paddy harvester was developed. Before, developing the grass cutter cum paddy harvester, operators opinion for health hazards and drudgery in operation with shoulder mounted brush cutter and also ergonomic evaluation of shoulder mounted brush cutter was taken, in order to improve the fit between the physical demand of tool and the worker who performs the work. The components of the grass cutter cum paddy harvester were developed based on ergonomic and mechanical considerations.

Initially the survey of shoulder mounted brush cutter regarding aspects in grass cutting and paddy harvesting was conducted in different villages in Ratnagiri district of Konkan by preparing a questionnaire. The questionnaire had included the description of workplace, worker description, description of shoulder mounted brush cutter, aspects in grass cutting and paddy harvesting operation, ergonomic aspects in grass cutting and paddy harvesting operation, technical aspects in grass cutting and

paddy harvesting operation, work safety in grass cutting and paddy harvesting operation, etc. From the survey it was observed that the users had posture related occupational hazards in which 97 per cent users suffered from shoulder pain. The reason for forced posture was engine weight.

To quantify the physiological cost and drudgery involved in shoulder mounted brush cutter the experiment was carried out with six male subjects. The performance and ergonomical evaluation carried out to know the field capacity, physiological parameters WHR, OCR, EER, Δ HR and subjective discomfort scores as, BPDS and ODR. The workload with shoulder mounted brush cutter was under 'moderately heavy' category for paddy harvesting as well as grass cutting operation. The WHR and EER with shoulder mounted brush cutter were 121.83 ($\pm$ 9.51) bpm and 24.03 ($\pm$ 5.8) kJ/min for paddy harvesting, whereas 101.17 ($\pm$ 8.66) bpm and 17.96 ($\pm$ 7.02) kJ/min for grass cutting operation.

In order to reduce the drudgery, it was decided to shift the weight of engine from operators shoulder to trolley. The components of grass cutter cum paddy harvester (GCCPH) were developed using anthropometric data of users population. The mechanical components as power requirement, transmission shaft, cutting blade, axel and transport wheels, engine mounting frame, handle, etc. were designed. The overall dimensions (size) of developed GCCPH was 1500 mm, 475 mm and 1011 mm in length, width and height, respectively. The weight of the machine was 17.75 kg.

The performance and ergonomic evaluation of developed GCCPH was carried out. From the experiment it was found that the WHR, Δ HR, Δ OCR were increased by 5.9 %, 46.2 % and 6.5 %, respectively in grass cutting operation. The, values of WHR and Δ OCR were decreased by 0.6 % and 3.6 %, respectively and Δ HR was increased by 4.02 % in paddy harvesting operation. The field capacity was increased by 55.5 % and 35.7 % in paddy harvesting and grass cutting, respectively. The physiological parameters were increased in prototype of GCCPH. To reduce the drudgery involved in prototype of GCCPH it was decided to develop second prototype of GCCPH.

In second prototype of GCCPH the swinging and tilting arrangements were added. Tilting arrangement was for dropping cut crop on field. The machine handle and swinging lever handle were designed based on anthropometric data of users population. The cutting blade was maintained parallel to the ground during the cutter

shaft movement from right to left with providing as bearing housing mounted on the frame.

The performance and ergonomic evaluation of developed second prototype of grass cutter cum paddy harvester was carried out. From the study it was observed that the physiological parameters like WHR and Δ HR were increased by 3.1% and 21.7% than SMBC but those values were decreased in comparison with prototype of GCCPH. OCR, Δ OCR, ODR and BPDS were decreased by 5.8%, 10.9%, 20.8% and 15.1% in comparison with SMBC. The field capacity was increased by 11.1% and 7.1% in paddy harvesting and grass cutting operation, respectively in comparison with SMBC. All the physiological parameters were decreased in second prototype of GCCPH in comparison with developed first prototype. However, the field capacity was less compared with first prototype of GCCPH, as the users were not well accustomed with the use of new mechanism.

The total cost for prototype of GCCPH was ₹ 26831/- including material and fabrication cost. The operating cost of GCCPH prototype was ₹ 116.74/h including fixed and variable cost. The total cost of second prototype of GCCPH was ₹ 28502/- including material and fabrication cost. The operating cost for second prototype of GCCPH was ₹ 119.09/h including fixed and variable cost.

Keywords: paddy harvesting, grass cutting, working heart rate, energy expenditure rate, overall discomfort score, body part discomfort score.

CHAPTER I

INTRODUCTION

Agriculture is the back bone of Indian economy. It provides food for more than 1.2 billion people and total employment to about 54.6% of the population (Khatkaret *al.*, 2016). The total geographical area of India is 328.7 Mha out of which 200.9 Mha is the gross cropped area of the country (61.11 % of the total geographical area). The food grain production covers 65 % (130.58 Mha) of the cropped area (Khatkaret *al.*, 2016). In 2019-20 the total food grain production in the country is estimated at record high about 296.65 million tonnes as against 285.21 million tonnes achieved during year 2018-19 (Anonymous, 2021). The food grain crops include cereals, pulses and other crops. The area under cereals and pulses are 5.7 Mha and 6.0 Mha, respectively (Khatkaret *al.*, 2016). India is the world's second-largest producer of wheat, rice and pulses (Anonymous, 2014; Khatkaret *al.*, 2016).

Paddy (*Oryza Sativa*) is a dietary staple food and the most important cereal crop in India. It is a nutritional staple food which provides instant energy and reach in carbohydrate (starch). Paddy (raw rice) is also used for treating many health related maladies such as indigestion, diabetes, arthritis, paralysis, epilepsy and give strength to pregnant and lactating mothers (Anonymous, 2014). A study conducted in Bangladesh shows that paddy (raw rice) is the main source of zinc intake, providing 49 % of dietary zinc to children and 69 % to women. It is a good source of thiamine (vitamin B1) (0.34 mg/g), riboflavin (vitamin B2) (0.05 mg/g) and niacin or nicotinic acid (vitamin B3) (4.7 mg/g) (Anonymous, 2014; Rohmanet *al.*, 2014).

India is the second largest producer and consumer of paddy in the world and accounts for 22.3% of global production. The production of paddy in India is about 105.3 million tonnes (Khatkaret *al.*, 2016). Paddy is grown in almost all states in the country. Paddy is the rice with husk, the top 10 major rice producing states in India are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Bihar, Orissa, Assam, Karnataka and Haryana which accounts more than 80% rice production (Shindeet *al.*, 2018). Rice is the most preferable staple food crop for about 65 % of the population of India (Ghoseet *al.*, 2013).

In Maharashtra, paddy is the second important crop which is grown over an area of 14.99 Mha with the production of 32.37 lakh tonnes in year 2008-09 and 15.56 Mha with production of 52.96 lakh tonnes in year 2015-16 in different regions

(Thawareet *al.*, 2011; Shindeet *al.*, 2018). The region wise area under paddy (Mha), production (lakh ton) and productivity (t/ha) are given in Table 1.1. The area of the paddy crop is more in the Vidarbha region but the highest productivity is reported in Konkan (Thawareet *al.*, 2011; Shindeet *al.*, 2018).

Table 1.1. Region wise area, production and productivity of paddy in the Maharashtra state: 2015-2016 (Shindeet *al.*, 2018)

Sr. No	Region	Area (Mha)	Production (lakh ton)	Productivity (kg/ha)
1	Konkan	3.69	15.69	4250
2	Western Maharashtra	3.55	12.77	3500
3	Vidarbha	8.15	24.46	3400

The district wise area under paddy (ha), production (tonnes) and productivity (kg/ha) in Konkan region is shown in Table 1.2. The highest area under cultivation of paddy was in Raigad (1094 ha) followed by Palghar (756 ha) and Ratnagiri (686 ha). While the Sindhudurg (4698 kg/ha) had highest productivity followed by Ratnagiri (4658 kg/ha) and Palghar (4163 kg/ha) in year 2015-2016 (Shinde, *et al.*, 2018). The district wise area (ha), production (tonnes) and productivity (kg/ha) is shown in Table 1.2.

Table 1.2. District wise area, production and productivity of paddy in Konkan region: 2015-2016 (Shindeet *al.*, 2018)

Sr. No	District	Area (ha)	Production (tonnes)	Productivity (kg/ha)
1	Thane	551	2139	3882
2	Palghar	756	3147	4163
3	Raigad	1094	4372	3997
4	Ratnagiri	686	3192	4658
5	Sindhudurg	604	2837	1698

One of the major field operation in rice production is the harvesting of paddy. The harvesting process begins when the crop is physiologically matured for getting more yield and fewer losses.

There are different methods of paddy harvesting, adopted by farmers. Traditionally, paddy is harvested manually with the help of sickle. However, it is a

time-consuming and high labour requirement process and takes from cutting to bundle making about 185-340 man-h/ha for paddy (Michel and Ojha, 1987). The average energy expenditure in manual harvesting is 20.58 kJ/min which is higher than mechanical harvesting with self-propelled harvester (Bini, 2012). Also, the majority of body part discomfort in manual harvesting is experienced in the mid back, lower back, buttocks, left thigh, right thigh, left leg and right leg reason (Bini, 2012). However, it is difficult to find the required number of labours for harvesting, during harvesting season whereas the wages are also maximum in this season. The unavailability of labours during harvesting time is the main reason in delay of paddy harvesting and consequently shattering losses of grain. The average cutting height of paddy stalk in manual harvesting with sickle is 5 cm and if proper care is not taken there may be 5-15 % chances of grain loss (Manjeet *et al.*, 2017).

The traditional method of harvesting is time consuming and laborious. In order to minimize above mentioned loss and to reduce harvesting time, the use of harvesting machines is necessary and their applications are increasing in recent years. Harvesting machinery is equipped with two types of cutting mechanisms viz. reciprocating type and rotary type. For harvesting cereal crops, both reciprocating and rotary cutter bar mechanisms are used and for harvesting forage crop and grasses rotary type cutting mechanism is used.

There are different types of paddy harvesting machines available in the market such as combine harvester, vertical conveyor reaper etc. India is a country of small and marginal farmers (Shinde *et al.*, 2017). The adoption of harvesting machines has limitation due to its high initial cost which is not affordable to the small and marginal farmer, in addition to this, small and fragmented land holdings is one of the major limitations in their adoption (Sarkar *et al.*, 2016). Some farmers group came forward to make these machines affordable by providing them on rent basis.

In Maharashtra, paddy cultivation is dominant in Konkan and Vidarbha. The farmers in the Konkan region are cultivating paddy on sloppy land with small and fragmented landholding. The adoption of harvesting machineries like combine harvester or reaper is limited in such conditions due to its high cost, skilled labour requirement, unavailability of roads etc., some of these limitations are already stated prior. Therefore, in Konkan region paddy is harvested mostly by the traditional method i.e. using sickle which is time consuming and drudgeries.

The development of the industries has caused the migration of agricultural labour from village to cities. Particularly in Konkan region the majority of male young generation is migrated to near by big cities. Due to this, the wages have touched the new height with acute scaracity of labourers during peak harvesting season.

The shoulder mounted grass cutter is widely adopted in Kokan region for grass cutting. It has two cutting attachments viz nylon head cutter used for grass trimming and a circular saw used for clearing bushes. The machine consists of petrol engine, drive shaft with housing, hanging band for operator and cutter head. The use of shoulder mounted grass cutter with circular saw for paddy harvesting is found sporadic in the Kokan region. It has attachment for windrowing the harvested crop. The primary discussions with users were carried out. During the operation the operator has to bear the weight of machine on his shoulder in standing posture. The cutting shaft is to be manipulated by one hand with right-left twisting his body above the waist. The standard duration of daily work with brush cutter was 3.5 hrs (Krzysztof, 2015). The continuous use of this machine may lead to musculoskeletal disorders in the long term (Viveket *al.*, 2020). Hence, is necessary to conduct operators survey regarding use of machine, drudgery in operation, safety during work etc. It is also required to ergonomically evaluate the machine being used for grass cutting and some places for paddy harvesting as well. Based on the outcome of users survey and ergonomical evaluation, the new machine for grass cutting as well as paddy harvesting is to be developed.

Hence, considering the above points, the research project entitled “Development of grass cutter cum paddy harvester” is undertaken with the following objectives.

- Ergonomic evaluation of available shoulder mounted grass cutter cum paddy harvester.
- Development of grass cutter cum paddy harvester.
- Ergonomic evaluation of developed grass cutter cum paddy harvester.

CHAPTER II

REVIEW OF LITERATURE

This chapter describes the review of the research work related and relevant to the present study's title and objectives. This chapter describes the review related to grass cutting and paddy harvesting technologies and drudgery induced with it and ergonomic evaluation. The reviews are classified into different sections as given below:

2.1 Cultivation and Production of Paddy

Ghoseet *al.*, (2013) studied the general situation and production trend of rice in Asian countries. They found that Asia was the largest rice production region in the world. India has become the world's second-largest rice-producing nation with the largest rice harvesting area in the world. Rice occupies about 24% of the total cropped area of the country and contributes 42% of total food grain production and 45% of total cereal production. Around 65% of the total population in India depends on rice and it accounts for 40% of their food production.

Khatkaret *al.*, (2016) studied the production and consumption of grains in India. India holds the second largest agricultural land (179.9 Million ha) in the world. Food grain production covers the dominant part of the cropped area (65%) in Indian agriculture. According to the FAO world agriculture statistics (2010), India was the world's largest producer of millets and the second-largest producer of wheat, rice and pulses.

Thawareet *al.*, (2011) reported that the region-wise area, production, environmental parameters and productivity of rice in Maharashtra. The area under paddy cultivation in Maharashtra was 14.99 lakh ha and in the Konkan region was 4.136 lakh ha. Rainfall in Konkan was very high and it's ranging from 2000 to 4000 mm. The relative humidity of the Konkan varies from 90-95% in the Kharif season and 80-85% in Rabi season. The minimum and maximum temperatures are 19.9°C and 34.0°C respectively.

2.2 Discomfort in Harvesting and Grass Cutting Methods

Azmiret *al.*, (2015) conducted a case study on the effect of hand vibration on vibration-induced disorder among grass cutter workers. It took the observations from 204 male subjects with age group 20-70 years. The hand-arm vibration exposure from

the grass cutter machine may cause various hand disorder symptoms called hand-arm vibration syndrome. According to the case study, 172 workers (84.3 %) suffered from a vascular disorder in the left hand, while 163 workers (79.9 %) suffered from the vascular disease in the right hand. According to an assessment done, more than 90 % of the workers had a risk stage of handgrip strength. It was concluded that the grass cutter workers had been exposed to high severity of vibration that induced hand disorder.

Bini (2012) experimented on the ergonomic evaluation of paddy harvester and thresher with farm women. The physiological response of women while performing field operations like harvesting with a sickle, harvesting with the self-propelled harvester, threshing by hand and threshing with mini thresher at different time intervals was observed. The maximum energy cost in harvesting with a sickle was 20.58 kJ/min and with a self-propelled harvester it was 17.93 kJ/min. It also observed that the mean overall discomfort rating for manual harvesting was more than moderate discomfort and for self-propelled harvester was moderate discomfort. The result showed that the arms and shoulder were concerned with areas of discomfort for machine operation. Harvesting after 11 am has resulted in 18% more energy expenditure than harvesting before 9 am. The oxygen uptake in terms of VO₂ max was 64.56 % for the self-propelled harvester and 74.12 % for manual harvesting.

Nkakini *et al.*, (2015) conducted an experiment to examine the favorable relationship between lawn mower, environment and the operator's comfort. Manual lawn clearing operation with hand tools like power saws, sickle etc. was often exposed to arm pains, muscular disorder and blisters on their palms being caused during the operational exercise. The experiment was conducted on the field with the lawn mower and at the end of the operation, each of the operators gave information concerning comfort rating within the range of 0 to 10. Based on their comfort ratings the comfort scale 10-point scale was obtained from the answers given by the operators. Obtained data were statistically analyzed using arithmetic mean and percentile calculations. The study found that lawn mower operators experienced discomfort on their shoulders, necks, backs (spinal cord) and in their knees, during operation.

Viveket *al.*, (2020) designed and fabricated an ergonomic hedge trimming machine with angle adjustment. It was stated the labor was subjected to hand-arm vibration (HAV) due to vibrating machines. The hand-arm vibrations (HAV) causes a

musculoskeletal disorder, numbness, and reduces handgrip strength. The developed hedge trimmer is shown in Plate 2.1 (b).

2.3 Preparation of Questionnaire

Kuorinka *et al.*, (1987) standardized the nordic questionnaires for the analysis of musculoskeletal symptoms. It was stated that musculoskeletal disorders and symptoms in a working population were common. The questionnaires have proved to be the most apparent means of collecting the necessary data. These standardized questionnaires presented the analysis of musculoskeletal symptoms in an ergonomic or occupational health context.

Nag (2011) developed an ergonomic checklist to examine work systems and find out the drudgery according to divergent approaches (mechanistic, biological, perceptual/motor, technical, and psychosocial) with corresponding individual and organizational outcomes. The weighting of the modules varied with the nature of the job to be analyzed, the country's specific features or population under study, organizational priorities, and the intended use of the analysis results. Respondents mark the “primary statement” as Yes/No. “Yes,” answers indicated the apparent absence of a problem, although the advisability of further scrutiny should not be ruled out. “No” answers stated the need for an ergonomic evaluation and improvement.

2.4 Paddy Harvester

Arvind *et al.*, (2015) designed and developed a mini paddy harvester. The developed machine was a walk-behind type. It worked the same as a brush cutter with two circular blades. The power source used for this machine was a 1.5 kW, 3000 rpm petrol engine. The required speed for cutting a paddy was 300 rpm. The cost of harvesting with the machine was comparable with the traditional method. The results of the harvesting test found that the developed machine reduced the cost of harvesting up to 53.33 %. The developed mini paddy harvester is shown in Plate 2.1 (a).

Charwaket *et al.*, (2019) designed and developed a crop cutting machine powered by a two-stroke petrol engine. The use of the machine was cost-effective. It was powered by 7.5 hp, 3200 rpm, two-stroke petrol engine. The engine used for the machine was kick start type. The fuel consumption of the machine was 2 lit/acre.

Chavan *et al.*, (2015) developed a manually operated reaper for paddy harvesting. It was stated that walking type vertical conveyer reaper, power tiller, and tractor front mounted reaper save about 50-60% labour cost and 60-70% harvesting

cost as compared to manually harvesting method and the height of a crop must be more than 10-15 cm for cutting operation. The height of the cutter bar of the machine was 7.5 cm above ground level. The distance between the two wheels was 36 cm and the length of the shaft was 40 cm. It was found that the effective working width of this machine was 30 cm, field efficiency was more than 66% with only 20 man-hr/ha required for harvesting operation. The drawback of the machine was it's unsuitable for non-uniform land with high power requirements due to more weight.

Murthy *et al.*, (2019) fabricated an economical semi-automatic paddy harvesting machine. The wheels were provided for easy movement of the harvester in fields which made the harvester portable. For cutting the crop chain saw was used which cut the crop in a rotary motion and powered by a two-stroke petrol engine. The collecting mechanism for the collection of crops to one side after cutting was also provided.

Nesaret *et al.*, (2012) designed and developed a cutting head for a portable brush cutter used in rice harvesting operations. The circular saw blade was of 24 cm diameter and 2 mm thickness. The cutting location and number of the stem were the significant factors in cutting energy and force, rice variety was not. The cutting energy and power were dependent on the diameter of the stem, maturity stage, moisture content, and bevel angle. It was found that increase in cutting height decreased the cutting force as well as its effectiveness. The Young's modulus of the stalk was in the range of .033-1.21 Mpa with an average of 0.78 MPa. The total power requirement (kW) was calculated based on idling power (kW/m of cutting width), specific cutting energy (kJ/m^2), forward speed (m/s), and cutting width (m). The cutting speed was between 25-35 m/s. The forward speed of portable reaper was commonly in the range of 0.7-1.1 m/s. Results of the test showed that the forward speed of the operator was 1 km/hr and harvesting time in each plot of 50 m^2 was to be 8 min with 1.5 m cutting width in each blade movement.

Ravindraet *et al.*, (2017) designed, developed and conducted a performance evaluation of manually controlled rotary type paddy cutter with the knapsack sprayer power utilization. The developed multipurpose machine was used for both sprayings as well as paddy harvesting. An engine of 1.64 kW power with a rated speed of 5600 rpm was used. A flexible shaft was used for power transmission with a diameter of 16 mm. The gear transmission system was designed with bevel gear with a speed ratio of

1:2 and the speed of the cutter was 3000 rpm. The field capacity of the developed machine was 0.082 ha/hour with a width of the cut was 30 cm.

Sarkar *et al.*, (2016) evaluated the performance of handheld cutter suitable for the harvesting of wheat and rice for small and marginal farmers. The results of the experiment showed that the field capacity of the crop cutter was 2.44 times higher than the manual operation. The labour requirement was 32.74 and 149.25 man-h/ha for crop cutter and manual operation, respectively. Thus, as compared to manual harvesting labour saving through crop cutter was 5.0 and 4.6 folds in wheat and rice harvesting, respectively.

Shindeet *al.*, (2017) designed and fabricated a mini harvester for harvesting crops to help small scale farmers with land holding less than 5 acres. The machine consisted of a petrol engine, cutting blade, screw conveyor and threshing unit. The scissoring type of motion was used to cut crop. The engine used in this machine was of 4 stroke petrol engine and had the power of 14.25 hp at 9000 rpm and maximum torque was 12.5 N-m. The forward speed of the machine was limited up to 2.77 m/s.

2.5 Grass Cutting Machine

Godwin (2017) designed a hand-held grass mowing machine with rotary blades for cutting grass on the lawn. The design consideration factors of the machine were strength, durability, lightweight, ease of assembly and disassembly. The performance test results showed that one square meter of grass was cut in 20 minutes.

Handaka and Joko Pitoyo (2011) modified a grass cutter into a small rice harvester. It was stated that the cutting energy increased for the same with the cutting forward speed of the machine. The performance of the machine was conducted at an average speed of 0.54-0.66 km/h with a power of 2 hp and an engine speed of 6,000 rpm. The efficiency of the machine was 90 % depending on field conditions, working width was 75-100 cm, and fuel consumption was 1 lit/ha.

Krzysztof (2015) studied the influence of cutting attachment on vibration emitted by brush cutters and grass trimmers. The study involved four models of brush cutters (STIHL manufactured) with three machines of each model, differing in size (displacement and engine power) and equipped with six cutting elements. The standard duration of daily work with grass trimmers was 4 hand with brush cutter was 3.5 h. The different methods for reduction in vibration of the machine were mentioned. The results of the study found that vibration acceleration was higher on the left handle, regardless of the mode of engine operation. Only in two cases (about

2%) out of the 96 cases, a higher vibration on the right handle was observed. Vibration hazards increased with increasing the size of the cutter

Pandeet *al.*, (2018) designed the grass cutting machine. The working principle of grass cutter was providing a high-speed rotation to the blade, which cut the grass. The result of the study found that the designed grass cutter reduced the manpower, reduced the human efforts, improved the economy. It was concluded that to increase the cutting effectiveness of the blade there should be minimum welding joints in the design.

Rubenteranet *al.*, (2017) designed and fabricated a portable lawn mower. The mower was powered by a rechargeable battery. A nylon string was used as the trimmer instead of traditional cutting blades. The mower was designed in an ergonomic approach. The height of the handle was 89 cm, the distance between the two hands was 68 cm. The distance between the two wheels was 38.5 cm. The designed machine did grass cutting operations faster by reducing the cutting time. It was lighter in weight, environmentally friendly and cost-effective.

2.6 Development of Grass Cutter Cum Paddy Harvester

2.6.1 Properties of the paddy stem

Rangannaet *al.*, (1995) studied the mechanical properties of paddy stems. They selected five high-yielding paddy varieties, namely IR 20, IR 50, IR 60, CO 43, and TNAU 80030. The study result found that 16.38 MPa to 35.18 MPa were the range cultivars' tensile strength. It also found that the dynamic cutting force was inversely proportional to the moisture content and directly proportional to the cultivar's cross-sectional area.

Alireza and Alizadeh(2016) experimented on specific cutting energy variations under different rice stem cultivars and blade parameters. The rice stem's cutting energy requirement was an essential factor in designing or optimizing the harvesting machine's cutting mechanism. The experiment results showed that the physical and mechanical properties of a plant stem, blade shearing components were influential on the cutting energy requirement. The rice cultivars and blade velocity had a significant effect on the specific cutting energy. When blade velocity was increased from 1.5 m/s to 2.5 m/s, specific cutting energy raised about 77 % and the cutting energy per stem was reduced when the number of stems cut simultaneously increased. It was found that at a 30° cutting angle and 30° bevel angle, the cutting energy was optimum.

Alizadehet *et al.*, (2011) studied the cutting energy of rice stem as influenced by internode position and dimensional characteristics of different varieties. The cutting energy of rice stem at different internode positions was examined. The study results indicated that cutting energy was affected by the internode position and dimensional rice stem characteristics. It also observed a highly significant and positive correlation between the cutting energy and stem wall thickness, major and minor diameters, and the rice stem's cross-sectional area. The study also revealed that the average of 32.5 % decreased the cutting energy of rice stem in the second internode compared to the third internode position. It was calculated that with increasing cutting height towards the second internode, more energy saving could be achieved by harvesting machines.

Muzamilet *et al.*, (2016) studied the influence of moisture content, loading rate, and internode position on the mechanical properties of paddy and wheat straw. The mechanical characteristics of paddy and wheat straw in terms of shearing strength, specific shearing energy and cutting force with the change in moisture content, internode position and loading rate were developed. The failure of crop structure and its separation occurs by compression, tension, bending, shearing and density of the plant. The result of the study showed that shear strength and specific shearing energy increased with an increase in moisture content and loading rate from first to third internode position. The cutting force required for paddy straw was varied between 13.4 to 24.6 N. The peak value of shear strength occurred at moisture content 19.5% which was 18.26 MPa (ranges from 5.49 to 18.26 MPa) for paddy straw and 24.8 MPa (ranges from 7.59 to 24.8 MPa) for wheat straw.

2.6.2 Design of handle

Ching-yi Wang and Deng-ChuanCai (2017) studied hand tool handle design based on hand measurement. Anthropometric data of 60 participants was used. The study concluded that the handle design was depend on the users' hand length and a hand-breadth. It concluded the handle length should be at least 100 mm. It was suggested that the handle cross-section should be elliptical for better gripping and the ratio of handle cross-section with width and length should be 1:1.25.

Kumar *et al.*, (2017) experiment the reducing discomfort in pushing an industrial trolley using ergonomics. The experiment was conducted in a laboratory on five subjects of varying stature 165 cm, 173 cm, 174 cm, 175 cm, and 182 cm with five different handle heights, viz. 90 cm, 95 cm, 100 cm, 105 cm and 110 cm. The experiment results found that at 110 cm handle height, the pushing force was

minimum and the compressive load also least. It also found that at 110 cm handle height and 150 mm wheel diameter helped to reduce worker discomfort.

Katharynet *et al.*, (1992) analyzed handle designs for reducing manual effort by the influence of grip diameters. Three handle diameters were evaluated by study viz. handle diameter matched with inside grip diameter, a handle 1 cm smaller than inside grip diameter, and a handle 1 cm larger than inside grip diameter. The results indicate that the smaller handle maximized grip strength. Grip strength was also more significant with the matched handle than with the larger handle. There were no differences in grip force exerted with different handles during the experiment. However, the effort was reduced using the smaller handle and provided the most incredible capacity for exerting grip force. The smaller handle also reduced forearm muscle activity. The study indicated 1.0 cm smaller than the user's inside grip diameter might reduce effort and the potential for injury.

2.6.3 Cutting mechanism

Yumnam and Pratap (1991) indicated that a rotary blade's power requirement was minimum at blade bevel angle between 25° and 30°. However, experiments on counter-edge cutting of ryegrass, lucerne, and oats suggested an optimum blade angle between 17° and 25°. Although at 25° bevel angle requirement of energy was minimum for, little difference was observed in energy requirement over a range of 25° to 50° blade bevel angle.

2.7 Ergonomic evaluation of grass cutter and paddy harvester

A comprehensive review of previous research work related to the ergonomic evaluation of farm tools and machinery is briefly reported under the following subtitles.

1. Selection of subject
2. Calibration of subject
3. Energy cost of work
4. Maximum aerobic capacity
5. Acceptable work load
6. Body part discomfort score
7. Overall discomfort rating
8. Work rest cycle

2.7.1 Selection of subject

The selection of the subject plays a significant role in the ergonomic evaluation of any farm machinery. The subjects were selected based on age, sex, physical fitness, etc.

Grandjhen (1982) presented the relationship between the oxygen consumption and age of the workers. He found the expected maximum percentage of work was found in the 20 to 30 year's age group. The loss of maximum performance of 20-30, 30-40, 40-50, 50-60, 60-65 age group was 75 %, 80%, 90%, 80% and 75% respectively.

Seidel *et al.*, (1980) experimented on human response to prolonged, repeated whole-body vibration. It stated that the selection of the subject plays a vital role in ergonomic studies. The subject should be medically fit to undergo trials. They selected the subjects based on detailed anamnesis, a general clinical state, and an ECG test. They noted that the average duration of subject sleep was 7 - 5 hr, and the main body mass did not vary from than 0.6 % during the experimental days.

2.7.2 Calibration of subject

Calibration of subject is the process of evaluating the physiological workload using heart rate. The relationship between the heart rate and oxygen uptake must be determined for each subject. Both variables have to be measured in the laboratory at several submaximal loads.

Kroemer *et al.*, (1997) stated that the heart rate and oxygen consumption rate had a linear and reliable relationship in the range of light work and heavy work. They suggested that the counting of heart rate was more straightforward than the oxygen measurement. Measurement of heart rate has another significant advantage over oxygen consumption as an indicator of metabolic processes. They found that the relationship may change within one person with training, and it differs from one individual to another.

Sander and McCormick (1993) stated that the linear relationship between heart rate and oxygen consumption rate was different for different subjects. They suggested taking the calibration of each subject to determine the relationship between heart rate and oxygen consumption rate.

Tewari *et al.*, (2005) studied the ergonomic evaluation of the self-propelled reaper. They used a bicycle ergometer to calibrate the subjects. The subjects peddled the bicycle ergometer at a predetermined speed and with varying breaking load. It

followed standard protocol to record the data of their physiological responses at different load conditions.

2.7.3 Energy cost of work

Singh *et al.*, (2014) conducted an ergonomic study of farm women during wheat harvesting by improved sickle. The study aimed to determine the physical fitness, time and activity profile, and physiological stress of farm women during wheat harvesting. The study results revealed an increase in 19.5 % of the working efficiency with a serrated sickle. It observed that one farm woman harvested 50 bundles of wheat by using serrated sickle while harvested only 39 bundles of wheat with a local sickle. The average working heart rate of women using serrated sickle was 110 bpm, and the energy expenditure rate was 12 kJ/s. The serrated sickle saved about 19 % cardiac cost of farm-worker per unit of output than the traditional practice of local sickle.

Tripathiet *al.*, (2015) experimented on the ergonomic evaluation of farm women through improved serrated sickle for harvesting wheat crop. It was tested to determine the physical fitness, time, activity profile, and farm women's physiological stress when harvesting wheat activity. The result of the experiment was found that the average heart rate was 33.93 bpm, and the energy expenditure rate was 12.33 kJ/s with a local sickle. With an improved serrated sickle, it was 17.46 bpm and 8.40 kJ/s, respectively.

2.7.4 Maximum aerobic capacity ($\dot{V}O_2$ max)

The term maximum aerobic capacity is the maximum capacity to transport and utilize oxygen during incremental exercise. Also, the maximum aerobic capacity is the acceptable measure of cardiorespiratory efficiency. The maximum aerobic capacity has been estimated by having subjects run on a treadmill or pedal bicycle ergometer while their oxygen uptake is measured. The running or cycling speed is increased incrementally, and oxygen uptake is measured approximately at every 3 minute after the subject has adapted to each new work rate. It is observed that the oxygen rate increases as the work rate increases. It is generally believed that individuals can work continuously over an 8 h shift at a rate of 30 to 50 per cent of their maximum capacity.

Ghosh *et al.*, (2017) studied the maximum aerobic capacity concerning body mass index before and after exercise in healthy young adults. It was mentioned that during exercise, the body's metabolic rate was increased 20 times more than the

resting level. The body oxygen uptake was the amount of oxygen extracted from the air as a body performs work. An Ardle equation was used to calculate maximum aerobic capacity. It was found that an increase in body mass index decreased the maximum aerobic capacity. The maximum aerobic capacity in normal active male was 38 ml/kg/min and in normal active female it was 29 ml/kg/min.

2.7.5 Acceptable work load (AWL)

Reinberget *al.*, (1970) reported that the peak of muscle strength for both men and women is reached between 25 to 35 years old. Older workers between 50 and 60 can produce only about 75 to 80 per cent of muscular strength compared to their younger days.

Sahaet *al.*, (1979) based on their study on the acceptable workload for Indian workers, reported that the acceptable workload for average young Indian worker while performing work under comfortable thermal environmental conditions would lie somewhere between 30 and 40 per cent of individuals maximum aerobic capacity. Further suggested that 35 percent may be considered the reasonable limit for which the corresponding energy expenditure rate was 18.0 kJ/min and heart rate would be around and 110 bpm.

2.7.6 Body part discomfort score (BPDS)

Aware *et al.*, (2017) conducted an experiment of physiological cost and drudgery in paddy transplanting at Agronomy field Dr. B.S.K.K.V, Dapoli. The experiment was conducted with calculations of maximum heart rate (HR max) for each subject was calculated with the help of the heart rate monitor in bpm (Polar, RS 400Tm), Energy Expenditure Rate (EER). The HR and OCR are measured with a mobile breath by breath metabolic system (K4b2, COSMED, Rome Italy). For body part discomfort score (BPDS), the standard protocol as suggested by Corlett and Bishop (1976) was followed. The study found that the ODR and BPDS values of subjects were less. The reason was that, working posture. The continuous bending caused undue stress on the spinal cord, lower back, legs, and knees.

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”.

Premkumari *et al.*, (2018) evaluated the agricultural worker's body part discomfort score during weeding operation. It was found that weeding operation was a task demanding high labor and directly associated with human drudgery. The study was aimed to find the level of human drudgery and musculoskeletal disorder of farmworkers involved in weeding operations. The overall discomfort rating (ODR) and body part discomfort rating (BPDS) subjective scales were used for identifying the discomfort level.

2.7.7 Overall discomfort rating (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”.

Rondlaet *et al.*, (2019) studied an evaluation of drudgery reducing agricultural technologies developed for farm women. It was estimated that the average of women in a day was about 8-9 hrs of farm operations like weeding, transplanting, harvesting, threshing and storage, etc. 30 farm women of the age group 30-40 years were selected to estimate the drudgery. The average height, weight, and body mass index was 151.5 cm, 50.5 kg, and 23.4, respectively. The results found that the amount of energy spent by the farm woman while performing activities with the improved technologies was low compared to the traditional method. Overall discomfort rating scale was used to calculate the discomfort of a farm woman.

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-heavy 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 occupation work load.

2.7.8 Work rest cycle

Murrel. (1965) discussed the performance rating, which provides a general target from individual performance, and Compensating Relaxation Allowances, which

indicate how much rest was required. He quoted from studies on the efficiency of ratings and allowances and discussed the variabilities that can arise. After examining progress in adopting physiological and psychological measurements of work intensity to determining workloads, he concludes by considering some of the present relationships between workload and resting time.



(a) Mini paddy harvester



(b) Hedge trimming machine with angular adjustment

Plate 2.1 Developed machines for paddy harvesting and grass cutting

CHAPTER III MATERIALS AND METHODS

This chapter deals with development of grass cutter cum paddy harvester. The methodology adopted for identification of drudgery in grass cutting and paddy harvesting, use of anthropometric data for deciding machine parameters, ergonomic evaluation of conventional as well as developed machine for grass cutting and paddy harvesting have been discussed and presented in this chapter.

3.1 Grass Cutting and Paddy Harvesting Methods

The conventional and modified grass cutting and paddy harvesting methods has been studied to identify the difficulties and drudgery involved in it.

3.1.1 Conventional method of paddy harvesting

Conventionally the grass cutting and paddy harvesting operations are carried out manually using sickle in squatting with forward bending posture. In bending posture, the human body consumes 2 kcal/min additional energy and the heart beats faster about 30 % (Bini, 2012). The farm workers faced musculoskeletal disorders due

to continuous working in squatting posture with forward bending (Kurdal,2019). The various body parts viz. mid-back, lower back, buttocks, left thigh, right thigh, left leg, right leg etc. experience discomfort during manual harvesting. The conventional method of harvesting was time-consuming and laborious. The paucity of labours during peak harvesting season causes delay in timely harvesting of the crop. The delay in harvesting for a week causes 6 per cent loss and delay in 10 days of harvesting 11 per cent loss (Ranganna *et al.*,1995). The energy cost of conventional method was 20.58 kJ/min and for self-propelled harvester it was 17.93 kJ/min (Bini, 2012). Plate 3.1 shows the conventional way of paddy harvesting method.



Plate 3.1 Conventional method of paddy harvesting

3.1.2 Grass cutting and paddy harvesting with shoulder mounted brush cutter (SMBC)

The different types of machines for paddy harvesting were available such as reaper, combine harvester, etc. The shoulder mounted brush cutter (SMBC) was widely used for grass cutting operations but it had some limitations for paddy harvesting operations. It was a small portable machine with a rotary cutting mechanism. It consisted of a petrol engine, a transmission shaft with housing, a hanging band (Harness) for the operator and a cutter head. The machine was operated in a standing posture mounted on the shoulder of the operator. During operation the cutter unit was moved from right to left. It was observed that the machine produced vibrations during the field operation which were directly transmitted to the operator's body.

The nylon line cutter head also known as grass trimmer was used for grass cutting, whereas a circular cutter blade with the windrowing system was used for paddy harvesting. The propulsion system of grass trimmer spins the wire at such a

speed, it was able to cut the grass with ease. The nylon line was hand wound on to a reel and leaving both ends extending from the reel housing before starting the operation. The reel was powered from the prime mover and cut the grass horizontally. The nylon line cutter head (grass trimmer) is shown in Plate 3.2 (a). A circular cutter blade with windrowing system was used for paddy harvesting operation. The cutter blade received power from prime mover through transmission shaft. Windrowing system of the brush cutter collected the cut paddy in specified manner. The cutter blade with attachment of windrowing system is shown in Plate 3.2 (b) and operation with shoulder mounted brush cutter is shown in Plate 3.2 (C).



(a) Nylon line cutter head



(b) Cutter blade with windrowing attachment



(c) Operation with shoulder mouted brush cutter

Plate 3.2 Shoulder mounted brush cutter (SMBC)

3.2 Survey of Shoulder Mounted Brush Cutter (SMBC)

The objective of the survey was to identify drudgery involved in grass cutting and paddy harvesting operation and to study the issues related to health hazards with shoulder mounted brush cutter (SMBC). The questionnaire was prepared for the survey is given in Appendix I (A) based on (Saha, *et al.*, 2006; Kurdal, 2019). The important points of the questionnaire were a description of the workplace, worker description and aspects of grass cutting and paddy harvesting operation. Total of 30 farmers had participated in the survey.

The farmers (subjects) were informed about the details of survey information and appealed to give the responses regarding the workplace and their personal information in a formal way. The information regarding aspects in grass cutting and paddy harvesting were taken in the form of ‘Yes’ or ‘No’ type questions. The ‘Yes’ response indicated that the absence of any problem and ‘No’ response indicated that there was a need to modify the workplace and the extent of the problem was analyzed by the rating given to the ‘No’ answer between 0 to 5 scale (0 for do not know or not applicable, 1 for strongly disagree, 2 for disagree, 3 for neither agree nor disagree, 4 for agree and 5 for strongly agree). The representative photograph of farmers during survey is given at Plate 3.3.



Plate 3.3 Survey of shoulder mounted brush cutter (SMBC)

3.2.1 Description of the workplace

The name of the village, farmer's name, information about the field, environmental parameters like temperature (DB, WB), humidity, etc., were covered in the description of the workplace. The majority of the workforce was male workers for grass cutting and paddy harvesting operations with brush cutter. The details about the description of the workplace is given in Appendix I (B) and discussed in detail in section 4.1.1.

3.2.2 Workers description

The worker's personal information (name, age, height, weight, marital status, educational status, annual income, experience, etc.), along with their physical health status, occupational hazards related to work and workplace, were recorded. The data related to the worker's description and occupational hazards is given in Appendix I (C) and Appendix I (D), respectively and summarized data is given in Table 4.1. In grass cutting and paddy harvesting operations with SMBC, the farmers suffered from musculoskeletal disorder due to hand-arm vibrations (HAV) (Vivek, *et al.*, 2020).

3.2.3 Description of shoulder mounted brush cutter (SMBC)

The information of SMBC with available power, type of prime mover, fuel requirement, type of cutting mechanism, etc. were covered. The details about the description of SMBC is given in Appendix I (E).

3.2.4 Aspects in grass cutting and paddy harvesting operation

The various aspects in grass cutting and paddy harvesting operation viz. job specialization, skill requirement, general physical activity were studied. The information related to tools and methods employed for grass cutting and paddy harvesting, requirements of elementary skills, etc. were collected with the farmer's response. The details about aspects in grass cutting and paddy harvesting operation with SMBC is given in section 4.1.4 and Appendix I (F).

3.2.5 Ergonomic aspects in grass cutting and paddy harvesting operation

The information of ergonomic aspects in grass cutting and paddy harvesting operation related to work posture, noise level of the machine, transmission of vibrations to the operator's body, handling of controls, etc. was collected (with farmers rating). The details about ergonomic aspects with SMBC is given in section 4.1.5 and the rating of farmers were given in Appendix I (F).

3.2.6 Technical aspects in grass cutting and paddy harvesting operation

The technical aspects in grass cutting and paddy harvesting operation were the machine's stability, maintenance of the machine, vibration damping, noise level etc. were collected with the farmer's response. The technical aspects of grass cutting and paddy harvesting operation are given in section 4.1.6 and Appendix I (F).

3.2.7 Work safety in grass cutting and paddy harvesting operation

In the work safety of machine studied, the available machine safety measures were practical to prevent accidents and health hazards or not. The details about work safety are given in Appendix I (F) and section 4.1.7.

3.3 Assessment of Physiological Cost and Drudgery Involved in Operation with Shoulder Mounted Brush Cutter (SMBC)

The grass cutting and paddy harvesting operations with shoulder mounted brush cutter (SMBC) were done in a standing posture (Plate 3.2 (c)). The details about the working of SMBC has been discussed in section 3.1.2. The vibrations produced by the machine were directly transmitted to the operator's body and according to survey 97 per cent, 70 per cent, 63.3 per cent, 70 per cent and 83.3 per cent users were

suffered from shoulder pain, lower arm pain, upper arm pain, upper back pain and lower back pain, respectively (Section 4.1.2). Therefore, it was necessary to quantify the drudgery involved in SMBC.

3.3.1 Calibration of subject

The subject was nothing but the men or female worker taking part in the experiment. The subject's calibration meant to develop the relationship between physiological parameters specifically heart rate (HR) and oxygen consumption rate (OCR). The OCR for the particular value of HR while conducting the field operation could be predicted from the relation between heart rate (HR) and oxygen consumption rate (OCR). The energy expenditure rate (EER) was calculated by using the measured parameter OCR.

3.3.2 Selection of subject

The selection of subject plays an essential role in conducting performance testing and ergonomic studies. The six male subjects were selected for the experiment. The care was taken that the subjects were medically fit for the study trials. They were genuinely representative of the user's population for grass cutting and paddy harvesting operation. The maximum oxygen consumption, heart rate and muscle strength decreased significantly with increasing age (Gite and Singh, 1997). The age group of the selected subjects were varied in the range of 20 to 60 years.

3.3.3 Instruments used for calibration of subject

The computerised bicycle ergometer (Sweden, Monark 839E) was used as a loading device for the experiment. A computerized energy measurement system (K4b₂) was used to measure the subject's heart rate (HR) and oxygen consumption (OCR).

3.3.3.1 The computerized bicycle ergometer (Sweden Monark 839E)

The computerised bicycle ergometer was a test cycle with an adjustable brake system where the brake force was read in kg or N. The ergometer computer was connected with computer. The pedal revolution (per minute), heart rate (bpm), exercise time in (minute and second), cycle speed in (km/h) or (mile/h), covered distance in (km) or (mile), burned calories (kcal), power on the cycle (watt) etc. were displayed on computer screen. The height of the saddle of the ergometer was adjustable so that the subject could sit comfortably. The precaution was taken that the subject's knee should be straight when the peddle was at its lower position. The computer controller for the bicycle ergometer was perform different protocols in

addition to manual operation. In Appendix II (A), the detailed specifications of the computerised bicycle ergometer (Sweden Monark 839E) are given. The computerised bicycle ergometer is shown in Plate 3.4.

3.3.3.2 Computerised energy measurement system (K4b₂)

The computerised energy measurement system (K4b₂) (COSMED, Italy) noted the physiological parameters like heart rate and oxygen consumption. This system could be used in the laboratory as well as in the test field. It had a portable unit, receiver unit, battery charger unit, flowmeter, oxygen sensor, carbon dioxide sensor, humidity absorber and environmental sensors. The specifications of the computerised energy measurement system (K4b₂) are given in Appendix II (B). The computerised energy measurement system (K4b₂) is shown in Plate 3.5.



Plate 3.4 Computerised bicycle ergometer (Sweden Monark 839E)



Plate 3.5 Computerised energy measurement system (K4b₂)

3.3.4 Calibration process

The subject's calibration was done with a computerised bicycle ergometer (Sweden Monark 839E) and a computerised energy measurement system (K4b₂). Before starting the calibration process, the electronic calibration of the computerised bicycle ergometer with a pendulum was done manually. The six male subjects were selected for the calibration process. The subject's calibration was carried out in the Ergonomics Laboratory of the department of Farm Machinery and Power, CAET, Dr. B. S. K. K. V., Dapoli.

Before using a computerised energy measurement system (K4b₂) for measuring oxygen consumption rate, its different calibrations such as room air, turbine, delay, and reference gas were done. After all successful calibration, K4b₂ was ready for use. The subjects were asked to report in the laboratory before 30 min of the actual calibration. Before reporting, ensured that everyone had breakfast and they have a good sleep in previous night. It was also confirmed that they were free from the influence of stimulants such as alcohol, drinks, cigarettes, etc. and has no cardiac disease.

Calibration of the subject was carried out to determine the aerobic capacity of subjects. The subject aerobic capacity was assessed by conducting submaximal tests on a computerised bicycle ergometer (Sweden Monark, 839E). The bicycle ergometer saddle height was kept such that the subject leg was almost straight at the knee when the peddle was at the lowest position. The subject was asked to pedal the bicycle at a pedaling rate of 50 rpm. The pedaling speed was maintained by using a metronome. The workload was automatically increased by 15 W at an interval of 2 min through the software. The heart rate (HR) and oxygen consumption rate (OCR) values were directly downloaded to the computer breadth by breadth. Those values were averaged for the one-minute duration to correlate heart rate and oxygen consumption rate. The representative photograph of calibration process is given in Plate 3.6.

A target heart rate (HR) was taken as approximately 75 % of the age predicted maximum heart rate. The following relationship computed the maximum heart rate attainable by the subject (Robergs and Landwehr, 2002)

$$\text{HR max} = 220 - \text{Age in years} \quad \dots (3.1)$$

Continued every test for the subject had attained 75 % of max HR, or up to the period the subject had fully exhausted whatever was reached earlier. The correlation between heart rate (HR) and oxygen consumption rate (OCR) at specified submaximal workload was developed. The regression line was extrapolated to the age predicted maximum heart rate (HR max) and noted VO_2 max corresponding to HR max. VO_2 max was nothing but OCR at HR max. The details about VO_2 max are given in the following section.



Plate 3.6 Calibration of Subject

3.3.4.1 Maximum aerobic capacity (VO_2 max)

The maximum aerobic capacity, also called maximum oxygen uptake capacity or VO_2 max, was conceived as an international reference standard of cardiorespiratory fitness (Gite and Singh, 1997). The maximum aerobic capacity (VO_2 max) was the accepted measure of cardiorespiratory efficiency. The value of VO_2 max in normal active males was 38 ml/kg/min (Gosh and Jahan, 2017). The maximum oxygen uptake was the highest oxygen uptake attainable in the subject, where a further increase in workload will not increase oxygen uptake. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO_2 max (Saha, *et al.*, 1979). To ascertain whether the selected implements operation was within the acceptable workload (AWL), it was necessary to compute the VO_2 max for each subject. Because of the risk involved in testing a person on a maximal task, various submaximal tests have been advocated. The intersection of the computed maximum heart rate (HR max) of the subjects with the plotted calibration chart line of fit to the oxygen uptakes defines the individuals maximum aerobic capacity (VO_2 max). The VO_2 max for all the subjects was computed and recorded.

The indirect method of predicting oxygen consumption rate was used for the two subjects because of the energy measurement system (K4b₂) was not working

properly. The following equations used to calculate OCR of those subjects from heart rate values (Anonymous, 2018)

Table 3.1 Equation for oxygen consumption rate

Age group, year	Equation	Correlation coefficient (r value)	Regression coefficient (R ²)
18 – 30	OCR = 0.019 HR – 1.2788	0.91	0.83
30 – 40	OCR = 0.0195 HR – 1.2814	0.90	0.81
40 – 50	OCR = 0.0208 HR – 1.4861	0.95	0.90

Where,

OCR – oxygen consumption rate (lit/min)

HR – heart rate (bpm)

3.3.5 Assessment of physiological cost and drudgery

The ergonomic evaluation of subject with shoulder mounted brush cutter (SMBC) was conducted for assessing drudgery. The experiment was conducted in Dept. of Agronomy, Dr. B. S. K. K. V. Dapoli during year 2019-2020. The information about experiment was given to the subject before starting. The ergonomic evaluation was carried out with the following parameters.

1. Heart rate (HR)
2. Oxygen consumption rate (OCR)
3. Energy cost of operation (Energy Expenditure Rate – EER)
4. Acceptable work load (AWL)
5. Limit of continuous performance (LCP)

3.3.5.1 Heart rate (HR)

Measuring a heart rate is one of the most useful way of assessing the workload because it can do very conveniently. Heart rate (HR) measurement has a measurable advantage over an oxygen consumption rate. The heart rate (HR) responds more quickly to changes in work demand and indicates more rapidly quick changes in body function due to change in work requirement (Kroemer, *et al.*,1997). Thus, the subjects heart rate(HR) was recorded during the operation of grass cutting and paddy harvesting by using Polar FT7 heart rate monitor (Plate 3.7) in bpm. This can be used directly on the field to record the heart rate (HR) of the subject. This polar heart rate monitor has an elastic strap (H10 heart rate sensor). This elastic strap having a connector which was placed in a central upright position on the chest of the subject.

Before starting the test, gave each subject 30 min of rest. Started each test with taking 10 min resting heart rate (HR) data. Averaged heart rate (HR) data of each subject was computed and recorded. After resting, each subject was asked to perform grass cutting and paddy harvesting operations for 20 min. During that period value of heart rate (HR) was recorded. The same procedure was applied for all the selected subjects. The detailed specifications of polar heart rate monitor are given in Appendix II (C).



Plate 3.7 Polar heart rate monitor

3.3.5.2 Oxygen consumption rate (OCR)

The oxygen consumption of each subject during the operation was calculated by the indirect method. The subjects were calibrated as explained in section 3.3.4. Plotted the calibration chart of each subject and showed oxygen consumption values corresponding to the average heart rate values. The oxygen consumption rate for each subject while operating brush cutter was predicted from the calibration chart of the individual subject.

3.3.5.3 Energy cost of operation (Energy Expenditure Rate – EER)

The energy expenditure rate was calculated from the heart rate(HR) values observed during the tests with shoulder mounted brush cutter (SMBC) and predicted corresponding oxygen consumption rate (OCR) values for each subject from the calibration chart of individual subjects.

By using the following relation, calculated the energy expenditure rate (EER) for the male subjects, 20.88 KJ/l is the calorific value of oxygen (Aware, *et al.*, 2017)

$$\text{Energy expenditure rate (kJ/min)} = 20.88 \times \text{OCR} \quad \dots (3.2)$$

The averaged values of heart rate (HR), oxygen consumption rate (OCR) and energy expenditure rate (EER) for all subjects were obtained and averaged to get the mean values for all the selected subjects.

3.3.5.4 Acceptable work load (AWL)

The physiological parameters of the subjects and the acceptable workload were interrelated to each other. The physiological parameters of subjects were dependent on the acceptable workload and the maximum values. Which could be attained in normal healthy individuals, will be up to VO_2 max however, at this extreme workload, a person can work only for few seconds. The physiological parameters of the subject increases as the workload increases. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO_2 max (Saha, *et al.*, 1979). To ascertain whether the grass cutting and paddy harvesting operations were within the acceptable workload (AWL), calculate the percent of VO_2 max for each subject were calculated.

3.3.5.5 Limit of continuous performance (LCP)

The limit of continuous performance is the extent to which a person may increase his work depending on how much he can increase his heart rate (HR) from resting to his maximum level. The increase in heart rate (HR) plays a significant role in increasing the cardiac output from rest to maximal work.

A meaningful comparison of physiological response, the heart rate values at resting (RHR) and heart rate values at operating (WHR) conditions were calculated. The values of physiological responses, i.e., heart rate (Δ HR) was the difference between the working heart rate (WHR) and resting heart rate (RHR) of the selected subject, also known as work pulse. The calculated work pulse values for each subject were compared with the acceptable work pulse values of 40 bpm (Suwathiga, *et al.*, 2020).

3.3.5.6 Subject discomfort rating

The subject's discomfort was estimated by using the subjective rating scale like overall discomfort rating (ODR) and body part discomfort score (BPDS) (Premkumari, *et al.*, 2018).

3.3.5.6.1 Overall discomfort rating (ODR)

The overall discomfort rating is the method used to evaluate the overall body part discomfort of subject during work. For the overall discomfort rating assessment, used a 10-point physiological rating scale (0 – no discomfort, 10 – extreme discomfort) (Corlett and Bishop, 1976). The rating of the scale linearly related to the heart rate (HR) expected for that level of exertion. The expected heart rate (HR) was 10 times to the given rating. The numbers on the scale showed the level of discomfort experienced by the subject during the experiment. The scale has a movable pointer to indicate the overall discomfort rating, as shown in Fig 3.1.

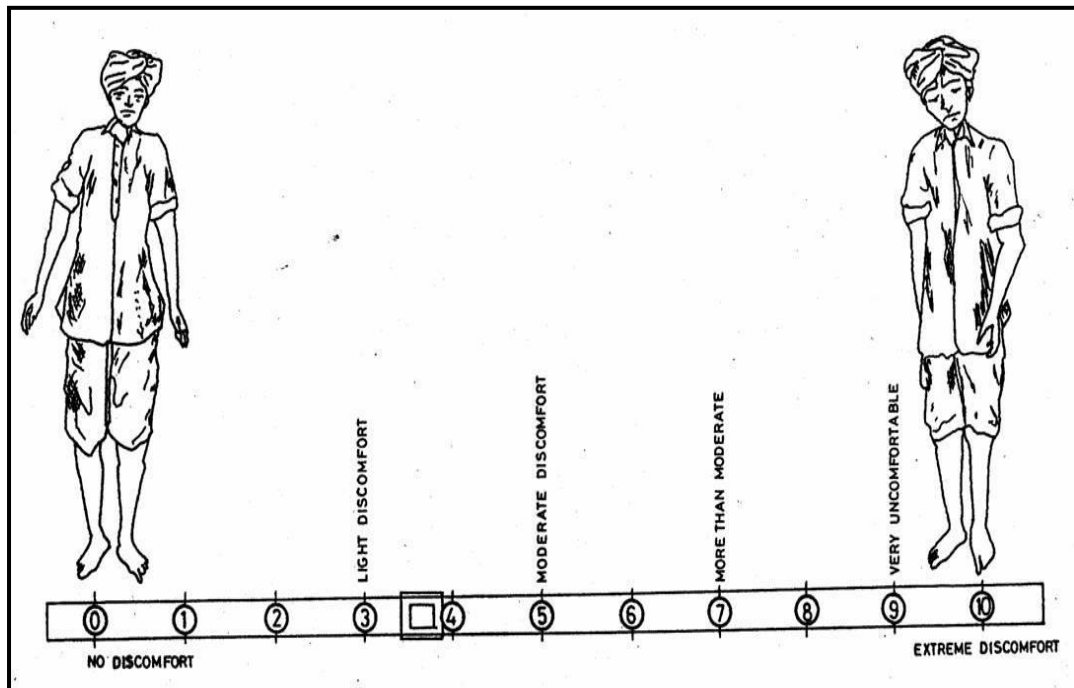


Fig. 3.1 Discomfort scale for assessment of overall body discomfort

The trial for discomfort rating for any given operation was carried out in the same field where physiological measurements were taken. At the end of each experiment with shoulder mounted brush cutter (SMBC), each subject was asked to indicate their overall discomfort rating on this scale. Each subject overall discomfort ratings were added and averaged to get the mean rating of overall discomfort (ODR).

After every 20 min operation with SMBC, each subject was asked to indicate the overall discomfort level on the 10 – point rating scale. The obtained values were tabulated and averaged. The details of ODR values and corresponding discomfort level is shown in Table 3.2.

Table 3.2 ODR values and corresponding discomfort levels

Sr. No.	ODR Rating	Discomfort Level
1	0.0	No discomfort
2	< 3.00	Light discomfort
3	3.00 to 5.00	Moderate discomfort
4	5.00 to 7.00	More than moderate discomfort
5	7.00 to 9.00	Very con-comfortable
6	9.00 to 10.00	Extreme discomfort

3.3.5.6.2 Body part discomfort score (BPDS)

The body part discomfort score was measured using the technique of dividing the body parts into 27 regions (Corlett and Bishop, 1976), as shown in Fig. 3.2. For evaluating the body part discomfort (BPDS), after completion of work, the subject was asked to mention all the body parts with discomfort, starting with the most painful, the next most painful, and so on until all parts have been mentioned (Lusted *et al.*, 1994). The body part chart was shown to the subject after finishing the grass cutting and paddy harvesting operation with SMBC for physiological evaluation. The subjects were asked to fix the pin on the body part in the order to of one pin for maximum pain, two pins for next maximum pain and so on (Legg and Mohanty, 1985).

The number of different body parts identified from extreme discomfort to no discomfort represents the number of intensity levels of pain experienced. The body part discomfort score (BPDS) for each subject was calculated by multiplying the number of body parts corresponding to each category. The whole body parts scored for a subject would be the sum of all individual scores of the body parts assigned by the subject. The body part discomfort score of all the subjects was added and averaged to get the mean score.

3.4 Ergonomic Evaluation of Shoulder Mounted Brush Cutter (SMBC)

The physiological cost and drudgery involved in shoulder mounted brush cutter (SMBC) was carried out in this section. The details of SMBC for grass cutting and paddy harvesting and its working is given in section 3.1.2. Six male subjects have participated in the experiment with existing SMBC. The details of subjects are provided in Appendix - III (A).

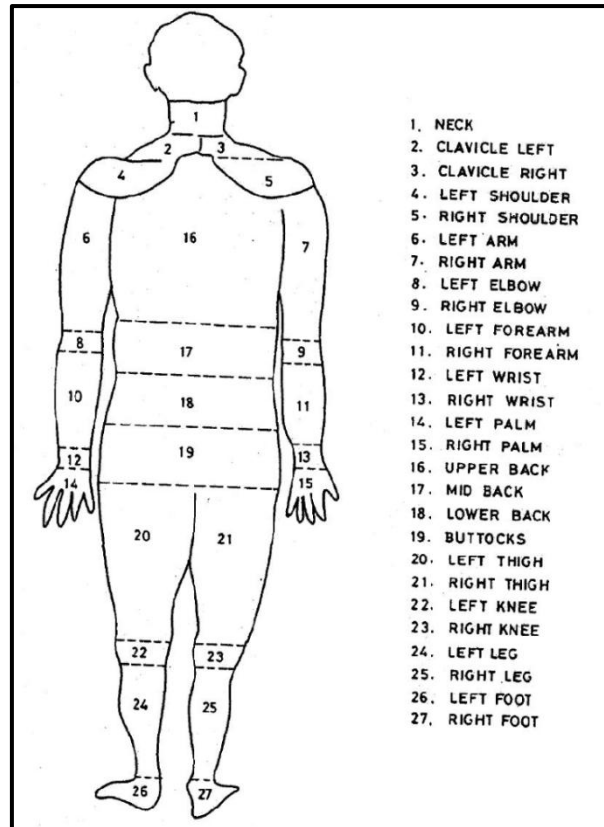


Fig 3.2 Regions for evaluating Body Part Discomfort Score

An experiment was conducted in the Department of Agronomy, Dr.B.S.K.K.V., Dapoli, during 2019-2020. Before starting the experiment, gave all the information about the experiment to each subject. Each subject's heart rate was recorded with a polar heart rate monitor (model - FT7) in bpm. The field capacity was noted for each subject and averaged for all subject.

Before starting the experiment, each subject was given 30 min rest. After that started the field trial by taking 10 min resting heart rate (RHR) data of the subject. The average resting heart rate (RHR) of the subject was computed and recorded for each subject by a polar heart rate monitor (FT7). Each subject was asked to work with a SMBC for 20 minutes. During that period, the values of heart rate (HR) for each subject were recorded. The average heart rate values from 11 minutes to 20 minutes of operation were used as working heart rates (WHR) for further calculation and analysis. The same procedure was adapted to all the selected subjects.

The following parameters were studied for ergonomic evaluation of SMBC.

1. Heart rate (HR)
2. Oxygen consumption rate (OCR)
3. Energy expenditure rate (EER)
4. Overall discomfort rating (ODR)

5. Body part discomfort score (BPDS)
6. Acceptable workload (AWL)
7. Limit of continuous performance (LCP)
8. Work rest cycle

The heart rate (HR), oxygen consumption rate (OCR), energy expenditure rate (EER), overall discomfort rating (ODR), body part discomfort score (BPDS), acceptable workload (AWL), limit of continuous performance (LCP) were calculated as explained in section 3.3.5. The work-rest cycle formulated for each subject was to assess how much rest pauses were required during operation.

3.4.1 Work rest cycle

The work rest cycle time is an essential parameter in assessing the risk of musculoskeletal disorder caused by repetitive work. At an extreme workload, a person can perform only for few seconds. The subject must take some rest after his farming operation for maximum work output. The rest pause dependent on workload and working time. The following equation was used for determining rest pause after the grass cutting and paddy harvesting operation theoretically (Murrel, 1965).

$$R = \frac{T(K-S)}{K-1.5} \dots (3.3)$$

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.

The ceiling for energy expenditure standard was taken as 4 kcal/min (Kavitkar, 2016). From the above relation the rest required for each subject during grass cutting and paddy harvesting with SMBC was computed.

3.5 Field Performance of Shoulder Mounted Brush Cutter (SMBC)

During the ergonomic evaluation of SMBC, the work output (field capacity) was also recorded for each subject. The machine performance parameters, such as effective field capacity, theoretical field capacity and field efficiency were determined. The photograph of SMBC used for grass cutting and paddy harvesting are given at Plate 3.8.



(a) Paddy harvesting



(b) Grass cutting

Plate 3.8 Field performance of SMBC

3.5.1 Theoretical field capacity

The machine's theoretical field capacity was the rate of field coverage that would be obtained if the machine was performing its function 100 % of the time at the rated forward speed and always covered 100 % of its rated width. It was expressed as hectare per hour and determined by the following formula (Kepner, *et al.*, 1978).

$$TFC = \frac{w \times s}{10} \dots (3.4)$$

Where,

TFC = Theoretical field capacity (ha/h)

w = Width of cut (m)

s = Speed of operation (km/h)

3.5.2 Effective field capacity

Effective field capacity is the machine's actual average rate of coverage, based upon the total field time. It was a function of the machine's rated width, the percentage of rated width utilized, speed of the travel and the amount of field time lost during the operation. Effective field capacity was usually expressed as hectare per hour (Kepner, *et al.*, 1978).

$$EFC = \frac{A}{T_p + T_i} \dots (3.5)$$

Where,

EFC = Effective field capacity (ha/h)

A = Actual area covered (ha)

T_p = Productive time (h)

T_i = Non-productive time (h)

3.5.3 Field efficiency

Field efficiency is the ratio of effective field capacity to the theoretical field capacity, expressed as a percentage. It includes the effect of time lost in the field and failure to utilize the machine's full width.

$$\text{Field efficiency (\%)} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \dots (3.6)$$

3.5.4 Instruments used in field performance

The following instruments were used while conducting the field performance of the shoulder mounted brush cutter (SMBC).

3.5.4.1 Measuring tape

The area covered by the operator during grass cutting or paddy harvesting operation was measured by using measuring tape.

3.5.4.2 Polar heart rate monitor (FT7)

Heart rate monitor (FT7) was used for measuring the WHR and RHR of the operator, for ergonomic evaluation. It measures the heart rate in bpm.

3.5.4.3 Whirling psychomotor

Whirling psychomotor was used to measure the dry bulb (DB) and wet bulb (WB) temperature in the atmosphere. The atmosphere's relative humidity was calculated from the dry bulb (DB) and wet bulb (WB) temperatures with a relative humidity table for psychomotor.

3.6 Development of Grass Cutter Cum Paddy Harvester (GCCPH) Prototype

The grass cutter cum paddy harvester prototype was developed to reduce drudgery involved with shoulder mounted brush cutter (SMBC).

As per initial survey of SMBC users 77 per cent farmers were suffered from body ache and headache, 97 per cent farmers had pain in shoulder and 83.3 per cent farmers had pain in lower back (Section 4.1.2). Also as per result of its ergonomic evaluation WHR for grass cutting and paddy harvesting was 101.17 bpm and 121.83 bpm, respectively with workload under 'moderately heavy' category. BPDS for grass cutting and paddy harvesting was 17.21 and 28.8, respectively with severely discomfort body part were observed. Considering above points it was decided to make it trolley mounted instead of shoulder mounted. The procedure adopted for developing a grass cutter cum paddy harvester prototype is given in following sections.

3.6.1 Ergonomic design features in grass cutter cum paddy harvester prototype

Anthropometric data for male workers of Konkan region in Maharashtra was used for designing the dimensions of the handle of grass cutter cum paddy harvester prototype (Anonymous, 2006). The handle of the machine was used to provide the push so as to rotate the wheels for forward movement and also it was used to provide the right left movement (swinging) for cutter shaft.

3.6.1.1 Height of handle

For continuous work, the desirable handle height should be 0.8 of 5th percentile to 0.7 of 95th percentile the acromial height leading to less work stress (Gite and Yadav, 1989). The anthropometric parameters considered for developing the handle

of a grass cutter cum paddy harvester prototype are given in Table 3.2. The definition of different anthropometric parameters is given in section 3.6.1.2 to 3.6.1.5.

3.6.1.2 Length of handle

The length of the handle and the angle of operation of the machine were interdependent. The angle of operation was based on the functional design and geometry of the tool and generally, it was in the range of 30 ° to 45 ° (Gite and Yadav, 1989; Gite, *et al.*, 2009 and Kavitkar, 2016).

3.6.1.3 Shape of grip

The desirable shape of the handle grip should be cylindrical.

3.6.1.4 Size of grip

The grip diameter should be such that the operator's longest finger should not touch the palm while holding the handle. At the same time, the grip should not exceed the internal grip diameter. The 95th percentile value of middle finger palm grip diameter and the 5th percentile value of the grip diameter were lower and upper limit, respectively (Gite, *et al.*, 2009). The anthropometric parameters considered for developing the handle of a grass cutter cum paddy harvester are given in Table 3.2.

3.6.1.5 Length of grip

The length of the grip of the handle of machine should be the 95th percentile value of hand breadth across thumb. The 95th percentile value of hand breadth across thumb was taken from the anthropometric data of the Konkan region. The anthropometric parameters considered for the development of the handle of grass cutter cum paddy harvester prototype are given in Table 3.3.

The free hand sketches of above-mentioned parameters are given in Fig. 3.3

Table 3.3 Anthropometric parameters of male agricultural workers considered to develop the handle of the machine (Anonymous, 2006).

(All dimensions are in mm)

Sr. No	Parameters	Mean	SD (±)	5 th percentile	95 th percentile
1	Middle finger palm grip diameter (mm).	28	3	22	34
2.	Acromial height (mm)	1345	61	1245	1445
3.	Elbow elbow breadth (mm)	397	41	329	465
4.	Grip diameter (inside) (mm)	49	6	39	59
5.	Hand breadth across thumb (mm)	95	6	86	105

3.6.1.6 Definitions of anthropometric parameters considered to develop a handle of grass cutter cum paddy harvester prototype (Gite, *et al.*, 2009).

1. Middle finger palm grip diameter

The diameter of the widest level of the cylinder which the subject can grasp with his palm and middle finger touching each other.

2. Acromial height

The vertical distance from the standing surface to the acromion.

3. Elbow-elbow breadth

The distance across the lateral surfaces of the elbows is fixed and resting lightly against the body.

4. Grip diameter (inside)

The diameter of the widest level of a cone which the subject can grasp with his thumb and middle finger touching each other.

5. Hand breadth across thumb

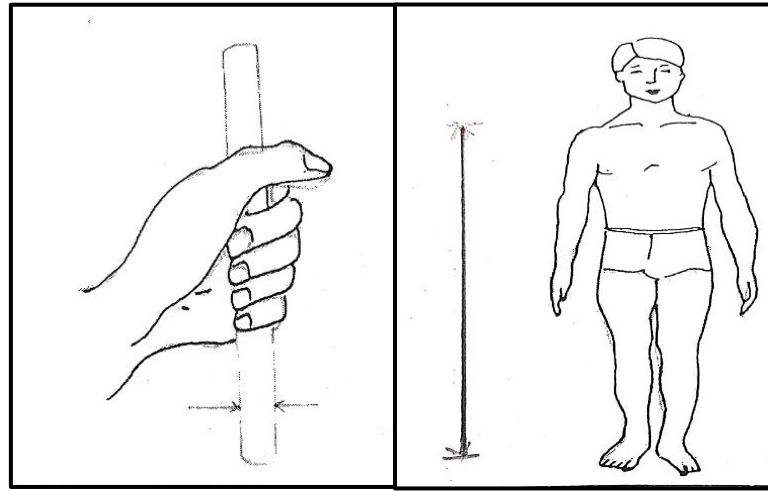
The breadth of the hand as measured at the level of distal end of the 1st metacarpal of the thumb.

3.6.2 Grass cutting and paddy harvesting principle

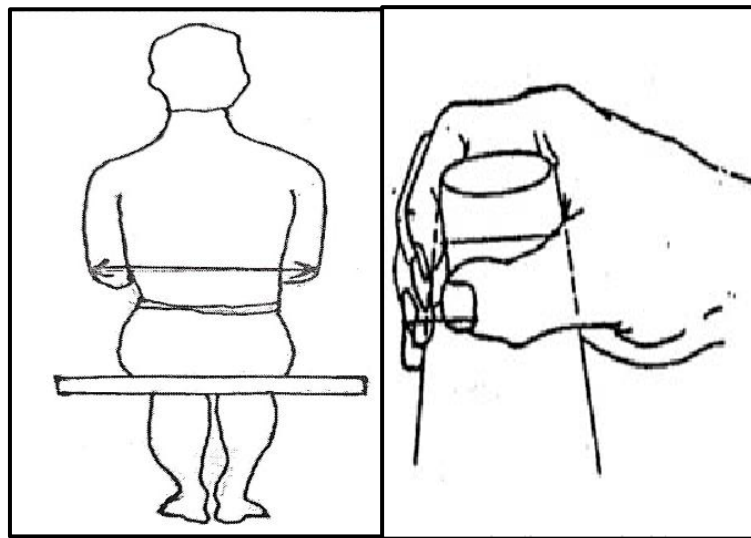
Harvesting is the process of gathering a ripe crop from fields. The first step in harvesting operation was the reaping. It is the process of cutting and gathering the cut crop from the field. The cutting process of grass and paddy was occurred by shearing failure or by the impact. The failure in shear or impact or both was possible when the system of forces was acting on the material. Shear failure was achieved either by using a single cutting element like a sickle or double cutting elements like reciprocating type cutter and rotary cutters. Before the shear failure, the material was first compressed and then sheared.

The number of stems, cross-sectional area of stem, cutting location and moisture content of the crop affect the maximum cutting force and cutting energy in the cutting operation. Some of them are physical properties of grass or crop and some of them are mechanical factors. The shearing energy which was required for the cutting process directly depends on the number of stems. The physical properties of paddy stalk and grass were essential to developing harvesting machines and the mechanical properties (maximum cutting force, cutting energy etc.) were required to find out power requirement of the machine.

The factors influencing the cutting operation of grass cutter cum paddy harvester are discussed detail in the following subtitles.



(a) Middle finger palm grip diameter (b) Acromial Height



(c) Elbow-elbow breadth (d) Grip diameter (inside)

Fig. 3.3. Freehand sketches of anthropometric parameters

3.6.3 Physical properties of paddy

The energy and power required for cutting operation was affected by different physical properties of crop or grass. The different properties as diameter of stem, moisture content, etc. are discussed in the following section.

3.6.3.1 Moisture content

The cutting operation of paddy stem and grass was significantly affected by moisture content. The procedure adopted for the determination of moisture content is as given below (Bacche and Kadam, 2019).

1. Took an amount of 25 gm of paddy/grass stem in a tarred aluminum dish having a diameter of at least 50 mm and a depth of about 20 mm.
2. Weighing the sample accurately.
3. After that the sample was placed in an air oven at 100 ± 2 °C and dried for 2 hrs.
4. After drying the sample was cooled in a desiccator and weighed.

The following formulae calculated the moisture content.

$$M = \frac{W_1 - W_2}{W_1} \dots (3.7)$$

Where,

M= Moisture content, percent by mass (WB)

W_1 = Mass of the dish with the material before drying, gm

W_2 = Mass of the dish with the dried material, gm

3.6.3.2 Diameter of the stem

The force and energy required for harvesting operation were significantly affected by the stem diameter and shear strength. Stem diameter varied with internode position and moisture content. The maximum value of shear strength was occurred at 19.5 per cent (wb) moisture content at third internode position (Muzamill,*et al.*, 2016). Therefore, the stem diameter at 19.5 per cent (wb) moisture content in third internode position was taken. It was 4.89 mm.

3.6.4 Mechanical design considerations in grass cutter cum paddy harvester prototype

The efficiency of the developed grass cutter cum paddy harvester were dependent on the factors such as the selection of cutting blade, design of transmission shaft, speed of operation, specific cutting energy, mass moment inertia of cutter, idling power, total power, design of the frame and design of the handle etc.

3.6.4.1 Design considerations for power requirement

The stem cross-sectional area and moisture content were the most significant factors affecting maximum cutting force and energy required for harvesting operation. The power requirement of grass cutter cum paddy harvester were depend on cutting energy, cutting force, width of cut and forward speed.

3.6.4.1.1 Power requirement

The selection of proper prime mover was crucial while developing the machine. Power requirement for grass cutter cum paddy harvester was calculated using the following formula (Nesar, *et al.*, 2012).

$$P_{wt} = (P_{ks} + E_{sc} V_f) W_c \quad \dots (3.7)$$

Where,

P_{wt} = Power required (kW)

P_{ks} = Idling power (kW/m of cutting width)

E_{sc} = Specific cutting energy (kJ/m²)

V_f = Forward speed (m/s)

W_c = Cutting width (m)

Mass moment inertia of cutting blade

The mass moment inertia of a cutting blade was a measure of blade resistance to change in direction of rotation. Considering, mass, diameter and thickness of the cutting blade as 0.7102 kg, 0.24 m and 2 mm, respectively.

The mass moment inertia of cutting blade was calculated from the following relation (Nesar, *et al.*, 2012).

$$M.I = \frac{1}{2} m r^2 \dots (3.8)$$

Where,

m = Mass of disc (kg)

r = Radius of disc (m)

Therefore,

$$\begin{aligned} M.I &= \frac{1}{2} 0.7102 \times (0.12)^2 \\ &= 5.113 \times 10^{-3} \text{kgm}^2 \end{aligned}$$

Angular velocity of cutting blade

Angular velocity was the rate of change of angular position of rotating body. The relation between angular velocity and cutting speed is given in following equation (Handka and Joko Pitoyo, 2011).

$$v = \omega r \dots (3.9)$$

Where,

ω – Angular velocity of blade (rad/s)

r – Radius of cutting blade (m)

The cutting speed required to cut one stem of paddy was in the range 25-35 m/s (Nesar, *et al.*, 2012). For the calculation of angular velocity consider the maximum cutting speed i.e. 35 m/s and radius of cutting blade 0.12 m. Therefore, the angular velocity of cutting blade was calculated from following equation,

$$\begin{aligned}\omega &= \frac{35}{0.12} \\ &= 291.66 \text{ rad/s}\end{aligned}$$

Idling power

The idling power was dependent on the mass moment inertia of cutting blade and angular velocity of blade. The idling power was calculated from the following equation,(Nesar, *et al.*, 2012).

$$P_k = \frac{M.I}{2} \times \omega^2 \quad \dots(3.10)$$

Where,

M. I = Mass moment inertia of circular blade (kgm^2)

ω = Angular velocity (rad/s)

Therefore, from equation 3.8 and 3.9 the idling power was,

$$\begin{aligned}P_k &= \frac{5.113 \times 10^{-3}}{2} \times (291.66)^2 \\ &= 0.217 \text{ kW}\end{aligned}$$

Cutting width of blade

The cutting width of the blade was considered as two third of its diameter (Nesar, *et al.*, 2012). The diameter of the blade was 0.24 m, therefore the cutting width of the blade,

$$W_c = \frac{2}{3} \times D_b \quad \dots(3.11)$$

Where,

W_c = Cutting width of blade (m)

D_b = Diameter of blade (m)

Therefore,

$$W_c = 0.16 \text{ m}$$

Hence,

Idling power obtained per meter of cutting width was 1.35 kW/m.

Maximum cutting force

The maximum cutting force required for grass cutting and paddy harvesting was considered as 24.6 N (Muzamil, *et al.*, 2016).

$$F_{\max} = 24.6 \text{ N}$$

Cutting energy

The cutting energy required to cut the crop was affected by the stem diameter and maximum cutting force. To calculate cutting energy the stem diameter was considered as 4.89 mm (Muzamil, *et al.*, 2016) (Section 3.6.3.2).

The following relationship was used to calculate the cutting energy(Nesar, *et al.*, 2012).

$$E_0 = F_{\max} \times \frac{d}{2} \dots (3.12)$$

Where,

E_0 = Cutting energy (J)

$F_{\max}$ = Maximum cutting force (N)

d = Diameter of the stem (m)

Therefore,

$$\begin{aligned} E_0 &= 24.6 \times \frac{0.00489}{2} \\ &= 0.06014 \text{ J} \end{aligned}$$

Specific Cutting energy

Specific cutting energy (SCE) is an intensive quantity that characterizes the cutting resistance offered by a given material. The specific cutting energy significantly affected by paddy cultivars and blade velocity. The cutting energy required for paddy cutting was reduced when the number of stems cut at the same time was maximum (Yore, *et al.*, 2002). The cutting energy was significantly affected by the internode position and dimensional properties of the paddy stem. With the increase in cutting height, lower energy was consumed by the harvester (Alizadeh, *et al.*, 2011).

The stem of paddy was hollow with circular cross section. Considering the diameter of the stem as 4.89 mm, the cross-sectional area of the stem was $18.7 \times 10^{-6} \text{ m}^2$ (Muzamil, *et al.*, 2016). The specific energy required for paddy harvesting was calculated from following equation (Nesar, *et al.*, 2012).

$$\begin{aligned}
E_{sc} &= \frac{\text{Cutting energy (J)}}{\text{Cross sectional area (m}^2\text{)}} \dots (3.13) \\
&= \frac{0.06014}{18.7} 10^6 \\
&= 3.204 \text{ kJ/m}^2
\end{aligned}$$

The forward speed of operator was considered as 1.8 km/h., i.e. 0.5 m/s (Sarkar, *et al.*, 2016). As per above calculations, the cutting width, idling power and specific cutting energy were 0.16 m, 1.35 kW/m and 3.204 kJ/m², respectively. Therefore, the power requirement was calculated as,

$$\begin{aligned}
P_{wt} &= [1.35 + (3.204 \times 0.5)] \times 0.16 \\
&= 0.4723 \text{ kW} \\
P_{wt} &= 0.629 \text{ hp}
\end{aligned}$$

Total power requirement

The total power requirement of the grass cutter cum paddy harvester was calculated from the following equation

$$P_t = \frac{\text{Power}}{\eta} \dots (3.14)$$

Where,

$$\begin{aligned}
P_t &= \text{Power required (hp)} \\
\eta &= \text{Transmission efficiency, (0.80)} \\
P_t &= \frac{0.629}{0.80} \\
&= 0.787 \text{ hp}
\end{aligned}$$

Considering the overloading factor to be 1.75 (Anonymous, 1998).

$$\begin{aligned}
\text{The total power} &= 1.75 \times 0.787 \\
&= 1.38 \text{ hp}
\end{aligned}$$

3.6.4.1.2 Validation of power requirement

The linear velocity of cutting blade was calculated from the following equation by considering cutting blade speed 3000 rpm and disc diameter 0.24 m (Ravindra, *et al.*, 2017).

$$(V_e) = \frac{\pi DN}{60} \dots (3.15)$$

Where,

$$V_e - \text{Velocity of cutting blade (m/s)}$$

D – Diameter of cutting blade, (m)

N – Speed of blade, (rps)

Therefore,

$$\begin{aligned}\text{Velocity of cutting blade} &= \frac{\pi \times 0.24 \times 3000}{60 \times 60} \\ &= 0.628 \text{ m/s}\end{aligned}$$

The maximum force required to cut one paddy stem was 24.6 N (Muzamil, *et al.*, 2016). Therefore, the power required to cut one stem was calculated from the following relation

$$\begin{aligned}\text{Power required to cut one stem (w)} &= V \times F_{max} \quad \dots(3.16) \\ &= 0.628 \times 24.6 \\ &= 0.0154 \text{ kW} \\ &= 0.020 \text{ hp}\end{aligned}$$

Considering the field capacity of the grass cutter cum paddy harvester was 124.61 m²/h (35113.8 mm²/s) (Sarkar, *et al.*, 2016) and two stubble in the spacing of 200 × 150 mm (Shinde, 2018). Therefore the number of stubble in 35113.8 mm² area were

$$\begin{aligned}&= \frac{35113.8 \times 2}{30000} \\ &= 2.34 \text{ stubble}\end{aligned}$$

Considering the number of tillers in one stubble was 21.33 (Promsomboon, *et al.*, 2019) therefore the number of tillers in 2.34 stubbles were

$$\begin{aligned}&= 2.34 \times 21.33 \\ &= 49.91 \text{ tillers}\end{aligned}$$

From equation 3.19 the power required to cut one stem (tiller) was 0.02 hp. Therefore, the power required to cut 49.91 tillers was

$$\begin{aligned}\text{Power requirement} &= 49.91 \times 0.02 \\ &= 0.99 \text{ hp}\end{aligned}$$

Considering the overloading factor to be 1.95 ((Anonymous, 1998),

$$\begin{aligned}\text{Total power} &= 1.75 \times 0.99 \\ &= 1.73 \text{ hp}\end{aligned}$$

Hence, two stroke petrol engine (make: BaharAgrotech) of power 1.95 hp at 6500 to 7500 rpm was selected as prime mover for development of grass cutter cum paddy harvester.

3.6.4.2 Design of transmission shaft

The transmission shaft of a machine transmits the power from the prime mover to the cutting unit. The transmission shaft was subjected to combined bending moment and twisting moment. The diameter of a shaft was calculated from the following equation (Ravindra, *et al.*, 2017).

$$d^3 = \frac{16 \times T}{F_s \times \pi} \dots (3.17)$$

Where,

d = diameter of shaft (mm)

F_s = Maximum allowable shear stress in material (N/mm²)

T = Torque acting on the shaft (N-mm)

Torque acting on a shaft

The torque of shaft was nothing but the force that tending to cause rotation. The torque acting on the shaft was calculated by using following formula (Khurmi and Gupta, 2005)

$$T = \frac{P \times 60 \times 10^3}{2 \times \pi \times N} \dots (3.18)$$

Where,

P = Power (kW)

T = Torque acting on shaft (N-m)

Considering the speed of the engine as 7500 rpm and engine power 1.16 kW (1.53 hp), therefore the required torque was

$$\begin{aligned} T &= \frac{1.15 \times 60 \times 10^3}{2 \times \pi \times 7000} \\ &= 1464 \text{ N-mm} \end{aligned}$$

Equivalent torque on shaft

Equivalent torque is the torque which produce the same maximum shear stress as produced by the bending moment. Considering the factor for suddenly applied load with major shock, $K_t = 2$ (Ravindra, *et al.*, 2017; Kurmi and Gupta, 2005).

Therefore, the equivalent torque was calculated as

$$\begin{aligned} T_e &= K_t \times T \\ &= 2 \times 1464 \\ T_e &= 2928 \text{ N-mm} \end{aligned} \dots (3.19)$$

Diameter of shaft

The diameter of the shaft was calculated from torsion equation (Ravindra, *et al.*,2017). The maximum allowable shear stress for the mild steel was 56 N/mm²(Ravindra, *et al.*,2017; Kurmi and Gupta, 2005). Torque acting on a shaft was taken from equation 3.19. Therefore, the diameter of the transmission shaft was calculated from the following relation,

$$d^3 = \frac{16 \times T}{F_s \times \pi} \dots (3.20)$$

Hence,

diameter of shaft was calculated as

$$d^3 = \frac{16 \times 2928}{56 \times \pi}$$

$$d = 6.43 \text{ mm}$$

Therefore, the diameter of the shaft has been taken with the higher available diameter of 7.8 mm $\approx$ 8 mm and length of shaft was 530 mm with 9 splines.

3.6.4.3 Design considerations for cutting mechanism

The harvesting machine was equipped with two types of cutting mechanisms. The cereal crop harvesting was done by reciprocating type mechanism and the rotary cutter blade type mechanism, but the reciprocating type mechanism was not used in the grass cutting operation. Therefore, a rotary cutting blade mechanism was used in a developed machine. At the time of paddy harvesting, plants were in parallel hills and regular space. For crop cutting, a unique impulse was needed so that two or more hills could be cut and nearly arranged in a single stack. The mass moment inertia of cutter blade, the cutter blade angular velocity, cutting energy required to cut grass/paddy, maximum cutting force, specific cutting energy, and cutting width of cutter blade are the essential factors which were calculated in section 3.6.4.1.1.

The grass cutting and paddy harvesting principle were to cut the grass or paddy by slicing action or by shearing action. For cutting paddy used a circular cutter blade (Plate 3.9 (a)) and for grass cutting a nylon line cutter head or grass trimmer (Plate 3.9 (b)) was used. The precaution was taken with trimmer head that the trimmer cord was wound tightly and evenly around the reel, otherwise the machine would generate harmful vibrations. Both cutters were powered by a prime mover. A transmission shaft transmitted the power to the cutting unit from the prime mover.

3.6.4.3.1 Design of cutting blade

The cutting blade of the grass cutter cum paddy harvester was designed by using the kinematic equation of cutter as given below (Ravindra, *et al.*, 2017).

$$\frac{V_m}{V_e} \leq \frac{n h}{2 \pi R} \dots (3.21)$$

Where,

V_m – Machine forward speed, m/s

V_e – Cutter peripheral velocity, m/s

n – No. of teeth on the periphery of the disc

h – Height of the teeth over the disc of the cutter, m

R – Radius of the cutter, m

The peripheral velocity of the cutter to cut one stem of paddy should be between 25 m/s to 35 m/s (Nesar *et al.*, 2012). Considering the speed of the cutter as 3000 rpm.

We know the peripheral velocity of the cutter

$$V_e = \frac{\pi D N}{60} \dots (3.22)$$

Therefore, the velocity of the cutter was

$$25 \leq \frac{\pi D N}{60} \leq 35$$

$$0.159 \leq D \leq 0.223$$

Considering the intermediate diameter of the cutter blade as 0.195 m. The peripheral velocity of the cutter with 0.195 m cutter blade diameter and 3000 rpm cutter speed was calculated as

$$\begin{aligned} V_e &= \frac{\pi \times 0.195 \times 3000}{60} \\ &= 30.63 \text{ m/s} \end{aligned}$$

The peripheral velocity of the cutter was in within the limit i.e 25-35 m/s. The number of teeth on the cutter was 80 and height of the teeth was 0.005 m. Therefore, the kinematic equation of the cutter was verified.

$$\begin{aligned} \frac{0.5}{30.63} &\leq \frac{80 \times 0.005}{2 \times \pi \times 0.0975} \\ 0.016 &\leq 0.65 \end{aligned}$$

The above equation shows that the design considerations were satisfied the kinematic equation of cutter.

Thus, a cutter blade with 250 mm diameter, 80 number of teeth, 380 gm in weight and 2 mm thickness was selected for paddy harvesting operation.



(a) Circular cutter blade

(b) Trimmer head

Plate 3.9 Cutting blade

3.6.5 Functional components of grass cutter cum paddy harvester prototype

The existing shoulder mounted brush cutter (SMBC) consisted of a cutter blade or trimmer head, transmission shaft, handle, prime mover (engine), throttle, etc. During the operation with the existing SMBC, the operator carried the weight of machine during the operation. The vibrations produced from the machine were directly transmitted to the operator's body. Hence, it was necessary to make the machine trolley mounted. So that the operator has to operate the handle for pushing the trolley and cutting the crop/grass. The various functional components of the prototype of the grass cutter cum paddy harvester are as given below and discussed in the following sections.

1. Frame
2. Axle
3. Bush
4. Handle
5. Prime mover (engine)
6. Transmission shaft
7. Transport wheels
8. Windrowing system
9. Grass guard
10. Fuel tank
11. Caster wheel

3.6.5.1 Transport wheels and axel

The axel of the machine connects the two transport wheels. The spacing between the two paddy stalk was 200×150 mm (Shinde,2018). Therefore, the distance between the two transport wheels was 450 mm. The plastic transport wheels with rubber tyres were purchased from market having rim diameter 350 mm. Both transport wheels were free to rotation on the axle. A caster wheel was also provided.

3.6.5.2 Engine mounting frame

The frame of the grass cutter cum paddy harvester prototype was fabricated by using G. I. square pipe and M. S flat plate of size $25 \times 25 \times 3$ mm thickness and $170 \times 115 \times 3$ mm thickness respectively. The width of the frame was 172 mm, and the length was 345 mm. Hollow pipe of diameter 27 mm and length 126 mm with thickness 4 mm was fixed to engine mounting frame at bottom. That pipe was inserted on the another hollow pipe (22 mm diameter, length 154 mm and 3 mm thickness) was fixed at the middle of axle. This arrangement was as like bush and facilitated the right and left movement of the engine shaft and there on cutter shaft. The transport wheels, axel and engine mounting frame are shown at Plate 3.10 (a).

3.6.5.3 Handle

The handle of the grass cutter cum paddy harvester prototype provided the sufficient push to the machine and facilitated the swinging moment of cutter bar. It was designed by considering the anthropometric data of male worker in Konkan region of Maharashtra. The lower part of handle was fabricated by using G.I square pipe of size $30 \text{ mm} \times 30 \text{ mm}$ (3 mm thickness) and where on upper part was fabricated using hollow G.I round pipe of diameter of 34 mm and 3 mm thickness. The total length of the handle was 1200 mm. Two plates welded at lower end of the bush and lower part of the handle was fixed with the help of nut bolts arrangement on those plates. The upper part of the handle was fixed with its lower part by similar arrangement. Handle height could be adjusted at two plates.

3.6.5.4 Prime mover (Engine)

The prime mover of the machine was important component. It provided power to the cutting mechanism through transmission shaft. The prime mover was selected by considering different factors like idling power, forward speed, width of cut and specific cutting energy etc. A two stroke engine with power 1.95 hp at 6500 to 7500 rpm speed was selected for the grass cutter cum paddy harvester prototype.

3.6.5.5 Transmission shaft

The splined transmission shaft transmitted the power from engine to the gear box. The length of the shaft was 530 mm and diameter was 8 mm. The rotating transmission shaft was covered by guide pipe with 25 mm diameter. The guide pipe was connected to the bevel gear case at one end and clutch housing to the another end as shown at Plate 3.10(b), (c) and (d).

3.6.5.6 Throttle lever

A hand operated throttle lever was provided for controlling the speed of the cutter and it was fitted on the right hand of the handle. The engine ON and OFF switch was provided at right hand of the operator.

3.6.5.7 Windrowing System

The windrowing system was installed, at the upper portion of the cutting blade. With this system the cut paddy straw was gathered and transported with the movement of the handle.

3.6.5.8 Grass guard

The guard was intended to prevent the throwing stones towards the operator and protect the operator from accidental contact with the cutting blade/trimmer. The grass guard was made from plastic. It was mounted on the guide pipe with the help of a screw. Transport wheel, axle, engine mounting frame, handle, windrowing system, grass guard, etc. are shown in Fig 3.4 (schematic view of GCCPH)

The schematic views of developed prototype of grass cutter cum paddy harvester are shown in Fig 3.4, isometric view is shown in Fig 3.5 and its photograph is shown in Plate 3.11. The detailed specifications of the developed grass cutter cum paddy harvester prototype are given in Table 3.4.

Table 3.4 Specifications of the developed grass cutter cum paddy harvester

Sr. No	Particulars	Specifications
1	Engine	2-stroke petrol engine
	Power, hp	1.95
	Speed, rpm	6500-7500
2	Transmission shaft	
	Length, mm	530
	Splines	9
	Diameter, mm	8
3	Wheels	

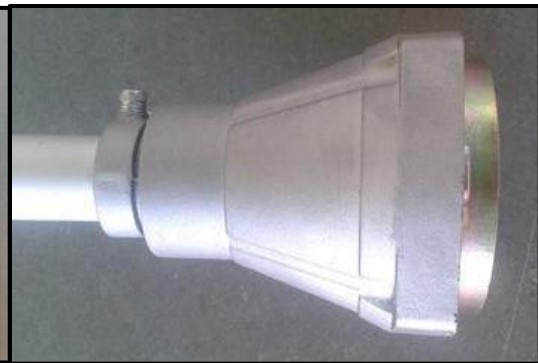
	No. of wheels	2
	Diameter, mm	350
	Material	Plastic rim rubber tyre
Sr. No	Particulars	Specifications
4	Cutter blade	
	Diameter, mm	250
	Thickness, mm	2
	Weight, gm	380
	No. of teeth	80
5	Handle	
	Material	G.I
	Square pipe, size thickness	30 × 30 × 3
	Round pipe, mm Diameter and thickness	ϕ 35 and 3
	Length, mm	1200
	Height, mm	1011.5
	Angle of operation	30° to 45°
6	Weight, kg	17.75
7	Length, mm	1500
8	Width, mm	475
9	Height, mm	1011



(a) Transport wheels and axel with engine mountning frame



(b) Bevel gear case

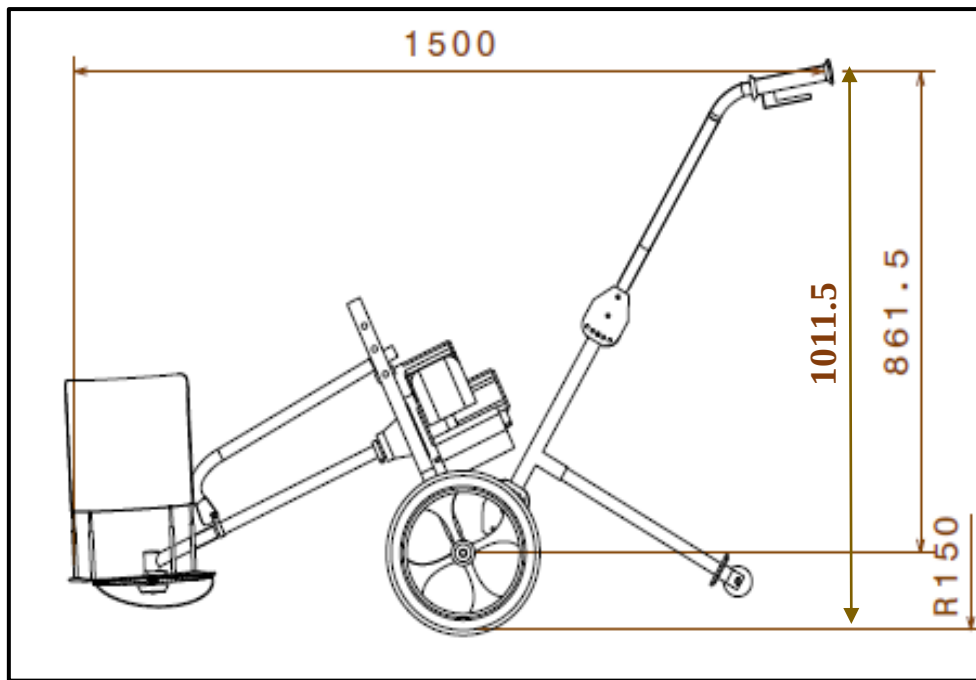


(c) Clutch housing

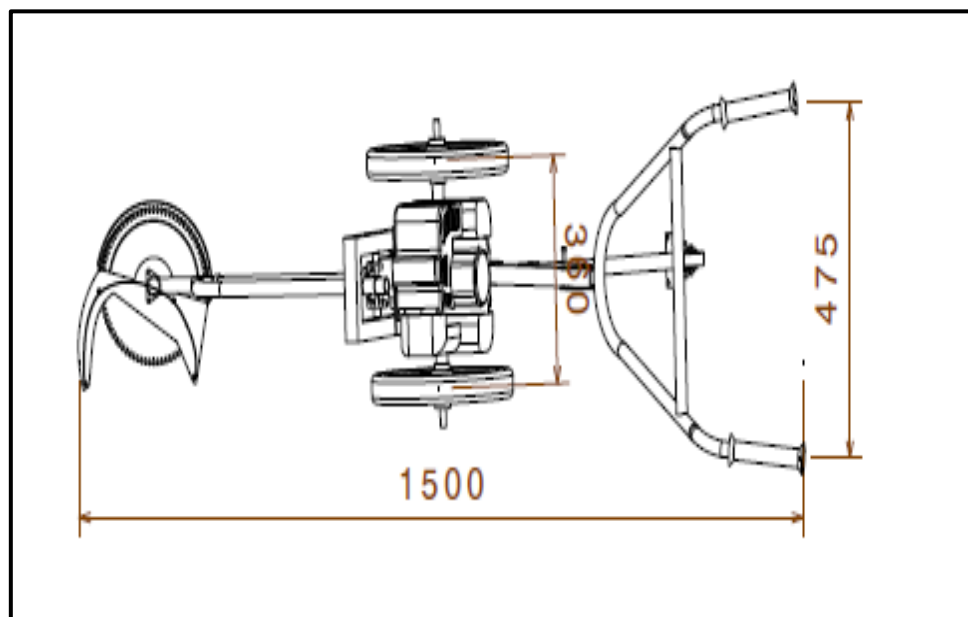


(d) Clutch housing, cutter shaft and bevel gear case

Plate 3.10 Component of the grass cutter cum paddy harvester



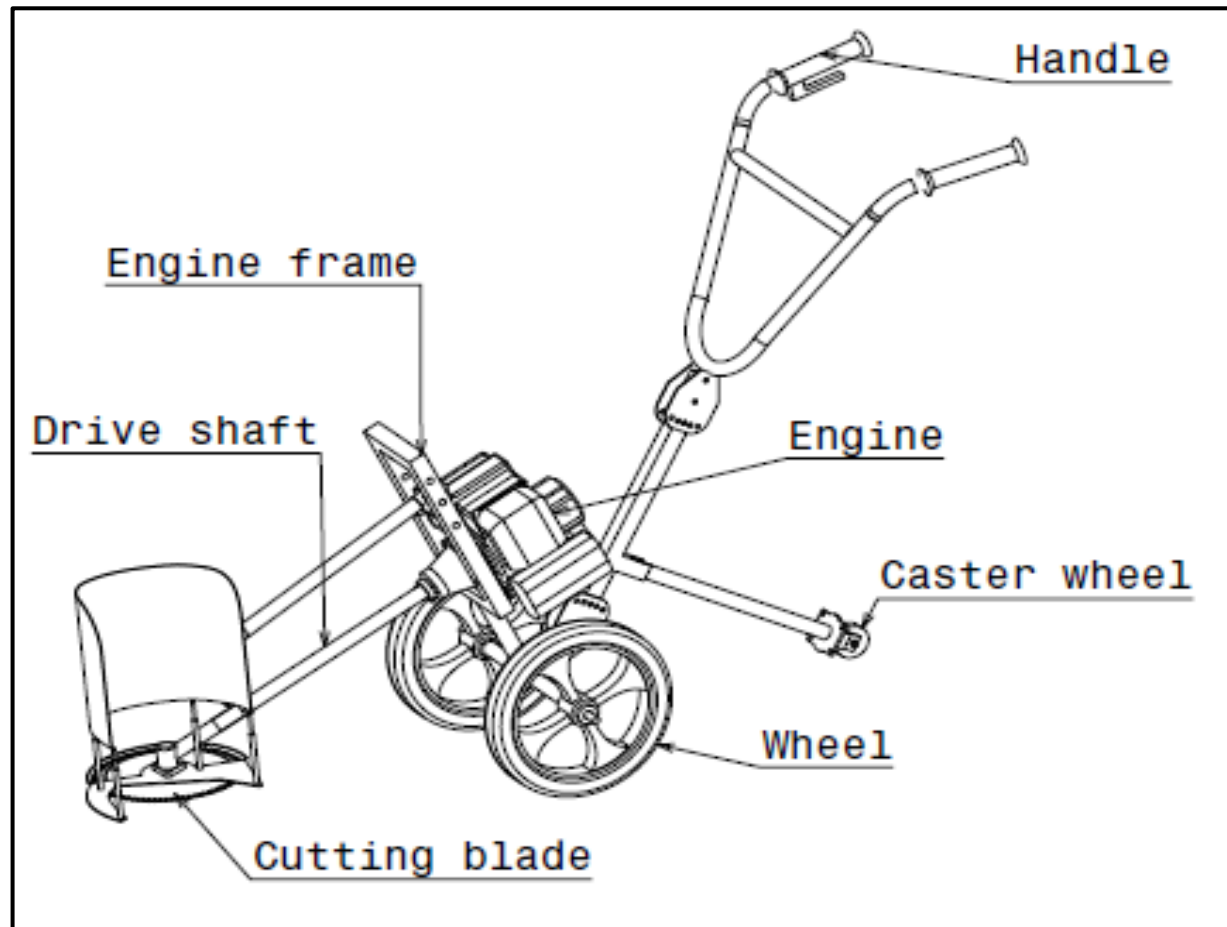
Side View



Top View

All dimensions are in mm

Fig 3.4 Schematic view of grass cutter cum paddy harvester prototype



Isometric View

Fig 3.5 Isometric view of prototype of grass cutter cum paddy harvester



Plate 3.11. Developed prototype of grass cutter cum paddy harvester

3.6.6 Working of developed grass cutter cum paddy harvester prototype

The developed grass cutter cum paddy harvester prototype was operated manually and driven by a prime mover. The engine was started by starting pulley. The transmission shaft received the power from the engine and transmitted it to the cutting mechanism. The nylon line cutter head or grass trimmer was used for grass cutting whereas cutter blade was used for paddy harvesting which were mounted on the front end of the transmission shaft. During the operation, the operator would hold the handle and give the swinging (right-left) moment to the cutting shaft through the concentric bushes. The throttle provided at the operator's right hand was helped to accelerate the speed of the cutter. After each stroke of operation, with the windrowing system, the harvested paddy was collected at the left side of the machine.

3.6.7 Performance evaluation of developed grass cutter cum paddy harvester prototype

The performance evaluation of a developed grass cutter cum paddy harvester prototype was carried out at Dept. of Agronomy, CAET, Dapoli during the year 2020-2021. The performance test was carried out to know the field capacity and field efficiency.

3.6.7.1 Ergonomic evaluation of developed grass cutter cum paddy harvester prototype

The ergonomic evaluation was carried out with six male subjects. The physiological parameters like resting heart rate (RHR), working heart rate (WHR), energy expenditure rate (EER), oxygen consumption rate (OCR) of the subjects during operation with grass cutter cum paddy harvester prototype were recorded as explained in section 3.3.5 and recorded data is given in section 4.4.2. The body part discomfort score (BPDS) and overall discomfort score (ODR) for the subject was calculated as explained in section 3.3.5.6.1 and 3.3.6.2, respectively. The obtained data is given in section 4.4.3. The work rest cycle for grass cutter cum paddy harvester prototype was worked out as explained in section 3.4.1 and details are given in section 4.4.4.

3.6.7.2 Field performance of developed grass cutter cum paddy harvester prototype

The field performance of developed grass cutter cum paddy harvester prototype was conducted simultaneously with the ergonomic evaluation on same field. The machine performance parameters, such as effective field capacity,

theoretical field capacity and field efficiency, were determined as explained in section 3.5 for grass cutting and paddy harvesting operations. The photograph of field performance of a developed grass cutter cum paddy harvester prototype is shown in Plate. 3.12.

Following constraints were observed in working with developed grass cutter cum paddy harvester prototype

1. Poor swinging moment
2. Tilting of windrowing attachment was there for discharging the harvested crop.
3. The cutting blade was not parallel to the ground (It got lifted up on cutter shaft moved from left to right)
4. High physiological cost and drudgery

Hence, it was decided to modify the grass cutter cum paddy harvester prototype further.



(a) Paddy harvesting



(b) Grass cutting

Plate 3.12 Filed performance of developed GCCPH prototype

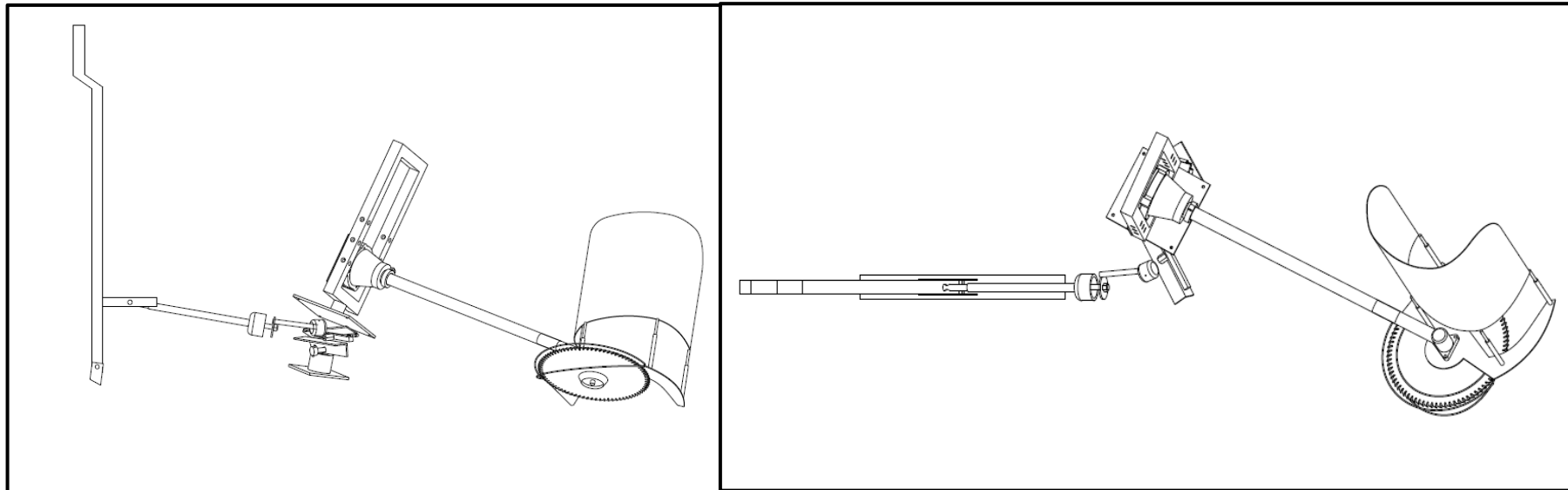
3.7 Development of Second Prototype of Grass Cutter Cum Paddy Harvester

In order to overcome above mentioned constraints in first prototype of GCCPH, the second prototype was developed. The detailed procedure of second prototype of grass cutter cum paddy harvester is given in following sections.

3.7.1 Swinging mechanism

The swinging mechanism of the second prototype of grass cutter cum paddy harvester was designed by four bar link mechanism, as shown in Fig 3.5. Link A was a fixed link and link B was pivoted on the link A at point E. Link B and link C were

interconnected by a flexible joint. Similarly, link C and link D also interconnected with a flexible joints. The link D of the swinging mechanism was rigidly connected to the support plate, which gave an angular movement to the cutter shaft through the bearing shaft. Thus, when the swinging lever (link B) was at its extreme backward position (side view Fig 3.6), the cutter shaft was at an extreme right end of the swing (top view Fig 3.6). On the other hand, as the swinging lever was pushed forward, at its extreme forward position, the cutter shaft was at an extreme left end of the swing (Fig 3.5 Top view). Link D responsible for transferring the oscillating moment of the swinging lever into an angular moment of the cutter shaft through the bearing shaft. With the swinging mechanism, an angular movement of the cutter shaft was 72° . These motions are also shown in isometric view in Fig 3.7.

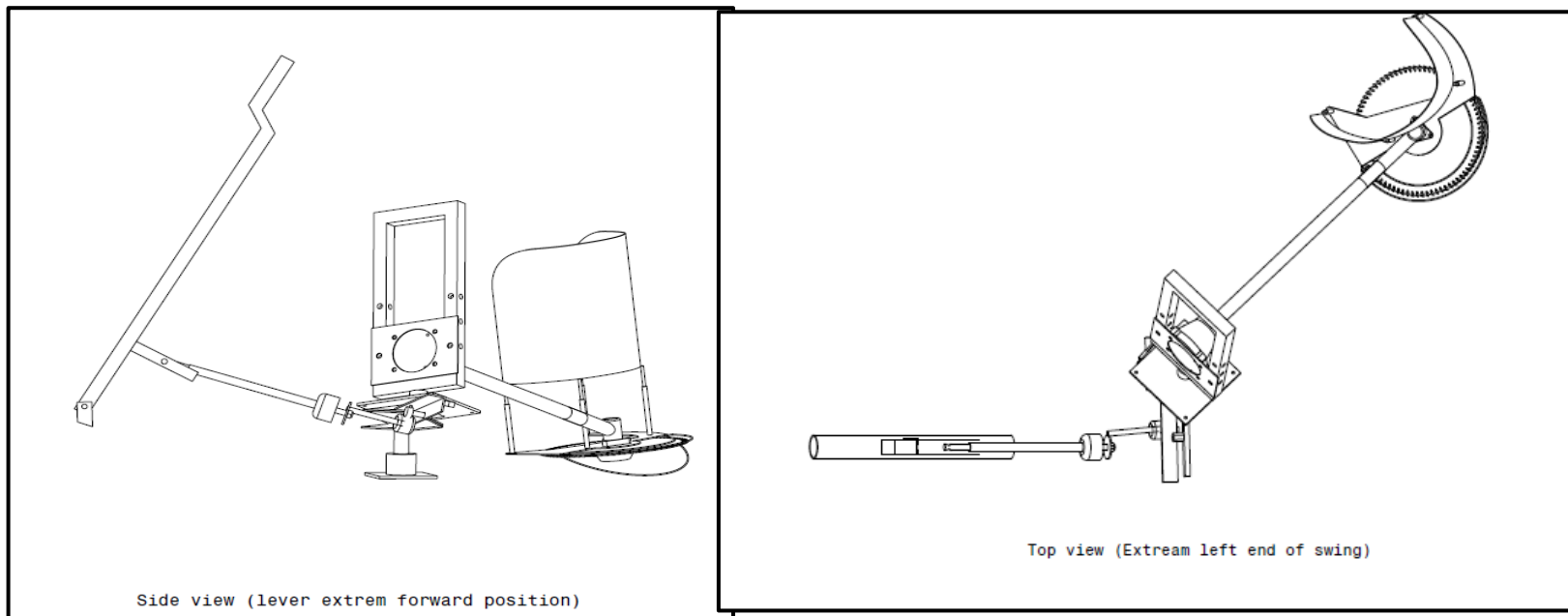


(c) Side view

(d) Top view

(a) Extreme backward position of lever

Fig 3.7 Isometric view of swinging mechanism



(a) Side view

(b) Top view

(b) Extreme forward position of lever
Fig 3.7 Isometric view of swinging mechanism

Length of arc covered in one oscillation of the swinging liver (link B)

The length of arc covered by the one stroke of swinging link was nothing but the cutting arc of cutter shaft of blade. In Fig 3.8 the relation between the linear and angular displacements are shown. Points A and B are the extreme right positions of the cutter shaft. Angle Θ was the angular distance covered by the cutting shaft in one oscillation of the swinging lever and r was the length of the cutter shaft.

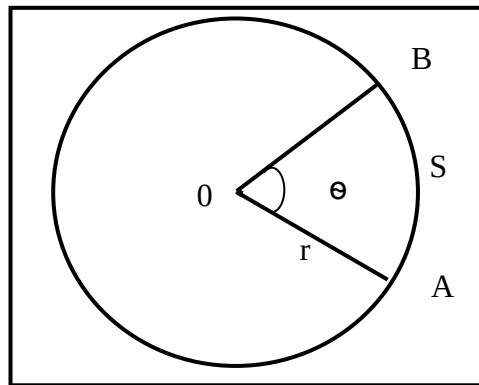


Fig 3.8 Arc traced by cutter by cutter shaft at blade

Were,

Θ – Angular displacement of the cutter shaft, radian

S – Linear displacement of the cutter shaft, mm

r – Length of the cutter shaft, mm

ω – Angular velocity

From the geometry of the Fig 3.8, cutting arc was given as

$$S = r \Theta \quad \text{.. (3.24)}$$

The length of the cutting shaft was 1000 mm and the angular displacement of the shaft was 72° (1.2567 rad). Therefore, length of cutting arc

$$\begin{aligned} S &= 1000 \times 1.2567 \\ &= 1256.7 \text{ mm} \end{aligned}$$

Hence, angular movement of cutter shaft was 72° with cutting arc as 1256.7 mm.

3.7.2 Arrangement for adjusting cutter height from ground

A hinge (hinge 1) was fixed on the bearing shaft. It was used to adjust the cutting height of the cutter as per requirement from the ground. The height of cut was adjusted with the nut bolt arrangement provided between the two plates of the hinge. The height of cutter shaft was adjusted from 50 mm to 650 mm from ground level.

3.7.3 Tilting mechanism

The tilting mechanism was used for dropping cutting paddy stalk on the ground at the end of stroke. Second hinge (hinge 2) was fixed between first hinge and support plate. It offered the tilting moment to the cutter shaft by pressing the left hand lever. A tilting lever was placed between the two plates of that hinge. By pressing the left hand lever, the tilting lever was pulled downward through cable and at the same time, the support plate moved in an upward direction. Because of the moment of the support plate, the tilting of the cutter shaft was achieved. The angle of 11° for cutting shaft was achieved by the tilting mechanism. The tilting mechanism of the second prototype of grass cutter cum paddy harvester is shown in Plate 3.13.

3.7.4 Arrangement to keep cutter blade always parallel to ground

In first prototype left right movement of the cutter shaft was achieved by an arrangement of two concentric hollow bushes placed on axle. An inclination of this arrangement (bushes) and that of cutter the shaft during cutting caused the lifting of cutter blade towards ends of swings. It was necessary to keep the cutting arrangement perfectly parallel with ground. It was achieved by fitting bearing parallel to ground and the bearing arrangement was mounted on its shaft shown in Plate 3.13.

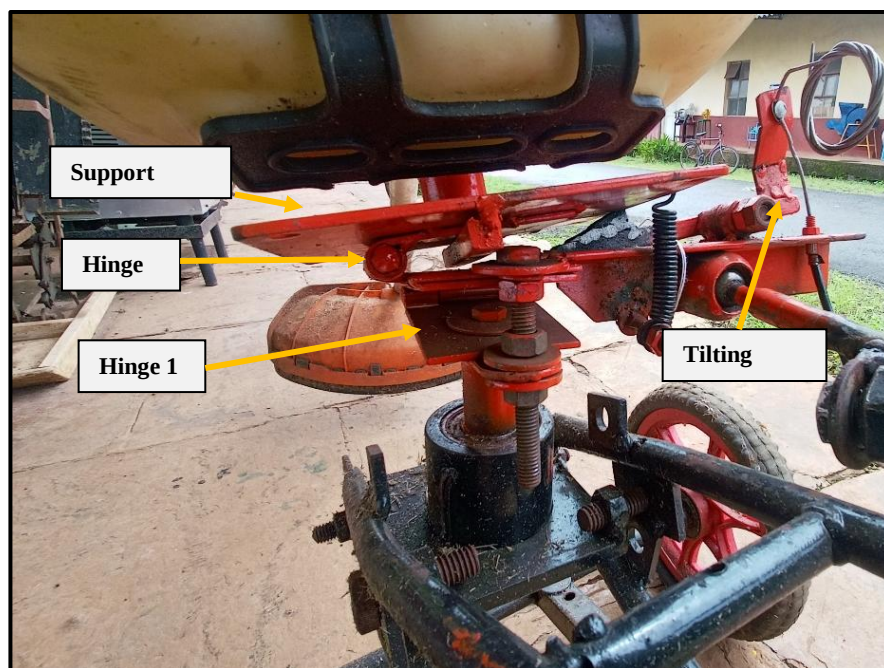


Plate 3.13 Tilting mechanism

3.7.5 Ergonomic considerations

The second prototype of grass cutter cum paddy harvester was also developed by considering the anthropometric data and strength data as explained in section 3.6.1.

3.7.5.1 Handle of swinging lever

The handle of the swinging lever was designed by considering ergonomic considerations. The shape of grip was cylindrical. The ergonomic consideration in handle design of swinging lever were the same as explained in section 3.6.1.3 to 3.6.1.5.

3.7.5.2 Lever of swinging mechanism

The swinging moment of the cutter was dependent on the arm reach of the operator from the wall, wall to acromial distance and abdominal extension to wall. For reach purpose the 5th percentile value of arm reach and 95th percentile value of abdominal extension to wall of user population was considered. The anthropometric data of Konkan region was considered for this purpose. The details of anthropometric data as given in Table 3.5 and the definition of the anthropometric parameters are given below (Anonymous., 2006).

1. Arm reach from the wall

The distance from the wall to the tip of the middle finger measured with subject shoulder against the wall, his hand and arm extended forward.

2. Abdominal extension to wall

The vertical distance from the most laterally protruding point of the abdomen to a wall against which the subject stands erect with minimal wall buttock contact and looking straight forward.

Table 3.5 Anthropometric parameters of male agricultural workers considered to design lever of swinging mechanism(Anonymous., 2006).

Sr. No	Parameters	Mean	SD (±)	5 th percentile	95 th percentile
1	Arm reach from the wall, mm	833	38	770	896
2	Abdominal extension to wall, mm	236	35	179	293

The stroke of swinging lever was calculated as,

$$L = (\text{arm reach from wall}) - (\text{abdominal extension to the wall}) \\ - (\text{allowance for handle})$$

$$= 770 - 293 - 150$$

$$= 327 \text{ mm}$$

Therefore,

The stroke of swinging lever was 327 mm.

3.7.5.3 Handle of grass cutter cum paddy harvester

The handle of second prototype of grass cutter cum paddy harvester was designed by considering the ergonomic considerations. Anthropometric data for male workers of Konkan region in Maharashtra was used for designing the dimensions of the handle of second prototype of grass cutter cum paddy harvester (Anonymous, 2006). The handle of grass cutter cum paddy harvester was designed as explained in section 3.6.1.

3.7.6 Functional component of second prototype of GCCPH

The various components of second prototype of GCCPH are as follows.

1. Main frame
2. Transport wheel
3. Hinges
4. Bearing housing with mounting plate and bearing shaft
5. Support plate
6. Bearing shaft
7. Ball bearing
8. Lever
9. Ball joints
10. Handle

3.7.6.1 Main frame

The main frame of the developed second prototype of GCCPH supports all components of the machine. The main frame was developed using a cycle frame. At the center of the frame, two square rod was welded of size 25 mm × 25 mm and 330 mm length. Those rods were fitted in the square pipe welded on the axle of the machine with nut bolts. The total length of the frame was 755 mm. The main frame of the developed grass cutter cum paddy harvester is shown in Plate 3.14 (a).

3.7.6.2 Transport wheels

The function of the transport wheels was the same as discussed in section 3.6.5.1. Total three wheels were used, having diameters of 250 mm (two no) and 375 mm. Two wheels of the same size were placed at the front and the larger wheel in the

backside of the machine for achieving better stability. The diameter of the front wheels was reduced than the prototype of grass cutter cum paddy harvester for achieving better stability. The distance between the two wheels was 600 mm. Two square pipes were welded on the axle of size 25 mm × 25 mm and length of 250 mm. The square rod attached at main frame and square pipe on the axle was interconnected with nut bolts. The length of the frame was adjusted with this arrangement.

3.7.6.3 Hinges

The lorry hinges were the important component of the grass cutter cum paddy harvester. It gave the tilting moment to the cutter at the end of the operation by pressing the lever and it also gave the inclination of the cutter shaft to the ground as explained at 3.7.2. The hinges were fabricated by using an M.S plate of sizes 62.5 mm × 62.5 mm × 3 mm thickness. One spring was placed at one side of the support plate and fitted on angle. The size of spring was 1.18 mm wire diameter and 20 number of coils.

The hinges were placed at 90°. The support plate was welded on the one side of the hinge and the other side of the hinge was mounted on the bearing shaft. When the distance between two plates of hinge was zero i.e the plates were at its initial position (Fig 3.9 (a)) the distance between cutter head and ground was maximum. Whereas the distance between the two plates of hinge was increased with the help of nut bolt fitted between the two plates (Fig 3.9 (b)). The hinges are shown in Plate 3.14 (b).

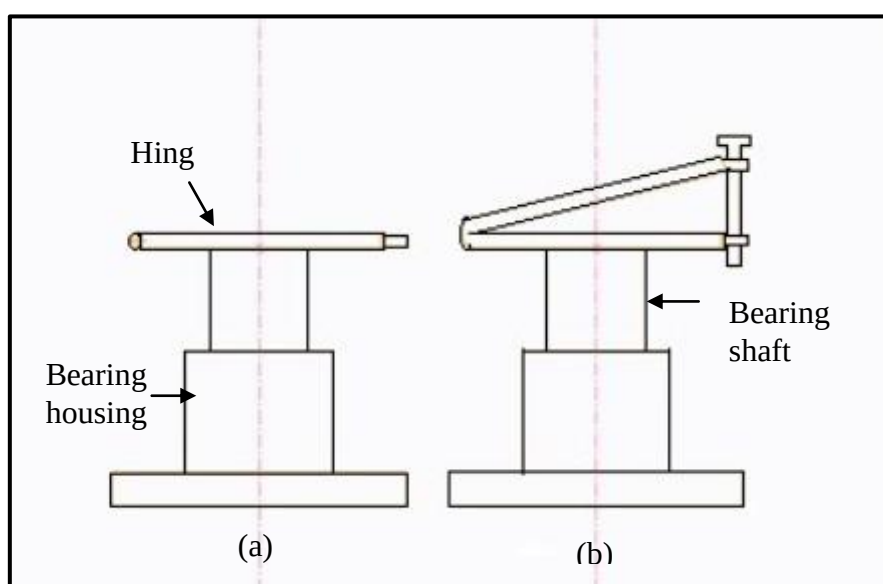


Fig 3.9 Hinge

3.7.6.4 Bearing housing with shaft and mounting plate

The bearing housing was fabricated to fit ball bearings. The bearing housing was fabricated using an M.S pipe of size 60 mm diameter, 60 mm length and 7.5 mm thickness. The bearing housing having an internal diameter of 47 mm was machined from both sides for fixing bearing with step length 14 mm. The bearing housing was fitted on M.S plate of size 105 mm in length, 97 mm width and 10 mm thickness. That plate with bearing housing was mounted on the main frame with nut bolts. The precaution was taken that the bearing housing should be parallel to the ground to avoid angular deflection of the cutting blade. The level of the bearing housing was checked using a hydraulic dumpy level. A bearing shaft was fitted in the bearing housing for fixing the ball bearings. The bearing housing with mounting plate is shown in Plate 3.12 (c)

3.7.6.5 Transmission shaft

The transmission shaft of the developed second prototype of grass cutter cum paddy harvester was designed as explained in section 3.6.4.2. The transmission shaft of the grass cutter cum paddy harvester transmitted the power from engine to cutting unit through bevel gear housing. The bevel gear housing reduced the speed of a transmission shaft. The transmission shaft was guided by a guide pipe this guide pipe was fitted between the clutch housing and bevel gear casing. The transmission shaft was fabricated of 1000 mm length and 8 mm diameter with 9 splines was used.

The detailed specifications of second prototype of grass cutter cum paddy harvester is given in Table 3.5

Table 3.6 Specifications of the developed grass cutter cum paddy harvester

Sr. No	Particulars	Specifications
1	Engine	2-stroke petrol engine
	Power, hp	1.95
	Speed, rpm	6500-7500
2	Transmission shaft	
	Length, mm	1000

	Splines	9
	Diameter, mm	8
Sr. No	Particulars	Specifications
3	Wheels	
	No. of wheels	3
	Diameter, mm	250 ϕ and 375 ϕ
	Material	Plastic rim rubber tyre
4	Cutter blade	
	Diameter, mm	250
	Thickness, mm	2
	Weight, gm	380
	No. of teeth	80
5	Handle	
	Material	G.I and M.S
	Square pipe, mm	25 $\times$ 25
	Round pipe (diameter), mm	22
	Length, mm	530
	Height, mm	1011
	Angle of operation	30° to 45°
6	Weight, kg	26
7	Length, mm	1410
8	Width, mm	610
9	Height, mm	1250

The schematic views and isometric view of the developed second prototype of grass cutter cum paddy harvester is shown in Fig 3.10 and Fig 3.11, respectively. The photograph of developed second prototype of grass cutter cum paddy harvester is shown in Plate 3.15.



(a) Main frame



(b) Hinges



(c) Bearing housing with mounting



(d) Support plate

Plate 3.14 Functional components of second prototype of grass cutter cum paddy harvester

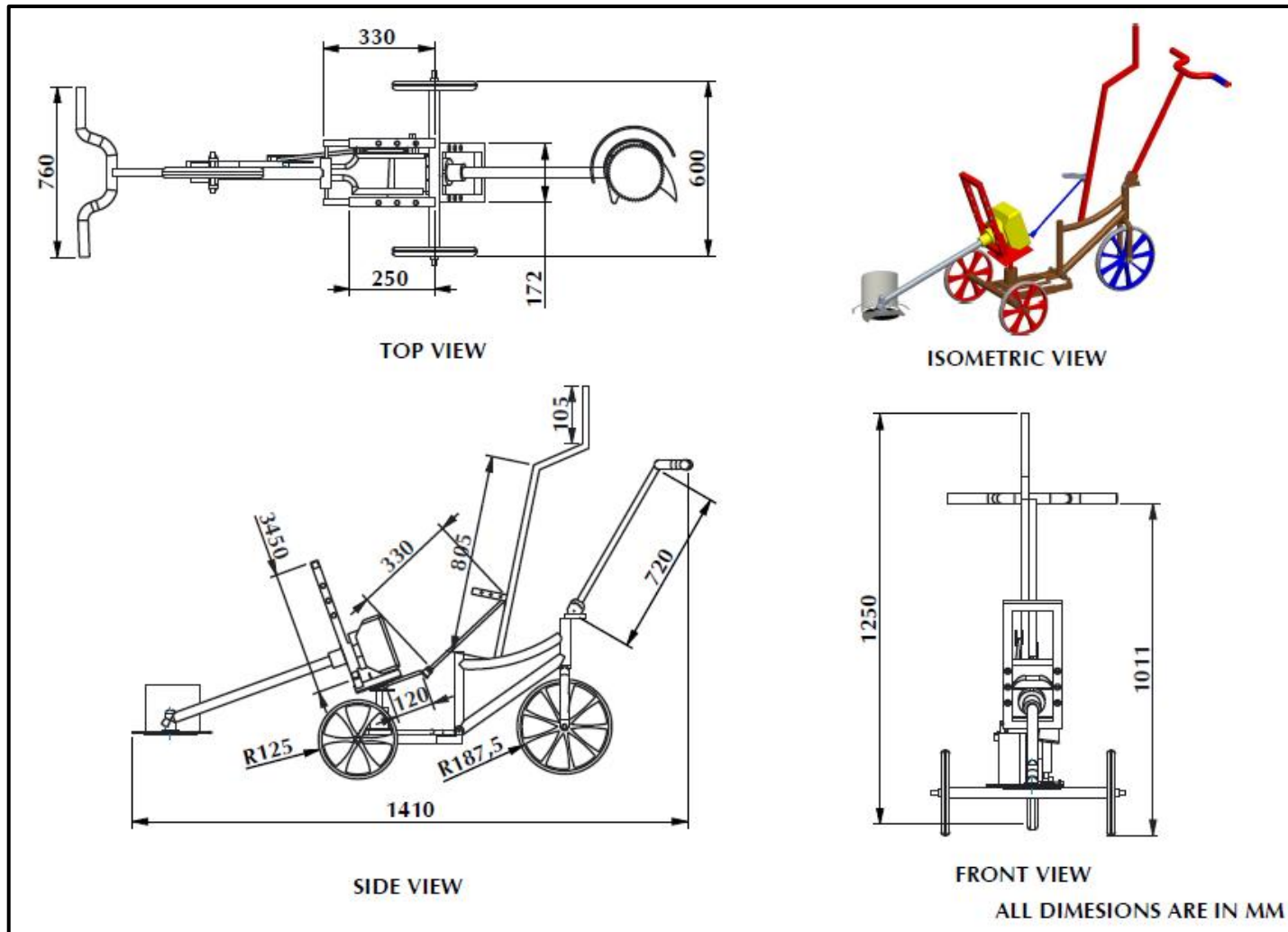


Fig 3.10 Schematic views of developed grass cutter cum paddy harvester

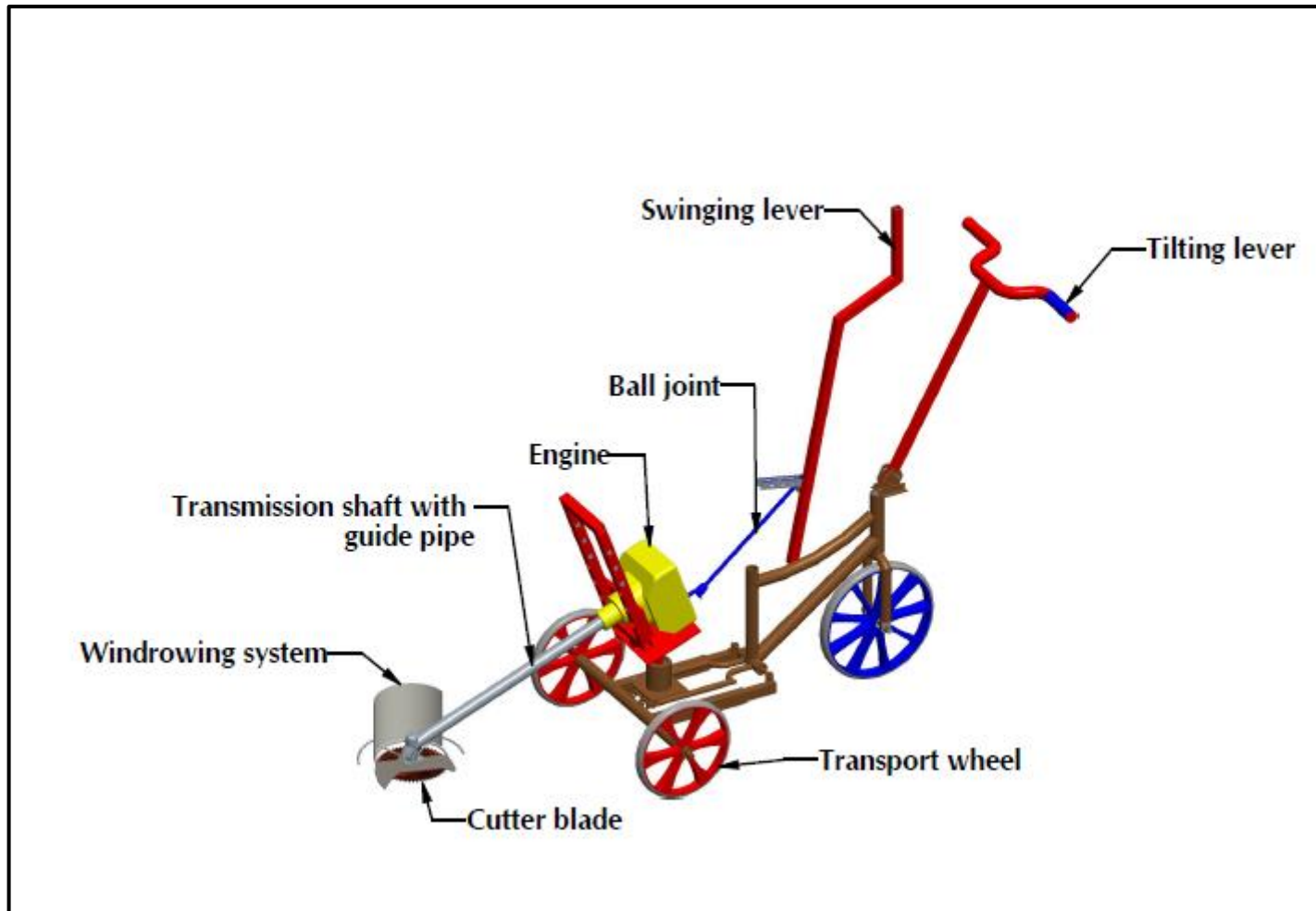


Fig 3.11 Isometric view of developed grass cutter cum paddy harvester



Plate 3.15 Developed second prototype of grass cutter cum paddy harvester

3.7.7 Working of second prototype of GCCPH

The developed second prototype of grass cutter cum paddy harvester was operated manually and driven by a prime mover (engine). The engine power was transmitted to the cutter or grass trimmer through the transmission shaft. The bevel gear case reduced the speed of the transmission shaft and further transmitted it to the cutter or grass trimmer. The harvesting of paddy and cutting of grass was done by pushing the machine with one hand and operating the swinging lever in forward and backward. From the forward-backward moment of the swinging lever, the right-left moment of the cutter shaft through bearing was achieved. As the lever was pulled towards the operator, the cutting unit changed its position from the center to the right side of the machine. Similarly, as swinging lever was pushed away from the operator the cutting unit moved to the left side. It is explained prior at section 3.7.1 Hence, cutting unit shifted left to right with push pull moment of the swinging lever. The tilting of cutter and windrowing system to drop the cut crop on the ground was achieved by pressing the left hand lever. Because of the tilting movement, the harvested crop (paddy) was placed at the left side of the machine properly. As the left hand lever were released the spring loaded lifting deactivated and cutter shaft came at its original position.

3.7.8 Performance evaluation of developed second prototype grass cutter cum paddy harvester

The performance evaluation of developed second prototype of grass cutter cum paddy harvester was carried out at Agriculture Research Center, Repoli, during 2020-2021.

3.7.8.1 Ergonomic evaluation of developed second prototype of grass cutter cum paddy harvester

The ergonomic evaluation was carried out with six male subjects. The physiological parameters like RHR, WHR, EER, OCR of the subjects during operation with grass cutter cum paddy harvester prototype were recorded as explained in section 3.3.5. The body part discomfort score (BPDS) and overall discomfort score (ODR) for the subject was calculated as explained in section 3.3.5.6.1 and 3.3.6.2, respectively. The work rest cycle for second prototype of grass cutter cum paddy harvester was calculated as explained in section 3.4.1.

3.7.8.2 Field performance of developed second prototype of grass cutter cum paddy harvester

The field performance of developed second prototype of grass cutter cum paddy harvester was conducted simultaneously with the ergonomic evaluation on same field. The machine performance parameters, such as effective field capacity, theoretical field capacity and field efficiency, were determined as explained in section 3.5.2 for grass cutting and paddy harvesting operations.

The photograph of field performance of a developed second prototype of grass cutter cum paddy harvester is shown in Plate 3.16.



(a) Paddy harvesting



(b) Grass cutting

Plate 3.16 Field performance of developed second prototype of GCCPH

3.8 Cost Economics of Grass Cutter Cum Paddy Harvester

The operating cost of developed grass cutter cum paddy harvester included fixed cost and variable cost was determined by following equations. The life of grass cutter/paddy harvester and its use per year were considered as 5 years and 360 (2 months× 60 days ×6hrs per day) h/yr, respectively.

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

The detailed cost economics were explained at Appendix - V

3.8.1 Cost economics for GCCPH prototype

1. Fixed cost

1. Depreciation (Rs./h) = $\frac{(C-S)}{(L \times H)}$
 $= \frac{(26831-2683)}{(5 \times 360)}$
 $= 13.4 \text{ ₹ /h}$
2. Interest @ 5 % (Rs./h) = $\frac{(26831+2683)}{2} \times \frac{5}{(100 \times 360)}$
 $= 2.04 \text{ ₹ /h}$

$$3. \text{ Housing (Rs./h) } = 1.5 \% \text{ of Initial cost}$$

$$= 1.5 \times 26831$$

$$= 1.12 \text{ ₹ /h}$$

$$4. \text{ Total fixed cost} = 1 + 2 + 3$$

$$= 13.4 + 2.02 + 1.12$$

$$= 15.54 \text{ ₹ /h}$$

2. Variable cost

$$1. \text{ Operators cost} = \text{Wages of operator} / \text{Working hours}$$

$$= 300 / 6$$

$$= 50 \text{ ₹ /h}$$

$$2. \text{ Fuel cost/hr} = 0.35 \times 100$$

$$= 35 \text{ ₹ /h}$$

$$3. \text{ Cost of lubricant/hr} = \text{Assume } 25 \% \text{ of fuel cost}$$

$$= 0.25 \times 35$$

$$= 8.75 \text{ ₹ /h}$$

$$4. \text{ Repair and maintenance (₹ /h) } = 10 \% \text{ of initial cost}$$

$$= 10 \times 26831$$

$$= 7.45 \text{ ₹ /h}$$

$$5. \text{ Total variable cost} = 1 + 2 + 3 + 4$$

$$= 50 + 35 + 8.75 + 7.45$$

$$= 101.2 \text{ ₹ /h}$$

3. Operating cost

$$\text{Operating cost} = \text{Fixed cost} + \text{Variable cost}$$

$$= 15.54 + 101.2$$

$$= 116.74 \text{ ₹ /h}$$

3.8.2 Cost economics for second prototype of GCCPH

1. Fixed cost

$$1. \text{ Depreciation (Rs./h) } = \frac{(C-S)}{(L \times H)}$$

$$= \frac{(28502-2850)}{(5 \times 360)}$$

$$= 14.25 \text{ ₹ /h}$$

$$2. \text{ Interest @ } 5 \% \text{ (₹ /h) } = \frac{(28052+2850)}{2} \times \frac{5}{(100 \times 360)}$$

$$= 2.14 \text{ ₹ /h}$$

$$3. \text{ Housing (₹ /h) } = 1.5 \% \text{ of Initial cost}$$

$$= 0.015 \times 28052$$

$$= 1.16 \text{ ₹ /h}$$

$$4. \text{ Total fixed cost} = 1 + 2 + 3$$

$$= 14.25 + 2.14 + 1.16$$

$$= 17.55 \text{ ₹ /h}$$

2. Variable cost

$$1. \text{ Operators cost} = \text{Wages of operator} / \text{Working hours}$$

$$= 300 / 6$$

$$= 50 \text{ ₹ /h}$$

$$2. \text{ Fuel cost/hr} = 0.35 \times 100$$

$$= 35 \text{ ₹ /h}$$

$$3. \text{ Cost of lubricant/hr} = \text{Assume } 25 \% \text{ of fuel cost}$$

$$= 0.25 \times 35$$

$$= 8.75 \text{ ₹ /h}$$

$$4. \text{ Repair and maintenance (₹ /h) } = 10 \% \text{ of initial cost}$$

$$= 0.1 \times 28052$$

$$= 7.79 \text{ ₹ /h}$$

$$5. \text{ Total variable cost} = 1 + 2 + 3 + 4$$

$$= 50 + 35 + 8.75 + 7.79$$

$$= 101.54 \text{ ₹ /h}$$

3. Operating cost

$$\text{Operating cost} = \text{Fixed cost} + \text{Variable cost}$$

$$= 17.55 + 101.54$$

$$= 119.09 \text{ ₹ /h}$$

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the result obtained from the survey of shoulder-mounted grass cutter cum paddy harvester. The details about the ergonomic evaluation of shoulder mounted grass cutter cum paddy harvester, development of grass cutter cum paddy harvester and its ergonomic evaluation has been presented and discussed. The manufacturing and operating cost of the developed grass cutter cum paddy harvester are also calculated.

4.1 Survey of Shoulder Mounted Brush Cutter (SMBC) for Identifying Occupational Health Hazard and Drudgery in Operation

Total of thirty farmers were surveyed, who were very well accustomed with operation and use of shoulder mounted brush cutter. The information was collected as described previously in section 3.2. Accordingly, the survey data has been presented in the following subsequent sections.

4.1.1 Workplace description

In the survey of health hazards and drudgery in operation with shoulder mounted brush cutter, the workplace information was collected and shown in Appendix I (B). All surveyed thirty farmers were male. During the survey, farmers were asked about the type of crop cultivated on their field and the month or the period of crop cultivation.

As per Appendix I (B), out of 30 farmers, 76.6 per cent of farmers had their own land. According to the survey, 52.2 per cent of farmers cultivated paddy. Similarly, 4.3per cent, 13per cent, 17.4per cent, 4.3per cent, 4.3per cent, and 4.3 per cent of farmers had cultivated cashew, paddy and vegetables, paddy and finger millet, mango and cashew, paddy and cashew, paddy and mango, respectively, in their fields. Amongst other crops, paddy cultivation was dominant. The details about crop cultivation is shown in bar graph at Fig. 4.1. As far as land holding was concerned 53.3 per cent, 13.3 per cent, 10 per cent and 3 per cent farmers were marginal, small land holding, semi-medium and large land holding, respectively. The details about farmer's land holding is shown in Fig 4.2.

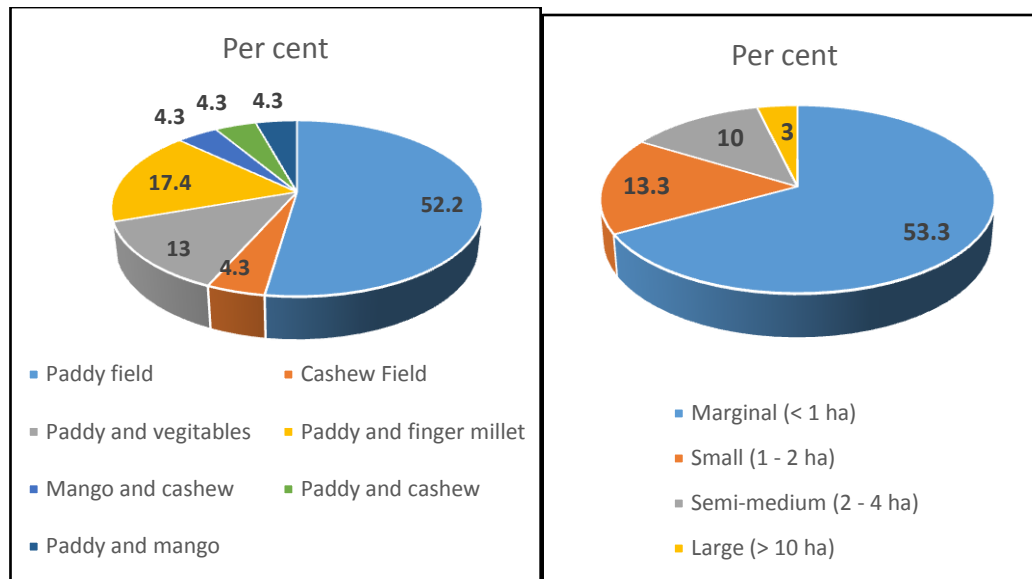


Fig 4.1 Crop cultivation

Fig 4.2 Land holding

4.1.2 Workers description and occupational health hazards

The information related to worker's description including their details, general health status, work output, precautionary measures taken and occupational health hazards, were collected and summarized. The detailed data is given in Appendix (C) and the summarized data is presented in Table 4.1.

It was observed that out of 30 farmers, 46.7 per cent of farmers were in the age group of ≤ 34 years, whereas 53.3 per cent of farmers were in the age group of ≥ 34 years. The height of 33.3 per cent of farmers was ≤ 165 cm whereas, that of 66.7 per cent of farmers was ≥ 165 cm. 53.3 and 46.7 per cent farmers had weights ≤ 62 kg and ≥ 62 kg respectively. Out of surveyed farmers, 66.7 per cent of farmers were married, whereas 33.3 per cent of farmers were unmarried. All surveyed farmers were literate. 46.7 per cent of farmers had experience ≤ 5 years where as 53.3 per cent of farmers had experience ≥ 5 years of shoulder mounted brush cutter for grass cutting and paddy harvesting operations. It was observed that the annual income of 63.3 per cent farmers was $\leq$ Rs.1,00,000/- whereas that of 36.7 per cent farmers was $\geq$ Rs.1,00,000/-. 53.3 per cent farmers had work duration at ≤ 7 h and 56.7 per cent had work duration ≥ 7 h in a day.

The grass cutting and paddy harvesting operations were being carried out in a standing posture using shoulder mounted brush cutter as explained in article 3.1.2. The existing machine was mounted on the operator's shoulder with the help of a hanging belt. The summarized data about worker's description with occupational health hazards is given in Table 4.1.

Table 4.1 Description of workers with occupational health hazards

Sr. No	Variables		Percent
1	Age, (y)	≤ 34	46.7
		≥ 34	53.3
2	Height, (cm)	≤ 165	33.3
		≥ 165	66.7
3	Weight, (kg)	≤ 62	53.3
		≥ 62	46.7
4	Marital Status	Married	66.7
		Unmarried	33.3
5	Educational Status	Educated	100
6	Annual Income, (Rs)	≤ 100000	63.3
		≥ 100000	36.7
7	Experience (y)	≤ 5	46.7
		≥ 5	53.3
8	Working Schedule (h)	≤ 7	43.3
		≥ 7	56.7
9	Work Posture	Standing	100
10	General Health Status		
	a) Complaints	Yes	80
		No	20
	b) Injuries	Yes	43.3
		No	56.7
11	Work Output		
	a) Grass Cutting (ha/h)	≤ 0.0213	26.7
		≥ 0.0213	73.3
	b) Paddy harvesting (ha/h)	≤ 0.0163	23.3
		≥ 0.0163	76.7
12	Precautionary measures		
	a) Nose mask	Yes	50
		No	50
	b) Gloves	Yes	80

		No	20
		Yes	13.3
	c) Earplugs	No	86.7
	d) Helmet	Yes	53.3
		No	46.7
	e) Goggle	Yes	20
		No	80
	f) Gumboot	Yes	23.3
		No	76.7

It was observed that 80 per cent of farmers had health complaints, and 43.3 per cent of farmers had frequent leg injury. The work output of 26.7 per cent of farmers was ≤ 0.0213 ha/h and that of 73.3 per cent farmers was ≥ 0.0213 ha/h for grass cutting. Similarly, the work output for paddy harvesting of 23.3 per cent farmers was ≤ 0.0163 ha/h and that of 76.7 per cent of farmers was ≥ 0.0163 ha/h. It was observed that the work output for grass cutting was more than the paddy harvesting. The results of the survey showed that only 50 per cent of farmers used nose mask as a precautionary measure during operation. Similarly, 80 per cent of farmers used gloves, 13.3 per cent of farmers used earplugs, 53.3 per cent of farmers used helmet, 20 per cent farmers used goggle, and 23.3 per cent farmers used gumboot during working with shoulder mounted grass cutter cum paddy harvester.

The summarized data of occupational health hazards is given in Appendix I (D). Considering work and workplace related data it was observed that 77 per cent of farmers had body ache and headache, 57 per cent of farmers had a frequent leg injury and 10 per cent of farmers had frequent hand injury with use of shoulder mounted brush cutter.

Similarly considering posture related health hazards, it was observed that out of 30 farmers, 13.3 per cent had pain in one or both hips, 33.3 per cent had pain in one or both thigh, 16.6 per cent had pain in one or both feet, 26.6 per cent of farmers had pain in their knee. About hand pain 97 per cent, 70 per cent, 63.3 per cent, 46.7 per cent and 16.6 per cent farmers had pain in shoulder, lower arm, upper arm, wrist and elbow, respectively. Similarly, 70 per cent and 83.3 per cent farmers had pain in upper back and lower back, respectively. It was observed that 20 per cent of farmers had neck pain and 33.3 per cent of farmers had waist pain. The bar graph depicting the

occupational health hazards related to posture adopted during the operation with shoulder mounted brush cutter is given in Fig 4.3.

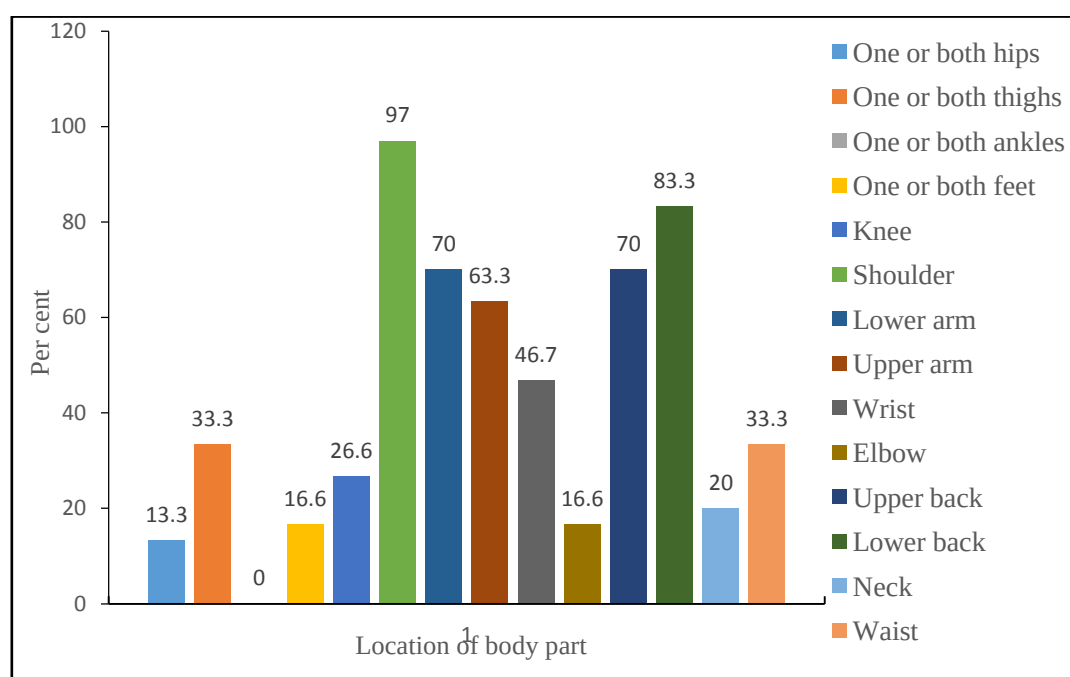


Fig. 4.3 Occupational health hazards related to work posture

4.1.3 Description of shoulder mounted brush cutter (SMBC)

The summarized data about the description of shoulder mounted brush cutter is given at Appendix I (E). During the survey, farmers were questioned about available power, type of prime mover, type of fuel used, fuel requirement, type of cutting mechanism pertaining to SMBC etc.

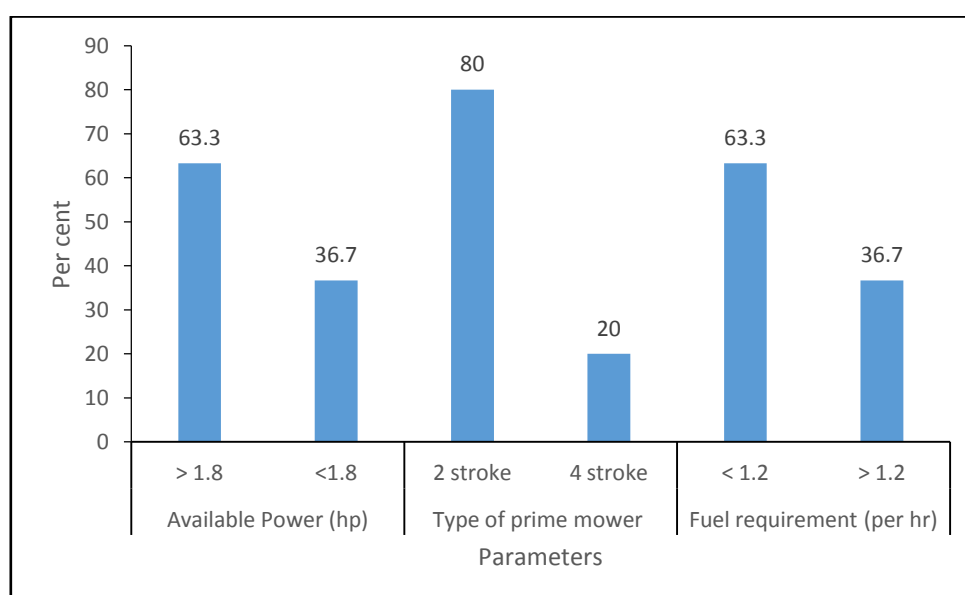


Fig. 4.4 Description of grass cutter cum paddy harvester machine

The bar graph (Fig. 4.4.) shows the farmer's response to description of shoulder mounted brush cutter. Out of 30 farmers, 36.7 per cent of farmers responded that power ≤ 1.8 hp whereas the rest of 63.3 per cent responded that the engine power was ≥ 1.8 hp. It was observed that 80 per cent of farmers used a two-stroke petrol engine as a prime mover and the rest of 20 per cent was used four stroke engines. 63.3 per cent of farmers answered that fuel requirement was ≤ 1.2 lit/h, and the rest of 36.7 per cent answered that requirement was ≥ 1.2 lit/h

4.1.4 Aspects in grass cutting and paddy harvesting operation

4.1.4.1 Requirement of job specialization

The summarized data of aspects in grass cutting and paddy harvesting operation is given in Appendix I (F). Out of 30 farmers, 40 per cent of farmers responded 'Yes' to the question whether the grass cutting and paddy harvesting operations were simple and uncomplicated, whereas 60 per cent responded 'No'. The bar graph showing the farmer's rating about job specialization requirements in grass cutting and paddy harvesting operation is given in Fig. 4.5.

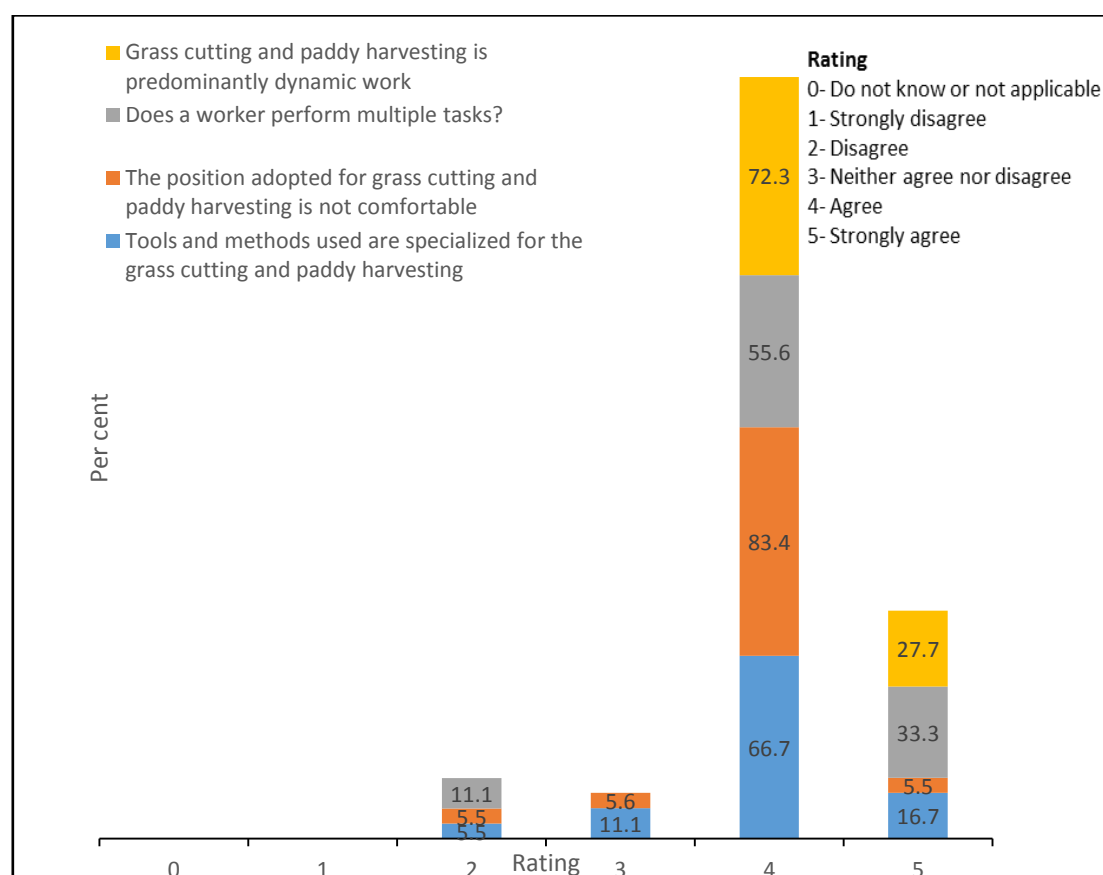


Fig. 4.5 Farmers rating about requirement of job specialization in grass cutting and paddy harvesting operation

Hence, out of 60 per cent farmers, 16.7 per cent farmers were strongly agreed, 66.7 per cent farmers were agreed, 11.1 per cent farmers were neither agreed nor disagreed, 5.5 per cent farmers were disagreed with the tools and methods used for the grass cutting and paddy harvesting were specialized. Similarly, 5.5 per cent of farmers strongly agreed, 83.4 per cent farmers agreed, 5.6 per cent farmers neither agreed nor disagreed, 5.5 per cent farmers disagreed with the position adopted for grass cutting and paddy harvesting was not comfortable. It was found that 33.3 per cent of farmers strongly agreed, 55.6 per cent agreed, and 11.1 per cent of farmers disagreed with the question whether the worker perform multiple tasks. 27.7 per cent of farmers strongly agreed and 72.3 per cent farmers agreed to the grass cutting and paddy harvesting operation was predominantly dynamic work.

4.1.4.2 Skill requirement

As per Appendix I (F), out of 30 farmers, 70 per cent farmers responded ‘Yes’ to the question of grass cutting and paddy harvesting dosent require elementary skills, and the rest of 30 per cent of farmers responded ‘No’. The bar graph showing the worker's rating about skill requirement is shown in Fig. 4.6.

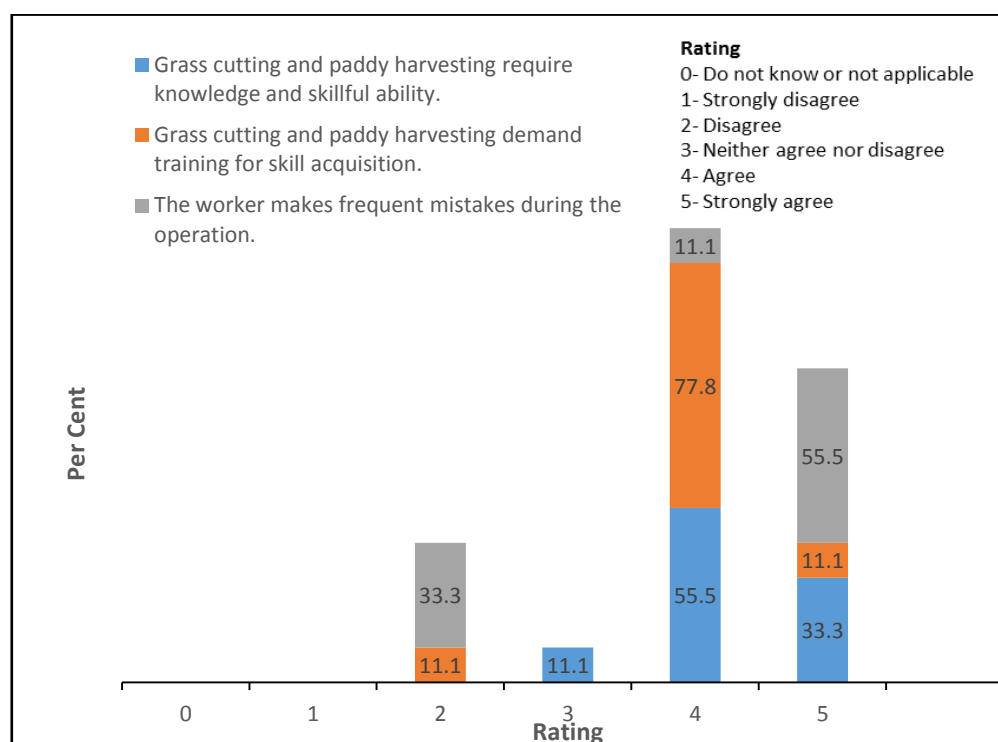


Fig. 4.6 Workers rating for skill requirement

Out of 30 per cent farmers, 33.3 per cent were strongly agreed, 55.5 per cent agreed and 11.1 per cent neither agreed nor disagreed to grass cutting and paddy harvesting require knowledge and skillful ability. The 11.1 per cent strongly agreed,

77.8 per cent agreed and 11.1 per cent disagreed with the grass cutting and paddy harvesting demand training for skill acquisition. Out of 30 per cent, 55.5 per cent strongly agreed, 11.1 per cent agreed and 33.3 per cent disagreed to the worker makes frequent mistakes during the operation.

4.1.4.3 General physical activity

As per Appendix I (F), out of 30 farmers, 66.6 per cent of farmers were reported 'Yes' to the question of physical activity is entirely determined and regulated by the worker rest of 33.3 per cent of farmers reported 'No.' The bar graph showing the farmers rating for general physical activity is shown in Fig. 4.7.

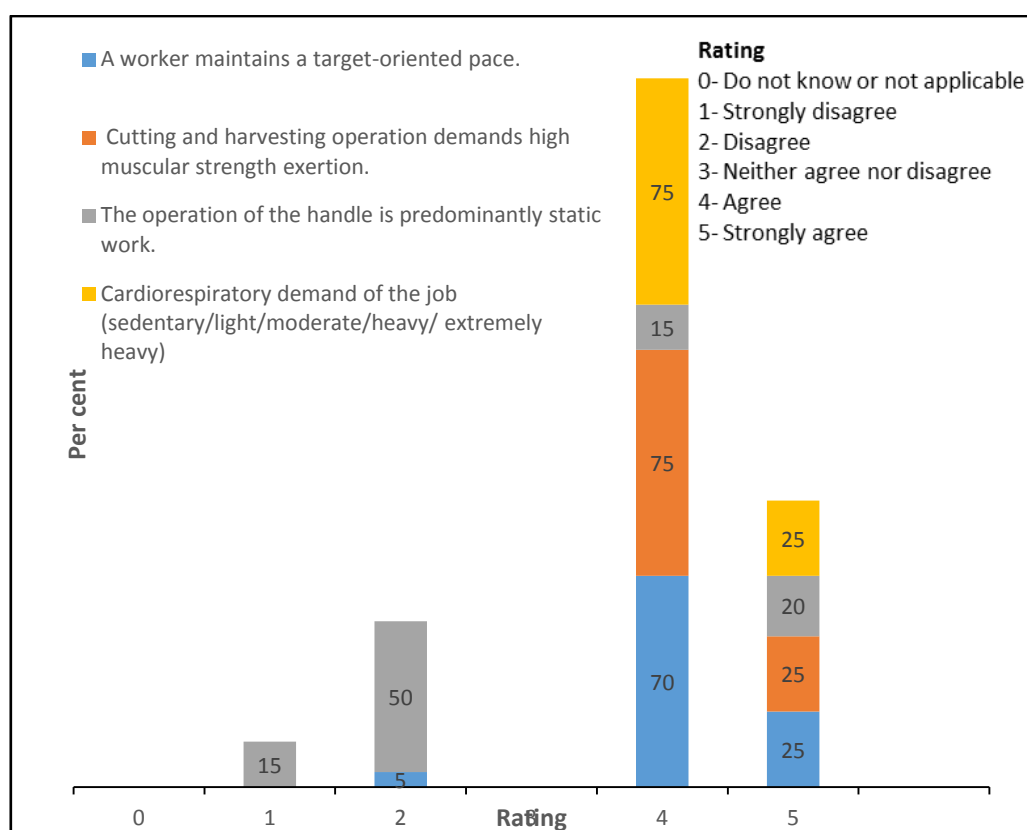


Fig. 4.7 Farmers rating for general physical activity

Out of 33.3 per cent farmers, 25 per cent of farmers were strongly agreed, 70 per cent farmers agreed and 5 percent of farmers disagreed with the question of whether a worker maintains a target-oriented pace. Twenty-five per cent of farmers strongly agreed and 75 per cent agreed that the cutting and harvesting operation demands high muscular strength exertion. Twenty per cent of farmers strongly agreed, 15 per cent of farmers agreed, 50 per cent farmers have disagreed and 15 per cent of farmers strongly disagreed that the handle's operation was predominantly static work. Out of 33.3 per cent of 30 farmers 3.3 per cent, 6.7 per cent, 20 per cent, 36.7 per cent

and 33.3 per cent farmers reported that the cardiorespiratory demand of work were sedentary, light, moderate, heavy and extremely heavy, respectively.

4.1.5 Ergonomic aspects in grass cutting and paddy harvesting operation

4.1.5.1 Work posture

The farmers' working posture during grass cutting and paddy harvesting affects the worker's efficiency and operation capacity. The working posture in grass cutting and paddy harvesting operation with shoulder mounted brush cutter was standing. Farmers were asked about the work posture during grass cutting and paddy harvesting. As per Appendix I (F), out of 30 farmers, 20 per cent farmers reported 'Yes' to the question of grass cutting and paddy harvesting allowed a relaxed work posture and the rest of 80 per cent of farmers were reported 'No.' The bar graph showing the farmer's rating about work posture is given in Fig. 4.8.

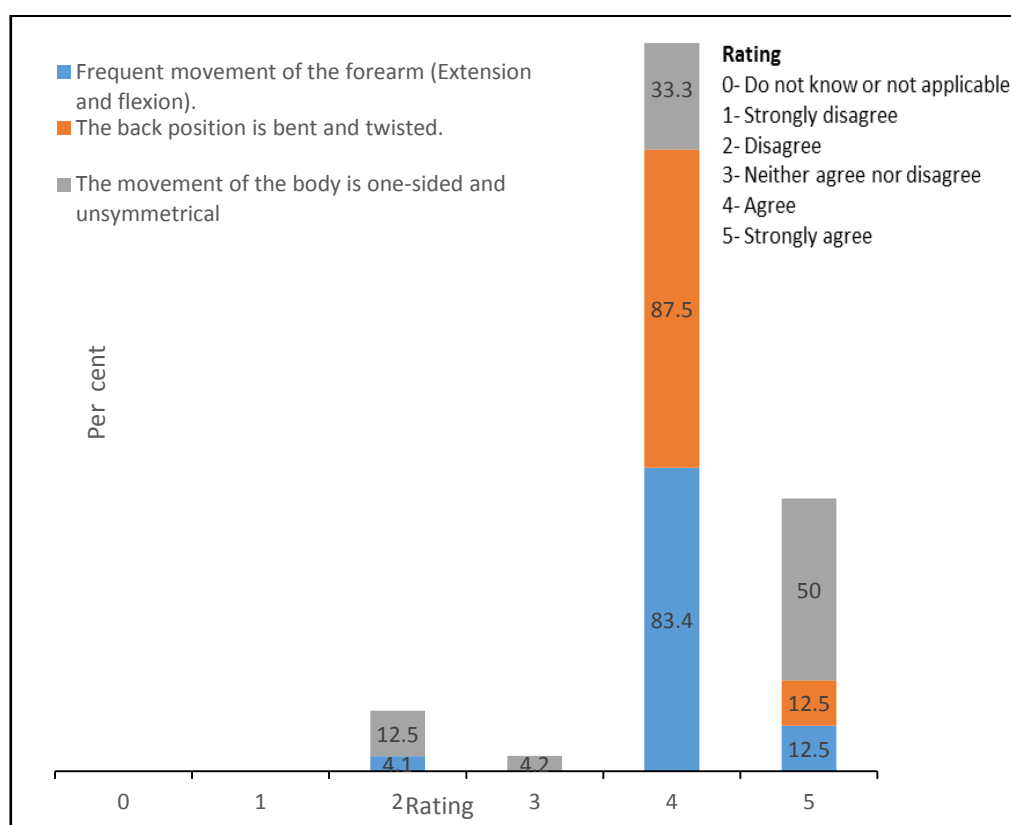


Fig. 4.8 Farmers rating about work posture

Out of 80 percent farmers, 12.5 per cent of farmers strongly agreed, 83.4 per cent agreed and 4.1 per cent disagreed with the forearm's frequent movement (Extension and flexion). 12.5 per cent of farmers strongly agreed and 87.5 per cent of farmers agreed to the back position was bent and twisted. Out of 80 per cent farmers, 50 per cent of farmers strongly agreed, 33.3 per cent farmer agreed, 4.2 per cent

farmers were neither agreed nor disagree and 12.5 per cent farmers disagreed with the body's movement one sided and unsymmetrical.

The farmers were informed to report their opinion about the reasons for forced posture. The bar graph for reasons for forced posture is given in Fig 4.9. Out of 30 farmers, 31.6 per cent reported that the forced posture was due to engine weight, 19.3 per cent reported that it was due to high density of grass, 21 per cent reported that it was due to the high weight of the machine, 18.2 per cent reported that due to length of the shaft and 9.8 per cent reported that due to improper belt (Harness) adjustment.

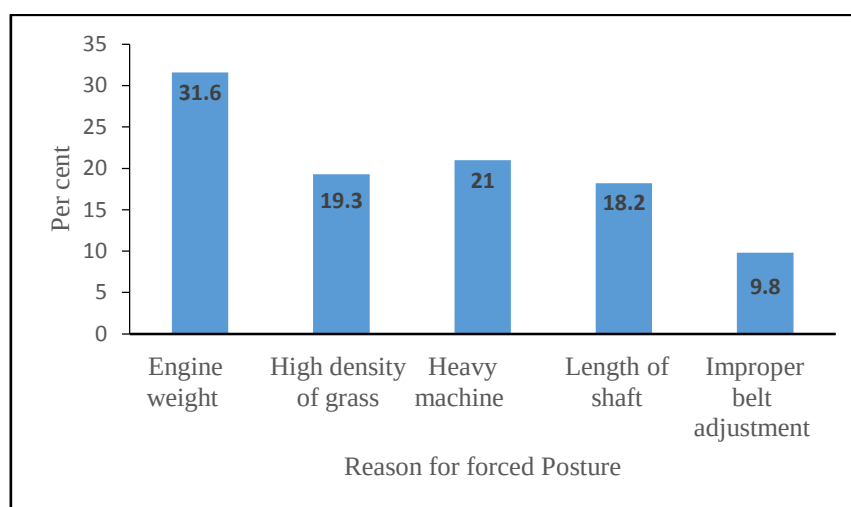


Fig. 4.9 Farmers response about reasons for forced posture

The farmers were also informed to report about the suitability of the location of the cutting blade. Out of 30 farmers, 81.7 per cent farmers reported that the cutting blade of shoulder mounted grass brush cutter was suitable. The rest of 18.3 per cent of farmers were reported that the location of the cutting blade of shoulder mounted brush cutter was unsuitable.

4.1.5.2 Noise

During the survey the question was asked about the ergonomic suitability for the noise emitted by the shoulder mounted brush cutter to the operator. As per Appendix I (F), out of 30 farmers, 56.6 per cent farmers reported 'Yes' to the question of whether the noise level during the operation with shoulder mounted brush cutter was below the normally bearable sound level and rest of 43.3 per cent farmers were reported 'No.'

4.1.5.3 Vibration

The vibrations transferred from the machine to the operator in shoulder mounted brush cutter operation affect the operator's health and efficiency. During the

survey, farmers were asked whether they felt vibrations transmitting from the machine to their body and also asked identify the sources of vibration.

As per Appendix I (F), out of 30 farmers, 86.7 per cent farmers were reported 'Yes' to the question, that they felt vibration transmitting from the machine to their body and the rest of 13.3 per cent farmers reported 'No'. The bar graph showing the farmer's rating about the machine's vibration is given in Fig. 4.10

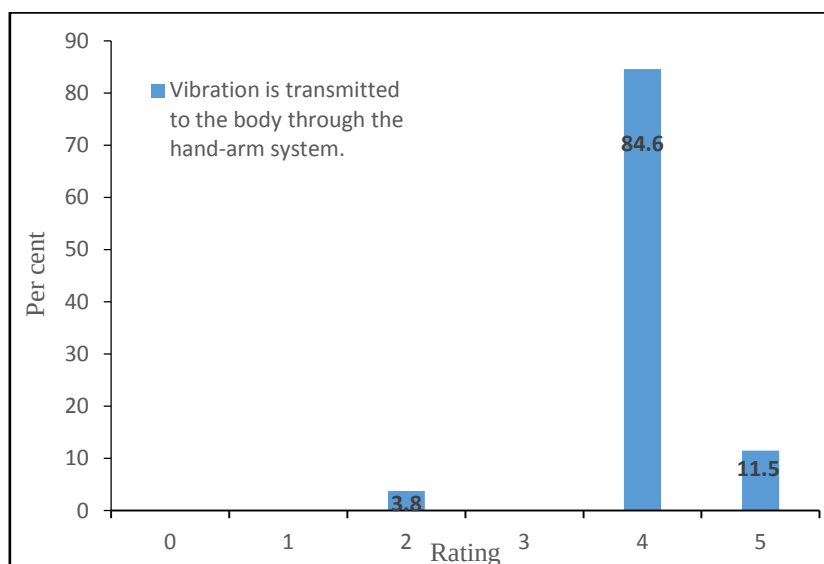


Fig. 4.10 Farmers rating about vibration

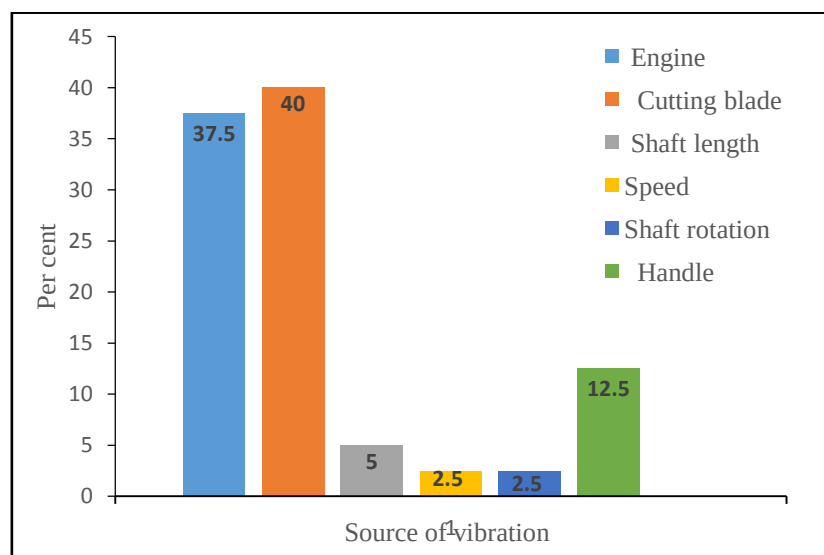


Fig. 4.11 Farmers response about source of vibration

Out of 13.3 per cent farmers, 11.5 per cent of farmers strongly agreed, 84.6 per cent farmers agreed and 3.8 per cent farmers disagreed that vibration was transmitted to the body through the hand-arm system

During the survey, the farmers were informed to report the source of the vibration from the machine. The bar graph about the source of vibration was plotted as shown in Fig 4.11. Out of 30 farmers, 37.2 per cent farmers reported that the vibration was due to the engine. Forty per cent of farmers were reported that the vibration was due to cutting blade, 5 per cent reported that the source of vibration was due to shaft length, 2.5 per cent reported that the source of vibration was due to the rotation of shaft and the rest of 12.5 per cent reported that the vibration was due to the handle.

4.1.5.4 Controls

During the survey, the suitability of control location was also studied. As per Appendix I (F), out of 30 farmers, 63.3 per cent of farmers were reported 'Yes' to the question of control location (e.g., switches, knobs etc.) were easy to handle and the rest of 36.7 per cent farmers said 'No'. The bar graph showing the rating of farmers about control is given in Fig. 4.12.

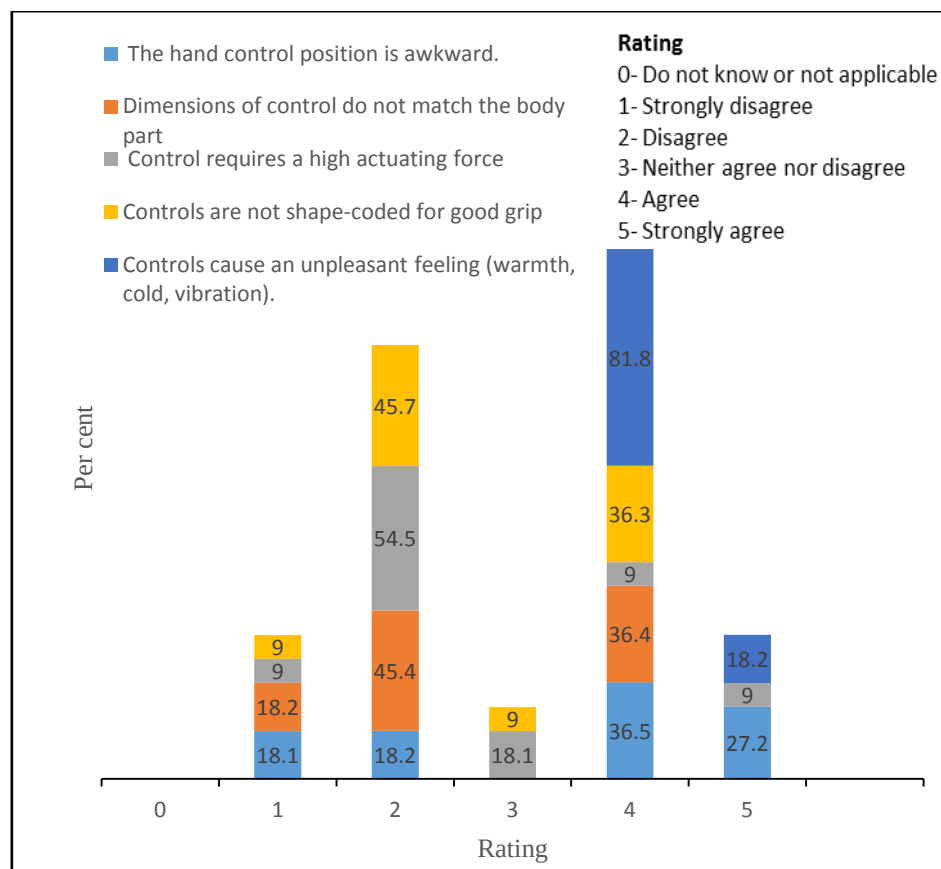


Fig. 4.12 Farmers rating about controls

Out of 36.7 per cent of 30 farmers 27.2 per cent of farmers strongly agreed, 36.5 per cent agreed, 18.2 per cent disagreed and 18.1 per cent of farmers were firmly

disagreed that the hand control position was awkward. The 36.4 per cent farmers agreed, 45.4 per cent disagreed and 18.2 per cent strongly disagreed that the dimensions of control did not match the body part. 9 per cent farmers strongly agreed and agreed, 18.1 per cent neither agreed nor disagreed, 54.5 per cent disagreed and 9 per cent strongly disagreed that the controls required a high actuating force. The 36.3 per cent farmers agreed, 9 per cent neither agreed nor disagreed, 45.7 per cent disagreed and 9 per cent strongly disagreed that the controls were not shape-coded for good grip. Out of 36.7 per cent of farmers, 18.2 per cent strongly agreed and 81.8 per cent agreed to the controls caused an unpleasant feeling (warmth, cold, vibration etc.).

4.1.6 Technical aspects in grass cutting and paddy harvesting operation

4.1.6.1 Machinery

The summarized data about technical aspects in shoulder mounted brush cutter is given in Appendix I (F). Out of 30 farmers, 33.3 per cent farmers were reported 'Yes' to the question of shoulder mounted brush cutter was easy to drive and work and the rest of 66.7 per cent farmers reported 'No'. The bar graph shows the farmers rating about the machine is given in Fig. 4.13.

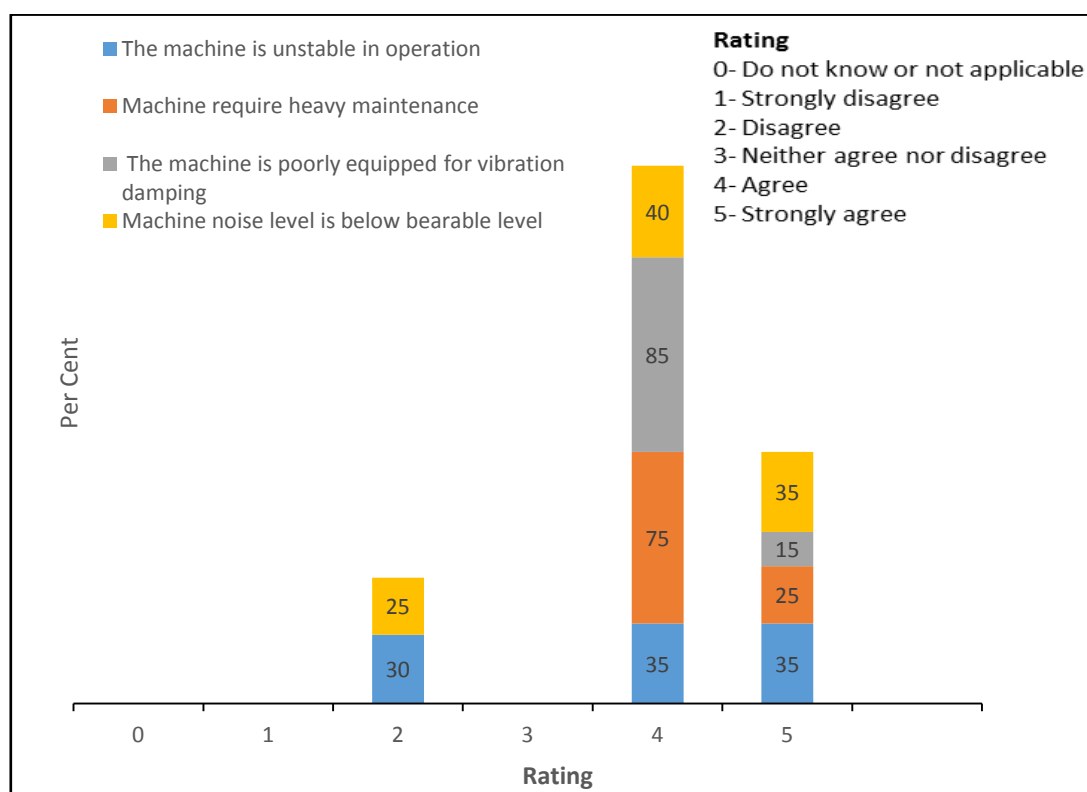


Fig. 4.13 Farmers rating about machine

Out of 66.7 per cent farmers, 35 per cent strongly agreed, 35 per cent agreed and 30 per cent were disagreed to the machine was unstable in operation. Twenty-five

per cent of farmers were strongly agreed and 75 per cent were agreed to the machine require heavy maintenance. Fifteen per cent of farmers were strongly agreed and 85 per cent agreed that the machine was poorly equipped for vibration damping. Similarly, 35 per cent of farmers were strongly agreed, 40 per cent were agreed and 25 per cent were disagreed to the machine noise level was below the bearable level.

4.1.7 Work safety in grass cutting and paddy harvesting operation

The summarized data about work safety in grass cutting and paddy harvesting operation is given in Appendix I (F). Out of 30 farmers, 53.3 per cent farmers reported 'Yes' to the question of whereas the machine safety measures were adequate to prevent accidents and health hazards and the rest of 46.7 per cent farmer reported 'No'. The bar graph shows the farmers' rating about work safety in grass cutting and paddy harvesting operation in Fig. 4.14.

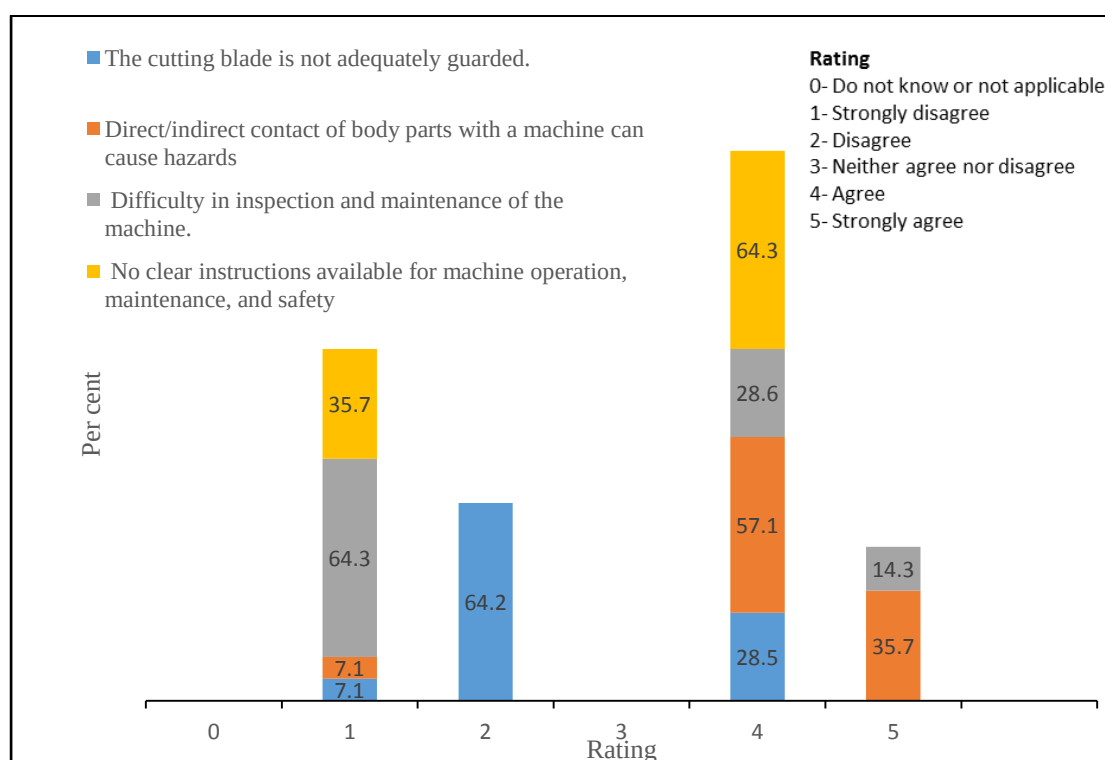


Fig. 4.14 Farmers rating about work safety in grass cutting and paddy harvesting operation

Out of 46.7 per cent farmers, 28.5 per cent of farmers were agreed, 64.2 per cent disagreed and 7.1 per cent strongly disagreed that the cutting blade was not adequately guarded. 35.7 per cent of farmers were strongly agreed, 57.1 per cent of farmers were agreed and 7.1 per cent farmers were strongly disagreed that the direct/indirect contact of body parts with a machine could be hazardous. 14.3 per cent of farmers were strongly agreed, 28.6 per cent agreed and 64.3 per cent strongly

disagreed that the inspection and maintenance of the machine was difficult. Similarly, 64.3 per cent of farmers agreed and 35.7 per cent of farmers strongly disagreed that there were no clear instructions for machine operation, maintenance and safety.

4.1.8 Findings of the survey

1. A total of nineteen places in Ratnagiri district were visited to survey health hazards and drudgery in operation with shoulder mounted brush cutter. The response of total of 30 farmers was collected. All of them were well accustomed with use of shoulder mounted brush cutter.
2. Out of 30 farmers, 75.6 per cent farmers were land holders. Out of 75.6 per cent farmers, 53.3 per cent farmers were marginal farmers and 13.3 per cent, 10 per cent and 3 per cent were with small, semi-medium and large landholdings. Of them, 52.2 per cent of farmers had cultivated paddy on their land and most of them transplanted paddy at the end of July.
3. The average age, weight, and height of the farmers were 34.23 (± 9.91) years, 61.66 (± 9.64) kg, and 164.76 (± 8.86) cm, respectively. Among all of the farmers, 66.7 per cent of farmers were married and 53.3 per cent of farmers had experience ≥ 5 years.
4. The grass cutting and paddy harvesting operation carried out in a standing posture. Eighty per cent of farmers had health complaints and 43.3 per cent of farmers had frequent leg injury with the shoulder mounted brush cutter.
5. It was observed that 73.3 per cent of farmers had a work output ≥ 0.0213 ha/h for grass cutting 76.7 per cent of farmers had a work output ≥ 0.0163 ha/h for paddy harvesting.
6. In work and workplace-related occupational hazard, 77 per cent of farmers were suffered from body ache and headache, 57 per cent of farmers were suffered from a frequent leg injury and 10 per cent of farmers were suffered from frequent hand injuries.
7. Considering posture-related occupational hazard, 13.3 per cent, 33.3 per cent, 16.6 per cent, 26.6 per cent, 97 per cent, 70 per cent, 63.3 per cent, 46.7 per cent, 16.6 per cent, 70 per cent, 83.3 per cent, 20 per cent and 33.3 per cent farmers were suffered from pain in one or both hips, one or both thighs, one or both feet, knee, shoulder, lower arm, upper arm, wrist, elbow, upper back, lower back, neck and waist, respectively.

8. Out of 30 farmers, 80 per cent farmers were used two-stroke petrol engine as a prime mover for shoulder mounted brush cutter. The power of shoulder mounted brush cutter of 63.3 per cent of farmers was > 1.8 hp.
9. The requirement as job specialization, skill requirement, general physical activity, ergonomic aspects related to work posture, noise, vibration, controls, etc., in operation with shoulder mounted brush cutter were studied. The technical aspects and work safety were also studied.
10. Accordingly, in requirement of job specialization, out of 60 per cent farmers, 27.7 per cent of farmers strongly agreed and 72.3 per cent of farmers were agreed to the grass cutting and paddy harvesting operation was predominantly dynamic work. 33.3 per cent of farmers strongly agreed, 55.6 per cent of farmers agreed to the point that worker had to perform multiple tasks. 83.4 per cent of farmers agreed and 5.5 per cent of farmers were strongly agreed to the position adopted for grass cutting and paddy harvesting was not comfortable. 66.7 per cent and 16.7 per cent of farmers agreed and strongly agreed, respectively to the tools and methods used were specialized for the grass cutting and paddy harvesting operation.
11. Out of 30 per cent farmers, 55.5 per cent farmers strongly agreed, 11.1 per cent agreed and 33.3 per cent farmers disagreed with the operator doing frequent mistakes during operation. 11.1 per cent farmers strongly agreed, 77.8 per cent agreed and 11.1 per cent disagreed with the grass cutting and paddy harvesting demand training for skill acquisition. 33.3 per cent farmers were strongly agreed, 55.5 per cent agreed and 11.1 per cent neither agreed nor disagreed to grass cutting and paddy harvesting require knowledge and skillful ability.
12. The physical activity of the operator during grass cutting and paddy harvesting were studied. Out of 33.3 per cent farmers, 25 per cent of farmers were strongly agreed and 75 per cent agreed to the cardiorespiratory demand of the job in shoulder mounted brush cutter and 33.3 per cent, 36.7 per cent and 20 per cent farmers reported that the cardiorespiratory demand of the job was extremely heavy, heavy and moderate, respectively. 50 per cent of farmers disagreed and 15 per cent of farmers were strongly disagreed to the operation of the handle was predominantly static work. 25 per cent of farmers strongly agreed and 75 per cent agreed to the cutting and harvesting operation demand

high muscular strength exertion. 25 per cent of farmers strongly agreed and 70 per cent agreed that operators maintained a target-oriented pace.

13. During the survey, the ergonomic aspects of grass cutting and paddy harvesting operations were studied. An aspect related to work posture, out of 80 per cent farmers, 50 per cent of farmers were strongly agreed, 33.3 per cent agreed and 12.5 per cent disagreed to the movement of the body was one-sided and unsymmetrical. It was found that 87.5 per cent farmers agreed and 12.5 per cent strongly agree that the position of the back was bent and twisted. 12.5 per cent farmers strongly agreed, 83.4 per cent agreed and 4.1 per cent disagreed that the frequent movement of the forearm (Extension and flexion).
14. Out of 80 per cent farmers, 31.6 per cent of farmers were reported that the reason for forced posture was engine weight. Similarly, 19.3 per cent, 21 per cent, 18.2 per cent and 9.8 per cent reported that the reasons for forced posture were the high density of grass, machine weight, length of the shaft and improper belt adjustment, respectively. 81.7 per cent of farmers were reported that the location of a cutting blade was suitable and the rest of 18.3 per cent reported that it was unsuitable.
15. The acceptability of noise was also studied during the survey. Out of 30 farmers, 56.6 per cent farmers were reported 'Yes' to the noise level during the operation was within the bearable limit and rest of 43.3 per cent farmers reported 'No'.
16. Out of 13.3 per cent of farmers 84.6 per cent farmers were agreed to that the vibration was transmitted to the body through the hand-arm system and 37.5 per cent reported that the source of vibration was the engine. Similarly, 40 per cent, 5 per cent, 2.5 per cent, 2.5 per cent and 12.5 per cent reported that the source of vibration was cutting blade, shaft length, speed, shaft rotation and handle, respectively.
17. The position of the control and handling of control were also studied during the survey. Out of 36.7 per cent, farmers 18.2 per cent farmers strongly agreed and 81.8 per cent were agreed that the controls caused an unpleasant feeling (warmth, cold, vibration). 36.3 per cent of farmers agreed and 45.7 per cent disagreed to the controls were not shape coded for good grip. 54.5 per cent farmers were disagreed and 18.1 per cent were neither agreed nor disagreed to that the control required a high actuating force. 36.4 per cent

farmers were agree, 45.4 per cent disagreed and 18.2 per cent strongly disagreed that the dimensions of control did not match the user reaches. 27.2 per cent farmers were strongly agreed, 36.5 per cent, 18.2 per cent and 18.1 per cent, agreed, disagreed and strongly disagreed, respectively that the hand control position was awkward.

18. The technical aspects in grass cutting and paddy harvesting operation with shoulder mounted brush cutter was studied during the survey. Out of 66.7 per cent farmers 25 per cent of farmers strongly agreed and 75 per cent farmers were agreed that the machine require heavy maintenance. The 35 per cent, 35 per cent and 30 per cent of farmers, respectively were strongly agreed, agreed and disagreed about the machine was unstable in operation.
19. The work safety in grass cutting and paddy harvesting operation was studied. Out of 46.7 per cent of 30 farmers, 64.3 per cent farmers were agreed and 35.7 per cent strongly disagreed to that the question of no clear instructions available for machine operation, maintenance and safety. 64.3 per cent farmers were strongly disagreed, 28.6 per cent agreed and 14.3 per cent strongly agreed that the maintenance and inspection of the machine was difficult. 64.2 per cent of farmers disagreed, 28.5 per cent agreed and 7.1 per cent were strongly disagreed that the cutting blade was not adequately guarded. Out of 46.7 per cent farmers 35.7 per cent farmers were strongly agreed, 57.1 per cent agreed and 7.1 per cent strongly disagreed with the direct or indirect contact of body part with a machine could cause hazards.

4.2 Assessment of Physiological Cost and Drudgery Involved in Shoulder Mounted Brush Cutter (SMBC)

The drudgery involved in shoulder mounted brush cutter (SMBC) was quantified and the results are discussed in the following sections.

4.2.1 Selection of subject

A total six male subjects were selected for the experiment. The average age, weight and stature of the subjects were 37.67 ($\pm$ 8.48), 55.67 ($\pm$ 8.43) and 165.17 ($\pm$ 7.19), respectively. The details of the male subject are given in Appendix III (A). The mean values of subject information are shown in Table 4.2.

4.2.2 Calibration of subject

The calibration of four male subjects was conducted in the Ergonomics Laboratory of CAET, Dr. B.S.K.K.V. Dapoli. The heart rate (HR) and corresponding

values of oxygen consumption rates (OCR) of the subjects were measured by using energy measurement system (K4b₂) the subjects were loaded using computerised bicycle ergometer (Sweden Monark 839E) at sub maximal load. The relationship between the heart rate (HR) and oxygen consumption rate (OCR) was developed as explained in section 3.3.4. The VO₂ max at HR max were determined from the calibration equation for the four subjects. The VO₂ max of remaining two subjects were calculated by indirect method as explained at section 3.3.4.1. The values of heart rate (HR) obtained from calibration process of subjects as given in Appendix IV (A) and the heart rate response are given in Appendix IV (B). The calibration chart of subject is given in Fig 4.15.

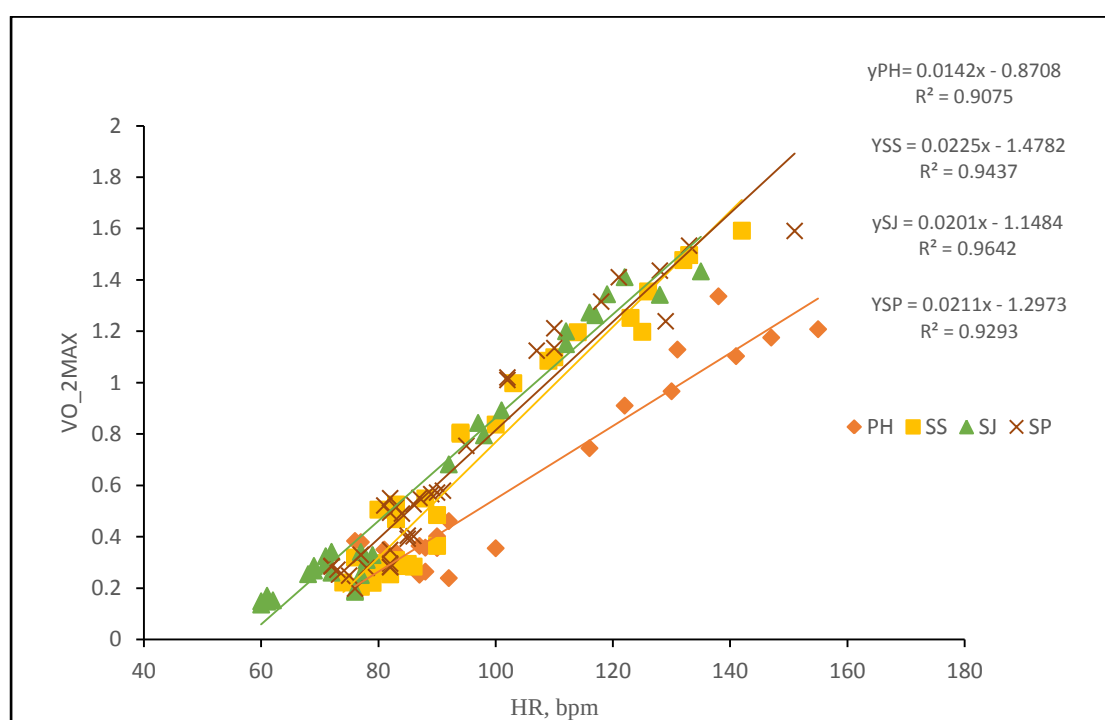


Fig 4.15 Calibration chart of subject

4.2.3 Maximum aerobic capacity (VO₂ max)

The maximum heart rate (HR max) of the selected subject was calculated by using equation 3.1. The maximum aerobic capacity (VO₂ max) was predicted as explained in Chapter III, section 3.3.4.1 and as explained above. It was the maximum oxygen uptake at maximum heart rate. The details about maximum heart rate (HR max) and maximum aerobic capacities (VO₂ max) are given at Table 4.2. The maximum heart rate (HR max) was found in the range of 169 to 193 bpm and the corresponding maximum aerobic capacity (VO₂ max) was found in the range of 1.92 to 2.99 l/min for selected subjects. The mean of maximum heart rate (HR max) and

maximum aerobic capacity (VO_2 max) for the selected subject were 182.3 (± 8.48) bpm and 2.39 (± 0.35) l/min, respectively. The details of subject are furnished in Table 4.2.

Table 4.2 Details of subjects

Sr. No	Subject Code	Age (Year)	Weight (kg)	Stature (cm)	Maximum Heart Rate (HR_{max}), bpm	Maximum Aerobic Capacity (VO_2 max), l/min
1	SS	39	53	160	181	1.92
2	PH	27	47	165	193	2.99
3	SJ	51	53	159	169	2.39
4	SP	39	70	174	181	2.36
5	HP	40	61	159	180	2.23
6	MP	30	50	174	190	2.42
Average		37.67	55.67	165.17	182.3	2.39
SD		± 8.48	± 8.43	± 7.19	± 8.48	± 0.35

4.2.4 Working heart rate (WHR), oxygen consumption rate (OCR) and energy expenditure rate (EER) with shoulder mounted brush cutter (SMBC)

The heart rate (HR) of the selected subjects were measured with polar heart rate monitor (model - FT7) while operating SMBC as explained in Chapter III, section 3.3.5.1. The field trial and ergonomic evaluation of SMBC was carried out at Department of Agronomy, Dr. B. S. K. K. V. Dapoli, in 2019-2020 for paddy harvesting operation and that of for the grass cutting operation was carried out at Department of Horticulture, Dr. B. S. K. K. V. Dapoli, in 2020-2021. The resting heart rate was the averaged first 10 minute HR data. The average values of HR from 11th to 20th minute for each subject was considered as WHR. The subject wise value of WHR, OCR, EER, work pluse (ΔHR) for selected subject during paddy harvesting and grass cutting operations with SMBC are given in Table 4.3 and Table 4.4, respectively. The energy grade of work for subjects was decided from working heart rate of the subjects during paddy harvesting and grass cutting operations (Sen, 1969).

Table 4.3 The physiological parameters as WHR, OCR, EER, Δ HR etc. for subjects during paddy harvesting with SMBC

Sr. No	Subject Code	Resting HR, (bpm)	Working HR, (bpm)	ΔHR, bpm	LCP, 40 beats/min	Working OCR, l/min	Per cent ofVO₂ max	AWL (35% VO₂max)	EER kJ/min	Energy grade of work
1	SS	72	110	38	(<LCP)	1.00	52.1	(>AWL)	20.81	Moderately heavy
2	PH	79	115	36	(<LCP)	0.76	25.42	(<AWL)	15.91	Moderately heavy
3	SJ	70	121	51	(>LCP)	1.28	53.56	(>AWL)	26.80	Moderately heavy
4	SP	101	135	34	(<LCP)	1.55	65.68	(>AWL)	32.39	Heavy
5	HP	79	131	52	(>LCP)	1.27	56.95	(>AWL)	26.58	Heavy
6	MP	81	119	38	(<LCP)	1.04	42.98	(>AWL)	21.69	Moderately heavy
Mean.		80.33	121.83	41.5	(>LCP)	1.15	49.45	(>AWL)	24.03	Moderately heavy
Std.		±11.02	±9.52	±7.89		±0.28	± 13.88		±5.76	

From Table 4.3 it was observed that, the value of WHR for selected subjects was ranged from 110 bpm to 135 bpm with mean value of 121.83 (± 9.52). The corresponding oxygen consumption rate (OCR) of the subjects were predicted by using calibration charts for four subject and OCR values of two subject were calculated as explained at section 3.3.4.1 and 4.2.2. The value of OCR was in the range of 0.76 l/min to 1.55 l/min, with mean 1.15 (± 0.28) l/min. The energy expenditure rate (EER) of subjects was calculated from the equation explained at section 3.3.5.3. The Δ HR also known as work pluse was calculated from the difference between working heart rate (WHR) and resting heart rate (RHR). The RHR was taken as first 10- minute average HR for each individual subject. From Table 4.3, Δ HR was in the range of 34 bpm to 52 bpm, with mean 41.5 (± 7.89) which was greater than the limit of continuous performance of 40 beats/min. The EER of subjects was in the range of 15.91 kJ/min to 32.39 kJ/min, with mean value of 24.03 (± 5.76) kJ/min. The overall energy grade of work for paddy harvesting with SMBC was “Moderately heavy”. Percent of VO_2 max of the subjects during paddy harvesting with SMBC was in the range of 25.42 % to 65.68 % with mean of 49.45 (± 13.88) %.

From Table 4.4 it was observed that, the value of WHR for selected subjects was in the range of 89 bpm to 114 bpm with mean value of 101.17 (± 8.66) bpm. The value of OCR was in the range of 0.64 l/min to 1.53 l/min, with mean 0.86 (± 0.34) l/min. The work pluse (Δ HR) of the subjects during grass cutting operation with shoulder mounted brush cutter was in the range of 6 bpm to 32 bpm with mean value of 17.67 (± 9.77) bpm. The energy expenditure rate of subjects was in the range of 13.37 kJ/min to 31.98 kJ/min with mean value of 17.96 (± 7.04). The overall energy grade of work for grass cutting with SMBC was “Moderately heavy”. The per cent of VO_2 max of subjects was varied from 26.78 % to 51.83 % with mean 35.35 (± 8.34) % for grass cutting operation.

4.2.5 Overall discomfort rating (ODR) and body parts discomfort score (BPDS) for SMBC

The overall discomfort rating (ODR) and body part discomfort score (BPDS) of the subjects during paddy harvesting and grass cutting operations with SMBC was taken as explained in section 3.3.5.6.1 and 3.3.5.6.2, respectively. The value of ODR and BPDS of subjects during paddy harvesting and grass cutting operations with SMBC are presented at Appendix IV (C) and Appendix IV (D), respectively. The details about

Table 4.4 The physiological parameters as WHR, OCR, EER, Δ HR etc. for subjects during grass cutting operation with SMBC

Sr. No	Subject Code	Resting HR, (bpm)	Working HR, (bpm)	Δ HR, bpm	LCP, 40 beats/min	Working OCR, l/min	Per cent of VO ₂ max	AWL (35% VO ₂ max)	EER kJ/min	Energy grade of work
1	SS	80	96	16	(<LCP)	0.68	35.41	(>AWL)	14.24	Light
2	PH	82	114	32	(<LCP)	1.53	51.17	(>AWL)	31.98	Moderately heavy
3	SJ	83	89	6	(<LCP)	0.64	26.78	(<AWL)	13.37	Light
4	SP	77	100	23	(<LCP)	0.81	34.32	(<AWL)	16.97	Light
5	HP	93	101	8	(<LCP)	0.69	30.94	(<AWL)	14.37	Moderately heavy
6	MP	86	107	21	(<LCP)	0.81	33.47	(<AWL)	16.81	Moderately heavy
Mean.		83.5	101.17	17.67	(<LCP)	0.86	35.35	(>AWL)	17.96	Moderately heavy
Std.		± 5.54	±8.66	±9.77		± 0.34	± 8.34		± 7.02	

mean ODR, mean BPDS and body parts found discomfort in paddy harvesting and grass cutting operation are given in Table 4.5.

Table 4.5 The details about mean ODR and BPDS for subjects during paddy harvesting operation with SMBC

Sr. No	Particulars	Values
Paddy harvesting		
1	Body parts found discomfort	Right arm, left thigh, lower back, left shoulder, right shoulder, right forearm, right wrist, left forearm, right thigh, right elbow.
2	Range of ODR	5 to 7
3	Mean ODR	6.167
4	Range of BPDS	20 to 42.75
5	Mean BPDS	28.79
Grass cutting		
1	Body parts found discomfort	Right shoulder, right elbow, right forearm, right leg, lower back, left shoulder, right arm
2	Range of ODR	4 to 5
3	Mean ODR	4.8
4	Range of BPDS	15.75 to 19.25
5	Mean BPDS	17.21

The overall discomfort rating (ODR) of subjects was in the range of 5 to 7 with mean value 6.167 in paddy harvesting operation and for grass cutting it was in the range of 4 to 5 with mean value of 4.8. The mean ODR was scaled as ‘more than moderate discomfort’ for paddy harvesting as well as grass cutting operations with SMBC.

The body part viz. right arm, right shoulder and right forearm were in sever discomfort, while left thigh, left forearm, lower back, left shoulder and right wrist were in moderate discomfort and right thigh, right elbow were in light discomfort in paddy harvesting operation. Whereas, right shoulder, left shoulder and right forearm were in sever discomfort and right elbow, right arm, right leg, lower back had moderate discomfort in grass cutting operation with SMBC. The BPDS was in the range of 20 to 42.75 with mean 28.79 for paddy harvesting and 15.75 to 19.25 with mean 17.21 for grass cutting operations.

4.2.6 Work rest cycle

As per the Table 4.3 the mean energy expenditure rate (EER) was 24.03 kJ/min (5.74 kcal/min) in paddy harvesting operation. The rest pauses for 60 min work was calculated by using equation 3.3, which was $32.2 \approx 32$ min. Hence 60 min work with 32 min rest would be suitable work rest cycle in paddy harvesting operation with SMBC. Similarly, from Table 4.4 the mean of EER was 17.96kJ/min (4.29 kcal/min) during grass cutting operation. Therefore, for 60 min work with $6.2 \approx 6$ min rest will be suitable work rest cycle for grass cutting operation.

4.2.7 Field capacity and field efficiency of SMBC

The field capacity and field efficiency SMBC for paddy harvesting and grass cutting operation was calculated as explained in section 3.5.2 and 3.5.3, respectively and given in Appendix IV (E).

The field capacity for paddy harvesting with SMBC was in the range of 0.001 to 0.014 ha/h with mean 0.009 ha/h whereas for grass cutting it was in the range of 0.018 ha/h to 0.035 ha/h with mean 0.028 ha/h. The field efficiency for paddy harvesting operation in SMBC was in the range of 23.3 % to 40.25 % with mean 26.46 %. Similarly, in grass cutting operation the field efficiency was in the range of 49.35 % to 97.5 % with mean 78 % with SMBC.

4.3 Ergonomic and Mechanical Design Consideration of Grass Cutter Cum Paddy Harvester (GCCPH) Prototype

The ergonomic and mechanical design considerations in grass cutter cum paddy harvester prototype are explained in the following section.

4.3.1 Ergonomic design considerations of grass cutter cum paddy harvester prototype

The grass cutter cum paddy harvester prototype was designed by considering the anthropometric and strength parameters of male workers in Konkan region of Maharashtra as explained in section 3.6.1. The details of the anthropometric design considerations are given in Table 4.6.

Handle height was considered based on acromial height which was 1011.5 mm. As the handle was attached at 178 mm above the ground level. Therefore, in order to determine handle length, 178 mm should be deducted from considered handle height.

$$\begin{aligned}\text{Actual handle height} &= \text{Handle height} - \text{location above the ground} \\ 1011.5 - 178 &= 833.5 \text{ mm},\end{aligned}$$

Hence, as per Table 4.6,

The actual handle length was calculated by,

$$\frac{833.5}{\sin 45^\circ} \text{ to } \frac{833.5}{\sin 30^\circ}$$

1179 mm to 1667 mm

Therefore,

The length of the handle was in the range of 1179 to 1667 mm.

Table 4.6 Ergonomic design considerations of developed grass cutter cum paddy harvester prototype

Sr. No	Design Considerations	Anthropometric considerations	Dimensions (mm)
1.	Height of handle	Acromial height: 0.8 of the 5 th percentile and 0.7 of the 95 th percentile acromial height (1245 mm and 1445 mm, respectively)	Range: 996 mm to 1011.5 mm Considered value: 1011.5 mm
2.	Length of handle	Angle of operation 30 ° to 45 °.	Range: 1179 mm to 1667 mm Considered value: 1200 mm
3.	Shape of grip		Cylindrical
4.	Size of grip	5 th percentile inside grip diameter to 95 th percentile middle finger palm grip diameter	Range: 34 mm to 39 mm. Considered value : 31 mm
5.	Length of grip	95 th percentile of hand breadth across thumb	105 mm

Hence, handle height and length were 1011.5 mm and 1200 mm, respectively.

The handle grip was cylindrical with its diameter and length as 31 mm and 105 mm, respectively.

4.3.2 Mechanical design considerations in development of GCCPH prototype

The mechanical consideration in development of grass cutter cum paddy harvester prototype are explained in section 3.6.4. The detailed mechanical considerations are given in Table 4.7.

Table 4.7 Mechanical design considerations in grass cutter cum paddy harvester prototype

Sr. No	Particulars	Specifications
1	Mass moment inertia of cutting blade (M.I), kgm^2	5.113×10^{-3}
2	Angular velocity of cutting blade (ω), rad/s	291.66
3	Idling power (P_k), kw/m	1.35
4	Cutting width of blade (W_c), m	0.16
5	Maximum cutting force ($F_{\max}$), N	24.6
6	Cutting energy (E_0), J	0.06014
7	Specific Cutting energy (E_{sc}), kJ/m^2	3.204
8	Total power requirement (P_t), hp	1.95
9	Torque acting on a shaft (T), N-mm	1569
10	Equivalent torque on shaft (T_e), N-mm	3138
11	Diameter of shaft (d), mm	8

4.3.2.1 Moisture content and stem diameter of paddy

The physical properties of paddy viz. moisture content and stem diameter was determined as explained at section 3.6.3.1 and 3.6.3.2, respectively. The details of physical properties of paddy is given in Table 4.8.

Table 4.8 Moisture content and stem diameter of paddy

Sr. No	Particulars	Values
1	Mass of the dish with the material before drying, gm (W_1)	55.61
	Mass of the dish with the dried material, gm (W_2)	44.51
	Moisture content, WB (%)	19.96
2	Diameter of stem, mm	4.89

4.3.2.2 Prime mover

The power requirement for grass cutting and paddy harvesting operation was calculated as explained in section 3.6.4.1. A two stroke petrol engine of 1.95 hp at speed of 6500 to 7500 rpm was procured from market.

4.3.2.3 Transmission shaft

The transmission shaft of the grass cutter cum paddy harvester prototype was designed as explained in section 3.6.4.2. Transmission shaft of 8 mm diameter and 530 mm length with 9 splines on both ends was procured from market.

4.3.2.4 Cutting blade

The detailed design procedure of cutting blade was explained in section 3.6.4.3.1. The cutting blade of 250 mm diameter, 80 number of teeth, 380 gm in weight and 2 mm in thickness was selected for paddy harvesting. A nylon line cutter head or grass trimmer made of plastic material was selected for grass cutting operation.

4.3.2.5 Functional components of GCCPH prototype

The material of construction and specifications of the machine component was given in following sections.

4.3.3.5.1 Axel and transport wheels

The axel was fabricated from a M. S. rod of 25 mm diameter. The length of the axel was 650 mm. The plastic rim rubber tyre of diameter 350 mm was purchased from the market.

4.3.3.5.2 Engine mounting frame

The frame was fabricated using G. I. square pipe and M. S flat plate of size $25 \times 25 \times 3$ mm thickness and $170 \times 115 \times 3$ mm thickness, respectively. The width of the frame was 172 mm and the length was 345 mm. Hallow pipe of diameter 27 mm and length 126 mm with thickness 4 mm was fixed to engine mounting frame at bottom. That pipe was inserted on the another hallow pipe of size 22 mm diameter, length 154 mm and 3 mm thickness which was fixed at the middle of axle.

4.3.3.5.3 Handle

The handle was fabricated by using G.I square pipe of $30 \text{ mm} \times 30 \text{ mm} \times 3$ mm thickness and G.I round pipe having diameter of 34 mm and thickness 3 mm. The length of the handle was 1200 mm.

The detailed specifications of material of GCCPH prototype are given at Table 4.9.

Table 4.9 Detailed specifications of material of grass cutter cum paddy harvester prototype

Sr. No	Component	Specifications
1	Engine	2-stroke petrol engine, 1.95 hp and 6500-7500 rpm
2	Transmission shaft	530 mm, 9 splines and 8 mm ϕ
3	Wheels	Plastic rim, rubber tyre and 350 mm ϕ
4	Cutter blade	250 mm ϕ , 2 mm thickness, 80 teeth
5	Handle	G.I. square pipe 30 $\times$ 30 $\times$ 3 mm thickness mm G.I round pipe 34 mm ϕ , 3 mm thickness
6	Engine mounting frame	G.I. square pipe 25 $\times$ 25 $\times$ 3 mm, thickness M.S. flat plate 170 $\times$ 115 $\times$ 3 mm
7	Axel	M.S. rod 25mm ϕ
8	Hallow pipe of engine mounting frame	G. I. pipe 27 mm ϕ , 126 mm length and 3 mm thickness G.I pipe 22 mm ϕ , 154 mm length and 3 mm thickness

4.4 Ergonomic Evaluation and Field Performance of GCCPH Prototype

The ergonomic evaluation and field performance of developed grass cutter cum paddy harvester prototype was conducted as explained in section 3.4 and 3.5. The field experiment of paddy harvesting was conducted in Agronomy Department of Dr. B. S. K. K. V. Dapoli in and field experiment of grass cutting was conducted at Dept. of Horticulture Dr. B. S. K. K. V. Dapoli in 2020-2021.

4.4.1 Details of subject

Total six male subjects were participated in the paddy harvesting and grass cutting operation with developed GCCPH prototype. The details of the subject were same as explained in section 4.2.1.

4.4.2 Working heart rate (WHR), oxygen consumption rate (OCR) and energy expenditure rate (EER) with grass cutter cum paddy harvester prototype

The heart rate (HR) of the selected subjects where measured with polar heart rate monitor (model - FT7) while operating a developed GCCPH prototype at Department of Agronomy, Dr. B. S. K. K. V. Dapoli, in 2020-2021 as explained in Chapter III, section 3.3.5.1. The mean dry bulb temperature and humidity during the evaluation was 31.8 °C and 65 %, respectively. The average values of heart rate (HR)

from 11th to 20th minute for each subject were considered as working heart rate (WHR). The subject wise value of WHR, OCR, EER, work pluse (Δ HR) for selected subject during paddy harvesting and grass cutting operations with developed grass cutter cum paddy harvester prototype is given in Table 4.10 and Table 4.11, respectively. The energy grade of work for subjects was decided from working heart rate of subjects during paddy harvesting and grass cutting operation (Sen, 1969).

From Table 4.10 and 4.11 it was observed that, the value of working heart rate (WHR) for selected subjects was in the range of 109 bpm to 145 bpm with mean value of 121 (± 14.51) during paddy harvesting and that of was in the range of 98 bpm to 114 bpm with mean value 107.67 (± 6.22) during grass cutting operation. The value of OCR was in the range of 0.86 l/min to 1.49 l/min, with mean 1.11 (± 0.23) l/min in paddy harvesting operation. Similarly, the OCR in grass cutting operation was in the range of 0.69 l/min to 1.04 l/min with mean 0.86 l/min (± 0.13) l/min. The per cent of % VO_2 max during paddy harvesting operation was in the range of 37.2 % to 63.14 % with mean 48.11 (± 13.26) % which was greater than the acceptable work load. Likewise, in grass cutting operation it was in the range of 23.1 % to 44.1 % with mean 36.81 (± 7.14) % which was also greater than the acceptable work load.

The Δ HR in paddy harvesting operation was in the range of 25 bpm to 67 bpm, with mean 43.17 (± 14.39) which was greater than the limit of continuous performance of 40 bpm and that of for grass cutting it was ranges from 12 bpm to 36 bpm, with mean 25.83 (± 9.83) which was within the limit of continuous performance.

The energy expenditure rate (EER) of subjects was calculated from the equation explained in section 3.3.5.3. The EER value of subjects were in the range from 18.03 kJ/min to 31.07 kJ/min, with mean of 23.18 (± 4.78) kJ/min in paddy harvesting operation. Similarly, the EER of the subject during grass cutting operation was in the range of 14.43 kJ/min to 21.82 kJ/min with mean 18.06 (± 2.79) kJ/min. The energy grade of work for paddy harvesting as well as grass cutting was in ‘Moderately heavy’ category.

Table 4.10 The physiological parameters as WHR, OCR, EER, Δ HR etc. for subjects during paddy harvesting with developed grass cutter cum paddy harvester prototype

Sr. No	Subject Code	Resting HR, (bpm)	Working HR, (bpm)	Δ HR, bpm	LCP, 40 beats/min	Working OCR, l/min	Per cent VO_2 max	AWL (35% VO_2 max)	EER kJ/min	Energy grade of work
1	SS	76	118	42	(>LCP)	1.18	61.45	(>AWL)	24.57	Moderately heavy
2	PH	78	145	67	(>LCP)	1.19	39.80	(>AWL)	24.81	Heavy
3	SJ	68	109	41	(>LCP)	1.04	43.51	(>AWL)	21.77	Moderately heavy
4	SP	82	132	50	(>LCP)	1.49	63.14	(>AWL)	31.07	Moderately heavy
5	HP	76	110	34	(<LCP)	0.86	38.57	(>AWL)	18.03	Moderately heavy
6	MP	87	112	25	(<LCP)	0.90	37.2	(>AWL)	18.85	Moderately heavy
Mean.		77.83	121	43.17	(>LCP)	1.11	48.11	(>AWL)	23.18	Moderately heavy
Std.		± 6.4	± 14.51	± 14.39		± 0.23	± 13.26		± 4.78	

Table 4.11 The physiological parameters as WHR, OCR, EER, Δ HR etc. for subjects during grass cutting operation with developed grass cutter cum paddy harvester prototype

Sr. No	Subject Code	Resting HR, (bpm)	Working HR, (bpm)	Δ HR, bpm	LCP, 40 beats/min	Working OCR, l/min	Per cent of VO_2 max	AWL (35% VO_2 max)	EER kJ/min	Energy grade of work
1	SS	86	98	12	(<LCP)	0.73	38.01	(>AWL)	15.18	Light
2	PH	77	110	33	(<LCP)	0.69	23.1	(<AWL)	14.43	Moderately heavy
3	SJ	68	102	34	(<LCP)	0.90	37.7	(>AWL)	18.83	Moderately heavy
4	SP	75	111	36	(<LCP)	1.04	44.1	(>AWL)	21.82	Moderately heavy
5	HP	92	111	19	(<LCP)	0.88	39.5	(>AWL)	18.43	Moderately heavy
6	MP	93	114	21	(<LCP)	0.94	38.84	(>AWL)	19.66	Moderately heavy
Mean.		81.83	107.67	25.83	(<LCP)	0.86	36.81	(>AWL)	18.06	Moderately heavy
Std.		± 10.07	± 6.22	± 9.83		± 0.13	± 7.14		± 2.79	

4.4.3 Overall discomfort rating (ODR) and body part discomfort score (BPDS) of subjects for developed GCCPH prototype

The ODR of the subjects during paddy harvesting and grass cutting operation with developed GCCPH prototype was taken as explained in section 3.3.5.6.1. The value of ODR and BPDS of subjects during paddy harvesting and grass cutting operation with developed grass cutter cum paddy harvester prototype is presented at Appendix IV (F) and Appendix IV (G), respectively. The details about mean ODR, mean BPDS and body parts found discomfort for paddy harvesting and grass cutting are given in Table 4.12.

Table 4.12 The details about mean ODR and BPDS for subjects during paddy harvesting operation with grass cutter cum paddy harvester prototype

Sr. No	Particulars	Values
(a) Paddy harvesting		
1	Body parts found discomfort	Right forearm, left forearm, right thigh, right shoulder, lower back and left shoulder
2	Range of ODR	4 to 6
3	Mean ODR	5
4	Range of BPDS	15.75 to 42.75
5	Mean BPDS	23.63
(b) Grass cutting		
1	Body parts found discomfort	Right arm, right forearm, right wrist, right shoulder, left shoulder, left arm, right arm, left thigh, right thigh,
2	Range of ODR	3 to 4
3	Mean ODR	3.33
4	Range of BPDS	4.5 to 22.5
5	Mean BPDS	15.75

The overall discomfort rating (ODR) of subjects was ranges from 4 to 6 with mean value as 5 for paddy harvesting and for grass cutting it was in the range of 3 to 4 with mean of 3.33. The mean ODR was scaled as “moderate discomfort” for paddy harvesting as well as grass cutting operation with developed prototype of grass cutter cum paddy harvester.

The body part discomfort score (BPDS) of selected subject was calculated as explained in section 3.3.5.6.2 for each individual subject. The body part viz. right forearm, left forearm, right thigh were found severe discomfort and right shoulder, lower back, left shoulder were found moderate discomfort while working with developed grass cutter cum paddy harvester prototype for paddy harvesting operation. Similarly, for grass cutting operation right shoulder, right arm, right forearm, right wrist were found severe discomfort and body parts like left shoulder, left thigh, left arm, right thigh were found moderate discomfort. The range of BPDS was 15.75 to 42.75 with mean 23.63 and 4.5 to 22.5 with mean of 15.75 in paddy harvesting and grass cutting operation, respectively.

4.4.4 Work rest cycle for GCCPH prototype

As per the Table 4.10 the value of mean energy expenditure rate (EER) for paddy harvesting was 23.18 kJ/min (5.54 kcal/min). The rest pauses for 60 min work was calculated by using equation 3.3, which was $22.8 \approx 23$ min. Hence 60 min work with 23 min rest will be suitable work rest cycle. Similarly, the mean of EER for grass cutting operation was 18.06 kJ/min (4.32 kcal/min). Therefore, in 60 min work with $6.8 \approx 7$ min rest will be suitable work rest cycle of GCCPH prototype.

4.4.5 Field capacity and field efficiency of grass cutter cum paddy harvester prototype

The field capacity and field efficiency of the developed grass cutter cum paddy harvester prototype for paddy harvesting and grass cutting operation was calculated as explained in section 3.5.2 and 3.5.3, respectively and given in Appendix IV (H).

The field capacity for paddy harvesting operation with developed GCCPH prototype was in the range of 0.009 ha/h to 0.019 ha/h with mean 0.014 ha/h and for grass cutting it was in the range of 0.019 ha/h to 0.051 ha/h with mean 0.038 ha/h, respectively. The field efficiency in paddy harvesting operation with 0.36 m cutting width was in the range of 27.63% to 54.39% with mean 37.51%. Similarly, in grass cutting operation the field efficiency of developed GCCPH prototype was in the range of 68.67 % to 98.96 % with mean 87.25 %.

4.5 Ergonomic and Mechanical Design Considerations of Second Prototype of Grass Cutter Cum Paddy Harvester

The ergonomic and mechanical design considerations were incorporated in second prototype of grass cutter cum paddy harvester for refabricate components of the machine.

4.5.1 Ergonomic design consideration

The anthropometric and strength parameters of male workers in Konkan region of Maharashtra was considered for design components of the second prototype of GCCPH as explained in Chapter III.

4.5.1.1 Handle of swinging lever

The handle of swinging lever was cylindrical in shape. The size of grip and length of grip for handle of swinging lever was calculated as explained in section 3.6.1.4. and 3.6.1.5 respectively. The details of the anthropometric considerations are furnished in Table 4.13. The handle of the swinging lever was fabricated using M.S round pipe of size 22 mm diameter and 3 mm thickness.

4.5.1.2 Lever of swinging mechanism

The lever of swinging mechanism was designed as explain in section 3.7.5.2. The details of the anthropometric considerations are furnished in Table 4.13. The lever was fabricated using M.S square pipe of size 20 mm × 20 mm. That lever was pivoted on the cycle frame by flexible joint.

4.5.1.3 Handle of second prototype of GCCPH

The handle of second prototype of grass cutter cum paddy harvester was designed as explained in section 3.6.1. The handle was designed by considering the anthropometric data and strength parameters of male workers in Konkan region of Maharashtra as explained at section 3.6.1. The details of the anthropometric considerations are given in Table 4.13.

The handle height was considered based on acromial height, which was 1011.5 mm. As the handle was attached at 585 mm above the ground level. Therefore, in order to determine the handle height, 585 should be deducted from considered acromial height.

Actual handle height = Handle height – location above the ground

$$1011.5 - 585 = 426.5 \text{ mm,}$$

Hence, as per table 4.13,

The actual handle length was calculated by,

$$\frac{426.5}{\sin 45} \text{ to } \frac{426.5}{\sin 30}$$

603.16 to 853

Therefore,

The length of the handle was in the range of 603.16 to 853 mm

Table 4.13 Ergonomic design considerations of developed second prototype of grass cutter cum paddy harvester

Sr. No	Design considerations	Anthropometric considerations	Dimensions
1	Arm reach	5 th percentile of arm reach	770 mm
2	Abdominal extension to wall	95 th percentile of abdominal extension to wall	293
3	Height of handle	Acromial height: 0.8 of the 5 th percentile and 0.7 of the 95 th percentile acromial height (1245 mm and 1445 mm, respectively)	Range: 996 mm to 1011.5 mm Considered value: 1011.5 mm
4	Length of handle	Angle of operation 30 ° to 45 °	Range: 603.16 mm to 853 mm Considered value: 720 mm
5	Shape of grip		Cylindrical
6	Size of grip	5 th percentile of insidegrip diameter to 95 th percentile middle finger palm grip diameter (39 mm) and (34 mm)	Range: 34 mm to 39 mm. Considered value: 35.6 mm
7	Length of grip	95 th percentile of hand breadth across thumb (105 mm)	105 mm

Hence handle height and length were 1011.5 mm and 720 mm, respectively. The handle grip was cylindrical with its diameter and length were 31 mm and 105 mm, respectively.

The handle of the machine was fabricated using a round M.S pipe and square G.I pipe of size 22 mm diameter and 20 mm × 20 mm size, respectively. The square pipe of the handle was fitted on the cycle frame with two plates having five holes. Those plates were used to adjust the height of handle as per requirement. On the other end of the square pipe a round pipe was fixed.

4.5.2 Mechanical design consideration of second prototype of grass cutter cum paddy harvester

4.5.2.1 Swinging mechanism of second prototype of GCCPH

The swinging mechanism of the second prototype of grass cutter cum paddy harvester was designed by four bar link mechanism as explained in section 3.7.1. The swinging lever of the mechanism was fabricated with a G.I square pipe of 20 mm × 20 mm size with 3 mm thickness and a round pipe of 22 mm diameter with 3 mm thickness. The square pipe of the swinging lever (link B) was pivoted on the cycle frame (fixed link A). At one end of the square pipe, a round pipe was fitted for better grip. Link B was connected to link C with a ball joint of 25 mm ball end diameter by a flexible joint (nut bolt). Link C was connected to the link D with another ball joint of 16 mm ball end diameter by a flexible joint. Link D of the swinging mechanism was rigidly connected to the one plate of the hinge through an angle.

The swinging mechanism of the second prototype of the grass cutter cum paddy harvester could turn the cutter shaft at 72° with a 1256.7 mm cutting arc, as explained in section 3.7.1.

4.5.2.2 Tilting mechanism of the grass cutter cum paddy harvester

The tilting mechanism of the second prototype of grass cutter cum paddy harvester was fabricated with hinges as size 62.5 mm × 62.5 mm × 3 mm thickness. One hinge was fixed on the bearing shaft of size 25 mm diameter and 106 mm length. The bearing shaft created the rigid support to the hinge. That bearing shaft was fitted in the bearing housing. The bearing housing was fabricated by using M.S pipe of size 60 mm diameter, 60 mm length and 7.5 mm thickness. The internal diameter of bearing housing was 47 mm from both sides with step length 14 mm. Two ball bearings were fitted in the bearing housing with an internal diameter 20 mm and outer diameter 47 mm. The assembly of bearing shaft, bearing and bearing housing was mounted on the mounting plate. The mounting plate was fabricated using M.S flat plate of size 105 mm in length, 97 mm width and 10 mm thickness and mounting plate was fitted on the cycle frame. The second hinge was fitted between the support plate of size 152 mm × 152 mm and first hinge. A square rod was provided between the two plates of second hinge. The brake cable of 1800 mm length was connected between the tilting lever and square rod.

4.5.2.3 Transmission shaft

The transmission shaft of the second prototype of GCCPH was designed as explained in section 3.6.4.2. The transmission shaft was fabricated as 1000 mm length and 8 mm diameter with 9 splines.

4.5.3 Components of second prototype of GCCPH

The details of the functional components of the second prototype of GCCPH is discussed in following sections. The details of the all specifications of second prototype of grass cutter cum paddy harvester is given in Table 4.14.

4.5.3.1 Prime mover

The same prime mover was used in second prototype of GCCPH. The specifications of prime mover (engine) was same as explained in Table 4.9.

4.5.3.2 Main frame

The cycle frame was used to refabricate the main frame of the machine with length 755 mm. Two square rod was attached on the main frame at center of size 25 mm × 25 mm and 330 mm in length.

4.5.3.3 Transport wheels

Three transport wheels were used in second prototype of grass cutter cum paddy harvester of size 250 mm in diameter and 375 mm in diameter. The plastic rim rubber tyer was used in the developed second prototype of GCCPH.

Table 4.14 Detailed specifications of material of grass cutter cum paddy harvester prototype

Sr. No	Component	Specifications
1	Engine	2-stroke petrol engine, 1.95 hp, 6500-7500 rpm
2	Transmission shaft	1000 mm, 9 splines, 8 mm ϕ
3	Transport wheels	Plastic rim, rubber tyre, 250 mm ϕ (two no) 375 mm ϕ (one no)
4	Main frame	M.S cycle frame: 755 mm length G.I square rod: 25 mm × 25 mm 330 mm length
5	Hinges	M.S plate: 625 mm × 625 mm
Sr. No	Component	Specifications

6	Bearing housing	M.S pipe: 60 mm ϕ , 60 mm length and 7.5 mm thickness
7	Mounting plate	M.S plate: 105 mm $\times$ 97 mm $\times$ 10 mm
8	Support plate	M.S plate: 152 mm $\times$ 152 mm
9	Bearing shaft	M.S rod: 25 mm ϕ and 106 mm length
10	Ball bearing	ID- 20 mm ϕ OD- 47 mm ϕ
11	Lever	G.I square pipe: 20 mm $\times$ 20 mm $\times$ 3 mm, 805 mm length G.I round pipe: 22 mm ϕ , 105 mm length, 3 mm thickness
12	Handle	G.I square pipe: 20 mm $\times$ 20 mm M.S round pipe: 22 mm ϕ
13	Brake cable	1800 mm length

4.6 Ergonomic evaluation and field performance of second prototype of grass cutter cum paddy harvester

The ergonomic evaluation and field performance of developed second prototype of GCCPH for paddy harvesting operation was conducted at Agriculture Research Center, Repoliduring 2020-2021 and that for grass cutting operation was conducted at Dept. of Horticulture, Dr. B. S. K. K. V. Dapoli.

4.6.1 Details of selected subject

Same subjects were participated in the paddy harvesting and grass cutting operation with developed second prototype of grass cutter cum paddy harvester as explained in section 4.2.1.

4.6.2 WHR, OCRand EER of subject with second prototype GCCPH

The heart rate of selected subject in paddy harvesting and grass cutting operation were measured with polar heart rate monitor as explained in section 3.3.5.1. The dry bulb temperature and humidity during the evaluation of paddy harvesting operation were 35 °C and 69.25 %, respectively. Likewise, the dry bulb temperature

Table 4.15 The physiological parameters as WHR, OCR, EER, Δ HR etc. for subjects during paddy harvesting with developed second prototype of GCCPH

Sr. No	Subject Code	Resting HR, (bpm)	Working HR, (bpm)	Δ HR, bpm	LCP, 40 beats/min	Working OCR, l/min	Per cent of VO ₂ max	AWL (35% VO ₂ max)	EER kJ/min	Energy grade of work
1	SS	77	96	19	(<LCP)	1.29	67.19	(>AWL)	26.92	Light
2	PH	76	101	25	(<LCP)	0.56	18.73	(<AWL)	11.76	Moderately heavy
3	SJ	72	93	21	(<LCP)	0.72	30.13	(<AWL)	15.05	Light
4	SP	90	130	40	(>LCP)	1.45	61.44	(>AWL)	30.19	Heavy
5	HP	88	125	37	(<LCP)	1.15	51.57	(>AWL)	24.14	Moderately heavy
6	MP	78	108	30	(<LCP)	0.82	33.88	(<AWL)	17.22	Moderately heavy
Mean.		80.17	108.83	28.67	(<LCP)	0.99	48.82	(>AWL)	20.87	Moderately heavy
Std.		± 7.17	± 15.41	± 8.55		± 0.35	± 19.14		± 7.26	

and humidity during evaluation of grass cutting operation were 28.25 °C and 86.33 %, respectively. The details of WHR, OCR, EER and Δ HR of selected subjects for paddy harvesting and grass cutting operation are given in Table 4.15 and Table 4.16, respectively.

From Table 4.15 it was found that, the working heart rate of the selected subjects in paddy harvesting operation was in the range of 96 bpm to 130 bpm with mean of 108.83 ($\pm$ 15.41). The corresponding values of oxygen consumption rate (OCR) was in the range of 0.72 l/min to 1.45 l/min with mean 0.99 ($\pm$ 0.35) l/min. The corresponding values of per cent VO_2 max was in the range of 18.73% to 67.19% with mean 48.82 %.

The energy expenditure rate of the selected subjects was calculated as explained in section 3.3.5.3. The EER of the subject was in the range of 11.76 kJ/min to 30.19 kJ/min with mean 20.87 ($\pm$ 7.26) kJ/min. The work pulse (Δ HR) of the individual subject was calculated from difference between WHR and RHR. The Δ HR of the selected subject was in the range of 19 bpm to 40 bpm with mean 28.67 ($\pm$ 8.55) bpm which was less than the limit of continuous performance. The energy grade of work during paddy harvesting with developed second prototype of GCCPH was in ‘moderately heavy’ category.

From Table 4.16 it was observed that, the working heart rate (WHR) of the selected subjects in grass cutting operation was in the range of 92 bpm to 118 bpm with mean of 104.83 ($\pm$ 8.75). The corresponding values of oxygen consumption rate (OCR) was in the range of 0.59 l/min to 1.02 l/min with mean 0.81 ($\pm$ 0.16) l/min. The per cent of VO_2 max was in the range of 20.74 % to 42.15 % with mean 34.41 % , which was within the acceptable work load. The EER of the subject was in the range of 12.36 kJ/min to 21.29 kJ/min with mean 16.88 ($\pm$ 3.53) kJ/min. The Δ HR of the selected subject was in the range of 7 bpm to 32 bpm with mean 21.5 ($\pm$ 11.13) bpm which was less than the limit of continuous performance. The energy grade of work in grass cutting operation with developed second prototype of GCCPH was in ‘moderately heavy’ category

Table 4.16 The physiological parameters as WHR, OCR, EER, Δ HR etc. for subjects during grass cutting operation with developed second prototype of grass cutter cum paddy harvester

Sr. No	Subject Code	Resting HR, (bpm)	Working HR, (bpm)	Δ HR, bpm	LCP, 40 beats/min	Working OCR, l/min	Per cent VO_2 max	AWL (35% VO_2 max)	EER kJ/min	Energy grade of work
1	SS	85	92	7	(< LCP)	0.59	30.73	(<AWL)	12.36	Light
2	PH	77	105	28	(< LCP)	0.62	20.74	(<AWL)	12.95	Moderately heavy
3	SJ	71	103	32	(< LCP)	0.91	38.08	(>AWL)	19.25	Moderately heavy
4	SP	75	101	26	(< LCP)	0.83	35.17	(>AWL)	17.41	Moderately heavy
5	HP	101	110	10	(< LCP)	0.86	38.57	(>AWL)	18.03	Moderately heavy
6	MP	91	118	32	(< LCP)	1.02	42.15	(>AWL)	21.29	Moderately heavy
Mean.		82.33	104.83	21.5	(< LCP)	0.81	34.14	(<AWL)	16.88	Moderately heavy
Std.		± 10.42	± 8.75	± 11.13		± 0.16	± 9.29		± 3.53	

4.6.3 Overall discomfort rating (ODR) and body part discomfort rating (BPDS) for developed second prototype GCCPH

The overall body part discomfort rating (ODR) and BPDS of the subject during paddy harvesting and grass cutting operation with developed second prototype of GCCPH was taken as explained in section 3.3.5.6.1 and 3.3.5.6.2, respectively. The obtained value of ODR and BPDS of subject during paddy harvesting and grass cutting operations are given in Appendix IV (I) and Appendix IV (J), respectively. The details of mean ODR, mean BPDS and body parts experienced discomfort are given in Table 4.17.

Table 4.17 The details about mean ODR and BPDS for subjects during paddy harvesting and grass cutting operation with developed second prototype of GCCPH

Sr. No	Particulars	Values
1. Paddy harvesting		
1	Body parts found discomfort	Left shoulder, right shoulder, right forearm, right wrist.
2	Range of ODR	4 to 6
3	Mean ODR	4.67
4	Range of BPDS	7 to 13
5	Mean BPDS	11.5
2. Grass cutting		
1	Body parts found discomfort	Right shoulder, right wrist, right knee, right forearm, right arm, right elbow, lower back, left thigh, right thigh
2	Range of ODR	3 to 5
3	Mean ODR	3.8
4	Range of BPDS	11.25 to 20.25
5	Mean BPDS	14.63

From Table 4.17 it was found that the ODR of the subject was in the range of 4 to 6 with mean 4.67 for paddy harvesting operation and 3 to 5 with mean 3.8 for grass cutting operation. The scale of ODR was “moderate discomfort” for paddy harvesting and grass cutting operation.

The BPDS of the selected subject was in the range of 7 to 13 with mean 11.5 for paddy harvesting operation and 11.25 to 20.25 with mean 14.63 for grass cutting operation. The body parts like right shoulder, left shoulder and right forearm experiences sever discomfort and right wrist experiences moderate discomfort in paddy harvesting operation. Likewise, right shoulder, right arm, right wrist, right elbow found sever discomfort and body parts like right knee, right forearm, right thigh and lower back found moderate discomfort in grass cutting operation.

4.6.4 Work rest cycle

As given in Table 4.15 the mean energy expenditure rate (EER) were 20.87 kJ/min (4.98 kcal/min). The rest pauses for 60 min work was calculated by using equation 3.3. Therefore, in 60 min work $16.8 \approx 17$ min rest was suitable for work rest cycle. Similarly, from Table 4.16 the mean energy expenditure rate was 16.88 kJ/min (4.03 kcal/min). Therefore, in 60 min $0.7 \approx 1$ min rest was suitable for work rest cycle.

4.6.5 Field capacity and field efficiency of developed second prototype of grass cutter cum paddy harvester

The field capacity and field efficiency of the developed second prototype of grass cutter cum paddy harvester was calculated as explained in section 3.5.2 and given in Appendix IV (K). The field capacity for paddy harvesting operation was in the range of 0.008 ha/h to 0.014 ha/h with mean 0.01 ha/h and for grass cutting it was in the range of 0.018 ha/h to 0.038 ha/h with mean 0.0303 ha/h. The field efficiency of developed prototype of grass cutter cum paddy harvester was in the range of 23.20 % to 38.50 % with mean 28.69 % for paddy harvesting operation and in grass cutting the field efficiency was in the range of 63.25 % to 93.6 % with mean 77.18%.

4.7 Comparative Ergonomic Evaluation of Different Machines for Grass Cutting and Paddy Harvesting

The comparative ergonomic evaluation of shoulder mounted brush cutter, prototype of grass cutter cum paddy harvester and second prototype of grass cutter cum paddy harvester has been elaborated in Table 4.18. Six subjects had participated in the study. The subject details are given prior section. Accordingly the average age, weight and stature were 37.67 (± 8.48), 55.67 (± 8.43) and 165.17 (± 7.19), respectively.

Table 4.18 Comparative ergonomic evaluation of different machines for grass cutting and paddy harvesting

Sr. No	Parameter	Shoulder mounted brush cutter		Grass cutter cum paddy harvester prototype		Second prototype of grass cutter cum paddy harvester	
		Paddy harvesting	Grass cutting	Paddy harvesting	Grass cutting	Paddy harvesting	Grass cutting
I	Physiological parameters						
1	RHR, bpm	80.33 ($\pm$ 11.02)	83.5 ($\pm$ 5.54)	77.83 ($\pm$ 6.40)	81.33 ($\pm$ 10.06)	80.17 ($\pm$ 7.16)	82.33 ($\pm$ 10.42)
2	WHR, bpm	121. 83 ($\pm$ 9.52)	101.17 ($\pm$ 8.66)	121 ($\pm$ 14.5)	107.67 ($\pm$ 6.22)	108.33 ($\pm$ 15.40)	104.83 ($\pm$ 8.75)
3	Δ HR, bpm	41.5 ($\pm$ 7.89)	17.67 ($\pm$ 9.77)	43.17 ($\pm$ 14.39)	25.83 ($\pm$ 9.83)	28.67 ($\pm$ 8.55)	21.5 ($\pm$ 11.13)
4	OCR, l/min	1.15 ($\pm$ 0.28)	0.86 ($\pm$ 0.34)	1.11 ($\pm$ 0.23)	0.86 ($\pm$ 0.13)	0.99 ($\pm$ 0.35)	0.81 ($\pm$ 0.16)
5	Δ OCR, l/min	0.84 (($\pm$ 0.19)	0.46 (($\pm$ 0.40)	0.81 ($\pm$ 0.21)	0.49 ($\pm$ 0.19)	0.66 ($\pm$ 0.25)	0.41 ($\pm$ 0.17)
6	EER, kJ/min	24.03 ($\pm$ 5.76)	17.96 ($\pm$ 7.02)	23.18 ($\pm$ 4.78)	18.06 ($\pm$ 2.79)	20.87 ($\pm$ 7.27)	16.88 ($\pm$ 3.53)
7	ODR	6.17 ($\pm$ 0.75)	4.8 ($\pm$ 0.41)	5 ($\pm$ 0.89)	3.33 ($\pm$ 0.52)	4.67 ($\pm$ 0.82)	3.83 ($\pm$ 0.75)
8	BPDS	28.79	17.21	23.63	15.75	11.5	14.63

9	Area of discomfort	Right arm, left thigh, lower back, left shoulder, right shoulder, right forearm, right wrist, left forearm, right thigh, right elbow.	Right shoulder, right elbow, right forearm, right leg, lower back, left shoulder, right arm	Right forearm, left forearm, right thigh, right shoulder, lower back, left shoulder	Right arm, right forearm, right wrist, right shoulder, left shoulder, left arm, right arm, left thigh, right thigh,	Left shoulder, right shoulder, right forearm, right wrist.	Right shoulder, right wrist, right knee, right forearm, right arm, right elbow, lower back, left thigh, right thigh
10	Energy grade of work	Moderately heavy	Moderately heavy	Moderately heavy	Moderately heavy	Moderately heavy	Moderately heavy
III	Field performance						
1	Field capacity, ha/h	0.009 (± 0.003)	0.028 $\pm$ 0.006)	0.014 ($\pm$ 0.036)	0.038 ($\pm$ 0.0119)	0.01 ($\pm$ 0.0021)	0.030 ($\pm$ 0.0068)
2	Field efficiency, %	26.46	78	37.51	87.25	28.69	77.11

As explained before, total six male subjects were participated in the experiment. From Table 4.2 it was found that the mean age, stature, weight and HR max of the subjects were 37.67 (± 8.48) years, 165.17 (± 7.19) cm, 55.67 (± 8.43) kg and 182.33 (± 8.48) bpm, respectively. From Table 4.18 it was observed that the mean WHR values for paddy harvesting operation were 121.83 (± 9.51) bpm, 121 (± 14.51) bpm and 108.33 (± 15.40) bpm with SMBC, GCCPH prototype and second prototype of GCCPH, respectively. Similarly, the mean WHR of subject for grass cutting operation with SMBC, GCCPH prototype and second prototype of GCCPH were 101.17 (± 8.66) bpm, 107.67 (± 6.22) bpm and 104.83 (± 8.75) bpm, respectively. The graphical representation for WHR with SMBC, GCCPH prototype and second prototype of GCCPH are shown in Fig 4.16.

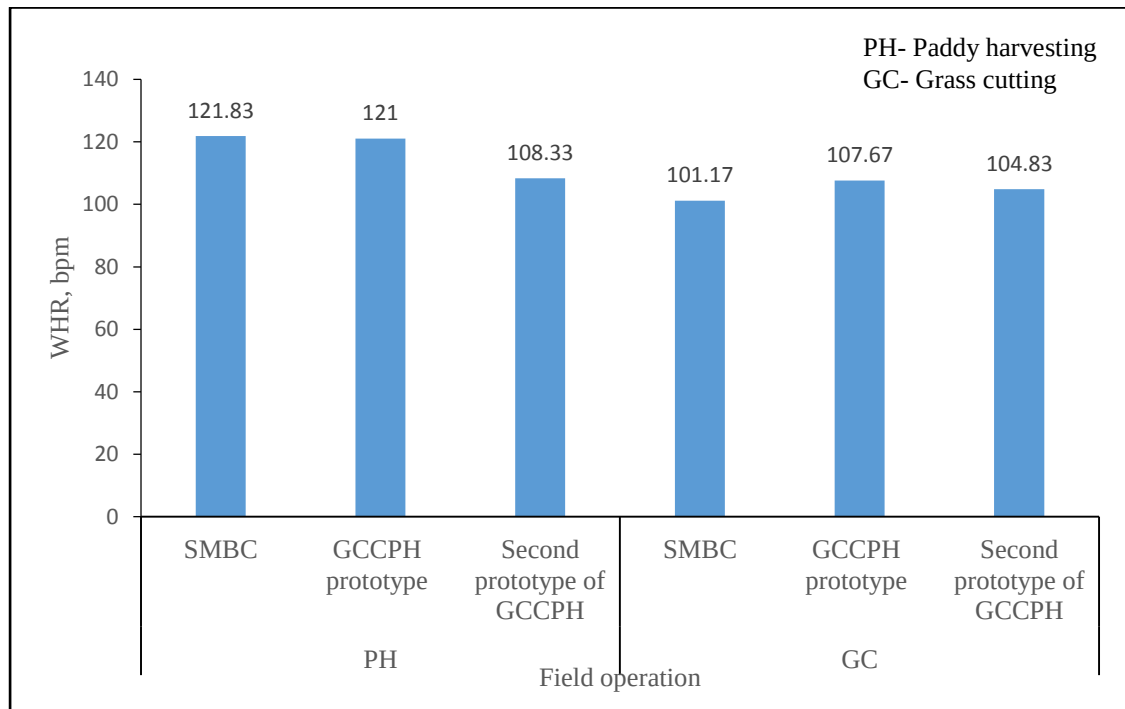


Fig 4.16 WHR of machine for paddy harvesting and grass cutting operation

The mean work pluse (Δ HR) values were 41.5 (± 7.89) bpm, 43.17 (± 14.39) bpm and 28.67 (± 8.55) bpm for paddy harvesting operation with SMBC, GCCPH prototype and second prototype of GCCPH, respectively. Those values were 17.67 (± 9.7) bpm, 25.83 (± 9.83) bpm and 21.5 (± 11.13) bpm with SMBC, GCCPH prototype and second prototype of GCCPH for grass cutting operation.

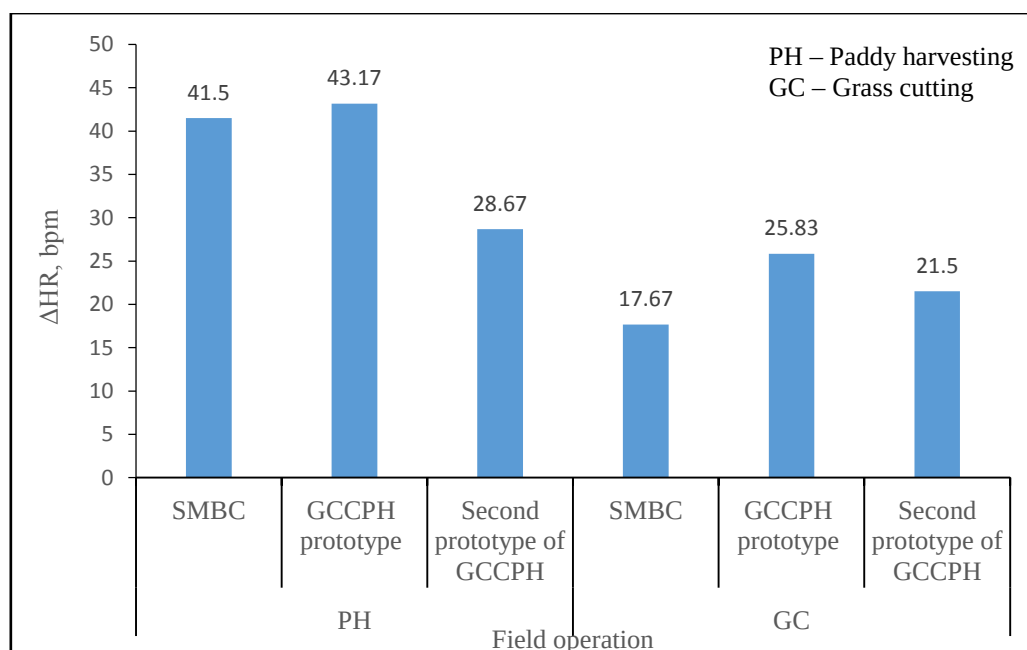


Fig 4.17 ΔHR of machine for paddy harvesting and grass cutting operation

From Fig 4.17 it was observed that the work pluse of the subject during paddy harvesting with GCCPH prototype was greater than the existing SMBC. The ΔHR of the subjects for developed GCCPH was within the limit of continuous performance (LCP) i.e 40 bpm. The work pluse of the subject for second prototype of GCCPH was less as compared to SMBC and GCCPH prototype and also less than the LCP.

From Table 4.18 the mean of working OCR for SMBC, GCCPH prototype and second prototype of GCCPH were 1.15 (± 0.28) l/min, 1.11 (± 0.23) l/min and 0.99 (± 0.35) l/min, respectively during paddy harvesting operation. Similarly, those values for SMBC, GCCPH prototype and second prototype of GCCPH were 0.85 (± 0.34) l/min, 0.86 (± 0.13) l/min and 0.81 (± 0.17) l/min, respectively for grass cutting operation.

The values of Δ OCR with SMBC, prototype of GCCPH and second prototype of GCCPH were, 0.84 (± 0.19) l/min, 0.81 (± 0.21) l/min and 0.66 (± 0.25) l/min, respectively for paddy harvesting operation. Those values were 0.46 (± 0.40) l/min, 0.49 (± 0.19) l/min and 0.41 (± 0.17) l/min for SMBC, GCCPH prototype and second prototype of GCCPH, respectively. The graphical representation of Δ OCR for SMBC, GCCPH prototype and second prototype of GCCPH are shown in Fig 4.18.

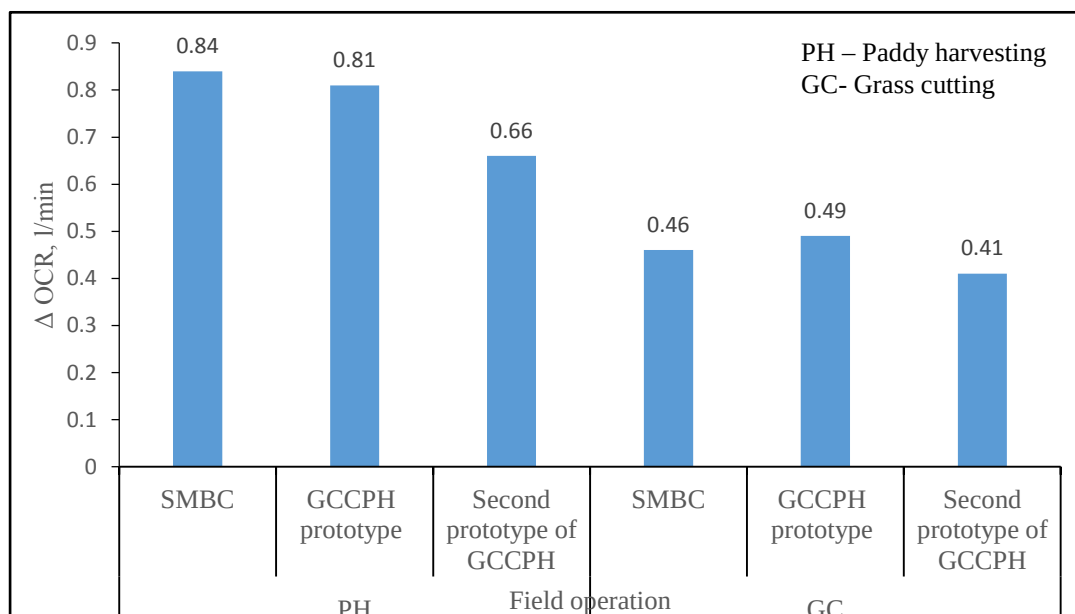


Fig 4.18 ΔOCR of machine for paddy harvesting and grass cutting operation

From Fig 4.18 it was observed that the value ΔOCR for prototype of GCCPH was greater than the existing SMBC in grass cutting operation. Similarly, those values were less in second prototype of grass cutter cum paddy harvester than shoulder mounted brush cutter as well as grass cutter cum paddy harvester prototype.

The mean of EER of the subject in field trail for SMBC, GCCPH prototype and second prototype of GCCPH were 24.03 (± 5.8) kJ/min, 23.18 (± 4.77) kJ/min and 20.87 (± 7.27) kJ/min, respectively for paddy harvesting operation. Those values were 17.96 (± 7.02) kJ/min, 18.06 (± 2.78) kJ/min and 16.88 (± 3.53) kJ/min for SMBC, GCCPH prototype and second prototype of GCCPH, respectively in grass cutting operation.

The mean ODR of the subject during paddy harvesting operation with SMBC, GCCPH prototype and second prototype of grass cutter cum paddy harvester were 6.17 (± 0.75), 5 (± 0.89) and 4.67 (± 0.82), respectively. Those values were 4.83 (± 0.41), 3.33 (± 0.52) and 3.83 (± 0.75) for SMBC, GCCPH and second prototype of GCCPH, respectively for grass cutting operation. The comparative evaluation of ODR for SMBC, GCCPH and second prototype of GCCPH are shown in Fig 4.19.

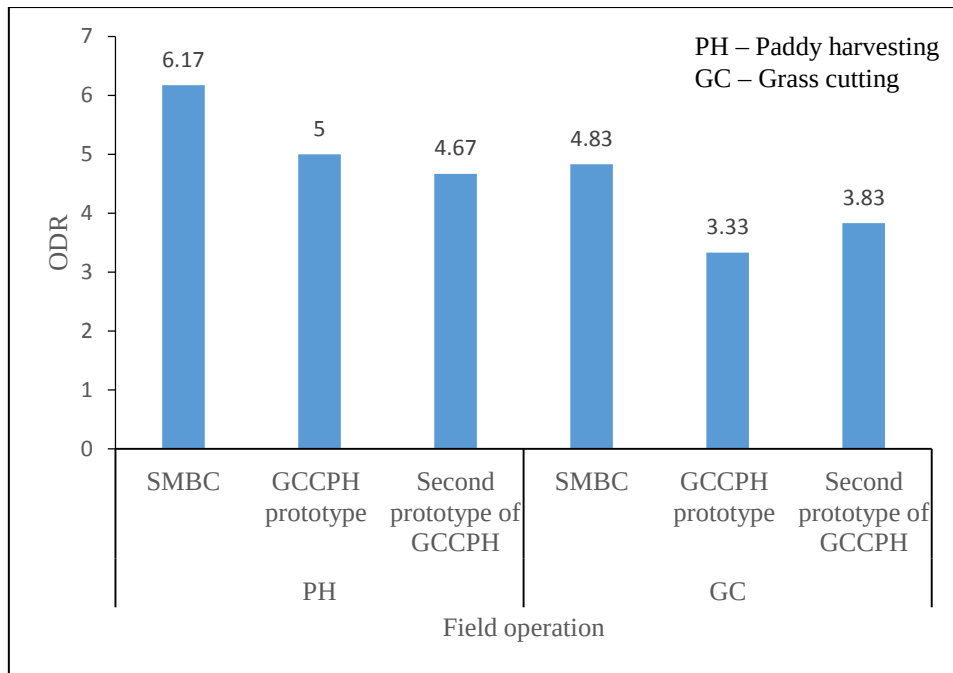


Fig 4.19 ODR of machine for grass cutting and paddy harvesting

The mean BPDS of the subjects for paddy harvesting with SMBC, GCCPH and second prototype of GCCPH were 28.79, 23.63 and 11.5, respectively. Similarly, those values were 17.21, 15.75 and 14.62 for SMBC, GCCPH and second prototype of GCCPH, respectively for grass cutting operation. The comparative data of BPDS for SMBC, GCCPH and second prototype of GCCPH are shown in Fig 4.20.

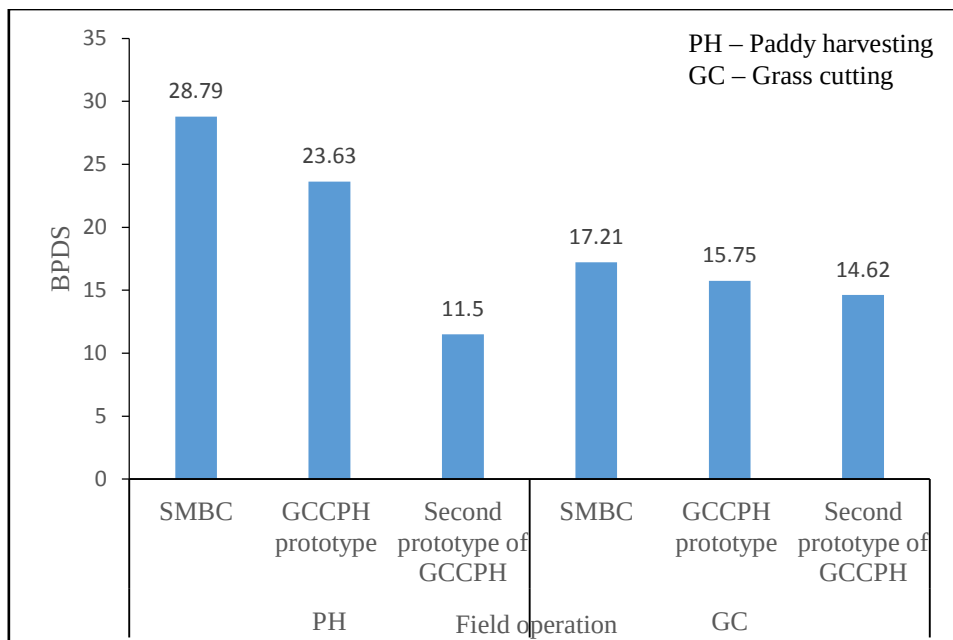


Fig 4.20. BPDS of machine for grass cutting and paddy harvesting

From Fig 4.20 it was observed that the mean BPDS of subjects for second prototype of grass cutter cum paddy harvester was less than shoulder mounted brush cutter as well as prototype of grass cutter cum paddy harvester.

The energy grade of work during grass cutting as well as for paddy harvesting operation for SMBC, GCCPH and second prototype of GCCPH were in the ‘moderately heavy’ category.

The mean of field capacity for SMBC, GCCPH prototype and second prototype of GCCPH were 0.009 (± 0.0033) ha/h, 0.014 (± 0.0036) ha/h and 0.010 (± 0.0021) ha/h, respectively for paddy harvesting operation. Whereas, the mean field capacity with SMBC, GCCPH prototype and second prototype of GCCPH were 0.028 (± 0.005) ha/h, 0.038 (± 0.011) ha/h and 0.030 (± 0.0068) ha/h, respectively for grass cutting operation. The graphical representation of field capacity for SMBC, GCCPH prototype and second prototype of GCCPH are shown in Fig 4.21.

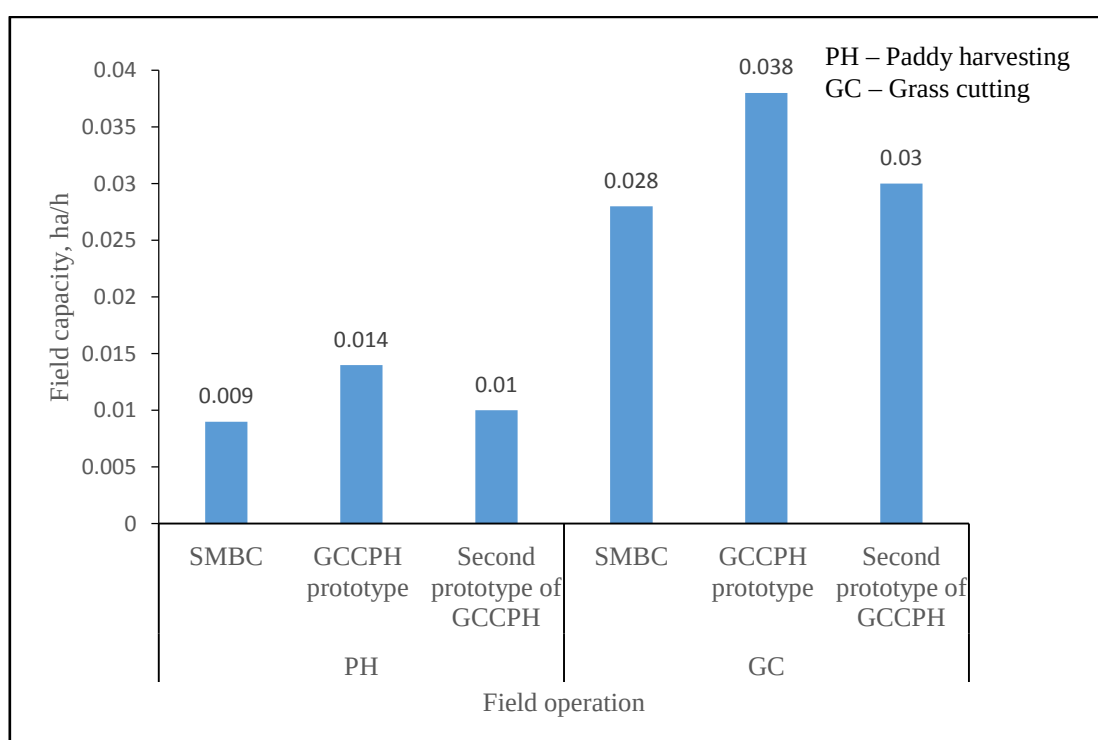


Fig 4.21. Field capacity of machine for paddy harvesting and grass cutting

The mean of field efficiency for SMBC, GCCPH prototype and second prototype of GCCPH were 26.46 %, 37.51 % and 28.69 %, respectively for paddy harvesting operation. Likewise, the mean of field efficiency for SMBC, GCCPH prototype and second prototype of GCCPH were 78 %, 87.25 % and 77.11 %, respectively for grass cutting operation.

The comparative evaluation data of SMBC, first prototype of GCCPH and second prototype of GCCPH given at Appendix V. As first prototype of GCCPH was used for paddy harvesting operation in comparison with SMBC, the physiological parameters viz. WHR, OCR, Δ OCR were decreased by 0.6 per cent, 3.5 per cent and 3.6 per cent, respectively. Whereas, Δ HR was increased by 4.02 per cent. ODR and BPDS were decreased by 19.4 per cent and 18.1 per cent, respectively. The field capacity was increased by 55.5 per cent. Similarly, as it was used for grass cutting operation, in comparison with SMBC, the physiological parameters viz. WHR, Δ HR, Δ OCR were increased by 5.9 per cent, 46.2 per cent and 6.5 per cent, respectively. The OCR was not affected for grass cutting. ODR and BPDS decreased by 31.3 per cent and 15.6 per cent, respectively. The field capacity for grass cutting was increased by 35.7 per cent.

The comparative performance of second prototype of GCCPH and that of SMBC for paddy harvesting operation depicted that the physiological parameters viz. WHR, Δ HR, OCR, Δ OCR and subjective ratings viz. ODR and BPDS all were decreased by 11.1 per cent, 30.9 per cent, 13.9 per cent, 21.4 per cent, 24.2 per cent and 59.6 per cent, respectively. Also all these parameters were decreased in comparison to first prototype of GCCPH. The field capacity was increased by 11.1 per cent. Similarly, in comparison to SMBC the physiological parameters viz. WHR and Δ HR were increased by 3.1 per cent and 21.7 per cent, respectively in grass cutting operation. However, these parameters were decreased by 2.6 per cent and 16.7 per cent in comparison with first prototype. OCR, Δ OCR subjective rating scales ODR and BPDS were decreased by 5.8 per cent, 10.9 per cent, 20.8 per cent and 15.1 per cent, respectively as compared those with SMBC. In comparison with first prototype, those parameters were decreased by 5.8 per cent, 16.3 per cent, 15.2 per cent and 6.4 per cent, respectively. The field capacity of second prototype of GCCPH was increased by 11.1 per cent and 7.1 per cent for paddy harvesting and grass cutting operation, respectively as compared with SMBC.

All physiological parameters were decreased with second prototype of GCCPH in comparison with the first prototype of GCCPH. The second prototype had swinging arrangement to left right movement and tilting arrangements for cutter bar to drop the cut crop on field in addition to first prototype. The operator had to operate the swinging lever and tilting lever simultaneously with pushing the machine forward. Being very new mechanism to the most of operators, who were not accustomed to its

use, might be the reason behind decrease in field capacity with respect to the first prototype of GCCPH. The field capacity would definitely increase, as the operators would acquire the operating skill.

4.8 Costing of Grass Cutter Cum Paddy Harvester

The details about the cost of developed grass cutter cum paddy harvester are given at section 3.8, while the details about its operating cost are furnished at Appendix VI.

The total cost of grass cutter cum paddy harvester prototype was ₹ 26831/- including material cost (₹ 15785/-) and fabrication cost (₹ 11046/-). The operating cost was calculated as 116.74 ₹ /h including fixed cost (15.54 ₹ /h) and variable cost (101.2 ₹ /h). The total cost of second prototype of grass cutter cum paddy harvester prototype was ₹ 28,502/- including material cost (₹ 16760/-) and fabrication cost (₹ 11742/-). The operating cost was calculated as 119.09 ₹ /h including fixed cost (17.55 ₹ /h) and variable cost (101.54 ₹ /h).

CHAPTER V

SUMMERY AND CONCLUSIONS

Paddy is the most important cereal crop and dietary staple food in India. It is the good source of vitamin B1, vitamin B2, and vitamin B3. India is the second largest producer and consumer of paddy in the world and accounts for 22.3% of global production with production 105.3 million (Khatkaret *al.*, 2016). In Maharashtra paddy is grown in different regions. The area under paddy cultivation is more in Vidarbha region but the productivity of the paddy is highest in Konkan region. Harvesting of paddy is one of the major field operation in rice production. Traditionally paddy is harvested manually with sickle and it require 185-340 man-h/ha (Michel and Ojha, 1987). Different type of paddy harvesting machines are available in the market, but it requires skilled person and high initial cost. Farmers in Konkan region cultivated paddy on sloppy land with small and fragmented landholding. Hence, adoption of harvesting machineries like combine harvester or reaper is limited. In Konkan paddy is harvested mostly by traditional method which is time consuming and drudgeries. The another method adopted for paddy harvesting is by shoulder mounted brush cutter. It is also used for grass cutting as well as paddy harvesting. It cuts paddy and grass with rotary cutting mechanism. The standard duration of daily work with brush cutter is 3.5 hrs. (Krzysztof, 2015). The forces and vibrations produced by brush cutter are directly transmitted to the operator's body. It is reported that the use of these machines may lead to musculoskeletal disorders in the long term (Viveket *al.*, 2020)

It was necessary to quantify the drudgery in shoulder mounted brush cutter for grass cutting and paddy harvesting operation. Before, developing the grass cutter cum paddy harvester, it was important to take operators opinion for health hazards and drudgery in operation with shoulder mounted brush cutter and also to evaluate it ergonomically, in order to improve the fit between the physical demand of tool and the worker who perform the work. The components of the grass cutter cum paddy harvester were developed based on ergonomic and mechanical considerations.

Initially the survey of shoulder mounted brush cutter regarding aspects in grass cutting and paddy harvesting was conducted in different villages in Konkan by preparing a questionnaire. The questionnaire included the description of workplace, worker description, description of shoulder mounted brush cutter, aspects in grass

cutting and paddy harvesting operation, ergonomic aspects in grass cutting and paddy harvesting operation, technical aspects in grass cutting and paddy harvesting operation, work safety in grass cutting and paddy harvesting operation, etc. From the survey it was observed that the users had posture related occupational hazards in which 97 per cent users suffered from shoulder pain. The reason for forced posture was engine weight.

To quantify the physiological cost and drudgery involved in shoulder mounted brush cutter the experiment was carried out with six male subjects. The performance and ergonomical evaluation carried out to know the field capacity, physiological parameters like working heart rate, oxygen consumption rate (OCR), energy expenditure rate, work pluse (ΔHR) and subjective discomfort scores as, body part discomfort score (BPDS) and overall discomfort rating (ODR). From the study it was found that, for grass cutting and paddy harvesting operation, the OCR was greater than the acceptable work load (AWL) and the operation caused the sever discomfort in the right shoulder, right forearm and right arm, etc. The workload with shoulder mounted brush cutter was under 'moderately heavy' category for paddy harvesting as well as grass cutting operation. The working heart rate (WHR) and energy expenditure rate (EER) with shoulder mounted brush cutter were 121.83 (± 9.51) bpm and 24.03 (± 5.8) kJ/min for paddy harvesting, whereas 101.17 (± 8.66) bpm and 17.96 (± 7.02) kJ/min for grass cutting operation.

In order to reduce the drudgery, it was decided to shift the weight of engine from operators shoulder to trolley. The components of grass cutter cum paddy harvester (GCCPH) were developed using anthropometric data of users population. The handle height, grip diameter and grip length etc. were designed ergonomically so as to make it suitable for worker. The handle height, grip diameter and grip length were taken as 1011.5 mm, 31 mm and 105 mm, respectively. The mechanical components as power requirement, transmission shaft, cutting blade, axel and transport wheels, engine mounting frame, handle, etc. were designed. The overall dimensions (size) of developed GCCPH was 1500 mm, 475 mm and 1011 mm in length, width and height, respectively. The weight of the machine was 17.75 kg. The performance and ergonomic evaluation of developed GCCPH was carried out. Six male subjects were participated in the experiment. From the experiment it was found that the filed capacity and field efficiency of developed GCCPH prototype was greater than the existing shoulder mounted brush cutter. The working heart rate

(WHR) and energy expenditure rate (EER) were 121 ($\pm$ 14.51) bpm and 23.18 ($\pm$ 4.77) kJ/min, respectively for paddy harvesting, whereas those values were 107.67 ($\pm$ 6.22) bpm and 18.06 ($\pm$ 2.78) kJ/min, respectively for grass cutting operation. The working heart rate of the subject with GCCPH prototype was greater than the existing SMBC. There was not proper provision for right left swinging of cutter bar at the end of cutting stroke the cutter bar got lifted up causing uneven stubble cutting height. Similarly, there was no tilting arrangement for cutter bar to discharge the cut crop at the end of stroke. Hence, second prototype of GCCPH was planned. It had cutter bar swinging and tilting arrangement. The swinging lever was operated by right hand. The tilting mechanism was operated through cable wire controlled through tilting lever placed on left handle of the machine.

The machine handle and swinging lever handle were designed based on anthropometric data of users population. Machine handle height, its grip diameter and length were 1011.5 mm, 35.6 mm and 105 mm, respectively. The swinging lever diameter and length were 22 mm and 1010 mm, respectively. Also, the cutting blade was maintained parallel to the ground during the cutter shaft movement from right to left with providing as bearing housing mounted on the frame. The performance and ergonomical evaluation of developed second prototype of grass cutter cum paddy harvester was carried out. Six male subjects were participated in this experiment. From the study it was observed that the physiological parameters like WHR, OCR and EER were 104.83 ($\pm$ 8.75) bpm, 0.81($\pm$ 0.17) l/min and 16.88 ($\pm$ 3.53) kJ/min, respectively for grass cutting operation, whereas those values for paddy harvesting operation were 108.33 ($\pm$ 15.40) bpm, 0.99 ($\pm$ 0.35) l/min and 20.87 ($\pm$ 7.27) kJ/min, respectively. The WHR, OCR, EER and Δ HR values were less than the shoulder mounted brush cutter as well as prototype of grass cutter cum paddy harvester.

Conclusions

- 1) From the results of the survey it was observed that there is a need to reduce the drudgery and health hazards in shoulder mounted brush cutter as well as evaluate it ergonomically.
- 2) The physiological cost and drudgery involved in shoulder mounted brush cutter was assessed, with six male subjects for grass cutting and paddy harvesting operation. The mean working heart rate (WHR) during paddy harvesting and grass cutting operation with SMBC were 121. 83 ($\pm$ 9.51) bpm and 101.17 ($\pm$ 8.66) bpm, respectively. The mean energy expenditure rate

(EER) during paddy harvesting and grass cutting operation were 24.03 ($\pm$ 5.8) kJ/min and 17.96 ($\pm$ 7.02) kJ/min, respectively. The work pluse (Δ HR) for paddy harvesting and grass cutting operation were 41.5 ($\pm$ 7.89) bpm and 17.67 ($\pm$ 9.7) bpm, respectively.

- 3) In operation with SMBC the mean overall discomfort rating (ODR) for paddy harvesting and grass cutting were 6.167 and 4.8, respectively. While the mean body part discomfort rating (BPDS) for paddy harvesting and grass cutting were 28.79 and 17.21, respectively. The field capacity of shoulder mounted brush cutter for paddy harvesting and grass cutting were 0.009 ha/h and 0.028 ha/h, respectively.
- 4) The workload with shoulder mounted brush cutter for paddy harvesting as well as for grass cutting was 'moderately heavy'.
- 5) The prototype of GCCPH was developed based on ergonomic and mechanical considerations. The various dimensions as handle height, length of handle, size of grip and length of grip, etc. were optimized based on anthropometric data of male worker of Konkan region which were 1011.5 mm, 1200 mm, 31 mm and 105 mm, respectively
- 6) The physiological cost and drudgery involved in developed GCCPH prototype was assessed, with six male subjects for grass cutting and paddy harvesting operation. The mean working heart rate (WHR) during paddy harvesting and grass cutting operation with GCCPH prototype were 121 ($\pm$ 14.505) bpm and 107.667 ($\pm$ 6.218) bpm, respectively. The mean energy expenditure rate (EER) during paddy harvesting and grass cutting operation were 23.18 ($\pm$ 4.77) kJ/min and 18.06 ($\pm$ 2.78) kJ/min, respectively. The work pluse (Δ HR) for paddy harvesting and grass cutting operation with GCCPH prototype were 43.17 ($\pm$ 14.39) bpm and 25.83 ($\pm$ 9.83) bpm, respectively.
- 7) The mean overall discomfort rating (ODR) with developed GCCPH prototype for paddy harvesting and grass cutting operation were 5 and 3.3, respectively. While the mean body part discomfort rating (BPDS) for paddy harvesting and grass cutting were 23.63 and 15.75, respectively. The field capacity of developed grass cutter cum paddy harvester prototype for paddy harvesting and grass cutting were 0.014 ha/h and 0.038 ha/h, respectively.
- 8) The workload in operation with grass cutter cum paddy harvester prototype for paddy harvesting as well as for grass cutting was 'moderately heavy'.

- 9) The second prototype of GCCPH was also developed based on ergonomic and mechanical considerations. The various dimensions as arm reach, handle height, length of handle, size of grip and length of grip etc. were optimized based on anthropometric data of male worker of Konkan region, which were 770 mm, 1011.5 mm, 720 mm, 35.6 mm and 105 mm, respectively
- 10) The physiological cost and drudgery involved in developed second prototype of GCCPH was assessed, with six male subjects for grass cutting and paddy harvesting operation. The mean WHR during paddy harvesting and grass cutting operation with second prototype of GCCPH were 108.33 (± 15.40) bpm and 104.83 (± 8.75) bpm, respectively. The mean EER during paddy harvesting and grass cutting operation were 20.88 (± 7.27) kJ/min and 16.88 (± 3.53) kJ/min, respectively. The work pluse (ΔHR) for paddy harvesting and grass cutting operation were 28.67 (± 8.55) bpm and 22.5 (± 11.13) bpm, respectively.
- 11) The mean overall discomfort rating (ODR) with developed second prototype of GCCPH for paddy harvesting and grass cutting operation were 4.67 and 3.83, respectively. While the mean body part discomfort rating (BPDS) for paddy harvesting and grass cutting were 11.5 and 14.62, respectively. The field capacity of second prototype of grass cutter cum paddy harvester for paddy harvesting and grass cutting were 0.010 ha/h and 0.030 ha/h, respectively.
- 12) The workload in operation with second prototype of grass cutter cum paddy harvester for paddy harvesting and grass cutting was 'moderately heavy'.
- 13) From the comparison of SMBC, GGCPH prototype and second prototype of GCCPH it was observed that ΔHR , ΔOCR , ODR, BPDS of second prototype of GCCPH in comparison with SMBC was decreased by 30.9%, 21.4%, 24.2% and 59.6%, respectively in paddy harvesting operation. Similarly, ΔOCR , ODR and BPDS scale was decreased by 10.9%, 20.8% and 15.1%, respectively in grass cutting operation. All the physiological parameters were decreased in second prototype in compared with first prototype.
- 14) The field capacity of second prototype of GCCPH was increased by 11.1% and 7.1% for paddy harvesting and grass cutting operation, respectively in comparison with SMBC. Similarly, those values were decreased by 28.6% and 21.1%, respectively in comparison with first prototype of GCCPH.

- 15) The operator had to operate the swinging lever and tilting lever simultaneously with pushing the machine forward. Being very new mechanism to the most of operators, who were not accustomed to its use, might be the reason behind decreased in field capacity with respect to the first prototype of GCCPH. The field capacity would definitely increase, as the operators would acquire the operating skill.
- 16) The total cost for prototype of GCCPH was ₹ 26831/- including material and fabrication cost. The operating cost of GCCPH prototype was ₹ 116.74/h including fixed and variable cost. The total cost of second prototype of GCCPH was ₹ 28502/- including material and fabrication cost. The operating cost for second prototype of GCCPH was ₹ 119.09/h including fixed and variable cost.

SUGGESTIONS FOR FUTURE RESEARCH WORK

Based on the working of second prototype of grass cutter cum paddy harvester, the following suggestions are proposed.

1. The swinging lever and tilting lever may be fitted on single handle for ease of handling.
2. The angular movement of the cutter shaft may be increased for more field capacity.
3. The tilting of hingmay be increased for easy discharge of cut crop on ground.

CHAPTER VI

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CHAPTER VII

APPENDICES

APPENDIX I

A. Questionnaire for Health Hazards and Drudgery In Operation with shoulder mounted brush cutter (SMBC)

Date:-----

Place:-----

I. Description of the workplace:

1. Name of the village:
2. Farmers Name:
3. Survey no:
4. Area of the field:
5. Type of field:
6. Location of the field from farmers residence:
7. Temperature (WB):
8. Temperature (DB):
9. Humidity (%):
10. Date of sowing:

II. Workerdescription:

1. Name:
2. Age: Sex: (Male/Female)
3. Height:
4. Weight -----kg
5. Maritalstatus: (Married / Unmarried)
6. Educationalstatus:
7. Annual Income(Rs.):
8. Experience(y)
9. Working time in aday (h):From to_____
10. Work posture adopted in grass cutting and paddy harvesting operation

a) Standing

11. General healthstatus for soulder mounted brush cutter

a) Complaints:

b) Injuries:

12. Work output

a) Grass cutting (ha/h)

b) Paddy harvesting (ha/h)

13. Precautionary measures are taken (Safety kit)

a) Nose mask (Y/N)

b) Gloves (Y/N)

c) Earplugs (Y/N)

d) Helmet (Y/N)

e) Goggle (Y/N)

f) Gumboot (Y/N)

14. Occupational hazards

A) Work and workplace related

a) Frequent hand injury

b) Frequent leg injury

c) Body ache and headache

B) Posture related

a) Leg Pain

i. One or both hips

ii. One or both thighs

iii. One or both ankles

iv. One or both feet

b) Knee pain

c) Hand Pain

i. Shoulder

- ii. Lower arm
 - iii. Upper arm
 - iv. Wrist
 - v. Elbow
- d) Back Pain
 - i. Upper back
 - ii. Lower back
- e) Neck Pain
- f) Waist Pain

Work description:

Give details of the grass cutting and rice harvesting work hazards if any

III. Description of shoulder mounted brush cutter.

- a) Available power
- b) Type of prime mower
- c) Type of fuel used
- d) Fuel requirement
- e) Type of cutting mechanism

IV. Aspects of grass cutting and paddy harvesting operation.

(Worker's answer/ratings)

1) A requirement of job Specialization:

Grass cutting and paddy harvesting operations are simple and uncomplicated.

Yes/No

If **No**, rate the following:

(Enter 0-5)

- 1) Tools and methods used are specialized for the grass cutting and paddy harvesting.
- 2) The position adopted for grass cutting and paddy harvesting is not comfortable.

3) Does a worker perform multiple tasks?

4) Grass cutting and paddy harvesting is predominantly dynamic work.

2) Skill Requirement:

Grass cutting and paddy harvesting do not require elementary skills. **Yes/No**

If **No**, rate the following: **(Enter 0-5)**

1) Grass cutting and paddy harvesting require knowledge and skillfulness.

2) Grass cutting and paddy harvesting demand training for skill acquisition.

3) The worker makes frequent mistakes during the operation.

3) General physical activity:

Physical activity is entirely determined and regulated by the worker. **Yes/No**

If **No**, rate the following: **(Enter 0-5)**

1) A worker maintains a target-oriented pace.

2) Cutting and harvesting operation demands high muscular strength exertion.

3) The operation of the handle is predominantly static work.

4) Cardiorespiratory demand of the job.

sedentary/light/moderate/heavy/ extremely heavy.

(What are the heavy work elements?):

V. Ergonomics aspect:

1) Work Posture

Grass cutting and paddy harvesting allow a relaxed work posture. **Yes/No**

If **No**, rate the following: **(Enter 0-5)**

- 1) Frequent movement of the forearm (Extension and flexion).
- 2) The back position is bent and twisted.
- 3) The movement of the body is one-sided and unsymmetrical.
- 4) Hips and legs are not well supported during operation.
- 5) Reasons for forced posture:
- 6) Location of a cutting blade

2) Noise

The noise level during the operation is below the normally bearable sound level **Yes/No**

3) Vibration

Do you feel whether the vibration are transmitted to your body through machine

Yes/No **If No, rate the following (Enter 0-5)**

- 1) Vibration is transmitted to the body through the hand-arm system.
- 2) Identify the sources of vibration.

4) Controls

Controls (e.g., switches, knobs) are easy to handle. **Yes/No**

If **No**, the causes are

- 1) The hand control position is awkward.
- 2) Dimensions of control do not match the body part.
- 3) Control requires a high actuating force.

4) Controls are not shape-coded for good grip

5) Controls cause an unpleasant feeling (warmth, cold, vibration).

Remarks and suggestions for improvement of the above item

VI. Technical aspect Your answer/ratings

Machinery

Shoulder mounted brush cutter is easy to drive and work

Yes/No

If **No**, rate the following **(Enter 0-5)**

- 1) The machine is unstable in operation
- 2) Machine require heavy maintenance
- 3) The machine is poorly equipped for vibration damping
- 4) The machine noise level is below bearable level

Remarks and suggestions for improvement of the above item

VII. Work safetyYour answer/ratings

Machine safety measures are adequate to prevent accidents and health hazards.

Yes/No

If **No**, rate the following **(Enter 0-5)**

- 1) The cutting blade is not adequately guarded.
- 2) Direct/indirect contact of body parts with a machine can cause hazards
- 3) Difficulty in inspection and maintenance of the machine.

- 4) No clear instructions available for machine operation, maintenance, and safety

Remarks and suggestions for improvement of the above item

APPENDIX I

B. Workplace description

Sr. No	Name of village	Name of farmer	Survey No	Area of field (ha)	Type of field	Location of field from farmers residence (km)	Atmospheric Temperature (WB)	Atmospheric Temperature (DB)	Relative humidity (%)	Date of sowing
1	Kudawale	VikasBhuvad	2424/1	0.405	Paddy	1.5	22.5	30.5	50	July
2	Kudawale	Kishor More	-	1.821	Paddy, Vegetables	0	22.5	30.5	50	July
3	Kudawale	DilipGhubde	-	-	-	-	22.5	30.5	50	-
4	Kadiwale	Ashish Sawant	-	0.121	Paddy	0.5	24	26	85	July
5	Awashi	SufalKamat	-	1.214	Paddy, Vegetables	0	22.5	30	52	July
6	Kudawale	ShekharKadam	58	1.416	Paddy	0.3	20.5	29.5	44	July
7	Kudawale	DarshanRahate	80/2	0.364	Paddy, Vegetables	1	26	30.5	70	July

8	Kudawale	Eknath More	287 288 1/2	1.669	Paddy, Finger millet	0.002	22.5	24	88	July
9	Kiramba	Sachin Sable	222	0.404	Paddy, Finger millet	0.05	20	26	58	July
10	Katkarwadi	PiyushWispute	187 2:2	0.058	Paddy	0.002	24	26	85	July
11	Karanjani	Prakash Oak	1182	20.23	Mango, Cashew	2	25	27.8	78	-
12	Katkarwadi	Anil Jadhav	-	4.047	Cashew	1	24	26	85	-
13	Bondiwali- Thorlekond	Vijay Nande	102	0.101	Paddy, Cashew	1.5	25	31	61	July
14	Bondiwali- Thorlekond	ArunKatkar	-	-	-	-	25	31	61	-
15	Kherdi	NareshPawar	-	0.404	Paddy, Finger millet	0.005	24.5	31.5	56	July
16	Thorlekond	Prathmesh Jade	-	-	-	-	26	32	62	July
17	Kondhalgond	BhaskarMurchw ade	103	0.0404	Paddy	0.005	22.5	31	48	June
18	Thorlekond	SandipPawar	-	-	-	-	26	32	62	-

19	Chondraugon	SudeshGawade	-	0.0404	Paddy	0.5	27	32	68	-
20	Ladghar	SahilSurve	-	2.428	Paddy, Mango	1	27	32	68	June
21	Navashi	Sachin More	-	0.152	Paddy	1	28.5	31.5	80	July
22	Mhalunge	Prasad Holkar	-	-	-	-	25	29	72	-
23	Jalgaon	ShubhamWadkar	-	0.0455	Paddy	0.5	25.5	28	82	July
24	Pangarwadi	ManojPawar	-	0.0202	Paddy, Finger millet	2	25	31	61	July
25	Kelashi	Shubham Vadurkar	-	0.0404	Paddy	2	28.2	32	74	July
26	Bagmandla	SiddheshKolthar kar	-	0.0404	Paddy	0.5	25.5	30	70	July
27	Ghimavne	Pankaj Duble	-	0.1214	Paddy	7	28	32	74	July
28	Gave	ManojGurav	-	-	-	-	28.5	32.1	74	-
29	Jalgaon	Ashish Govle	126/1B	0.202	Paddy	2	27	31	73	June
30	Ghimavan	Prasad Bhuwad	-	2.0234	Paddy, Finger millet, Mango, Cashew	5	25	29	72	July

APPENDIX I

C. Workers description

Name	Age	Height (cm)	Weight (kg)	Marital status	Annual income (₹)	Educational status	Experience (y)	time in a day (h)	Work posture	Health status		Work output (ha/h)		Precautionary measures					
										Previous complaints	Previous injuries	Grass cutting	Paddy harvesting	Nose mask	Gloves	Earplugs	Helmet	Goggle	Gumboot
VikasBhuvard	27	165	65	U	≤100000	Educated	6	6	Standing	Y	Y	0.012	0.0101	Y	N	N	Y	N	N
Kisan More	30	150	65	M	100000	Educated	5	8	Standing	Y	Y	0.0212	0.0168	N	N	N	Y	N	N
DilipGhubade	45	180	55	M	≤100000	Educated	2	7	Standing	N	N	0.0152	0.0101	N	N	Y	Y	N	N
Ashish Swanat	22	150	70	U	≤100000	Educated	4	7	Standing	N	N	0.0152	0.0101	N	N	N	N	N	N
Sufal Kamath	47	180	70	M	≥100000	Educated	3	8	Standing	Y	N	0.0303	-	Y	Y	Y	Y	N	Y
ShekharKadam	40	168	78	M	100000	Educated	8	8	Standing	Y	Y	0.0354	0.0202	Y	N	N	N	N	N
DarshanRahate	23	168	53	U	≤100000	Educated	3	7	Standing	N	N	0.0152	0.0202	N	Y	N	Y	N	N
Eknath More	43	165	66	M	≥100000	Educated	4	10	Standing	Y	Y	0.0202	-	Y	Y	N	Y	N	N

Sachin Sable	38	165	70	M	≤100000	Educated	10	8	Standing	N	N	0.0152	0.0102	N	Y	Y	Y	N	Y
PiyushWisp ute	37	168	80	M	≥100000	Educated	10	7	Standing	Y	N	0.0202	0.0354	Y	N	N	Y	Y	Y
Prakash Oak	60	165	70	M	≥100000	Educated	10	2	Standing	Y	N	0.0101	-	Y	N	N	Y	N	Y
Anil Jadhav	21	180	48	M	≤100000	Educated	5	8	Standing	Y	N	0.0152	0.0253	Y	N	N	Y	Y	Y
Vijay Nande	48	165	68	M	≤100000	Educated	4	5	Standing	Y	Y	0.0506	0.0303	Y	N	N	N	N	N
ArunKatkar	34	162	54	M	≤100000	Educated	3	9	Standing	Y	Y	0.0251	0.0151	N	N	N	N	N	N
NareshPawa r	48	180	82	M	≤100000	Educated	16	7	Standing	N	N	0.0202	0.0152	N	N	N	N	N	N
Prathmesh Jade	21	160	52	M	≤100000	Educated	3	10	Standing	Y	Y	0.0202	-	N	N	N	N	Y	N
BhaskarMur chwade	40	165	60	M	≤100000	Educated	5	8	Standing	Y	N	0.0202	0.0303	Y	N	N	Y	Y	Y
SandipPawa r	36	163	58	M	≤100000	Educated	4	7	Standing	Y	Y	0.0251	0.0101	N	N	N	N	N	N
SudeshGava de	32	159	60	M	≤100000	Educated	1	9	Standing	Y	Y	0.0101	0.0101	N	N	N	Y	N	N
SahilSurve	23	162	55	U	≥100000	Educated	1	3	Standing	Y	N	0.0202	-	Y	Y	N	Y	N	N
Sachin More	35	165	50	M	≤100000	Education	1	3	Standing	Y	Y	0.0303	-	N	N	N	N	N	N
Prasad Holkar	26	165	46	U	≥100000	Educated	2	3	Standing	Y	Y	0.0101	0.0101	N	N	N	N	N	N
Manoj Pawar	43	170	50	M	≥100000	Educated	10	8	Standing	N	N	0.0151	0.0101	Y	N	N	N	Y	Y

ShubhamWadakar	26	150	55	U	≤ 100000	Educated	6	2	Standing	Y	N	0.0202	-	Y	Y	Y	N	N	Y
ShubhamVadurkar	26	168	70	U	≥ 100000	Educated	3	3	Standing	Y	N	0.0202	-	N	N	N	N	N	N
SiddheshKotharkar	25	159	52	U	≥ 100000	Educated	2	2	Standing	Y	N	0.0252	-	N	N	N	Y	N	N
PankajDuble	26	174	60	U	≤ 100000	Educated	3	7	Standing	Y	Y	0.0505	-	N	N	N	N	Y	N
ManojGurav	35	145	56	M	100000	Educated	8	9	Standing	Y	N	0.0151	0.0101	Y	N	N	N	N	N
AshishGovale	28	168	67	U	≤ 100000	Educated	6	8	Standing	Y	Y	0.0151	0.0101	Y	N	N	Y	N	N
PrasadBhuwad	42	159	65	M	≥ 100000	Educated	8	6	Standing	Y	N	0.0213	0.0163	Y	N	N	Y	N	N

APPENDIX I

D. Occupational hazards

Sr. No	Particulars	Nos. (per cent)	
		Yes	No
1	Work and workplace related		
	Frequent hand injury	10	90
	Frequent leg injury	57	43
	Body ache and headache	77	23
2	Posture related		
	a) Leg pain		
	i) One or both hips	13.3	86.7
	ii) One or both thighs	33.3	66.7
	iii) One or both ankles	0	100
	iv) One or both feet	16.6	83.4
	b) Knee pain	26.6	73.4
	c) Hand pain		
	i) Shoulder	97	3
	ii) Lower arm	70	30
	iii) Upper arm	63.3	36.6
	iv) Wrist	46.7	53.3
	v) Elbow	16.6	83.4
	d) Back pain		
	i) Upper back	70	30
	ii) Lower back	83.3	16.6
	e) Neck Pain	20	70
	f) Waist pain	33.3	66.7

APPENDIX I

E. Description of Shoulder Mounted Brush Cutter (SMBC)

Sr. No.	Parameters	Per cent
1.	Available power (hp)	
	a. ≤ 1.8	36.7
	b. ≥ 1.8	63.3
2.	Type of prime mower	
	a. Two stroke	80
	b. Four stroke	20
3.	Type of fuel used	
	a. Petrol and oil	80
	b. Petrol	20
4.	Fuel requirement (l/h)	
	a. ≤ 1.2	63.3
	b. ≥ 1.2	36.7

APPENDIX I - F

A. Rating

0- Do not know or not applicable

1- Strongly disagree

2- Disagree

3- Neither agree nor disagree

4- Agree

5- Strongly agree

B. Aspects in grass cutting and paddy harvesting operation

1	Requirement of job specialization	Yes	No	Rating (per cent)					
				0	1	2	3	4	5
	Grass cutting and paddy harvesting operations are simple and uncomplicated	40	60						
	a. Tools and methods used are specialized for the grass cutting and paddy harvesting					5.5	11.1	66.7	16.7
	b. The position adopted for grass cutting and paddy harvesting is not comfortable					5.5	5.6	83.4	5.5
	c. Does a worker perform multiple tasks?					11.1		55.6	33.3
	d. Grass cutting and paddy harvesting is predominantly dynamic work.							72.3	27.7

2.	Skill Requirement								
	Grass cutting and paddy harvesting doesn't require elementary skills.	70	30						
	a. Grass cutting and paddy harvesting require knowledge and skillful ability.						11.1	55.5	33.3
	b. Grass cutting and paddy harvesting demand training for skill acquisition.					11.1		77.8	11.1
	c. The worker makes frequent mistakes during the operation.					33.3		11.1	55.5
3.	General physical activity								
	Physical activity is entirely determined and regulated by the worker.	66.6	33.3						
	a. A worker maintains a target-oriented pace.					5		70	25
	b. Cutting and harvesting operation demands high muscular strength exertion.							75	25
	c. The operation of the handle is predominantly static work.				15	50		15	20

	d. Cardiorespiratory demand of the job (sedentary/light/moderate/heavy/extremely heavy)							75	25
	i. Sedentary	3.3							
	ii. Light	6.7							
	iii. Moderate	20							
	iv. Heavy	36.7							
	v. Extremely heavy	33.3							

C. Ergonomic aspects in grass cutting and paddy harvesting operation

1.	Work posture								
	Grass cutting and paddy harvesting allow a relaxed work posture.	20	80						
	a. Frequent movement of the forearm (Extension and flexion).					4.1		83.4	12.5
	b. The back position is bent and twisted.							87.5	12.5
	c. The movement of the body is one sided and unsymmetrical					12.5	4.2	33.3	50
	d. Reasons for forced posture:								
	i. Engine weight	31.6							
	ii. High density of grass	19.3							
	iii. Heavy machine	21							
	iv. Length of shaft	18.2							
	v. Improper harness	9.8							

	adjustment								
	e. Location of a cutting blade								
	i. Suitable	81.7							
	ii. Unsuitable	18.3							
2.	Noise								
	Noise level during operation is below normally bearable sound level	56.6	43.3						
3.	Vibration								
	Do you feel whether the vibration are transmitted to your body through machine	86.7	13.3						
	a. Vibration is transmitted to the body through the hand-arm system.					3.8		84.6	11.5
	b. Identify the sources of vibration.								
	i. Engine	37.5							
	ii. Cutting blade	40							
	iii. Shaft length	5							
	iv. Speed	2.5							
	v. Shaft rotation	2.5							
	vi. Handle	12.5							
4.	Controls								
	Controls (e.g., switches, knobs) are easy to handle	63.3	36.7						
	a. The hand control position is awkward.				18.1	18.2		36.5	27.2
	b. Dimensions of				18.2	45.4		36.4	

	control do not match the body part								
	c. Control requires a high actuating force				9	54.5	18.1	9	9
	d. Controls are not shape-coded for good grip				9	45.7	9	36.3	
	e. Controls cause an unpleasant feeling (warmth, cold, vibration).							81.8	18.2

D. Technical aspect in grass cutting and paddy harvesting operation

1.	Machinery								
	Shoulder mounted brush cutter is easy to drive and work	33.3	66.7						
	a. The machine is unstable in operation					30		35	35
	b. Machine require heavy maintenance							75	25
	c. The machine is poorly equipped for vibration damping							85	15
	d. Machine noise level is below bearable level					25		40	35

E. Work safety in grass cutting and paddy harvesting operation

1	Work safety
----------	--------------------

	Machine safety measures are adequate to prevent accidents and health hazards.	53.3	46.7						
	a. The cutting blade is not adequately guarded.				7.1	64.2		28.5	
	b. Direct/indirect contact of body parts with a machine can cause hazards				7.1			57.1	35.7
	c. Difficulty in inspection and maintenance of the machine.				64.3			28.6	14.3
	d. No clear instructions available for machine operation, maintenance, and safety				35.7			64.3	

APPENDIX II

A. Specifications of bicycle ergometer (Monark 839E) (Annonomus, 2014)

Sr. No	Particulars	Specifications
A)	Dimensions	
1.	Length, mm	1150
2.	Width, mm	

	At handlebar	517
	At support tube	640
3.	Height, mm	
	At handlebar, mm	945-1295
	At seat, mm	790-1110
4.	Weight, kg	56
5.	Maximum user weight, kg	250
B)	Electrical	
1.	Voltage (AC), v	18
2.	Brake power at 200 rpm, w	0-1400
3.	Current, mA	650
C)	Measured quantities	
1.	Distance: (meters, miles)	
2.	Energy: (kcal)	
3.	Heart rate: (bpm)	
4.	Force: (N), (kp)	
5.	Power: (w)	
6.	Time: (min, sec)	
7.	Weight: (kg)	
D)	Preprogramed protocols	
1.	Astrand	
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

APPENDIX II

B. Specifications of the energy measurement system (K4b²) (COSMED, Italy) (Anonymous, 2003).

Sr. No.	Particulars	Specifications
A)	Portable Unit	
1.	Memory, breaths	16,00
2.	Display LCD	2 lines × 16 characters
3.	Serial port	RS 232C

4.	Power Supply	Ni-MH rechargeable batteries
5.	Thermometer, °C	0-50
6.	Barometer, Kpa	53-106
7.	Dimensions of portable unit, mm	170 × 55 × 100
8.	Dimensions of battery, mm	120 × 20 × 80
9.	Weight, g	400
B)	Receiver Unit	
1.	Transmission range, m	800
2.	Battery, v (AC)	4 × 1.5
3.	Dimensions, mm	170 × 48 × 90
4.	Weight, g	550
5.	PC interface	RS 232
C)	Battery charger Unit	
1.	Power supply, v	120 - 240
2.	Power consumption, w	25
D)	Flowmeter	
1.	Type	Bidirectional digital turbine ϕ 28 mm
2.	Flow range, l/s	0.03 - 20
3.	Accuracy, %	± 2
4.	Ventilation range, lit × min	0 - 300
E)	Oxygen Sensor (O₂)	
1.	Response time, ms	< 150
2.	Range, %	7 - 24
3.	Accuracy, %	± 0.02
F)	Carbon Dioxide Sensor (CO₂)	
1.	Response time, ms	< 150
2.	Range, %	0 - 8
3.	Accuracy, %	± 0.01

G)	Humidity absorber	
1.	Capillary of Nafion	
H)	Power Supply	
1.	Voltage, v	100 - 240
2.	Power consumption, w	60
I)	Environmental Sensors	
1.	Temperature, °C	0 - 50
2.	Barometer, mm Hg	400 - 800
3.	Humidity, %	0 - 100

APPENDIX II

C. Specifications of Computerized polar heart rate monitor (FT7) (Polar China)

Sr. No	Particulars	Specifications
A)	Transmitter	
1.	Battery type	CR2025
2.	Battery life	400 h
3.	Operating temperature	-10°C to +50°C
4.	Strap material	Polyamide (38%), Polyurethane (29%), Elastane (20%), Polyester (13%), Silicon prints
B)	Wrist unit (Polar FT7)	

1.	Battery type	CR1632
2.	Battery life	Average 11 months (training 1 h/day, 7 days/week)
3.	Operating temperature	-10°C to +50°C
4.	Back cover	Polyamide
5.	Wrist strap material	Polyurethane
6.	Watch accuracy	Better than ± 0.5 sec/day at 25°C teperature

APPENDIX III

A.Details of subjects

Sr. No	Name	Code	Age (Year)	Weight (kg)	Stature (cm)	HR max (bpm)
1	Sachin Sable	SS	39	53	160	181
2	Prasad Holkar	PH	27	47	165	193
3	Sanjay Jadhav	SJ	51	53	159	169
4	SujitPawar	SP	39	70	174	181
5	Hemant Pagade	HP	40	61	159	180

6	Manoj Pawar	MP	30	50	174	190
Average			37.67	55.67	165.17	182.33
SD			± 8.48	±8.43	±7.19	±8.48

B. Maximum aerobic capacity of subject (VO₂ max)

Subject	Subject Code	Maximum Heart Rate (HR _{max}), bpm	Maximum Aerobic Capacity (VO ₂ max), l/min
1	SS	181	1.92
2	PH	193	2.99
3	SJ	169	2.39
4	SP	181	2.36
5	HP	180	2.23
6	MP	190	2.42
Average		182.333	2.39
SD		± 8.477	± 0.3463

APPENDIX IV

A. Subjects heart rate during calibration process

Sr. No.	Time	SS	PH	SJ	SP
1	00:01:00	77	78	60	77
2	00:02:00	81	76	61	72
3	00:03:00	78	81	62	75
4	00:04:00	74	83	61	73
5	00:05:00	76	77	60	72
6	00:06:00	79	92	79	86
7	00:07:00	83	90	72	81
8	00:08:00	80	87	71	82

9	00:09:00	83	88	71	82
10	00:10:00	88	100	69	84
11	00:11:00	100	106	68	83
12	00:12:00	94	104	69	86
13	00:13:00	94	116	77	89
14	00:14:00	103	122	92	90
15	00:15:00	109	130	97	87
16	00:16:00	110	131	101	95
17	00:17:00	114	141	112	102
18	00:18:00	123	147	116	102
19	00:19:00	126	155	112	107
20	00:20:00	133	138	128	110
21	00:21:00	132	103	135	110
22	00:22:00	142	92	122	118
23	00:23:00	125	90	119	121
24	00:24:00	90	87	117	128
25	00:25:00	90	88	98	133
26	00:26:00	84		78	151
27	00:27:00	81		72	129
28	00:28:00	85		77	91
29	00:29:00	86		76	85
30	00:30:00	83		76	85
31	00:31:00	82			82
32	00:32:00	81			82
33	00:33:00	79			82
34	00:34:00				78
35	00:35:00				82
36	00:36:00				76
Avg.		95.30303	104.08	86.93333	93.55556
SD		±19.58872	±23.97728	±23.2378	±19.66933

APPENDIX IV

B. Heart rate response of the subjects during the calibration process

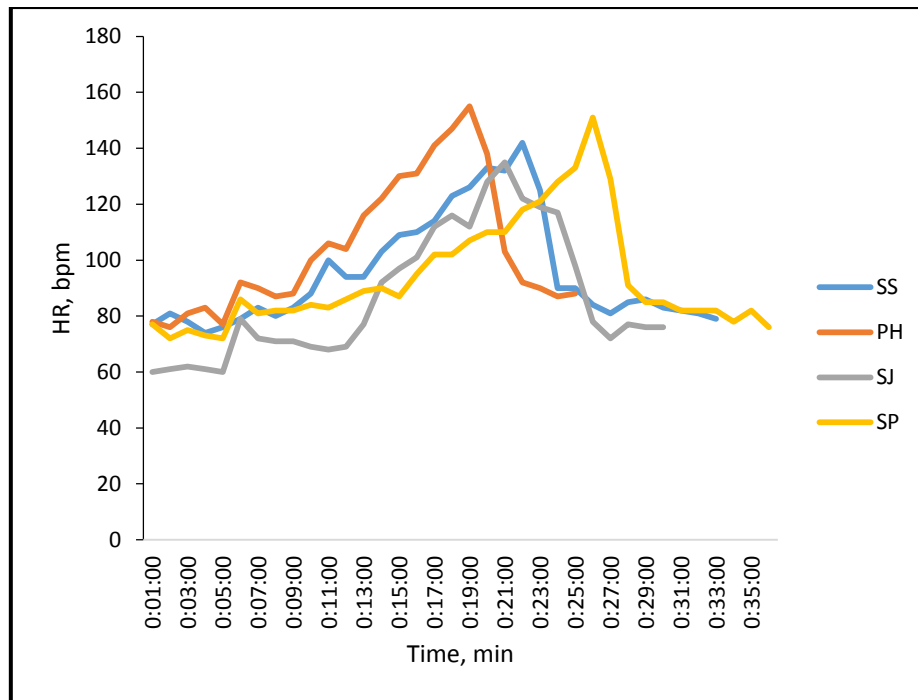


Fig. Heart rate response of subject

APPENDIX IV

C. Overall discomfort rating (ODR) of subjects in shoulder mounted brush cutter (SMBC)

Sr. No.	Subject Code	ODR	Scales
(a) Paddy Harvesting			
1	SS	6	> More than moderate discomfort
2	PH	6	> More than moderate discomfort
3	SJ	5	Moderate discomfort
4	SP	7	> More than moderate discomfort
5	HP	6	> More than moderate discomfort
6	MP	7	> More than moderate discomfort
Mean		6.167	> More than moderate discomfort
(b) Grass cutting			
1	SS	5	Moderate discomfort
2	PH	5	Moderate discomfort
3	SJ	5	Moderate discomfort
4	SP	5	Moderate discomfort
5	HP	4	Moderate discomfort
6	MP	5	Moderate discomfort
Mean		4.8	Moderate discomfort

APPENDIX IV

D) Body Part Discomfort Rating (BPDS) of subjects for shoulder mounted brush cutter (SMBC)

1. Paddy harvesting

Category	Weightage	Body part expiring pain						Score					
		SS	PH	SJ	SP	HP	MP	SS	PH	SJ	SP	HP	MP
I	10	7	4,5	5	11,5	4	5	10	20	10	20	10	10
II	7.5	20	18	4,11	4,10	18	4	7.5	7.5	15	15	7.5	7.5
III	5	-	20	13	18	20	18	-	5	5	5	5	5
IV	2.5	18	-	-	21	9	-	2.5	-	-	2.75	2.5	-
Total								20	32.5	30	42.75	25	22.5
Mean								28.79					

2. Grass cutting

Category	Weightage	Body part expiring pain						Score					
		SS	PH	SJ	SP	HP	MP	SS	PH	SJ	SP	HP	MP
I	7	5	5	4,5	5	5	11,25	7	7	14	7	7	14
II	5.25	9	11	7	9	25	7	5.25	5.25	5.25	5.25	5.25	5.25
III	3.5	11	18	-	11	4	-	3.5	3.5	-	3.5	3.5	-
IV	1.75	25	-	-	-	-	-	1.75	-	-	-	-	-
Total								17.5	15.75	19.25	15.75	15.75	19.25
Mean								17.21					

APPENDIX IV

E. Field performance of subjects with shoulder mounted brush (SMBC) cutter for paddy harvesting

Sr. No.	Subject code	Area Covered, m ²	Time required (min)	Field capacity (ha/h)	Field efficiency (%)
1. Paddy harvesting					
1	SS	40	20	0.012	33.33
2	PH	48.3	20	0.014	40.25
3	SJ	23.8	20	0.007	19.83
4	SP	28	20	0.008	23.33
5	HP	32	20	0.001	26.67
6	MP	18.44	20	0.006	15.37
Average		31.76	20	0.009	26.46
2. Grass cutting					
1	SS	102.81	20	0.031	85.68
2	PH	103	20	0.031	85.83
3	SJ	59.22	20	0.018	49.35
4	SP	94.5	20	0.028	78.75
5	HP	117	20	0.035	97.5
6	MP	85.1	20	0.026	70.91
Average		93.61	20	0.028	78.00

APPENDIX IV

F. Overall discomfort rating (ODR) of subjects in grass cutter cum paddy harvester prototype

Sr. No.	Subject Code	ODR	Scales
(a) Paddy harvesting			
1	SS	4	Moderate discomfort
2	PH	4	Moderate discomfort
3	SJ	5	Moderate discomfort
4	SP	6	> More than moderate discomfort
5	HP	6	> More than moderate discomfort
6	MP	5	Moderate discomfort
Mean		5	Moderate discomfort
(b) Grass cutting			
1	SS	3	Moderate discomfort
2	PH	4	Moderate discomfort
3	SJ	3	Moderate discomfort
4	SP	3	Moderate discomfort
5	HP	3	Moderate discomfort
6	MP	4	Moderate discomfort
Mean		3.3	Moderate discomfort

APPENDIX IV

G. Body Part Discomfort Rating (BPDS) of subjects for grass cutter cum paddy harvester prototype

1. Paddy harvesting

Category	Weightage	Body part expiring pain						Score					
		SS	PH	SJ	SP	HP	MP	SS	PH	SJ	SP	HP	MP
I	9	11	11	10	11	11	21	9	9	9	9	9	9
II	6.75	5	5	11,5,18	5	18,5	10,4,16	6.75	6.75	20.25	6.75	13.5	20.25
III	4.5	-	-	-	-	-	5,11,18	-	-	-	-	-	13.5
IV	2.25	-	-	-	-	-	-	-	-	-	-	-	-
Total								15.75	15.75	29.25	15.75	22.5	42.75
Mean								23.63					

2. Grass cutting

Category	Weightage	Body part expiring pain						Score					
		SS	PH	SJ	SP	HP	MP	SS	PH	SJ	SP	HP	MP
I	9	-	5	-	-	5	4	-	9	-	-	9	9
II	6.75	7	11	6,7	-	13	11	6.75	6.75	13.5	-	6.75	6.75
III	4.5	13	4	20	11	-	6	4.5	4.5	4.5	4.5	-	4.5
IV	2.25	-	-	21	-	-	-	-	2.25	2.25	-	-	-
Total								11.25	22.5	20.25	4.5	15.75	20.25
Mean								15.75					

APPENDIX IV

H. Field performance of subjects with grass cutter cum paddy harvester prototype

Sr. No.	Subject code	Area Covered, m ²	Time required (min)	Field capacity (ha/h)	Field efficiency (%)
1. Paddy harvesting					
1	SS	65.21	20	0.019	54.34
2	PH	44.87	20	0.013	37.39
3	SJ	42.92	20	0.013	35.77
4	SP	33.16	20	0.009	27.63
5	HP	33.16	20	0.009	27.63
6	MP	50.72	20	0.015	42.27
Average		45.01	20	0.014	37.51
2. Grass cutting					
1	SS	122.25	20	0.037	91.88
2	PH	121.5	20	0.036	84.58
3	SJ	63.07	20	0.019	68.67
4	SP	169.3	20	0.051	96.25
5	HP	118.75	20	0.036	98.95
6	MP	170.5	20	0.051	83.17
Average		127.56	20	0.038	87.25

APPENDIX IV

I. Overall discomfort rating (ODR) of subjects in developed second prototype of grass cutter cum paddy harvester

Sr. No.	Subject Code	ODR	Scales
1. Paddy harvesting			
1	SS	4	Moderate discomfort
2	PH	5	More than moderate discomfort
3	SJ	4	Moderate discomfort
4	SP	4	Moderate discomfort
5	HP	5	More than moderate discomfort
6	MP	6	More than moderate discomfort
Mean		4.67	Moderate discomfort
2. Grass cutting			
1	SS	5	More than moderate discomfort
2	PH	4	Moderate discomfort
3	SJ	4	Moderate discomfort
4	SP	4	Moderate discomfort
5	HP	3	More than light discomfort
6	MP	3	More than light discomfort
Mean		3.8	Moderate discomfort

APPENDIX IV

J. Body Part Discomfort Rating (BPDS) of subjects for developed second prototype of grass cutter cum paddy harvester

1. Paddy harvesting

Category	Weightage	Body part expiring pain						Score					
		SS	PH	SJ	SP	HP	MP	SS	PH	SJ	SP	HP	MP
I	4	5	5,13	5	5,4	4,11	5,11	4	8	4	8	8	8
II	3	13	4	4,11	13	5	4	3	3	6	3	3	3
III	2	-	-	13	11	13	-	-	-	2	2	2	-
IV	1	-	11	-	-	-	13	-	1	-	-	-	1
Total								7	12	12	13	13	12
Mean								11.5					

2. Grass cutting

Category	Weightage	Body part expiring pain						Score					
		SS	PH	SJ	SP	HP	MP	SS	PH	SJ	SP	HP	MP
I	9	5	5	7	-	-	-	9	9	9	-	-	-
II	6.75	13	-	20	7	5	9	6.75	-	6.75	6.75	6.75	6.75
III	4.5	23	11	21	11	11	18	4.5	4.5	4.5	4.5	4.5	4.5
IV	2.25	-	-	-	-	-	-	-	-	-	-	-	-
Total								20.25	13.5	20.25	11.25	11.25	11.25
Mean								14.63					

APPENDIX IV

K. Field performance of subjects with developed second prototype of grass cutter cum paddy harvester

Sr. No.	Subject code	Area Covered, m ²	Time required (min)	Field capacity (ha/h)	Field efficiency (%)
1. Paddy harvesting					
1	SS	37.69	20	0.011	31.41
2	PH	34.92	20	0.010	29.10
3	SJ	31.23	20	0.009	26.03
4	SP	46.20	20	0.014	38.50
5	HP	28.70	20	0.009	23.92
6	MP	27.84	20	0.008	23.20
Average		34.43	20	0.010	28.69
2. Grass cutting					
1	SS	112.32	20	0.034	93.6
2	PH	126.5	20	0.038	63.25
3	SJ	59	20	0.018	49.17
4	SP	101.7	20	0.031	84.75
5	HP	108.85	20	0.033	90.29
6	MP	98.40	20	0.029	82
Average		101.05	20	0.0303	77.18

APPENDIX V

The comparison evaluation data of SMBC, GCCPH prototype and second prototype of GCCPH

Parameter	SMBC		First prototype		Second prototype	
	PH	GC	PH	GC	PH	GC
WHR	121.83	101.7	121 0.6% decreased than SMBC.	107.67 5.9% increased than SMBC.	108.33 11.1% decreased than SMBC. 10.5 % decreased than first prototype.	104.83 3.1 % increased than SMBC. 2.6% decreased than first prototype.
Δ HR	41.5	17.67	43.17 4.02 % increased than SMBC.	25.83 46.2% increased than SMBC.	28.67 30.9% decreased than SMBC 33.6% decrease than first prototype.	21.5 21.7% increased than SMBC. 16.7% decrease than first prototype.
OCR	1.15	0.86	1.11 3.5% decreased than SMBC.	0.86 -	0.99 13.9% decreased than SMBC. 10.8% decreased than first prototype.	0.81 5.8% decreased than SMBC. 5.8% decreased than first prototype.
Δ OCR	0.84	0.46	0.81 3.6% decreased than SMBC.	0.49 6.5% increase than SMBC.	0.66 21.4% decreased than SMBC. 18.5% decreased than first prototype.	0.41 10.9% decreased than SMBC 16.3% decreased than first prototype.
ODR	6.2	4.8	5 19.4% decreased than SMBC.	3.3 31.3 % decreased than SMBC.	4.7 24.2% decreased than SMBC.	3.8 20.8% decreased than SMBC.

					6% decreased than first prototype.	15.2% increased than first prototype.
BPDS	28.8	17.2	23.6 18.1% decreased than SMBC.	15.6 9.3% decreased than SMBC.	11.5 59.6% decreased than SMBC. 51.3% decreased than first prototype.	14.6 15.1% decreased than SMBC. 6.4% decreased than first prototype.
F.C	0.009	0.028	0.014 55.5% increased than SMBC.	0.038 35.7% increased than SMBC.	0.01 11.1% increased than SMBC. 28.6% decreased than first prototype.	0.03 7.1 % increased than SMBC. 21.1% decreased than first prototype.

APPENDIX VI

Cost estimation of developed grass cutter cum paddy harvester

Sr. No	Particulars	Material and specifications	Rate Rs./kg	Amount Rs.
I. Grass cutter cum paddy harvester prototype				
1	Engine	2-stroke petrol engine, 1.95 hp and 6500-7500 rpm	-	9900
2	Transmission shaft	530 mm, 9 splines and 8 mm ϕ	-	1350
3	Wheels	Plastic rim, rubber tyre and 350 mm ϕ	-	2200
4	Cutter blade, with windrowing system	250 mm ϕ , 2 mm thickness, 80 teeth	-	600
5	Handle	G.I. square pipe 30 $\times$ 30 $\times$ 3 mm thickness mm G.I round pipe 34 mm ϕ , 3 mm thickness	50	100
6	Engine mounting frame	G.I. square pipe 25 $\times$ 25 $\times$ 3 mm, thickness M.S. flat plate 170 $\times$ 115 $\times$ 3 mm G. I. pipe 27 mm ϕ , 126 mm length and 3 mm thickness G.I pipe 22 mm ϕ , 154 mm length and 3 mm thickness	50	100
7	Axel	M.S. rod 25mm ϕ	50	75
8	Trimmer head	125 mm ϕ	-	750
9	Caster wheel	50 mm ϕ	-	210
10	Miscellaneous	Nut bolts, washers etc	-	500
Total material cost				15,785
II. Second prototype of grass cutter cum paddy harvester				
1	Transmission shaft	1000 mm, 9 splines, 8 mm ϕ	-	1625
2	Transport wheels	250 mm ϕ (two no) 375 mm ϕ (one no)	-	1000
3	Main frame	M.S cycle frame: 755 mm length G.I square rod: 25 mm $\times$ 25 mm	-	576

		330 mm length		
4	Hinges	M.S plate: 625 mm × 625 mm	50	80
5	Bearing housing	M.S pipe: 60 mm ϕ 60 mm length 7.5 mm thickness	50	200
6	Mounting plate	M.S plate: 105 mm × 97 mm 10 mm thickness	50	75
7	Support plate	M.S plate: 152 mm × 152 mm	50	40
8	Bearing shaft	M.S rod: 20 mm ϕ , 59 mm length 25 mm ϕ , 47 mm length	50	30
9	Ball bearing	ID- 20 mm ϕ OD- 47 mm ϕ	-	375
10	Lever	G.I square pipe: 20 mm × 20 mm × 3 mm, 805 mm length G.I round pipe: 22 mm ϕ , 190 mm length, 3 mm thickness	50	75
11	Handle	G.I square pipe: 20 mm × 20 mm M.S round pipe: 22 mm ϕ	50	40
12	Brake cable	1800 mm length	-	150
13	Engine	2-stroke petrol engine, 1.95 hp and 6500-7500 rpm	-	9900
14	Trimmer head	125 mm ϕ	-	750
15	Cutter blade, with windrowing system	250 mm ϕ , 2 mm thickness, 80 teeth	-	850
16	Miscellaneous	Ball joints, washers, nut, bolts etc.	-	1000
Total material cost				15540

I. Grass cutter cum paddy harvester prototype

Total cost = Material cost + Fabrication cost (70% of material cost)
= 15785 + 11046
= 26831

II. Second prototype of grass cutter cum paddy harvester

Total cost = Material cost + Fabrication cost (70% of material cost)
= 16766 + 11736.2
= 28502.2 $\approx$ 28502

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