

**Development of Roller Rake Weeder with Special Emphasis on Developing  
a Novel Mechanism for Intra-Row Weeding**

*A thesis submitted*

*in partial fulfillment of the requirements*

*for the award of*

**DOCTOR OF PHILOSOPHY**

*by*

**SAPUNII SEBASTIAN**



School of Agro & Rural Technology

**INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI**

**ASSAM, INDIA – 781039**

**January 2025**

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## Certificate

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This is to certify that the thesis entitled “*Development of Roller Rake Weeder with Special Emphasis on Developing a Novel Mechanism for Intra-Row Weeding*” is a bonafide work carried out by **Sapunii Sebastian**, a research scholar in the School of Agro & Rural Technology, for the award of Doctor of Philosophy under my supervision and guidance. No part of the work is submitted elsewhere for the award of any diploma, degree, fellowship, or other personal benefits.

**Place:** Guwahati, Assam

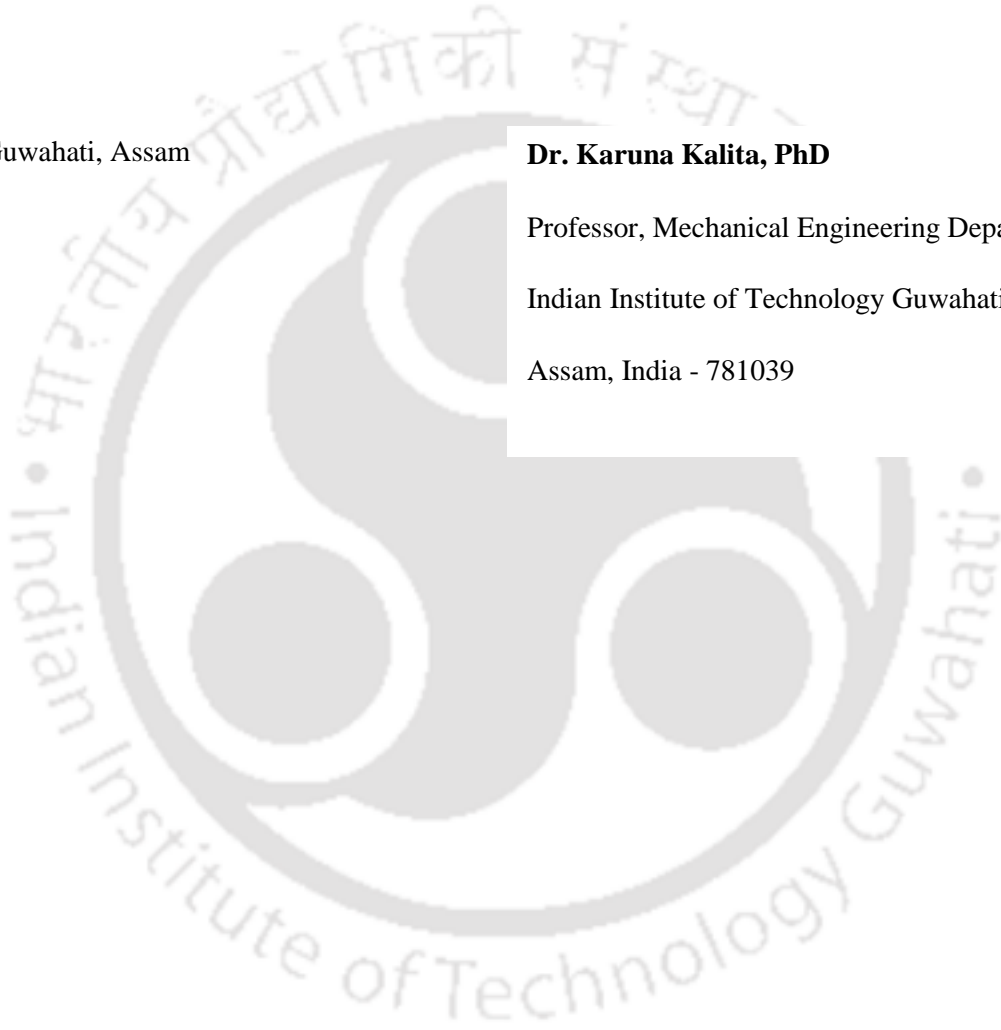
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## Abstract

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Hand weeding, despite its effectiveness, poses significant challenges due to its labor-intensive nature and time-consuming process. In contrast, mechanical weed extraction holds the promise of saving both time and money on labor. However, the widespread adoption of mechanical methods faces several hurdles, particularly in rural and hilly regions. Small-scale farmers, already grappling with financial constraints, often find power weeders prohibitively expensive and impractical. Moreover, the irregular planting of crops exacerbates the issue, limiting the utility of machines in such diverse agricultural landscapes. Research comparing various mechanical paddy field weeders sheds light on critical differences in field capacity, running costs, and weeding efficiency. These insights underscore the urgent need for labor-saving weed control methods tailored to specific regional challenges, particularly in isolated highland areas. Recognizing the limitations of current weeders, efforts have been directed towards innovation. One such solution is the development of the 'Roller Rake Weeder,' featuring a fixed rake and a roller with spikes as soil-engaging components. This proposed alternative aims to address the shortcomings of existing weeders and offer a more efficient and practical solution. Testing of the 'Roller Rake Weeder' has revealed promising results, with weeding efficiency ranging from 88.5% to 95.4% and a field capacity between 0.038 and 0.04 ha/h. These figures surpass the performance of manually operated weeders currently in use, signaling the potential for significant improvements in weed control practices.

In addition to the inter-row weeds, intra-row weeds pose significant losses in crop yield. This study also aims to design and develop a mechanism that could eradicate weeds in the inter and intra-row zones in a single pass. To achieve this, critical components of the weeder such as the power source, trapezoidal and lateral plates, cutting blades, rotor shaft, and various support structures were meticulously considered from a design perspective. Finite element analysis (FEA) was employed to assess the structural integrity of these components, utilizing theoretical equations to derive numerical values. These values were then inputted into SolidWorks software for further strength analysis, ensuring the reliability and durability of the machine. The results obtained from this analysis were found to closely align with those generated by the SolidWorks software, validating the accuracy of the design process. In addressing the challenge of intra-row weed eradication, a novel approach was adopted wherein a sinusoidal curve path was devised for the intra-row unit. This innovative trajectory allows the weeder to navigate seamlessly around paddy plants, effectively targeting weeds in the narrow spaces between

rows. Subsequently, a comprehensive 3-Dimensional (3-D) CAD model of the paddy field weeder was developed, incorporating all design elements and structural features. The designed model was then fabricated in the workshop. Lab testing shows that the developed inter cum intra-row weeder works satisfactorily as per the design.



## Table of Contents

---

<b>Certificate .....</b>	<b>i</b>
<b>Acknowledgment.....</b>	<b>ii</b>
<b>Abstract.....</b>	<b>iii</b>
<b>Notations .....</b>	<b>x</b>
<b>List of Figures.....</b>	<b>xiii</b>
<b>List of Tables .....</b>	<b>xvii</b>
<b>1 General introduction .....</b>	<b>1</b>
1.1 Background.....	1
1.2 Type of weeds .....	1
1.2.1 Agrestals weeds .....	4
1.2.2 Ruderals .....	4
1.2.3 Grassland weeds or weeds of pastures, meadows (and lawns).....	5
1.2.4 Water weeds (or Aquatic weeds) .....	5
1.2.5 Forestry weeds .....	5
1.2.6 Environmental weeds.....	5
1.3 Other weed-types .....	5
1.4 Weed flora associated with direct-seeded rice.....	6
1.5 Weed Management in Rainfed Rice .....	6
1.6 Losses in crop yield due to weeds.....	7
1.7 Weed control methods .....	7
1.8 Soil-engaging types of equipment .....	9
1.8.1 Harrowing .....	9
1.8.2 Sweeping.....	10
1.8.3 Hoe-ridging .....	10
1.9 Non-soil-engaging techniques .....	11
1.10 Necessity of this research.....	11

1.11 Aim .....	12
1.12 Objectives .....	12
1.13 Layout of the thesis .....	13
<b>2 Literature review .....</b>	<b>15</b>
2.1 Comparative study of various types of paddy weeders developed in India.....	15
2.1.1 Ride-on type paddy weeder .....	15
2.1.2 Self-propelled type cono-weeder .....	16
2.1.3 Rotary power weeder .....	17
2.2 Important performance parameters for paddy weeders .....	19
2.3 Performance analysis of various weeders .....	19
2.3.1 Weeding efficiency .....	19
2.3.2 Actual Field capacity .....	20
2.3.3 Cost of Operation.....	20
2.3.4 Performance analysis of hand weeding.....	20
2.3.5 Performance analysis of Cono-weeders.....	21
2.3.6 Performance analysis of Ambika Weeder.....	21
2.3.7 Performance analysis of Rotary Power Weeder .....	21
2.4 Challenges and Opportunities in Farm Mechanization and its Status for Northeastern India's Agriculture.....	28
2.4.1 Transitioning Dynamics of Farm Power Sources .....	28
2.4.2 Farm power availability and productivity in the Northeastern states of India.....	29
2.4.3 Categorization of Farm Power Availability .....	33
2.4.4 Farm equipment manufacture in North-eastern states .....	34
2.4.5 Tools and implements used.....	35
2.4.6 Operational holdings size.....	39
2.4.7 Constraints to agricultural mechanization .....	42
2.4.8 Suggestions .....	42
2.5 Mechanization in Intra-Row Weeding.....	43

2.5.1 Mechanical Devices for Intra-Row Weed Management.....	45
2.5.2 Automated Technology for Intra-Row Weeding .....	51
2.5.3 Electrically Powered Weeders .....	53
2.5.4 Conceptual Design of Inter Cum Intra-Row Weeder for Wetland Paddy Cultivation .....	54
2.6 Conclusions.....	56
<b>3 Design, development, and performance evaluation of Roller Rake Weeder.....</b>	<b>58</b>
3.1 Introduction.....	58
3.2 Methodology .....	60
3.2.1 Overall structural design consideration .....	60
3.2.2 Estimation of Various Performance Parameters .....	63
3.2.3 Operating Speed.....	63
3.2.4 Draft Requirement .....	64
3.2.5 Power Requirement.....	64
3.2.6 Theoretical Field Capacity.....	64
3.2.7 Actual Field Capacity .....	64
3.2.8 Field Efficiency.....	65
3.2.9 Weeding Efficiency .....	65
3.3 Initial design of the prototype .....	65
3.4 Finite Element Analysis of the Weeder Rake .....	69
3.5 Design of the Weeder (Final Product) .....	72
3.5.1 Design of handle grip.....	72
3.5.2 Design of handle height .....	73
3.6 The Working Principle of the Designed Weeder.....	74
3.7 Machine Performance and Evaluation .....	74
3.8 Draft Measurement of the Weeder.....	78
3.9 Results and discussion .....	78
3.10 Conclusions.....	82

<b>4 Design and analysis of wetlands inter cum intra-row paddy field weeder .....</b>	<b>84</b>
4.1 Introduction.....	84
4.2 Functions of various components .....	86
4.2.1 Source of power requirement.....	87
4.2.2 Circular disk.....	87
4.2.3 Rectangular link .....	88
4.2.4 Trapezoidal plate.....	89
4.2.5 Sliding rod.....	89
4.2.6 Rotor blade.....	89
4.2.7 Lateral plate extension .....	89
4.2.8 Float .....	89
4.3 The working principle of the designed mechanism .....	90
4.4 Theoretical analysis of various parameters.....	92
4.4.1 Calculation of power requirement .....	92
4.4.2 Torque transmitted by the engine shaft.....	94
4.4.3 Design of rotor shaft .....	94
4.4.4 Design of cutting blades.....	96
4.4.5 Shank for intra-row weeding .....	99
4.4.6 Height of intra-row weeding shank.....	100
4.5 Finite element analysis of various components .....	102
4.5.1 Finite Element Analysis of Rotor Shaft.....	103
4.5.2 Finite Element Analysis of Cutting Blade .....	104
4.5.3 Finite Element Analysis of Intra-row Shank .....	105
4.5.4 Rectangular link .....	107
4.6 Kinematic Analysis of the Designed Mechanism.....	108
4.6.1 Creation of individual components and assembly .....	108
4.6.2 Stages of the motion study .....	108

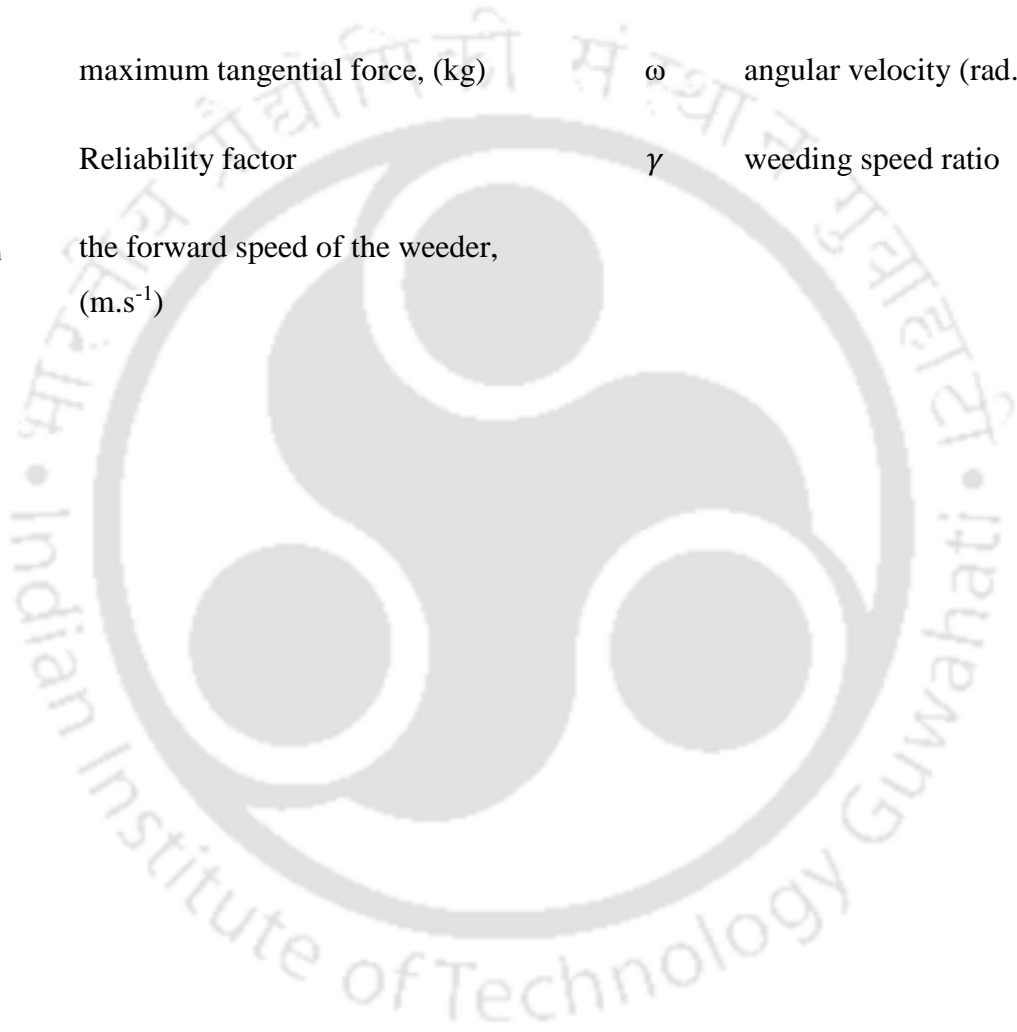
4.6.3 Running the design study.....	109
4.7 Position analysis of the weeding units .....	110
4.8 Simulation of the intra-row path .....	112
4.9 Motion analysis of the inter-row weeding unit .....	114
4.10 Motion analysis of the intra-row weeding unit .....	116
4.11 Assumptions and limitations.....	117
4.12 Conclusions.....	118
<b>5 Development of inter cum intra-row weeder.....</b>	<b>119</b>
5.1 Introduction.....	119
5.2 Fabrication of various components .....	119
5.3 Problems encountered during the fabrication process .....	124
5.4 Assembly of various components .....	125
5.5 Laboratory testing of the developed model .....	127
5.6 Conclusions.....	128
<b>6 Summary and conclusions.....</b>	<b>130</b>
6.1 Summary .....	130
6.2 Conclusions.....	133
6.3 Future scope of the work.....	133
<b>Publications .....</b>	<b>150</b>
<b>Patents.....</b>	<b>151</b>
<b>Cover page of the test report (Roller Rake Weeder).....</b>	<b>152</b>

## Notations

2, 4 - D	2, 4 – Dichlorophenoxyacetic acid	US\$	United State dollar
TNAU	Tamil Nadu Agricultural University	%	percentage
Kg	Kilogram	Rs.	rupee
JNKVV	Jawaharlal Nehru Krishi Viswavidyalaya	<i>et al</i>	and others
WP	wettable powder	<i>fb</i>	followed by
IGKV	Indira Gandhi Krishi Viswavidyalaya	MJ	mega Joule
NA	data not available	Ha	hectare
MMT	million metric tonnes	kW	kilo Watt
GoI	government of India	FPA	farm power availability
ICAR	Indian Council of Agricultural Research	MB	mould board
ANGRAU	Acharya N. G. Ranga Agricultural University	CIAE	Central Institute of Agricultural Engineering
IS	Indian standard	MS	mild steel
Hp	horse power	MIC	Ministry of Education's Innovation Cell
DC	direct current	Ah	Ampere hour
CAD	computer-aided design	$N_c$	engine power (HP)
FEA	finite element analysis		
$N.mm^{-2}$	Newton per square millimeter	$\eta_c$	the forward rotation's traction efficiency for the rotor shaft

km/h	kilometer per hour	$\eta_z$	coefficient of reservation of engine power
mm	millimetre	$U_{\min}$	minimum tangential speed of the blades ( $\text{m.s}^{-1}$ )
m	meter	$M_s$	maximum moment on the rotor shaft (kg. mm)
kW	kilowatt	D	diameter of rotor shaft, (mm)
$\text{N.m}^{-2}$	Newton per square metre	$\tau_{\text{all}}$	allowable stress on the material, (mPa)
rpm, N	revolution per minute	$K_e$	soil force acting on the blade, (N)
N	Newton	$C_p$	overload factor of an individual working element
MPa	mega Pascal	i	number of working sets in the machine
DAS	days after sowing	$Z_e$	number of blades on each side of the flange
$S_r$	soil resistance, ( $\text{N.m}^{-2}$ )	$n_e$	fraction determining the number of working elements that operate simultaneously
d	depth of operation (m)	$\sigma_{zg}$	bending stress ( $\text{N.mm}^{-2}$ )
w	effective width of cut (m)	$\sigma_{\text{skt}}$	shear stress ( $\text{N.mm}^{-2}$ )
v	speed of operation ( $\text{m.s}^{-1}$ )	$\sigma_{zt}$	equivalent stress ( $\text{N.mm}^{-2}$ )
$P_a$	power required for intra-row weeding (kW)	G.L.	ground level

$P_b$	power required for inter-row weeding (kW)	$L$	height of the intra-row shank (mm)
$P_t$	total power required for the weeder (kW)	$H$	height of the seedling (mm)
$T$	torque transmitted by the shaft, (Nm)	$h$	depth of operation of intra-row unit (mm)
$K_s$	maximum tangential force, (kg)	$\omega$	angular velocity ( $\text{rad.s}^{-1}$ )
$C_s$	Reliability factor	$\gamma$	weeding speed ratio
$V_m$	the forward speed of the weeder, ( $\text{m.s}^{-1}$ )		



## List of Figures

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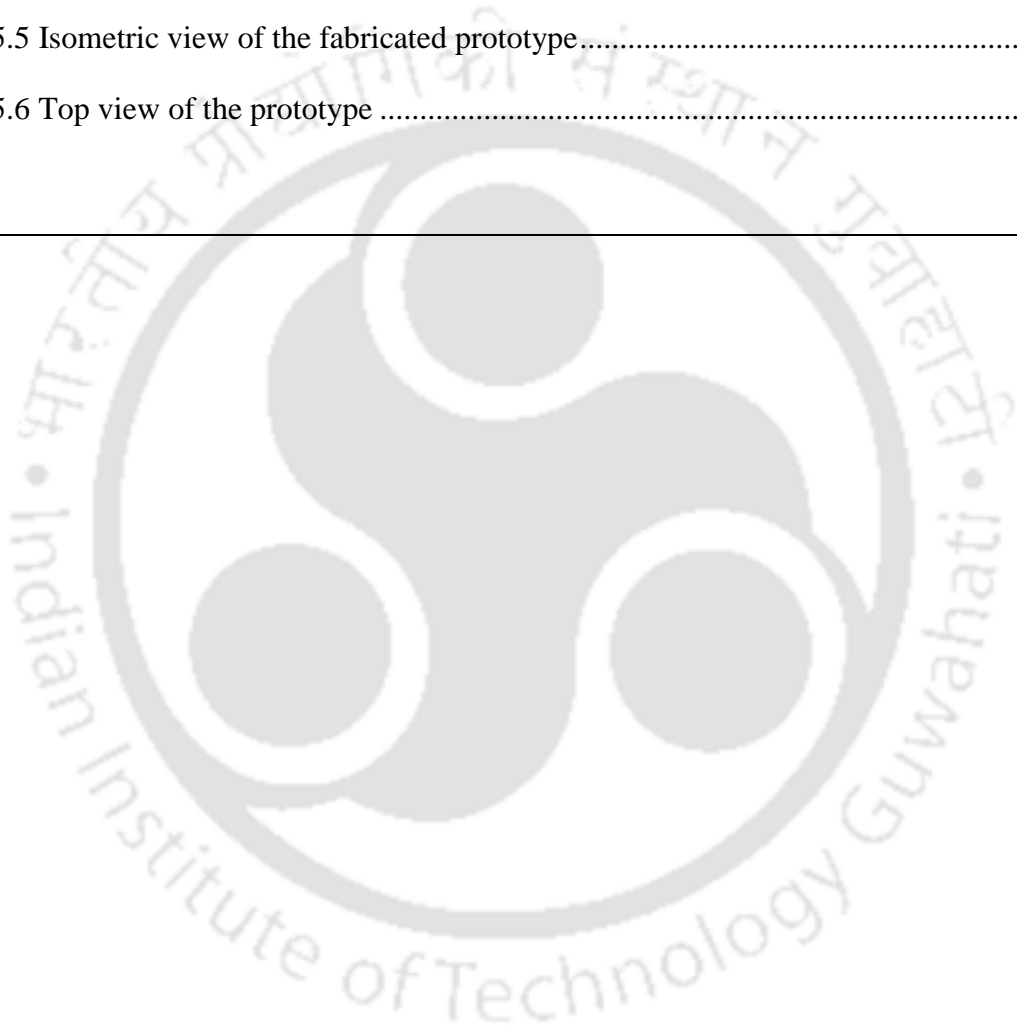
Figure 1.1 Major weed of transplanted puddled lowland rice (www.agritech.tnau.ac.in; Dr. R. Jagannathan, Professor of Agronomy, TNAU, Coimbatore).....	3
Figure 1.2 Economic losses (USD in million) due to weeds in 10 major field crops in India (Gharde et al., 2018) .....	8
Figure 1.3 Weed control methods (Home, 2003) .....	9
Figure 1.4 Floating spring-tine harrow weeder (Home, 2003) .....	10
Figure 1.5 Hoe-ridger (Dedousis, 2007) .....	11
Figure 2.1 A self-propelled ride-on type paddy weeder .....	15
Figure 2.2 Views of the self-propelled cono-weeder .....	16
Figure 2.3 Self-propelled type cono-weeder.....	17
Figure 2.4 Components of the self-propelled cono-weeder .....	17
Figure 2.5 Rotary-type power weeder .....	18
Figure 2.6 Comparison of weeding efficiency.....	26
Figure 2.7 Comparison of field capacity.....	27
Figure 2.8 Comparison of operating cost.....	27
Figure 2.9 Share of animate and mechanical power during different periods (Singh et al., 2014) .....	29
Figure 2.10 Farm power availability vs productivity among the North-eastern states during the year 2016-2017 (Anon, 2021).....	31
Figure 2.11 Comparison of farm power availability (FPA) between North-eastern states and the rest of India during the year 2016-2017 (Anon, 2021) .....	32
Figure 2.12 Comparison of food grain productivity (kg/ha) between North-eastern states and the rest of India during the year 2016-2017 (Anon, 2021) .....	32
Figure 2.13 State-wise operational holdings during 2015-16 (Anon, 2016) .....	40
Figure 2.14 Inter and intra-row zones.....	44
Figure 2.15 Various types of mechanical intra-row weeders .....	46

Figure 2.16 Integrated inter and intra-row weeding system (Chandel et al., 2021) .....	47
Figure 2.17 Rotating disc tine (Cavalieri et al., 2001).....	49
Figure 2.18 The cycloid hoe (Griepentrog et al., 2007).....	49
Figure 2.19 The Radis intra-row weeder (Bleeker, 2005) .....	50
Figure 2.20 Description of the weeder with the weeding tool at the rear (Åstrand & Baerveldt, 2002) .....	50
Figure 2.21 The rotary hoe (Gobor & Lammers, 2007) .....	51
Figure 2.22 Autonomous navigation in a field with a robot platform (Bakker, 2003) .....	52
Figure 2.23 Schematic diagrams of the weeding system: (a) conceptualized weeding mechanism (LR = left row, RR = right row) and (b) computer-aided design (Pandey et al., 2023) .....	54
Figure 2.24 A schematic representation of the proposed inter cum intra-row paddy field weeder .....	55
Figure 3.1 A SolidWorks sketch of the initial design.....	67
Figure 3.2 Photographs of the initial stage prototype .....	68
Figure 3.3 Soil-engaging components .....	68
Figure 3.4 The initial developed prototype in the workshop .....	68
Figure 3.5 Sketch of the prototype during the idea generation stage.....	69
Figure 3.6 Isometric and front views of the rake (All dimensions are in mm).....	70
Figure 3.7 Stress analysis of the rake.....	71
Figure 3.8 Displacement analysis of the rake .....	71
Figure 3.9 Roller Rake Weeder .....	73
Figure 3.10 Schematic representation of an operator handling the weeder ( <i>After</i> Sebastian & Kalita, 2023) .....	75
Figure 3.11 Photograph of an operator during testing of the weeder .....	75
Figure 3.12 Field conditions before and after the operation of the weeder (orange boundary indicates before the operation of the weeder and blue boundary indicates after the operation of the weeder).....	76

Figure 3.13 Schematic representation of arrangement for draft measurement.....	78
Figure 3.14 Measurement of the draft.....	79
Figure 3.15 Comparison of weeding efficiency with various weeders.....	80
Figure 4.1 Power flow diagram .....	87
Figure 4.2 Technical route involved in the process of designing the weeder.....	88
Figure 4.3 Pen and paper sketch of the prototype during the idea generation stage.....	90
Figure 4.4 Schematic diagram depicting the power flow from the IC engine to the units .....	91
Figure 4.5 Various views of the initial design of the weeder .....	92
Figure 4.6 A 3-D model of the designed paddy field weeder.....	93
Figure 4.7 Rotor shaft (all dimensions are in mm) .....	96
Figure 4.8 CAD model of the designed blade (All dimensions are in mm) .....	97
Figure 4.9 Intra-row weeding unit (All dimensions are in mm) .....	100
Figure 4.10 Schematic diagram of paddy seedling along with the intra-row weeding unit ..	101
Figure 4.11 Analysis of the rotor shaft .....	103
Figure 4.12 Stress distribution on the blade.....	104
Figure 4.13 Strain distribution of the blade .....	104
Figure 4.14 The resultant displacement of the blade .....	105
Figure 4.15 Stress distribution on the shank.....	106
Figure 4.16 Deflection of shank upon the force application.....	107
Figure 4.17 Analysis of rectangular link.....	108
Figure 4.18 Activation of rotary and linear motor.....	110
Figure 4.19 Maximum lateral position.....	111
Figure 4.20 Minimum lateral position .....	111
Figure 4.21 Middle position (a: trapezoidal plate; b: rectangular link; c: circular disk) .....	111
Figure 4.22 Top view of the weeder in operation during simulation.....	113
Figure 4.23 Schematic analysis of the movement of the rotor blades .....	115

Figure 4.24 Path traced by an intra-row weeding unit.....	116
Figure 4.25 Schematic diagram depicting the field plot.....	117
Figure 5.1 A typical structure of trapezoidal and lateral plates .....	121
Figure 5.2 Trapezoidal and lateral plates fabricated with sliding grooves .....	121
Figure 5.3 Photograph of the prototype during the assembly stage.....	123
Figure 5.4 Linear guides .....	125
Figure 5.5 Isometric view of the fabricated prototype.....	127
Figure 5.6 Top view of the prototype .....	128

---



## List of Tables

---

Table 2.1 Performance parameters of hand weeding.....	21
Table 2.2 Performance parameters of cono weeders .....	22
Table 2.3 Performance parameters of Ambika Weeders .....	23
Table 2.4 Performance parameters of power-operated rotary weeders .....	24
Table 2.5 Average of the performance parameters of all the weeders.....	26
Table 2.6 Farm power availability and productivity during 2014-2017 (Anon, 2021) .....	30
Table 2.7 Categorization of Farm Power Availability.....	33
Table 2.8 Traditional and improved agricultural implements being used by the farmers for different operations and improved agricultural machinery to be introduced for popularization among the northeastern states of India (Alam, 2006).....	35
Table 2.9 Area of Operational Holdings by Size Group (2015-16) (Anon, 2016).....	40
Table 2.10 The efficacy of various intra-row weeding devices (Updated from Kumar et al., 2022) .....	47
Table 3.1 Specifications of the rake.....	70
Table 3.2 Specification of the developed weeder .....	60
Table 3.3 Summary of field, crop, and weed condition.....	76
Table 3.4 Field Performance Test Results .....	81
Table 4.1 Dimensions of various components.....	101
Table 4.2 Material properties used for FEA (ASTM A36).....	102
Table 5.1 Specification of the engine .....	126

## CHAPTER ONE

### 1 General introduction

#### 1.1 Background

Any plant that grows in the wrong spot at the wrong time and causes more harm than good is considered a weed (Parish, 1990). When it comes to water, light, nutrients, and space, weeds compete with the crop. Weeds thus lower crop yields and interfere with the effective operation of machinery (Parish, 1990). Effective farming techniques are necessary to produce crops with a high yield. Weed control is one of the most crucial procedures. About 350 species in more than 150 genera and 60 plant families have been reported as weeds of rice (Anon, 1983). *Echinochloa crus-galli* is the most troublesome weed of rice in the world (Holm et al., 1977)

Despite decades of research and the development of weed management technologies, weeds remain a persistent challenge due to their dynamic nature. Sustaining the equilibrium between crops and weeds while tackling emerging weed problems requires continuous observation and the creation of suitable weed control methods. Before the advent of 2,4-D in 1948, which sparked research on herbicides in India, farmers mainly used mechanical weeding techniques and hand weeding (Rao, 2018). The majority of Indian weed management research initially focused on herbicide-based techniques. However, due to its negative consequences and health risks, the mechanical weeding method is currently preferred. Weeds are a severe crop production hindrance, resulting in enormous economic losses estimated to be worth US\$ 11 billion for India's ten main crops (Gharde et al., 2018). To adequately meet the food and nutritional needs of the expanding Indian population and increase farmers' earnings, effective weed control is essential for increasing crop output and resource use efficiency. To maximize harvestable crop yields, integrated weed management systems work to reduce weed competition and enhance crop consumption of resources including soil fertility, water, and sunlight.

#### 1.2 Type of weeds

Weed composition changes over time and space, and its competition is influenced by soil,

climate, and management practices. The weed flora in lowland rice is a diverse crop that includes grasses, sedges, broad-leaved plants, and algae. Photographs of major types of weeds of transplanted lowland rice are presented in Figure 1.1.

---

### Grasses

---



*Echinochloa colona*



*Chloris barbata*



*Cynodon dactylon*



*Leptochloa chinensis*



*Echinochloa crus-galli*

---

### Broad-leaved weeds

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*Ammania baccifera*



*Asteracantha longifolia*



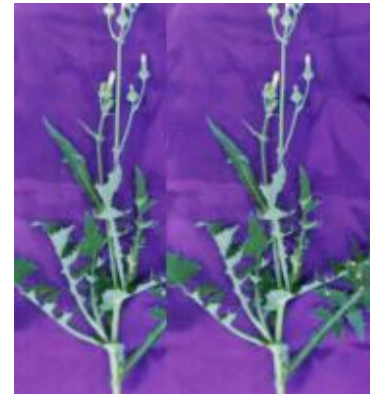
*Commelina benghalensis*



*Marselia quadrifolia*



*Rotala densiflora*



*Sonchus oleraceus*

---

### Sedges

---



*Cyperus difformis*



*Cyperus iria*



*Fimbristylis miliacea*

---

**Figure 1.1 Major weed of transplanted puddled lowland rice ([www.agritech.tnau.ac.in](http://www.agritech.tnau.ac.in);  
Dr. R. Jagannathan, Professor of Agronomy, TNAU, Coimbatore)**

Weeds like *Echinochloa* spp., *Paspalum* spp., *Cyperus iria* and *Fimbristylis miliacea* predominates in irrigated and shallow depths of water while with more than 2.5 cm of water weeds like *Sphenoclea zeylanica*, *Monochoria vaginalis*, *Ammania baccifera*, *Hydrolea zeylanica* are the most predominant (Duary et al., 2015). The predominant weed flora associated with lowland rice in Eastern India were *Ammania baccifera*, *Fimbristylis miliacea*, *Cyperus microiria*, *Ludwigia parviflora*, *Monochoria vaginalis*, *Echinochloa crusgalli*, *Echinochloa colona*, *Lindernia ciliata*, *Marsilea quadrifolia*, *Spilanthus acmella*, *Cyperus difformis* and *C. iria* (Duary et al., 2015; Mondal et al., 2005). *Echinochloa crusgalli*, *E.*

*colona*, *Panicum repens*, *Sacciolepis interrupta* and *Paspalum distichum* among the grasses, *Cyperus difformis*, *C. iria*, *C. microiria*, *F. dichotoma*, *F. miliacea*, *Scirpus acutus* and *Scripus grossus* among sedges and *Alternanthera philoxeroides*, *Ipomoea aquatica*, *Nymphaea odorata*, *Monocharia vaginalis*, *Sphenoclea zeylanica*, *Eclipta alba*, *Aeschenomene indica* L., *Ludwigia parviflora*, *L. octovulvis*, *Cyanotis axillaris*, *Ammania baccifera*, *Marsilia quadrifolia*, *Lemna minor*, *Aeschenomene aspera*, *Potamogeton distinctus* and *Eichhornia crassipes* among broadleaved were the predominant weeds under puddled medium lowland conditions during rainy season (Teja, Duary, & Bhowmik, 2015; Teja, Duary, Kumar, et al., 2015)

Weed problems arise when a plant species or a group of species interfere with man's activities, his health, or his pleasures'. Not only plants that are a nuisance for some reason, but simply most plants that are 'unsightly' or just good for nothing are considered undesirable and thus classified as 'weeds'. The most common way to classify weeds is according to their habitat. The following groups can thus be distinguished under (Holzner, 1982).

### **1.2.1 Agrestals weeds**

These are weeds of tilled, arable land comprising weeds from fields of cereals and root crops, orchards, hoed garden areas, plantations, and so on. Each special plant cultivation has its special weed. This may include rubber weeds, sugar cane weeds, coffee weeds, banana weeds, lowbush blueberry weeds, tea weeds, etc.

### **1.2.2 Ruderals**

Ruderals are plants occurring on 'ruderal' sites (debris) but used with a very broad meaning, comprising such different habitats as earth heaps, dunghills, trash deposits, roadsides, railway lines, roofs, margins of wastewater ditches, and so on. All these sites have a more or less severe human disturbance in common.

### **1.2.3 Grassland weeds or weeds of pastures, meadows (and lawns)**

From an extreme stance, all plants (including some grasses and all non-grasses in lawns) that are not very productive and nutritious can be viewed as undesirable and weedy. Weeds in agricultural grasslands are, from a reasonable point of view, plants that negatively impact the animals grown, their product, or both. They can also be unpalatable and very competitive with other desirable species.

### **1.2.4 Water weeds (or Aquatic weeds)**

Unrestricted plants that develop and finish their life cycle in water are known as aquatic weeds, and they negatively impact the aquatic ecosystem both directly and concerning the surrounding ecosystem. Since they could potentially reduce pollution from homes, businesses, and agriculture, many aquatic plants are desired (Lancar & Krake, 2002).

### **1.2.5 Forestry weeds**

Apart from common hostile plants found in tree nurseries, many common forest species or pioneers of clear-cutting may be deemed weeds if their dense growth impedes the development of new trees.

### **1.2.6 Environmental weeds**

Aggressive, invasive plants known as environmental weeds invade native vegetation and partially suppress native species (Amor & Stevens, 1976).

## **1.3 Other weed-types**

Grasslands and fields are being abandoned in many nations, especially in places that are not ideal for intensive cultivation. In certain locations, secondary succession takes place, producing vegetation that is commonly thought of as weedy. A plant can turn into a weed if people don't

like it. Thus, some plant species or groups of plants are weeded because they harbor pathogens, hazardous creatures, or adversaries of humans.

#### **1.4 Weed flora associated with direct-seeded rice**

Direct seeding results in a change in the relative abundance of weed species. In particular, *Echinochloa* spp., *Ishaemum rugosum*, *Fimbristylis miliacea*, and *Cyperus difformis* were widely adapted to the conditions of direct-seeded rice (Rao et al., 2007). The major weed floras associated with direct seeded rice were *Echinochloa colona*, *Echinochloa crussgali*, *Digitaria sanguinalis*, *Cyperus iria*, *Eleusine indica*, and *Eclipta alba* etc (Phukan et al., 2021). The predominant weed species found in dry-seeded rice were *Trianthema portulacastrum*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Eleusine indica*, *Echinochloa crussgalli*, *Portulaca oleraceae*, *Ipomea aquatic*, *Leptochloa chinensis*, *Cyperus rotundus* and *Cyperus iria* (Khaliq & Matloob, 2011).

#### **1.5 Weed Management in Rainfed Rice**

In rainfed upland rice, combined use of good land preparation (two plowings 15 days before sowing and two plowings at sowing) and timely sowing (last week of June) markedly reduced the infestation of all types of weeds (Singh & Ghosh, 1992). Barker & Herdt (1979) research offers insights into the distribution of rainfed rice cultivation across the globe. They estimated that approximately one-third of the world's rice-growing regions rely on rainfall for irrigation. Within these rainfed areas, two main categories exist: shallow rainfed and medium-deep rainfed. Shallow rainfed fields typically have water levels ranging from 5 to 15 centimeters deep, while medium-deep rainfed fields have deeper water levels, spanning from 16 to 100 centimeters.

Notably, the majority of rainfed rice cultivation in Asia, comprising about two-thirds of the total rainfed area, falls under the shallow rainfed category, as identified by Barker & Herdt (1979).

## 1.6 Losses in crop yield due to weeds

The increased yields obtained from weed control measures leave no room for doubt about the magnitude of the yield losses caused by unchecked weed growth. Weed co-existence in crops, or their continued growth in situations where they are not desired, is inimical to crop production. Out of the total 40 % yield loss in rice caused by various pests and insects, weeds caused nearly 10% of the yield loss, which under DSR may go up to 32% (Shekhawat et al., 2020). Nutrient removal by weeds has been reported to be about 21-42 kg N, 10-13.5 kg P, and 17-27 kg K/ha in transplanted rice depending upon the soil, condition of cropping, and location of growing rice (Gowda et al., 2009; Sudhalakshmi et al., 2005). Estimates of actual economic losses were the highest in the case of rice (USD 4420 million) followed by wheat (USD 3376 million) and soybean (USD 1559 million), respectively. Rice experienced only 14% actual average yield loss in transplanted and 21% in direct-seeded condition but due to high production in India, it is considered as the most economically affected crop than others considered here. Overall, the total economic loss in 10 major crops in 18 states of India was estimated at approximately USD 11 billion due to weeds alone (Gharde et al., 2018) (Figure 1.2)

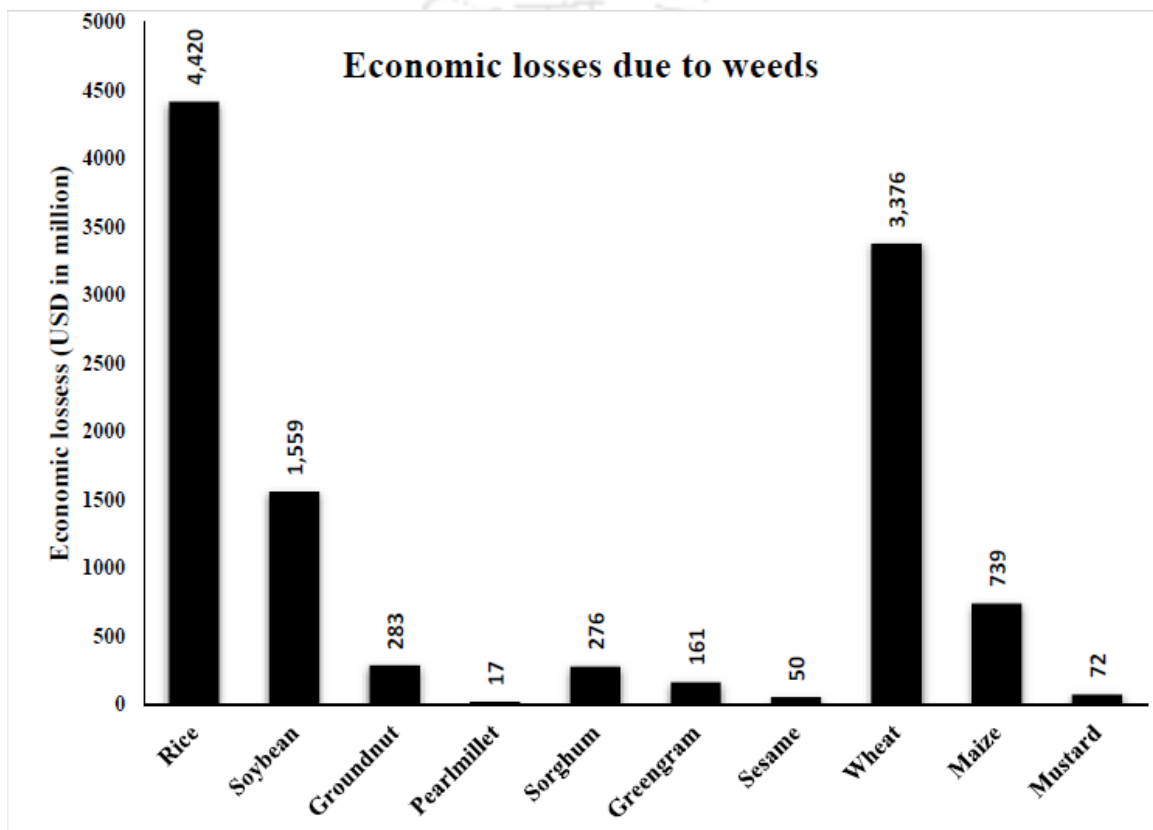
At Visva-Bharati University in India, yield loss due to weeds was 90% in direct-seeded puddled rice and 17% in transplanted rice (Mukhopadhyay, 1981). Research conducted at the Central Rice Research Institute of India revealed that without effective weed control measures, the yield losses were substantial: 46% for direct-seeded rice in dry soil, 20% for direct-seeded rice in puddled soil, and only 11% for transplanted rice in puddled fields (De Datta, 1981).

## 1.7 Weed control methods

Weeds can be controlled either manually or by using external power sources. Manual weeding can be used in conjunction with chemical, mechanical, and biological techniques to control weeds. Although labor-intensive, cumbersome, and expensive, manual weeding with either bare hands or hand-held power tools is thought to be the most efficient (Datta et al., 2017).

Because chemical weeding is typically more expensive, risky, and selective, mechanical weeding is recommended. Furthermore, mechanical weeding maintains a loose soil surface by creating soil mulch, which improves aeration and moisture retention. Herbicide spraying is the

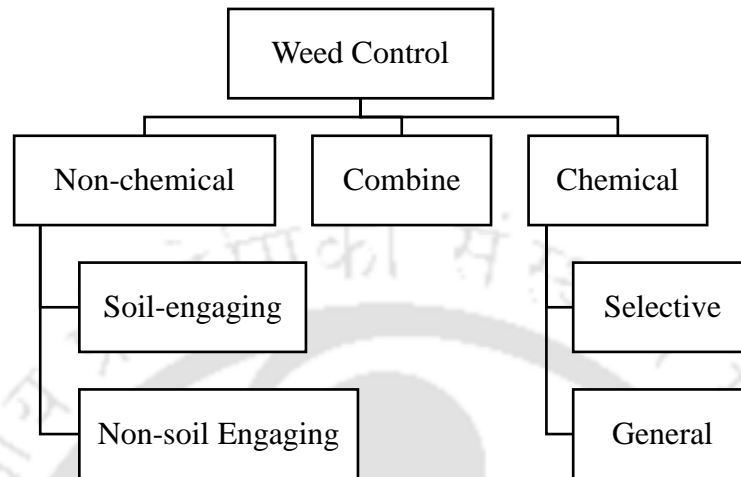
most popular method of controlling weeds, but many consumers now demand non-chemically treated products. The main drawback of using herbicides is their negative effects on the environment, including soil and water pollution. The immediate eradication of weeds without their replication is the virtue of chemical weed control, though this also relies on the weed's tolerance. In addition, chemical weed control requires less energy than other weed control methods or burning applications.



**Figure 1.2 Economic losses (USD in million) due to weeds in 10 major field crops in India (Gharde et al., 2018)**

Some farmers implement agronomic techniques aimed at enhancing crop competitiveness, like sowing robust crop seeds at comparatively shallow depths and sowing immediately following a weed control procedure. By using this technique, it is possible to guarantee that crop plants emerge before weed plants and to stop weed seeds from sprouting before the crop is planted.

This procedure will guarantee an increased crop yield, lessen weed infestation, and minimize any economic losses. A flowchart of weed control methods is given in Figure 1.3



**Figure 1.3 Weed control methods (Home, 2003)**

### **1.8 Soil-engaging types of equipment**

The soil-engaging techniques include hand-hoeing, harrowing, sweeping, hoe-ridging, tilling, etc. Probably the most common tillage tool used worldwide is the hoe. Using a scything motion, it can be used to remove large patches of weeds or to turn the soil over and bury the smaller weeds (McRobie, 1990). Some horticultural farmers still employ manual weeding as a method of weed management in and around the rows, despite its lack of widespread use. Rotary tillers fitted with L-type blades are common for wetland weeding. In addition, conical drums with straight and serrated blades arranged alternately on their periphery are generally used with cono weeders in wetland paddy cultivation.

#### **1.8.1 Harrowing**

The harrow controls both intra- and inter-row weeds uniformly throughout the entire region. Its relative simplicity has made it one of the most widely used weed management tools, albeit with the drawbacks listed below. The spring tine harrow and the chain harrow are the two most

popular types of harrows. A floating spring tyne Harrow weeder is presented below in Figure 1.4



**Figure 1.4 Floating spring-tine harrow weeder (Home, 2003)**

### **1.8.2 Sweeping**

The condition of the cutting edge is the primary element in the buildup of plant material on the sweep, according to Kotov's (1977) analysis of the parameters of sweep design. Sweeps clean themselves best in heavy conditions with a swept angle of roughly  $57^\circ$ . While a wide-swept angle works best for self-cleaning, it's not always the best for killing weeds.

### **1.8.3 Hoe-ridging**

Hoe-ridgers are used to suppress weeds inside rows by burial and to suppress weeds between rows by subsurface cutting and burial. Terpstra & Kouwenhoven's (1981) research on inter- and intra-row weed control revealed that when a hoe-ridger passed by, 57% of the inter-row weeds were destroyed by burying them with soil and 33% by uprooting them and drying them in the soil's surface. A photograph of a hoe-ridger is given in Figure 1.5.



**Figure 1.5 Hoe-ridger (Dedousis, 2007)**

### **1.9 Non-soil-engaging techniques**

This technique includes thermal, electrocution, mowing, freezing, steaming, solarisation, microwave radiation, water cutting, band heating, and lasers. Due to their high costs, potential risks, and low labor rates, non-soil engagement techniques are seldom employed by producers. While additional research is focused on alternatives, future technology advancements can lead to a change in the way that we think now. Since subsurface cutting and burial can effectively eliminate weeds, the project has concentrated on soil-engaging devices.

For non-chemical weed management, thermal and mechanical methods are employed nowadays without any precise application. In addition, a variety of methods have been devised to meet the demands of organic food production, lower chemical expenses in conventional agriculture, and control weeds without the use of chemicals (Parish, 1990).

### **1.10 Necessity of this research**

The necessity of this research can broadly be divided into two broad categories. The first one focuses on small hand-held weeders for hilly regions and the second one focuses on the inter and intra-row weeding mechanism.

Although many weeders have been developed and are in use practically, there exist some disadvantages. An easily portable and lightweight machine is always the best choice for hilly terrain regions. One such machine (weeder) is a cono weeder. However, due to its inefficiency in destroying the weeds, there is a need to redesign the weeder to improve its efficiency. Narwariya et al. (2016) and Remesan et al. (2007) reported that cono weeders perform well in the initial stage of weed growth. However, in the later stage of weed growth, the cono weeder cannot perform well in destroying the weeds. There is a chance that the conical-shaped roller just over the ground surface without destroying the weeds, especially in hardpan soil. Thus, this research aims to overcome the challenges faced by the existing weeder.

Secondly, Wetland systems account for over 85% of the global rice harvest area, with irrigated wetland rice accounting for roughly 75% of rice production (Bouman et al., 2007). However, the majority of studies on intra-row weeders are for use in dryland vegetable crops, with only a few experiments on intra-row devices (Choi et al., 2015; Liu et al., 2023) conducted specifically for use in wetland paddy agriculture. Hence, this reveals that there is a need to develop intra-row weeders to overcome the existing challenges specifically for wetland paddy cultivation.

### **1.11 Aim**

The aim of this research is to address and overcome the inefficiencies of existing hand-held weeders, particularly for hilly terrain thereby redesigning the weeder to enhance its performance. Additionally, this research also aims to develop inter cum intra-row weeders specifically tailored for wetland paddy cultivation to address the current gap in the application of weeders in wetland rice systems.

### **1.12 Objectives**

To achieve the aims, the following objectives were articulated;

a) for roller rake weeder (for inter-row weeding),

1. To identify the problems faced by the existing weeders

2. To redesign and improve soil-engaging components of the weeder
3. To develop and evaluate the performance of the designed weeder in actual field conditions

b) for inter cum intra-row weeder

1. To design an integrated mechanism for wetland paddy cultivation that can eliminate weeds in the inter- and intra-row zones in a single pass
2. To develop the designed mechanism
3. To test the developed prototype of the proper functioning of every component provides the necessary output motion

The following steps were involved in achieving the objectives:

1. Collection of various data related to wetland paddy weeder
2. Identification of soil-engaging components for hand-held weeding
3. Identification of the key components necessary for its movement for inter-row as well as intra-row weeding
4. Finite Element Analysis (FEA) of various components necessary for the functioning of the proposed mechanism
5. Simulation of the designed mechanism in commercial software

### 1.13 Layout of the thesis

This thesis is divided into 6 (Six) Chapters as given below:

**Chapter – 1** gives a general introduction to the type of weeds, control methods, and type of soil-engaging techniques

**Chapter – 2** covers the literature survey of different kinds of soil-engaging equipment and weeding mechanisms for both intra- and inter-row zones. The level of farm mechanization in the northeastern Indian states, the equipment and tools

utilized, the many restrictions and limitations, and the recommendations that should be put into practice have all been covered. Various paddy field weeders are being used in India and abroad; their drawbacks and recommendations for enhancements have been explored. This chapter has examined various intra-row weeder types, their drawbacks, and their challenges.

**Chapter – 3** centers the discussion around the design, development, and performance evaluation of a novel agricultural implement known as the ‘Roller Rake Weeder’. This chapter outlines the shortcomings of existing weeders and presents the innovative features incorporated into the Roller Rake Weeder to address these limitations. Through rigorous testing and evaluation, the effectiveness and efficiency of this new weeding tool are assessed, offering valuable insights into its practical applicability and potential impact on weed management practices.

**Chapter – 4** offers a detailed exploration of the design and development process of an Inter Cum Intra-Row Paddy Field Weeder suitable for wetland cultivation. It outlines the design criteria, incorporates finite element analysis to ensure structural integrity, and simulates the performance of the designed model. This chapter demonstrates the feasibility and effectiveness of the proposed weeding implementation, highlighting its potential to revolutionize weed management practices in wetland paddy cultivation contexts.

**Chapter – 5** elucidates the procedure for the physical prototype development of the designed weeder analyzed in the previous chapter (i.e., Chapter Four). Results of the laboratory testing after the fabrication are also given in this chapter.

**Chapter – 6** gives the summary and conclusions of various chapters

## CHAPTER TWO

### 2 Literature review

#### 2.1 Comparative study of various types of paddy weeders developed in India

In general, paddy weeders can broadly be divided into two categories: manually operated and power operated. The majority of manually operated weeders are push-pull types. Power-operated weeders may be of self-propelled or self-propelled ride-on type or push-behind type. Paddy weeders' effectiveness and operational expenses can differ based on several variables, such as the type of weeder, its design, power source, and maintenance requirements. Various types of paddy weeders are described below.

##### 2.1.1 Ride-on type paddy weeder

Basavaraj et al. (2018) developed a self-propelled ride-on type paddy weeder (Figure 2.1) at Tamil Nadu Agricultural University, Coimbatore. It was powered by a gasoline engine of 4.045 kW. The weight of the engine was 13.5 kg. The overall width, height, and length of the weeder were 250 mm, 950 mm, and 1500 mm respectively. The field capacity of the machine was found to be 0.0306 ha/h with a weeding efficiency of 84.4 percent. The cost of operation of the developed machine was 2741.11 Rs. /ha. The machine was found to be comfortable working at a speed of 1.8 km/h.

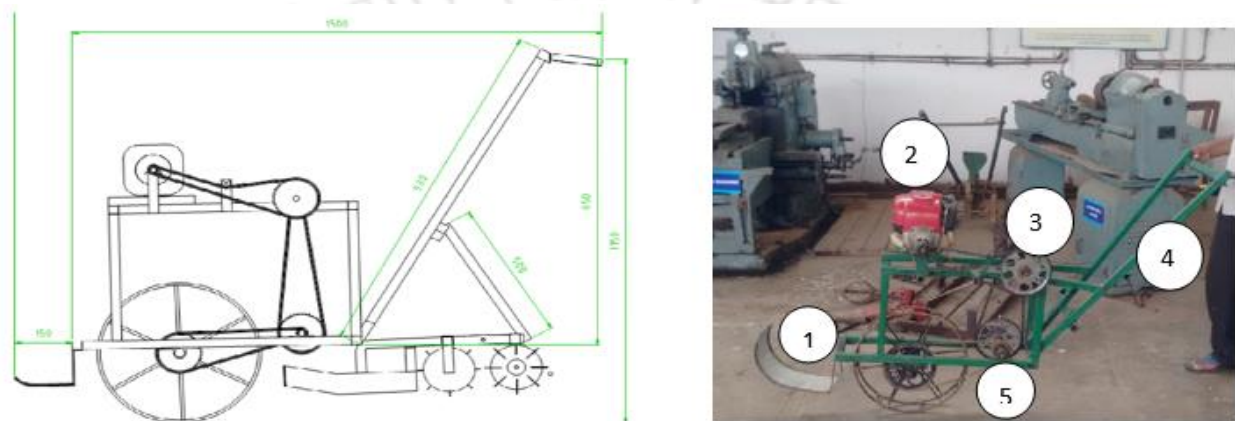


1. Engine unit (prime mover)
2. Ground wheel
3. Seat
4. Foot-rest
5. Float

**Figure 2.1 A self-propelled ride-on type paddy weeder (Basavaraj et al. 2018)**

### 2.1.2 Self-propelled type cono-weeder

Kanth et al. (2020) designed and developed a self-propelled cono-weeder at the College of Agricultural Engineering, JNKVV, Jabalpur. The weeder was powered by a 1.0 kW Honda petrol start and kerosene run engine having a working width of 150 mm. The overall dimensions i.e. length, width, and height of the weeder were 1650 mm, 200 mm, and 1156 mm, respectively. It was found that the self-propelled cono-weeder has a field capacity of 0.033 ha/h with 73.92% weeding efficiency and 89% field efficiency. Different views of the cono-weeder are shown in Figure 2.2.

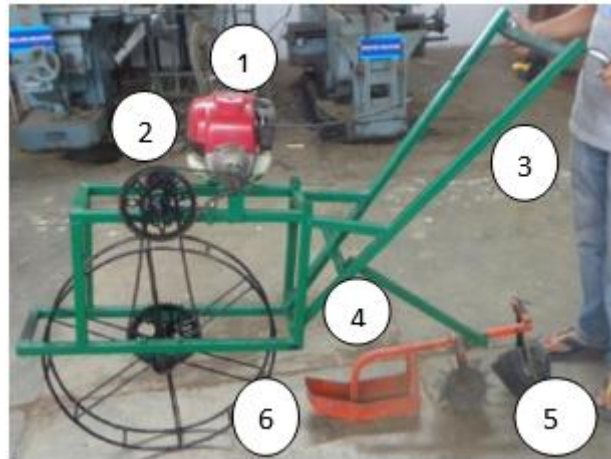


**Figure 2.2 Views of the self-propelled cono-weeder** (Kanth et al. 2020)

(1. Float 2. Engine unit 3. Chain sprocket system 4. Handle 5. Ground wheel)

Ningthoujam & Kumar (2018) developed a self-propelled type cono-weeder at the College of Agricultural Engineering, JNKVV, Jabalpur. The machine was operated by a 1.0 kW Honda petrol start and kerosene run engine. The field capacity and weeding efficiency of the machine were found to be 0.0323 ha/h and 68.77%, respectively. The machine was operated at a travel speed of 2.28 km/h.

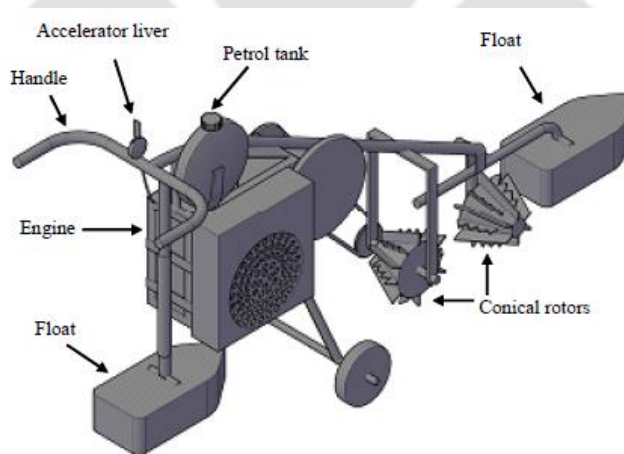
Kunnathadi et al. (2016) developed and tested a self-propelled cono-weeder (Figure 2.3) for rice cultivation at the College of Horticulture, Kerala Agricultural University, Thrissur to reduce drudgery involved in manual cono-weeding in rice. An air-cooled 2-stroke petrol engine was used as a prime mover. It had a rated power of 0.9 kW at 5500 RPM with a specific fuel consumption of 650 g/kW.h.



1. Engine unit
2. Chain sprocket system
3. Handle
4. Float
5. Cones with spikes/blades on the periphery
6. Ground wheel

**Figure 2.3 Self-propelled type cono-weeder** (Ningthoujam & Kumar, 2018)

It was found that the self-propelled cono-weeder had a field capacity of 0.1 ha/h at an operating speed of 2.0-3.0 km/h. The weeding efficiency of the unit in rice was at par with that of the manual cono-weeder operated twice at 15 and 30 days after transplanting. The weight of the developed weeder was 36 kg. The CAD view of the developed self-propelled cono-weeder is shown in Figure 2.4.



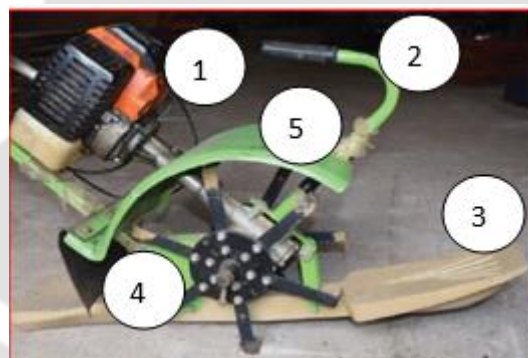
**Figure 2.4 Components of the self-propelled cono-weeder**

### 2.1.3 Rotary power weeder

Ragesh et al. (2018) developed a modified power weeder at Swami Vivekanand College of Agricultural Engineering Technology and Research Station, Raipur. The machine is run by a 1

kW petrol start kerosene run engine. The developed machine was tested and compared with hand weeding as well as mechanical weeding (*Ambika weeder*) and reported that the machine had a weeding efficiency of 86%. The cost of operation of the machine was 928 Rs. /ha. The overall dimensions of the modified power weeder were 1900 mm in length, 700 mm in width, and 900 mm in height. The weight of the machine was 98 kg.

Sirmour and Verma (2018) developed a power-operated single-row weeder (Figure 2.5) in the Faculty of Agricultural Engineering, IGKV, Raipur. The average working speed of the machine was 2.45 km/h with a maximum field capacity of 0.054 ha/h. The working width of the developed machine may be adjustable between 140 to 250 mm. The overall dimensions of the developed power weeder were 1345.8 mm in length, 573 mm in width, and 1020 mm in height. The total weight of the weeder was 14.5 kg. The weeding efficiency was observed as 88.62% under a single-row active power weeder. The operating cost of the rotary paddy weeder was 980 Rs./ha as compared to 2300 Rs./ha with traditional manual weeding. The saving in cost of weeding was 60% and the saving in time was 65% as compared to manual weeding.



1. Engine unit
2. Handle
3. Float
4. Rotor blades
5. Mud guard

**Figure 2.5 Rotary-type power weeder (Sirmour and Verma, 2018)**

Singh (2017), modified a rice weeder for dry field conditions at IGKV Raipur. Parameters including rotary blades, axle extension shaft, wheels, mud flap, operational safety, and easiness in fabrication were considered during modification. A single-cylinder, 2- 2-stroke petrol engine of 1.49 kW with a side valve and the air-cooled engine was used as a prime mover in a modified power weeder. Performance evaluation of the modified weeder was conducted with a different number of blades. The weeding efficiency of the modified power weeder was a maximum of 73.25% with 8 blades followed by 68.21% with 6 blades and 65.46% with 4 blades. In wet field conditions, maximum weeding efficiency (70.12%) was observed with 8 blades followed

by 66.28% with 6 blades and 62.1% with 4 blades. The average field capacity of the machine was 0.03 ha/h. The operation cost of the modified weeder for dry field conditions was higher (1800 Rs. /ha) as compared to wetland conditions (1434 Rs. /ha).

## **2.2 Important performance parameters for paddy weeders**

Various parameters affect the performance of weeders. These parameters should be considered while designing, testing, or selecting the weeders. These parameters include the speed of operation (km/h), energy consumption (MJ /ha), fuel consumed (L/h) (in case of power-operated weeders), heart rate ( $\text{beats}\cdot\text{min}^{-1}$ ), oxygen consumption rate ( $\text{l}\cdot\text{min}^{-1}$ ), theoretical field capacity (ha/h), actual field capacity (ha/h), field efficiency (%), weeding efficiency (%), performance index (%), plant damage (%), cost of operation (Rs/ha). However, most of the parameters are interdependent. For instance, the speed and width of the operation affect the field capacity. That is, the more the speed, the more will be the field capacity, and vice-versa. Considering two weeders operating at the same speed, the weeder that has more operating width will have more field capacity. Similarly, for manually operated weeders, traveling at a higher speed will require a higher heart rate and energy consumption as compared to one operating at a lower speed. In the same manner, the field efficiency of a paddy weeder depends directly on actual field capacity and theoretical field capacity. Considering these points, only a few parameters are sufficient to determine the performance evaluation of any type of paddy weeder's effectiveness and its practical applicability. These parameters include weeding efficiency, actual field capacity, and cost of operation of the machine.

## **2.3 Performance analysis of various weeders**

The performance of various weeders has been analyzed as follows.

### **2.3.1 Weeding efficiency**

The average weeding efficiency when done by hand is 95.4%, which is higher than when done mechanically. In certain instances, hand weeding can achieve 100% weeding efficiency. Ambika weeders, Cono weeders, and Rotary power weeders have average weeding efficiency

values of 78.05%, 73.51%, and 79.92%, respectively. Figure 2.6 and Table 2.5 show various data about weeding efficiency.

### **2.3.2 Actual Field capacity**

The average operational efficiency is highest with the rotary power weeder, reaching 0.0793 ha/h. Conversely, hand weeding exhibits the lowest efficiency at 0.00414 ha/h, while Ambika weeders and Cono weeders show intermediate efficiencies of 0.0276 ha/h and 0.0178 ha/h, respectively. The operational efficiency of the machine is contingent upon the number of rows in the field; more rows correspond to higher efficiency, and vice versa. Detailed data concerning operational efficiency are provided in Table 2.5, and Figure 2.7.

### **2.3.3 Cost of Operation**

The average cost of operation is highest in the case of hand weeding. The average cost amounts to Rs. 5104.14/ha. The average cost of operation of Ambika weeders, cono weeders, and Rotary power weeders are 1701.83 Rs/ha, 1634.25 Rs/ha, and 1169.59 Rs/ha, respectively. Various data related to operational cost are presented in Table 2.5, and Figure 2.8.

### **2.3.4 Performance analysis of hand weeding**

Hand weeding is most laborious and drudgery as compared to other methods of weeding. Although it has the highest weeding efficiency (95.412%), the cost of operation is also the highest (5104.14 Rs/ha). For hand weeding, the worker has to uproot and destroy the weeds in a stooping posture thus resulting in drudgery. This might be the reason for having the lowest field capacity (.001414 ha/h). The average values of various performance parameters of hand weeding are presented in Table 2.1.

### 2.3.5 Performance analysis of Cono-weeders

Cono weeders are one of the most commonly used available manually operated weeders. The average weeding efficiency of cono-weeders is 73.51%, which is the lowest as compared to other types of weeders. The average field capacity of cono weeders is 0.0178 ha/h which is at par with Ambika weeders. The average operating cost of cono weeders is 1634.25 Rs/ha which is very low as compared to hand weeding (5104.14 Rs/ha). The average values of various performance parameters of cono weeders are presented in Table 2.2.

### 2.3.6 Performance analysis of Ambika Weeder

Most Ambika weeders are of single-row type. Thus, the performance parameters of Ambika weeders and Cono weeders are comparable. The average weeding efficiency and average field capacity are 78.05% and 0.0276 ha/h, respectively. The cost of operation of Ambika weeder is almost similar to cono weeder i.e., 1701.83 Rs/ha and 1634.25 Rs/ha, respectively. The average values of various performance parameters of Ambika weeders are presented in Table 2.3.

### 2.3.7 Performance analysis of Rotary Power Weeder

Among all types of weeding machines, the rotary power weeder is the most suitable method for weeding operation. It has an average actual field capacity of 0.0793 ha/h which is highest among other types of weeders. The average cost of operation is also the lowest (1169.59 Rs/ha) as compared to other methods of weeding. The weeding efficiency (79.92%) is lower as compared to hand weeding (95.412%) but higher than other methods. The average values of various performance parameters of rotary power weeders are presented in Table 2.4.

The comparison of various parameters of paddy weeders is given in the below tables.

**Table 2.1 Performance parameters of hand weeding**

	Parameters
--	------------

Sources	Weeding efficiency (%)	Actual field capacity (ha/h)	Cost of operation (Rs. /ha)
Netam <i>et al.</i> , (2018)	95.28	0.0026	4250.00
Sirmour <i>et al.</i> , (2018)	NA	NA	2300.00
Ningthoujam <i>et al.</i> , (2018)	NA	NA	NA
Prakash <i>et al.</i> , (2016)	100.00	NA	5390.63
Ragesh <i>et al.</i> , (2018)	92.10	NA	5765.50
Singh (2017)	NA	NA	NA
Tayade (2016)	NA	NA	3450.00
Narwariya <i>et al.</i> , (2016)	99.01	0.0072	6152.00
Shakya, (2016)	90.67	0.0040	6250.00
Remesanet <i>al.</i> , (2007)	NA	0.00275 <sup>\$</sup>	7275.00 <sup>\$</sup>
Average value	95.412	0.00414	5104.14

<sup>\$</sup> - Average performance parameters of male and female

NA - Data not available

**Table 2.2 Performance parameters of cono weeders**

Parameters

Sources	Weeding efficiency (%)	Actual field capacity (ha/h)	Cost of operation (Rs. /ha)
Netamet <i>et al.</i> , (2018)	70.90	0.0130	1160.00
Sirmour <i>et al.</i> , (2018)	NA	NA	NA
Ningthoujam <i>et al.</i> , (2018)	68.77	0.0323	NA
Prakash <i>et al.</i> , (2016)	76.56	0.0100	NA
Ragesh <i>et al.</i> , (2018)	NA	NA	NA
Singh (2017)	NA	NA	NA
Tayade (2016)	NA	NA	NA
Narwariya <i>et al.</i> , (2016)	70.40	0.0180	2447.00
Shakya <i>et al.</i> , (2016)	81.94	0.0160	1755.00
Remesan <i>et al.</i> , (2007)	72.50 <sup>\$</sup>	0.0180 <sup>\$</sup>	1175 <sup>\$</sup>
Average value	73.51	0.0178	1634.25

<sup>\$</sup> - Average performance parameters of male and female

NA - Data not available

**Table 2.3 Performance parameters of Ambika Weeders**

Parameters

Sources	Weeding efficiency (%)	Actual field capacity (ha/h)	Cost of operation (Rs. /ha)
Netam et al, (2018)	78.03	0.0589	1050.00
Sirmour <i>et al.</i> , (2018)	NA	NA	NA
Ningthoujam <i>et al.</i> , (2018)	NA	NA	NA
Prakash <i>et al.</i> , (2016)	NA	NA	NA
Ragesh <i>et al.</i> , (2018)	76.00	0.0100	2481.50
Singh (2017)	NA	NA	NA
Tayade (2016)	80.11	0.0140	1574.00
Narwariya <i>et al.</i> , (2016)	NA	NA	NA
Shakya <i>et al.</i> , (2016)	NA	NA	NA
Remesan <i>et al.</i> , (2007)	NA	NA	NA
Average value	78.05	0.0276	1701.83

NA - Data not available

**Table 2.4 Performance parameters of power-operated rotary weeders**

	Parameters		
Sources	Weeding efficiency (%)	Actual field capacity (ha/h)	Cost of operation (Rs. /ha)

Netam <i>et al.</i> , (2018)	91.00	0.1900*	808.42
Sirmour <i>et al.</i> , (2018)	82.92	0.0540#	980.00
Ningthoujam <i>et al.</i> , (2018)	NA	NA	NA
Prakash <i>et al.</i> , (2016)	70.98	0.0600	747.12
Ragesh <i>et al.</i> , (2018)	80.11	0.0680	889.00
Singh (2017)	69.35	0.0317#	1617.00
Tayade, (2016)	NA	NA	NA
Narwariya <i>et al.</i> , (2016)	85.13	0.0500	1976.00
Shakya <i>et al.</i> , (2016)	NA	NA	NA
Remesan <i>et al.</i> , (2007)	NA	NA	NA
Average value	79.92	0.0793	1169.59

NA - Data not available

\* - Three-row weeder

# - Single row weeder

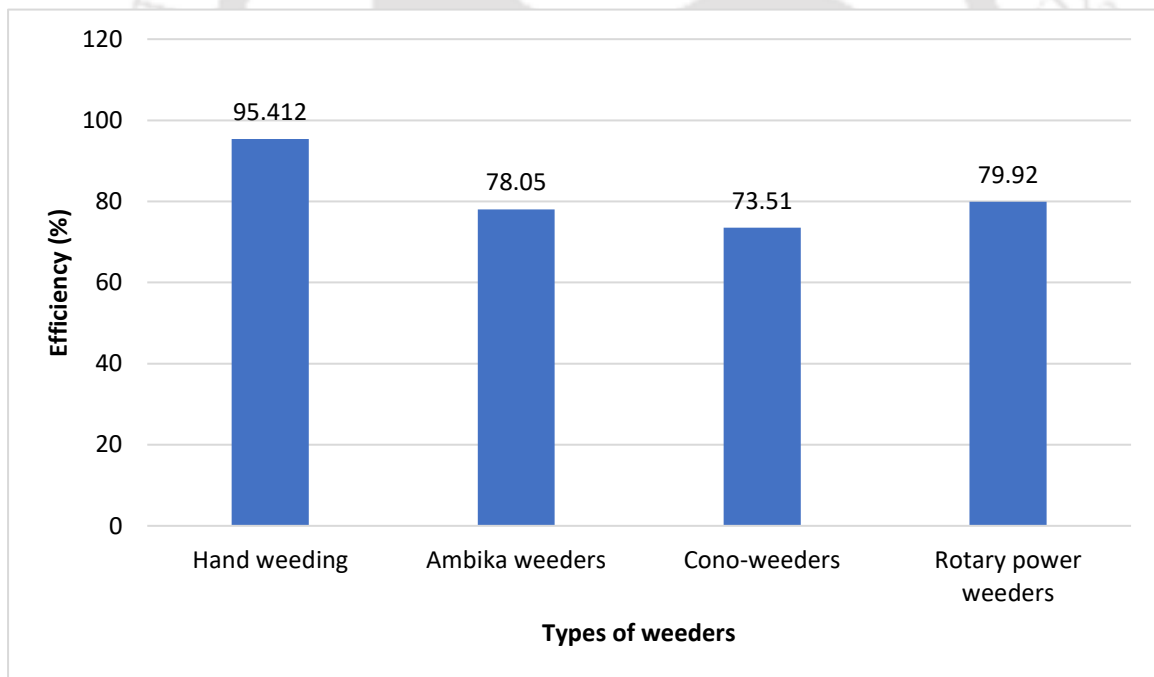
Note: 1. Ambika weeders and Conoweeders are considered single-row paddy weeders

2. The remaining belongs to two-row weeders

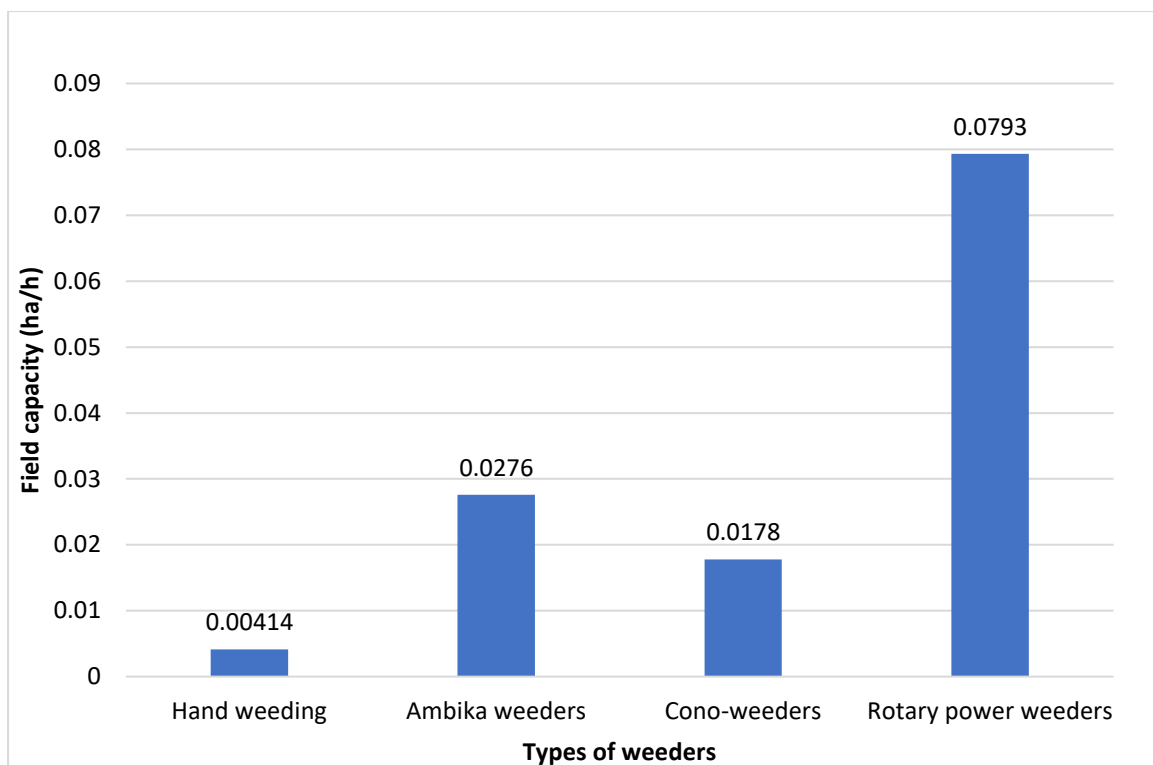
**Table 2.5 Average of the performance parameters of all the weeders**

Weeders type	Weeding efficiency (%)	Actual field capacity (ha/h)	Cost of operation (Rs/ha)
Hand weeding	95.412	0.00414	5104.14
Ambika weeders	78.05	0.0276	1701.83
Cono-weeders	73.51	0.0178	1634.25
Rotary power weeders	79.92	0.0793	1169.59

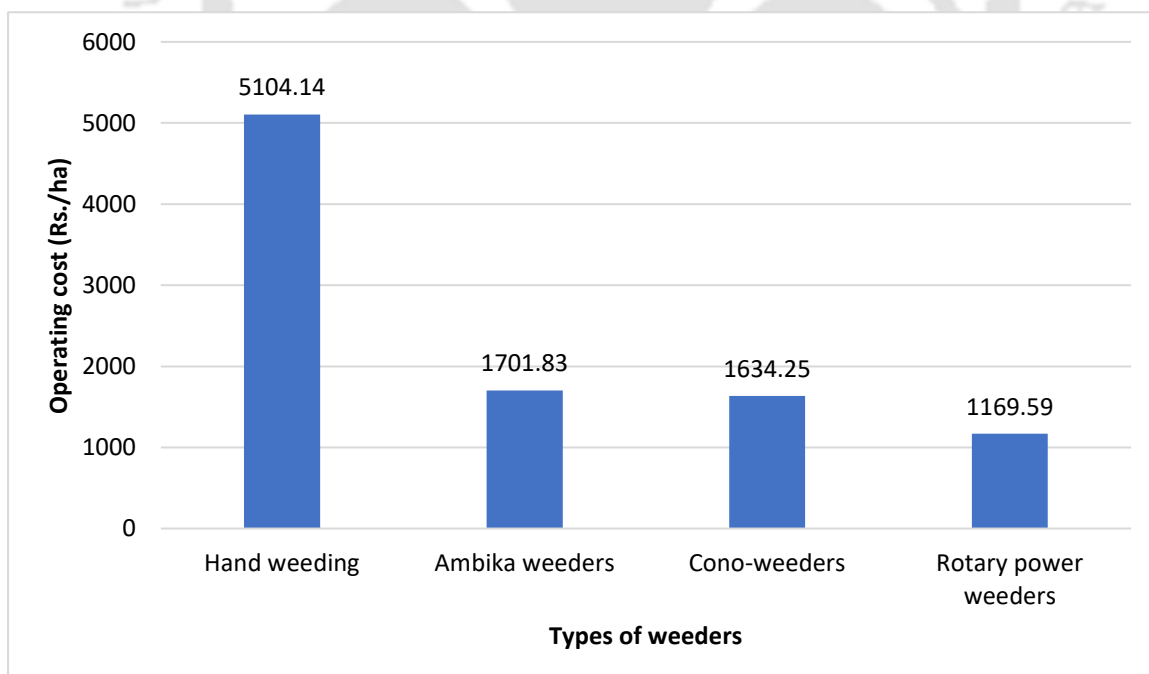
The graphical comparison of various parameters is depicted below.



**Figure 2.6 Comparison of weeding efficiency**



**Figure 2.7 Comparison of field capacity**



**Figure 2.8 Comparison of operating cost**

## **2.4 Challenges and Opportunities in Farm Mechanization and its Status for Northeastern India's Agriculture**

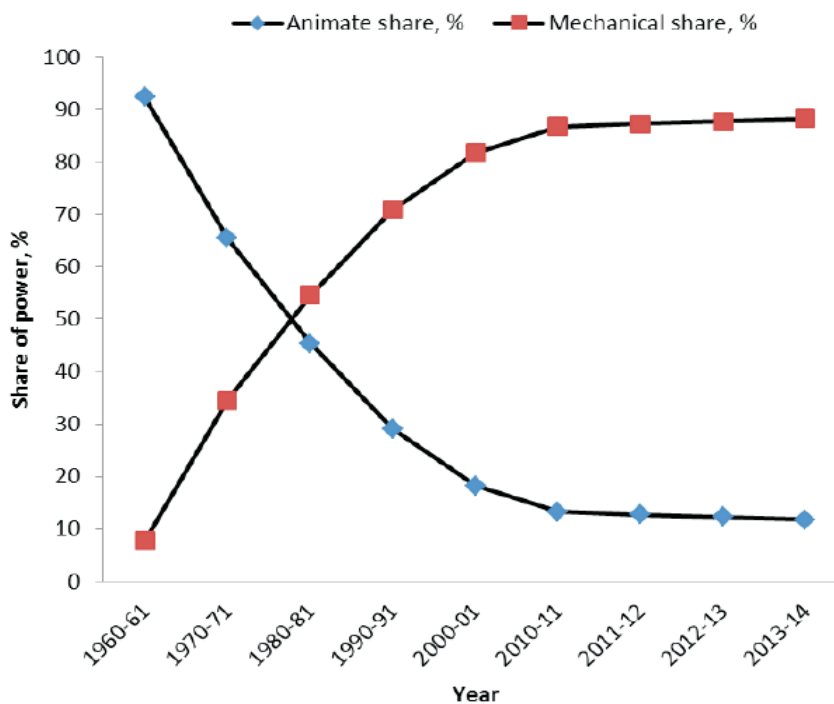
The availability of farm power has been immeasurably low in all the North-Eastern states namely, Assam (0.99 kW/ha), Arunachal Pradesh (0.46 kW/ha), Manipur (0.50 kW/ha), Meghalaya (0.28 kW/ha), Mizoram (0.48 kW/ha), Nagaland (0.50 kW/ha), Sikkim (0.53 kW/ha), and Tripura (1.32 kW/ha) (Anon, 2021) compared to other parts of India. This is due to hilly topography, high transportation costs, non-availability of suitable machinery, smaller landholdings, and limited infrastructural availability for such states. The sale of tractors during the year 2022-2023 in Assam was 5279 and only 7 tractors were sold in other parts of northeastern states and union territories (Anon, 2022). Efforts were made, however, to encourage and improve farm mechanization to increase agricultural production and lessen the drudgery of labor-intensive farming. The current article examines farm power availability from various sources, operating holdings, and food grain productivity among the northeastern states of India.

To study the farm mechanization status for Northeastern states, data has been collected from (i) various issues of Agricultural Statistics at a Glance, Ministry of Agriculture and Cooperation, Directorate of Economics and Statistics (ii) Several issues of Agricultural Census, Ministry of Agriculture (iii) various issues of Agricultural situation in India (iv) various Annual Report of the department of agriculture and farmers welfare and (v) various journal articles.

### **2.4.1 Transitioning Dynamics of Farm Power Sources**

Farm power sources are derived from agriculture workers, draught animals, diesel engines, electric motors, power tillers, and tractors. Studies reveal that there is a decline in the power source from animate power (human and animal power) as compared to mechanical power. Singh & Singh (2021) reported that the share of mechanical power available has increased 112.56 times while animate power available decreased 0.624 times from the year 1961-62 to 2020-21, respectively. Further, Tiwari (2019) estimated that the percentage of farm workers in the total workforce would reduce to 49.9% in 2033 and 25.7% in 2050 from 54.6% in 2011. It also states that the share of agricultural workers in total power availability in 1960-61 was about 16.3%, which is going to reduce to 2.3% in 2032–33. Similarly in the Northeastern of Assam, Barman and Deka (2021) stated that 94.32 percent of household ploughing was done

mechanically while 4.58% used draught animals for ploughing purposes. It further reports that operations like weeding were carried out by human laborers using small hand tools but the lack of adequate availability of farm laborers during that period resulted in a reduction in yield due to higher crop-weed competition for soil moisture and nutrients. Over the years, there has been a shift of power from manual to mechanical and electrical power. Singh et al., (2014) reported that during 1960-61 about 92.30% of farm power was coming from animate sources. However, In 2013-14 the contribution of animate sources of power reduced to about 11.80% and that of mechanical and electrical sources of power increased from 7.70% in 1960-61 to about 88.20% (Figure 2.9).



**Figure 2.9 Share of animate and mechanical power during different periods (Singh et al., 2014)**

#### 2.4.2 Farm power availability and productivity in the Northeastern states of India

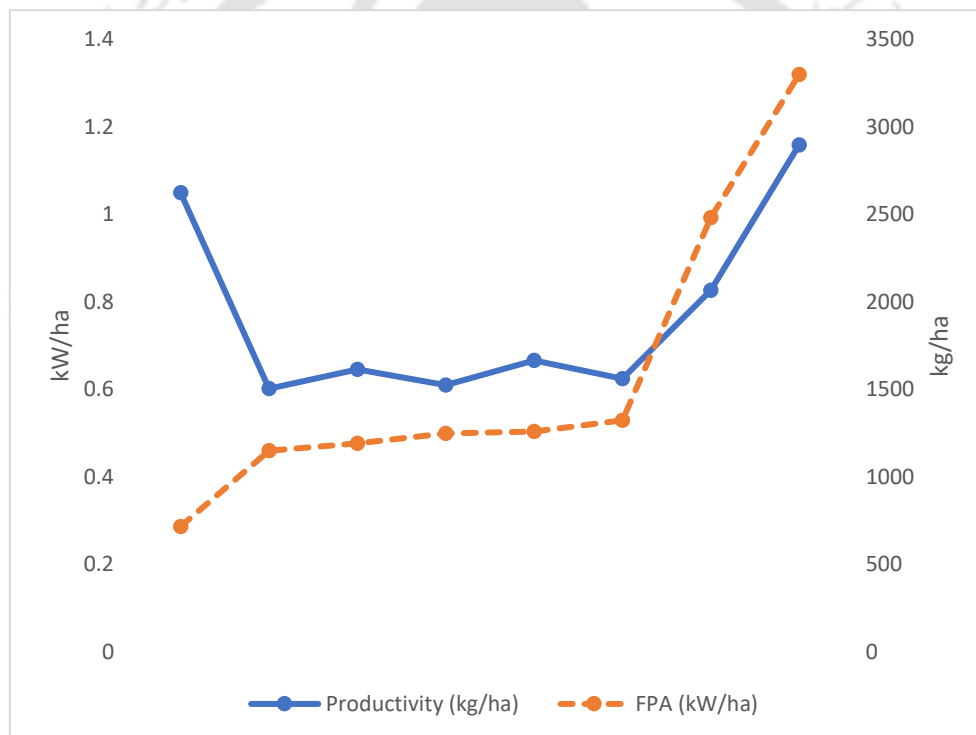
Even though India does not currently follow the developed world's trend of mechanization—being dominated by small and marginal land holdings—it will soon catch up. Productivity rises in tandem with the availability of more agricultural power (Figure 2.10). At the end of 2016–

17, the nation's total available farm power was 2.03 kW/ha, while certain states still had less than the national average. Of the 28 states of India, 64.29% of the states are below the national average (Figure 2.11 and Table 2.6). Of the total 8 Northeastern states, only Meghalaya (2624 kg/ha) and Tripura (2898 kg/ha) have productivity above the national average of 2393 kg/ha (Figure 2.12). The percent change in farm power availability from 2014 to 2017 is 17.3%. To achieve the targeted average cropping intensity and productivity by 2030, it is expected to require a farm power consumption of 4.00 kW/ha. Thus, the states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura need farm power availability of 1.97 kW/ha, 1.57 kW/ha, 1.39 kW/ha, 0.75 kW/ha, 2.19 kW/ha, 1.13 kW/ha, 1.61 kW/ha, and 3.48 kW/ha respectively by 2030.

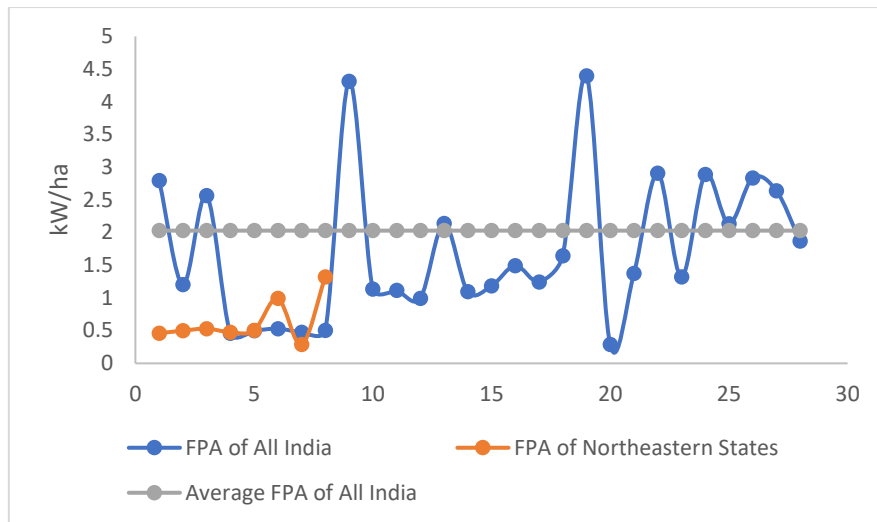
**Table 2.6 Farm power availability and productivity during 2014-2017 (Anon, 2021)**

	As on 31.3.2014		As on 31.3.2017		Percent Change in Farm Power Availability	Productivity of Foodgrain (kg/ha)
	Number of Tractors	Farm Power availability	Number of Tractors	Farm Power availability		
Assam	34075	0.869	46975	0.993	14.3	2067
Arunachal Pradesh	512	0.322	1230	0.460	42.6	1505
Manipur	776	0.34	1495	0.50	47.2	1526
Meghalaya	832	0.188	1760	0.287	52.3	2624
Mizoram	419	0.305	839	0.477	56.7	1615

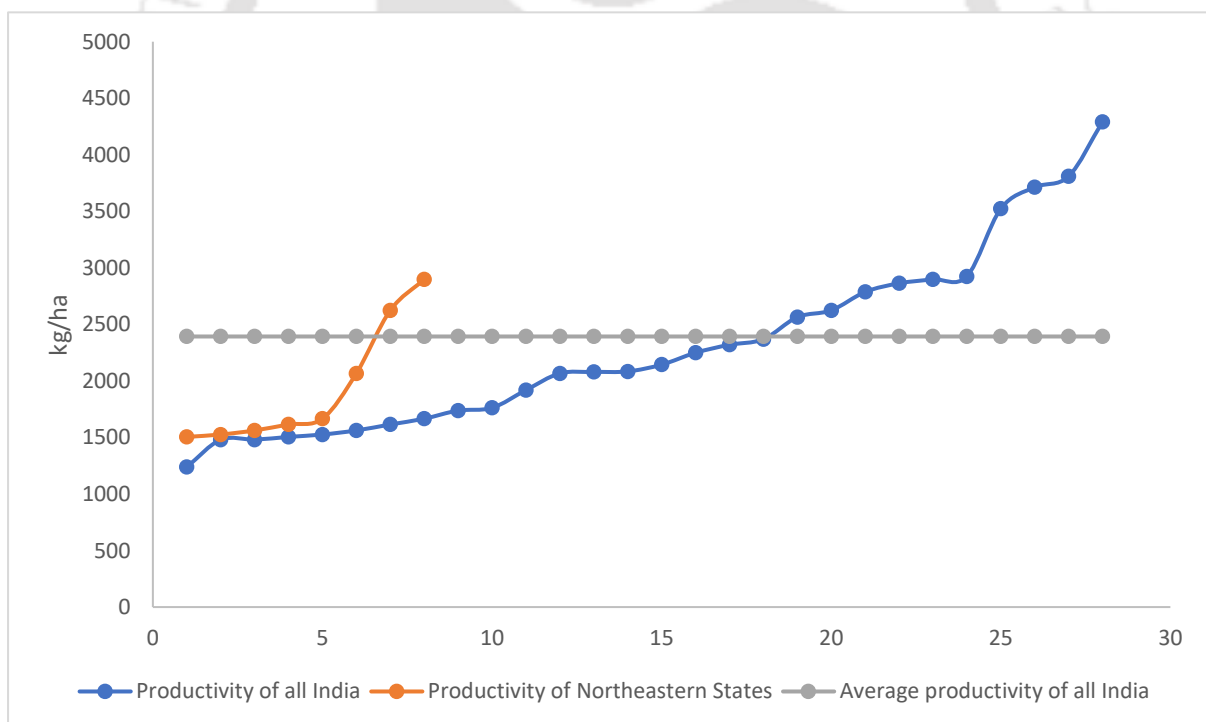
Nagaland	956	0.415	1346	0.504	21.4	1666
Sikkim	13	0.360	88	0.530	47.2	1562
Tripura	4183	1.04	5737	1.32	26.9	2898
All India	4913768	1.726	4913768	2.05	17.3	2393



**Figure 2.10 Farm power availability vs productivity among the North-eastern states during the year 2016-2017 (Anon, 2021)**



**Figure 2.11 Comparison of farm power availability (FPA) between North-eastern states and the rest of India during the year 2016-2017 (Anon, 2021)**



**Figure 2.12 Comparison of food grain productivity (kg/ha) between North-eastern states and the rest of India during the year 2016-2017 (Anon, 2021)**

### 2.4.3 Categorization of Farm Power Availability

The farm power availability (FPA) of different states which was evaluated at the end of 2016-17, has been categorized into four groups (Anon, 2018). Category I has farm power availability of more than the national average of 2.03 kW/ha; Category II with farm power availability between 2.03 and 1.726 kW/ha; Category III has farm power availability between 1.726 and 1.00 kW/ha and Category IV has farm power availability of less than 1.00 kW/ha. On the basis above-said criteria, the states are classified as given in Table 2.7. It was found that 7 (seven) states out of the 8 (eight) belong to Category IV which has a farm power availability of less than 1 kW/ha, except Tripura which belongs to Category III which has a farm power availability of 1.32 kW/ha. Thus, the north-eastern states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura have 51%, 77.3%, 75.3%, 85.8%, 76.4%, 75.1%, 73.8%, and 34.8% respectively less farm power availability than the national average of 2.03 kW/ha.

**Table 2.7 Categorization of Farm Power Availability**

Farm Power Availability (kW/ha)			
More than 2.025  (Category I states)	Between 2.025 to 1.726  (Category II states)	Between 1.726 to 1.000  (Category III states)	Less than 1.000  (Category IV states)
Andhra Pradesh	West Bengal	Jharkhand	Assam
Bihar		Himachal Pradesh	Arunachal Pradesh
Gujrat		Jammu & Kashmir	Manipur
Haryana		Kerala	Meghalaya

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Karnataka	Maharashtra	Mizoram
Punjab	Madhya Pradesh	Nagaland
Tamil Nadu	Chhattisgarh	Sikkim
Telangana	Odisha	
Uttar Pradesh	Rajasthan	
Uttarakhand	Tripura	

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#### **2.4.4 Farm equipment manufacture in North-eastern states**

There are mostly blacksmiths who use traditional equipment to create hand tools and implements. Among the north-eastern states, only a few units in Manipur and Assam are large enough to have more than 75 square meters of floor space (Alam, 2006). Alam stated that the Indian Council of Agricultural Research (ICAR) has approved a revolving fund scheme called 'Commercialization of Farm Tools and Machinery for Hill Agriculture' worth Rs 22.98 lakhs, under which 39 different types of agricultural machinery and tools are manufactured in response to requests from farmers or organizations involved in agriculture production in the region. The survey also reports that the majority of manufacturing units/workshops in Assam are found in the districts of Kamrup, Barpetta, Golaghat, and Jorhat whereas, manufacturing units in Manipur are concentrated in two areas: Wangkhei Thangjam Leirak in Imphal East District and Sagolband Thangjam Leirak in Imphal West District. It further mentions that the majority of the units in Meghalaya are found in the villages of Myllem, Sohryngkham, and Smith in the East Khasi Hills district, and Ronkhon, Rongram, Ampati, Raajabala, and Garobadha in the Garo Hills area.

## 2.4.5 Tools and implements used

Because farm power is scarce, animate power (animal and human power) sources are used for the majority of agricultural tasks. In an irrigated environment, engines and electric motors are not frequently utilized as power sources.

There is a lot of room for the use of enhanced hand tools in the sector of agriculture because the majority of farm operations are performed by hand, particularly in hilly areas where traditional hand tools are used. Promoting both power-operated tools and equipment drawn by animals can help mechanize the seedbed preparation processes. To prepare the ground, ridger ploughs, disc harrows, and better bakhar blades might be used. For harvesting, better sickles and tubular maize shellers could be used. Disc harrow and animal-drawn M.B. plough are used in irrigated areas. It is recommended that the northeastern state promote various agricultural equipment such as aero-blast sprayers, zero-till drills, strip-till drills, vegetable transplanters, multi-crop threshers, self-propelled vertical conveyor reapers, animal-drawn ridgers, blade harrows, puddlers, manual rice transplanters, manual rice seeders, animal-drawn three-tine cultivators, and potato planters. The various tools and implements being used and improved implements suggested for introduction are presented in Table 2.8.

**Table 2.8 Traditional and improved agricultural implements being used by the farmers for different operations and improved agricultural machinery to be introduced for popularization among the northeastern states of India (Alam, 2006)**

Operation	Implements being used		Improved implements suggested for introduction
	Traditional	Improved	
Seedbed preparation	Khasi spade;	Khasi spade, MB	Power tiller mounted 12.5 cm MB
Ploughing	local plough	plough	plough; Animal

			drawn Puddler; 10 cm light ridger plough
Harrowing	Peg tooth harrow	Disc harrow (offset); power tiller	Peg tooth puddler; comb harrow; ANGRAU animal-drawn puddler
Shallow cultivation	–	–	3 tines cultivator (Animal drawn/Power tiller)
Clod crushing	Local plough	–	–
Land leveling	Leveler	–	Animal drawn leveler
Seeding/planting	Dibbler	–	Metallic dibbling stick; B.D. seed drill; CIAE seed drill; pre-germinated paddy seed drill; seed-cum-fert. drill
Sowing			
Planting	–	–	Manual and self-propelled mechanical rice transplanter; semi-automatic vegetable transplanter; sugarcane cutterplanter
Weeding and hoeing			
Weeding	Khasi spade (small)	–	8 cm weeder; wheel hoe with showel and V-blade
Interculture	Khasi spade (small);	–	V-blade hand hoe; CIAE low cost

	hand fork		weeder
Bund/furrow making	Khasi spade	–	Bullock drawn and Power tiller operated bund/border former
Spraying and dusting			
For field crops	–	–	Hand rocking sprayer; foot sprayer; hand compressed sprayer; knapsack sprayer; power sprayer
For tall crops	–	–	Hand rocking sprayer; foot sprayer; hand compressed sprayer; knapsack sprayer; power sprayer
For trees/shrubs	–	–	Hand rocking sprayer; foot sprayer; hand compressed sprayer; knapsack sprayer; power sprayer
Irrigation			
Water lifting	Swing bucket	Shallow tube wells	Diesel and electric pumping sets; foot pumps; diaphragm pumps
On field application	–	–	Drips; sprinklers
Harvesting/diggi	Sickle	–	Serrated sickle; fruit

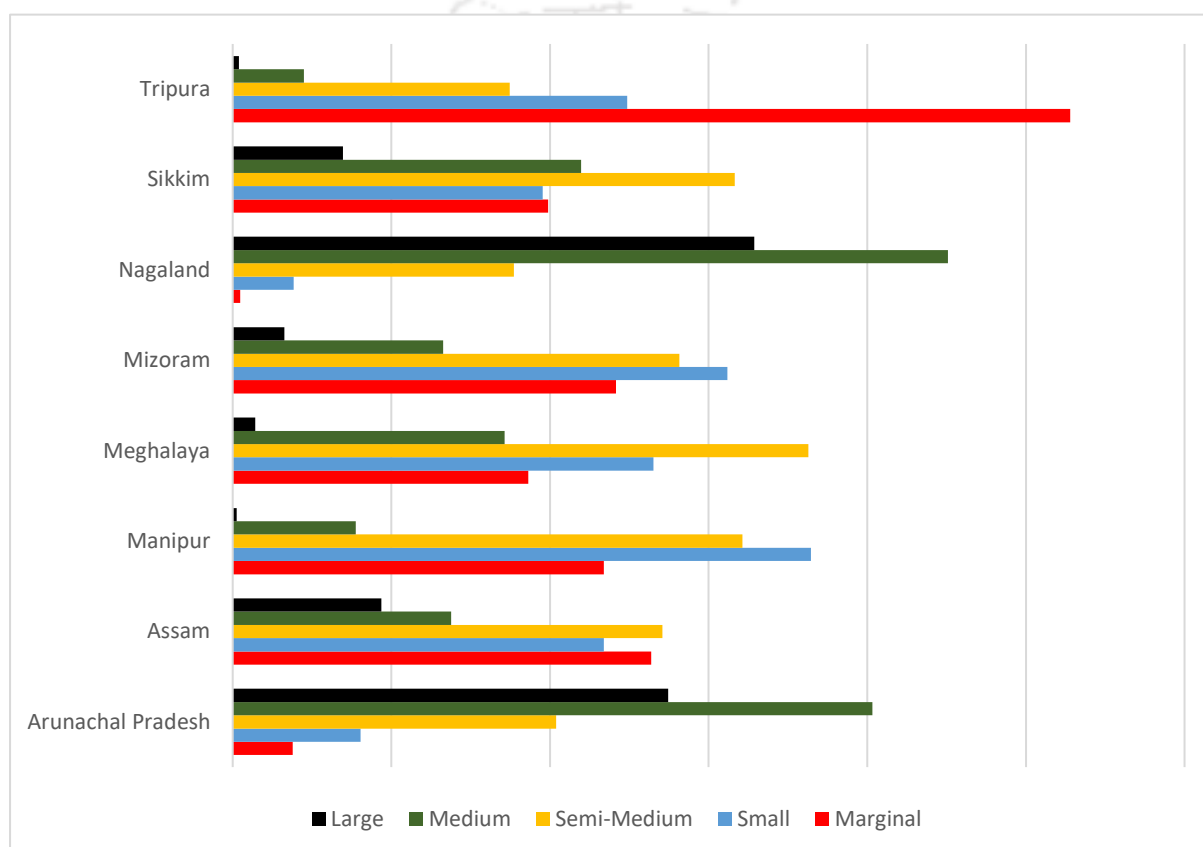
ng/ uprooting			harvester; orchard ladder; walking-type vertical conveyor reaper
Threshing/shelling	Maize sheller	Pedal-operated paddy thresher	Tubular maize sheller; power operated drum paddythresher; axial flow power thresher; multi-crop thresher
Winnowing/ cleaning/ grading	—	—	Manual and power-operated winnowing fan; grainpre- cleaner; fruit grader
Straw management	—	—	Auxillary engine-operated bush/grass cutter
Reaping	Manual	—	Shredding with tractor- mounted shredder and incorporation with MB plough; retrieval, composting, and vermicomposting
Incorporating in soil	Manual	—	Shredding with tractor- mounted shredder and incorporation with MB plough; retrieval, composting, and vermicomposting
Baling	—	—	Baler
Densifying	—	—	Feed block-making machine
Stubble shaving	—	—	Power tiller, Tractor-mounted stubble shaver
Other			

operations (not listed above)			
Milling of cereals, pulses, and oilseeds	Counter poise foot pounder	Huller	Mini grain mill; mini rice mill; mini dal mill; mini oil expeller
Cutting trees	Dao	–	Auxillary engine-operated disc and chain saw
Chaff cutting	Dao	–	Manual and power-operated chaff cutter
Horticultural tools	Dao, knife	–	Horticultural tools

#### 2.4.6 Operational holdings size

Operational holdings are divided into five categories namely; marginal (< 1 hectare), small (1-2 hectares), semi-medium (2-4 hectares), medium (4-10 hectares), and large (> 10 hectares). The area covered in each category among the Northeastern states is presented in Table 2.9. The state of Assam, Manipur, Meghalaya, Mizoram, Sikkim, and Tripura has 26.37%, 23.40%, 18.64%, 24.156%, 19.89%, 52.80% and 20.76% marginal size holdings against its total land holdings except the states of Arunachal Pradesh and Nagaland which has only 3.78% and 0.48% marginal size against its total land holdings respectively. On the other hand, the state of Assam, Manipur, Meghalaya, Mizoram, Sikkim and Tripura has only 9.37%, 0.25%, 1.41%, 3.25%, 6.95%, 0.38% large size holdings against the total operational holdings except for the states of Arunachal Pradesh and Nagaland which has 27.45% and 32.87% respectively large size holdings against its total size holdings. Arunachal Pradesh and Nagaland have the highest proportion of medium-sized land holdings (4-9.99 hectares), accounting for 40.33% and 45.08% of the total land holdings, respectively. Assam, Meghalaya, and Sikkim have 27.09%,

36.29%, and 31.66% of their land holdings in the semi-medium size group (2-3.99ha). The state of Manipur and Mizoram belongs to a small size group (1-1.99 ha) having 36.46% and 31.18% of its total land holdings. Tripura is the only state among the eight Northeastern states of India that accounts for 52.80% of the total land belonging to the marginal size group (< 1 ha) (Figure 2.13). As a result, none of the states in northeast India fit into the large size category (> 10 hectares).



**Figure 2.13 State-wise operational holdings during 2015-16 (Anon, 2016)**

**Table 2.9 Area of Operational Holdings by Size Group (2015-16) (Anon, 2016)**

State	Marginal	Small	Semi-	Medium	Large	All
						Holding

Medium						s
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Arunachal Pradesh	14356.98	30640.11	77432.38	153215.31	104294.29	379939.07
Assam	784971.32	696107.03	806250.00	410090.50	278835.70	297625.456
Manipur	40295.68	62773.84	55322.02	13357.23	432.42	172181.19
Meghalaya	55929.89	79595.89	108904.36	51413.49	4236.04	300079.67
Mizoram	27167.00	35063.65	31671.94	14908.92	3653.20	112464.71
Nagaland	4608.78	36803.15	169447.92	431165.51	314413.88	956439.24
Sikkim	18073.30	17755.51	28763.89	19957.59	6315.02	90865.31
Tripura	148777.52	70095.55	49196.28	12633.75	1082.06	281785.17
All India	37923352.95	36150710.41	37619306.71	31810426.98	14313539.22	157817336.26

(Figure are in hectares)

#### **2.4.7 Constraints to agricultural mechanization**

Some of the difficulties encountered in increasing farm mechanization in the North Eastern states were as follows:

- a. Topography and Terrain: The mountainous and harsh terrain in many sections of the Northeast might make traditional agricultural machinery adoption difficult.
- b. Small Landholdings: Many farmers in the region have small landholdings, making large-scale mechanization difficult. Farmers must be educated and trained on the correct operation and maintenance of agricultural machinery.
- c. Infrastructure: The ineffective use of machinery can be hampered by a lack of suitable infrastructure, such as good roadways and storage facilities.
- d. Financial constraints: The cost of agricultural machinery might be prohibitively expensive for small and marginal farmers.
- e. Cultural practices: Some of the region's traditional farming techniques may not be compatible with modern technology.

#### **2.4.8 Suggestions**

Some of the initiatives to be taken up effectively by the government to improve mechanization status amongst the North Eastern states are as follows:

- a. Introduction of small hand tools: By introducing relevant and adequate implements that have been created elsewhere, portable small hand tools and implements can be improved and made available for marginal and small farmers.
- b. Subsidies and Schemes: The government, both at the federal and state levels, should effectively implement several schemes and subsidies to encourage farmers to use automated agricultural equipment. These programs should aim to offer farmers financial aid for the purchase of tractors, power tillers, and other agricultural machinery.
- c. Custom Hiring Centers: The establishment of custom hiring centers for agricultural machinery should be made available in various locations to make pricey machinery more accessible to small and marginal farmers who cannot afford their equipment so that farmers could rent machinery from these sites for specific tasks.

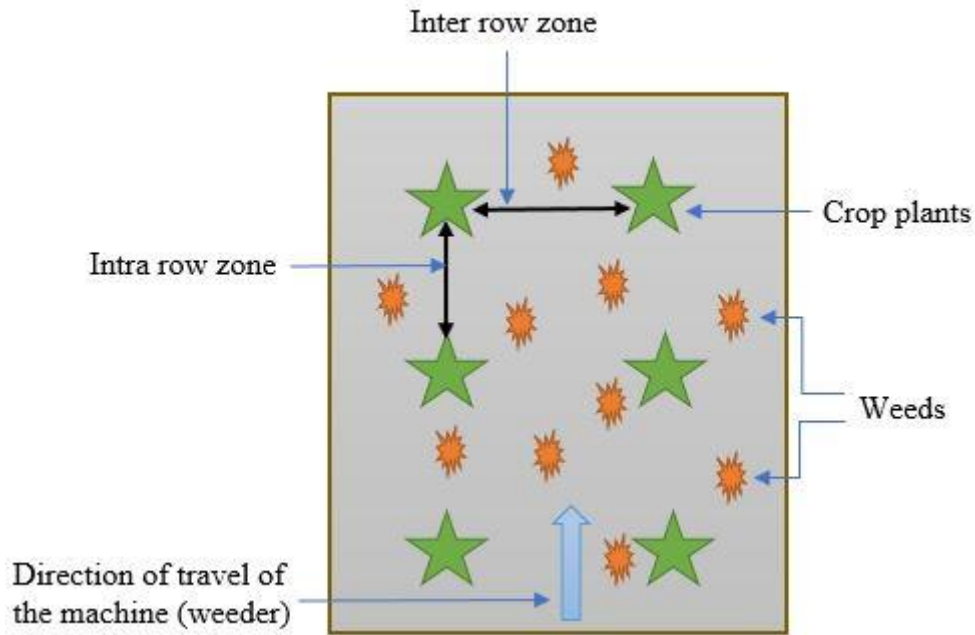
- d. Local Adaptations: Because each state has a distinct geographical and cropping pattern, efforts should be made to produce and promote regionally adapted crops.
- e. Training and Capacity Building: Training programs should be conducted in different remote areas to teach farmers how to use and maintain various agricultural machinery properly.

## 2.5 Mechanization in Intra-Row Weeding

We have largely covered weeders for inter-row weeding in the preceding sections. This section is devoted to reviewing the literature on intra-row weeders.

Apart from inter-row weeds, intra-row weeds (Figure 2.14) have the potential to significantly lower yields by 18–76% (Alba et al., 2020; Chandel et al., 2015; Gharde et al., 2018). As such, eliminating these weeds is equally important. Several studies on crop weed control have been done during the previous decade, with an emphasis on high-value crops such as vegetables (Fogelberg & Kritz, 1999). This research extensively used instruments such as brush weeders, finger weeders, and torsion weeders, which are routinely used for intra-row weed management. Additionally, more studies have been conducted to create innovative methods for achieving adequate control of weeds within the rows (Bontsema, Van, et al., 1998; Dedousis, 2007; Griepentrog et al., 2007; Home, 2003; Kouwenhoven, 1997). Wetland systems account for over 85% of the global rice harvest area, with irrigated wetland rice accounting for roughly 75% of rice production (Bouman et al., 2007). However, the majority of studies on intra-row weeders are for use in dryland vegetable crops, with only a few experiments on intra-row devices (Choi et al., 2015; Liu et al., 2023) conducted specifically for use in wetland paddy agriculture (Sebastian & Kalita, 2022).

Several crops saw productivity increases and weed biomass reductions when plants were grown with greater regularity and planting densities combined (Marín & Weiner, 2014; Olsen et al., 2012; Weiner et al., 2001). The results of the research on the ideal plant spacing under various conditions have been conducted using stochastic and 3-dimensional models (Colbach et al., 2014; Fischer & Miles, 1973) and have shown that weed competition decreases as plant arrangements become more uniform, that is when inter and intra-row spacings are comparatively equal.



**Figure 2.14 Inter and intra-row zones**

Moreover, when the crops are not planted uniformly, there is an additional requirement for the weeder to detect and identify the difference between crops and weeds. Paddy fields present this issue due to varying physical traits of leaves, stems, density, and other variables and the leaves of paddy plants are orientated in multiple directions. Therefore, there's a good chance that planting rice seedlings uniformly could eliminate the need for intricate weed-detecting systems in intra-row devices. Maintaining row-to-row and plant-to-plant spacing during crop planting can also avoid the need for a sophisticated algorithm to evaluate weed density and a line guidance system of intra-row devices during its operation. In addition, uniform planting of crops could save time and energy during the weeding season.

Therefore, in this study, various articles based on intra-row weeders have been presented and a conceptual design of inter cum intra-row weeder for wetland cultivation also have been proposed.

### 2.5.1 Mechanical Devices for Intra-Row Weed Management

It soon becomes clear that mechanical devices are not merely simple tools as we set out on this voyage through the mechanical realms of intra-row weed management; rather, they represent a paradigm shift in the way we approach weed control in modern agriculture. This investigation, which covers the development of mechanical weed control throughout history and ends with contemporary cutting-edge technologies, hopes to provide significant perspectives to the continuing conversation about effective and sustainable farming methods. The range of mechanical solutions, which includes robotic weed eaters and precision cultivators, not only solves the immediate problem of weed interference but also fits in with the larger agricultural objectives of resource efficiency, decreased environmental effect, and higher output. The various performance parameters of some intra-row weeders are presented in Table 2.10.

Even when the inter-row weeds are managed with mechanical weeders, the intra-row weeds are still uncontrolled. As a result, intra-row weeders were occasionally developed as well. A hand-guided brush weeder was developed (Kouwenhoven, 1997; B. Melander, 1997), including flexible nylon or fiberglass brushes that rotated along either vertical or horizontal axes (Figure 2.15a). The weeder apart from uprooting weeds, can also bury and kill them. To prevent harm to the crop, a protective guard was provided. It was best to have an operator guide the brushes by hand to remove weeds that were closest to agricultural plants without endangering them.

A torsion weeder (Van Der Weide et al., 2008) was developed with two spring tines connected to a stiff frame that was slanted backward or downward within the row so that the two short segments could operate parallel to the soil surface and extremely close to one another (Figure 2.15b). The interrow weeds must be controlled by a secondary hoe; the intra-row weeds are managed by the tines. The weeder has an easy-to-use design and is reasonably priced. The diameter of the tine can be changed to alter the tool's level of aggression. The benefits of a torsion weeder include good in-row weed management, a straightforward design that reduces the need for cultivator repairs, and cost-effectiveness as compared to an already-existing cultivator (Bellinder, 1997). However, accurate and cautious operation is required while operating it.

The finger weeder (Dedousis, 2007) is a device made especially to control weeds in the intra-row zone. Normally, an inter-row cultivation blade would be utilized with it. The fingers on the wheel's periphery are pushed into the soil as propelled by the ground-driven wheels (Figure 2.15c). There is scuffing within the row as a result of the rubber fingers and spiked tines having different rolling radii. According to Bellinder (1997), the finger weeder works best on small-acreage, high-value crops. Finger weeders perform well at speeds exceeding 10 km/h (Kouwenhoven, 1998). However, many researchers (Bleeker et al., 2002; Bleeker & Weide, 1998; Kurstjens & Bleeker, 2000; Peruzzi et al., 1998; Søggaard, 1998) suggested studying the effect of finger weeders in different soils.

Torsion and finger weeders traverse the intra-row area, and both treat the weeds as well as the crops. Crop plants need to be more resilient to soil disturbance than weeds since the weed growth stage at the time of treatment is inversely correlated with weeding efficacy (Bo Melander et al., 2005). Determining the optimal number of treatments and machine parameters is critical (Ascard & Fogelberg, 2008). Particularly in broad-leaved crops, torsion and finger weeders are typically more selective than spring-tine harrows (Ascard & Fogelberg, 2008; Bleeker et al., 2002). Torsion weeders tend to suppress weeds better than finger weeders, but they also reduce crop plants more than finger weeders (Bleeker et al., 2002).

An Eco-weeder (Anon, 2011) is a mechanical intra-row weeding device driven by a tractor with a three-point hitch mechanism (Figure 2.15d). Tractor Power Take-off (PTO) provides the power for the weeding apparatus. When compared to human weeding, the ECO-weeder might save up to 60% on weeding costs.



**Figure 2.15 Various types of mechanical intra-row weeders**

(a: Melander, 1997; b and c: Dedousis, 2007; d: Anon, 2011)

An integrated inter cum intra-row weeding system (Figure 2.16) for row crops was developed and evaluated by Chandel et al, (2021). The machine has a field capacity of 0.22–0.26 ha/h at the suggested operating speeds of 0.50-0.56 m/s, with less than 6% plant damage.



**Figure 2.16 Integrated inter and intra-row weeding system (Chandel et al., 2021)**

**Table 2.10 The efficacy of various intra-row weeding devices (Updated from Kumar et al., 2022)**

<b>Devices</b>	<b>Operating depth (mm)</b>	<b>Operational speed (km/h)</b>	<b>Field capacity (ha/h)</b>	<b>Efficiency of weeding (%)</b>	<b>Source</b>
Inter- and intra-row weeding mechanism	15-25	5		80	(Dedousis, 2007)
A combined inter cum intra-row weeding system for row crops	30	1.8-2.016	0.22-0.26	88.4	(Chandel et al., 2021)

Inter and intra-row weed control		2.052-4.284	1.28	88	(Home, 2003)
Finger weeder	10-40		0.3-0.6	55-60	(Kumar et al., 2022)
Torsion weeder	10-25		0.1-1.4	60-80	(Kumar et al., 2022)
Eco weeder	25-50		0.05-0.15	60-80	(Anon, 2011)
Flame weeder	On the surface		0.1-0.5	80-90	(Kumar et al., 2022)

Wageningen University developed an intra-row weed management device (Lempens et al., 1996) that comprises a 300 mm diameter vertical rotating disc to which two or more knives are mounted with springs and which rotates above the crop row (Figure 2.17). Because the centrifugal force is greater than the spring force, the blades fold out while the revolving disc rotates at a steady 850 revolutions per minute. The detecting system which is located in front of the disc is made up of three infrared transmitters and receivers that travel the length of the crop row at a consistent height (Bontsema, Van, et al., 1998). Research by Jones et al. (1995 & 1996) shows that if one of the three possible modes of action—cut, cover, or uproot—is used exclusively, the effectiveness of the weed-killing process is diminished. Furthermore, the detecting method is only suitable for transplanted plants because it is unable to distinguish between plants and weeds.



**Figure 2.17 Rotating disc tine (Cavalieri et al., 2001)**

Cycloid hoe (Figure 2.18) is a high-tech device for intra-row cultivation. It combines the circular movement of the tines with the linear movement of the implement, resulting in a cyclic route (Cavalieri et al., 2001). Each rotor has eight tines with a rotating diameter of 0.234 m arranged in a circle around an axis (Griepentrog et al., 2007).

Griepentrog et al. (2007) tested the system at a top speed of 1.44 km/h and found that it caused considerable crop damage and had very low weed control effectiveness. The cycloid hoe is currently being developed.



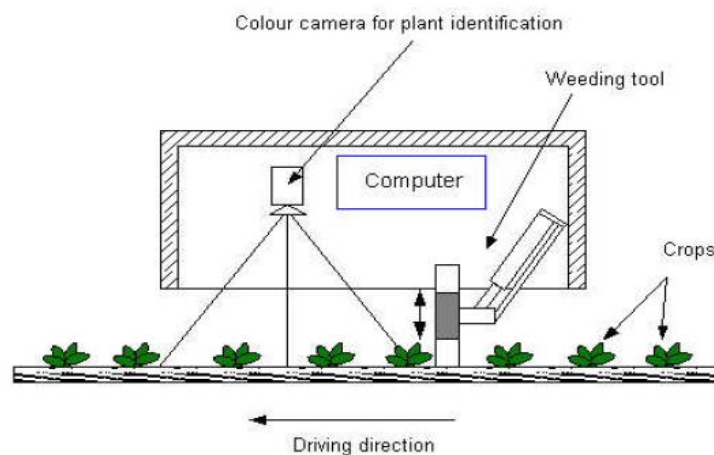
**Figure 2.18 The cycloid hoe (Griepentrog et al., 2007)**

Radis Mechanisation designed an intra-row weed control device with blades mounted on a pivoting arm (Figure 2.19). According to Bleeker (2005), the intra-row hoe's mechanical transition allows for a maximum speed of 3 km/h. The system may operate with a minimum intra-row spacing of 220 mm and is intended for vegetables that are spread widely apart (Bakker, 2003).



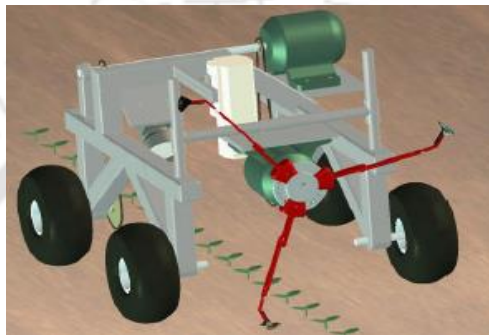
**Figure 2.19 The Radis intra-row weeder (Bleeker, 2005)**

A revolving wheel perpendicular to the crop row is the basis of an intra-row weed management system developed by Halmstad University (Figure 2.20). A pneumatic cylinder raises the revolving wheel when a computer vision guide detects the crop, and then lowers the wheel once the plant has passed (Åstrand & Baerveldt, 2005). In greenhouse testing with sugar beet plants spaced 170 mm apart, Åstrand & Baerveldt (2002) assessed the system and noted that “the robot was able to recognize all the plants and the weeding tool worked well.” However, the effectiveness of weed management and working speed are not specified.



**Figure 2.20 Description of the weeder with the weeding tool at the rear (Åstrand & Baerveldt, 2002)**

A rotary hoe that rotates around its horizontal axis above the crop row makes up the intra-row weed management system that the University of Bonn developed (Figure 2.21). According to Gobor & Lammers (2006), the hoeing tool is made up of an arm holder and three or more integrated arms that rotate around a horizontal axis above the crop row. The weeding tool and motor are connected by a shaft, and the entire assembly's operating height is movable (Gobor & Lammers, 2007).



**Figure 2.21 The rotary hoe (Gobor & Lammers, 2007)**

### **2.5.2 Automated Technology for Intra-Row Weeding**

The use of automated technology in agriculture has resulted in a considerable revolution by addressing the shortcomings of traditional approaches. The development of automated technologies has resulted in a significant paradigm shift in the essential field of weed management, particularly intra-row weeding. Apart from increasing accuracy, these technologies have the ability to alleviate the consequences of manpower shortages, reduce reliance on chemical pesticides, and, eventually, promote ecologically friendly farming methods. With the expanded availability of advanced machine learning algorithms and precision-guided robotic devices, farmers can now manage the complex difficulties that intra-row weeds present with unprecedented efficiency and control. This section presents a comprehensive analysis of automated intra-row weeding technologies as they exist now, highlighting the various methods, workings, and advantages that these advancements offer to the field of modern agriculture.

Zuydam & Sonneveld (1994) studied the precision of a laser-directing system steered to a weed-controlling tool. The guidance system consisted of a transmitter, a side-moving unit, and a second operator with a hand-held receiver. A hydraulic cylinder was activated using an electrohydraulic valve, which translated a lateral error indication. It helps to direct the laser guidance system to a precise side. The chosen laser has an average steering accuracy of  $\pm 6$  mm over a 250 m length and can operate up to 500 m. The maximum deviation was no longer greater than 19. According to Tillett (1991), ultrasonic guiding may achieve a high accuracy of 99% over a distance range of 100 mm to 10 m.

Åstrand & Baerveldt (2002) developed a vision-steering machine (Figure 2.22) that can differentiate between crop plantings that are direct-seeded, crop plant length, and the presence of weeds at concentrations of up to 200 weeds per  $m^2$ . The Hough transform, which estimates the row location using a few rectangular regions for crop size, served as the main inspiration for this machine. The system's overall functionality has been confirmed, demonstrating the subsystems' capacity for productive cooperation. The robot's ability to suppress weeds inside a row of crops was demonstrated in the first testing conducted in a greenhouse.



**Figure 2.22 Autonomous navigation in a field with a robot platform (Bakker, 2003)**

### 2.5.3 Electrically Powered Weeders

An innovative development in agricultural technology, electrically driven weeders provide effective and long-lasting weed control solutions for contemporary farming methods. As environmental sustainability and resource efficiency become more important considerations, electrical weed eaters have become a viable option to traditional techniques that depend on labor-intensive manual labor or fossil fuels. These cutting-edge devices reduce labor expenses and environmental impact while offering accurate and efficient weed control through the use of electricity. Electric weeders also reduce greenhouse gas emissions, soil compaction, and chemical inputs associated with traditional weed control methods, which is in line with the growing need for sustainable farming practices. Farmers looking for economical and eco-friendly solutions find them appealing because of their quiet operation, low maintenance needs, and simplicity of use.

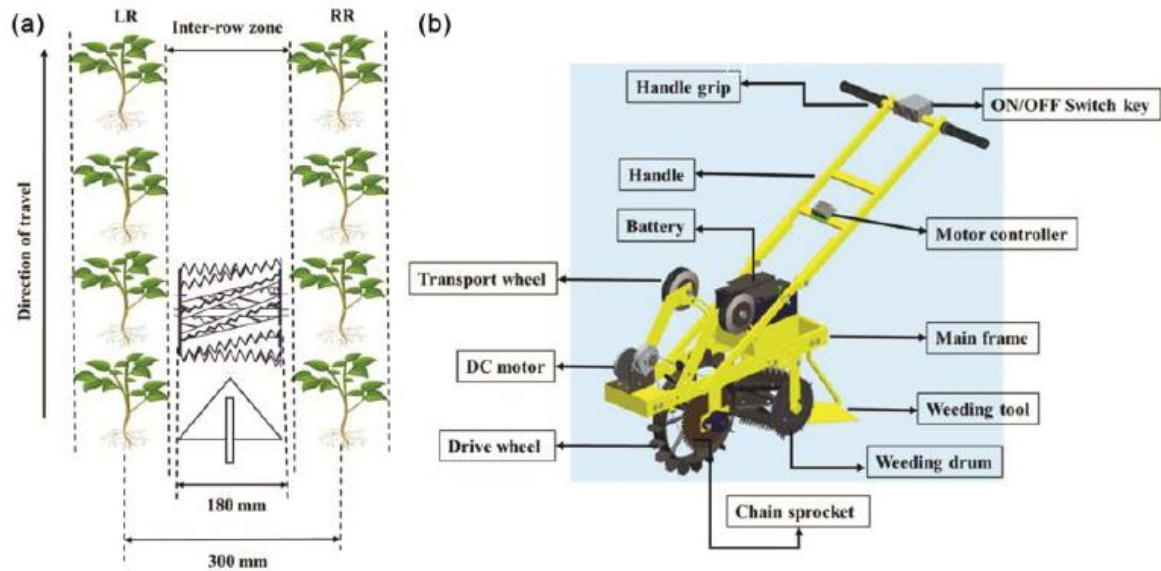
Promising advances are being made in the investigation of novel strategies in agricultural engineering for weed management. These initiatives represent a progressive shift towards sustainable and technologically driven farming methods. A few of the research is discussed below.

The Agricultural Engineering Department's laboratory developed and tested a swing mechanical arm outfitted with an electric weeder (Sehsah, 2018). The experiment was conducted at Kafrelsheikh University in Egypt on a Washington navel orange farm. The rotary blade Weeder was driven by a 12V DC electric motor. Two types of blades were used to evaluate various rotational speeds (1600 rpm, 2200 rpm, and 2600 rpm) and forward speeds (3.2 km/h, 4.1 km/h, and 5.7 km/h). The highest weeding efficiency in orange orchards was demonstrated by combining a rotational speed of 2600 rpm with a forward speed of 3.2 km/h.

Lysakov et al. (2021), suggested employing a tubular linear electric motor for weed removal. They developed an experimental model of this motor and found that at 8 A current, the movable rod generated a mechanical force of 500 N, deemed adequate for weed control. Building on these findings, they designed a weeding robot equipped with two tubular linear electric motors to operate the weed control mechanism both horizontally and vertically.

An e-powered weeder was developed by Pandey et al. (2023) during 2019–2020. It features a weeding mechanism consisting of a drum and a V-shaped tool, with the tool cutting weeds behind the drum. The motor controller is linked to a 24 V, 24 Ah battery pack, powered by two

12 V batteries connected in series with AWG 12-size wires. The weeding mechanism performed best with a 175 mm drum diameter at forward speeds of 3 km/h, demonstrating a field capacity 3–4 times greater than a wheel hoe. A schematic representation of the developed system is presented in Figure 2.23.



**Figure 2.23 Schematic diagrams of the weeding system: (a) conceptualized weeding mechanism (LR = left row, RR = right row) and (b) computer-aided design (Pandey et al., 2023)**

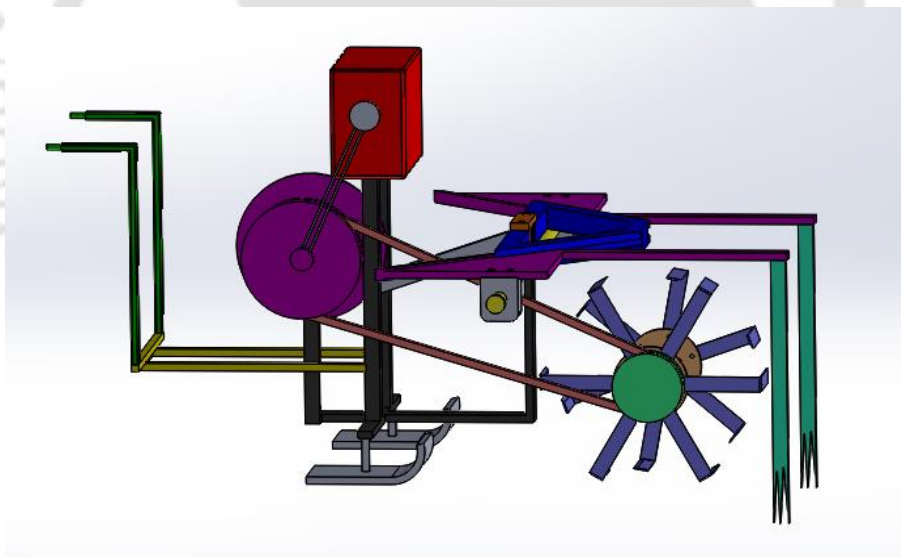
#### 2.5.4 Conceptual Design of Inter Cum Intra-Row Weeder for Wetland Paddy Cultivation

The following attributes were called upon while designing the proposed weeder.

1. The weeder should be able to eliminate and destroy weeds both in inter and intra-row zones in one go.
2. The intra-row weeding units should traverse between the plants which follows a sinusoidal path along with the forward motion of the weeder.
3. The only source of power is an IC engine and thus, the use of sensors, cameras, hydraulic systems, etc is eliminated which in turn could increase the cost.

4. Only one person should be able to operate the weeder.
5. It should preferably be lightweight for easy portability and maneuverability.

To sum up, the design considerations for the proposed weeder represent a calculated effort to handle particular difficulties in the cultivation of wetland paddy. Efficiency and economy are given priority in this design, which emphasizes the capacity to remove weeds in both inter and intra-row zones concurrently that employ an IC engine as the only power source. Apart from making the design simpler, the exclusion of additional components like sensors and hydraulic systems also makes it more affordable. The weeder's practicality is further enhanced by its lightweight construction and emphasis on one-person operation, which makes it easier to transport and operate in the difficult terrain of marsh paddy fields. Overall, the proposed weeder aligns with the unique requirements of wetland paddy cultivation, presenting a promising solution to address weed-related challenges efficiently and cost-effectively. A schematic representation of the proposed weeder is presented in Figure 2.24.



**Figure 2.24 A schematic representation of the proposed inter cum intra-row paddy field weeder**

## 2.6 Conclusions

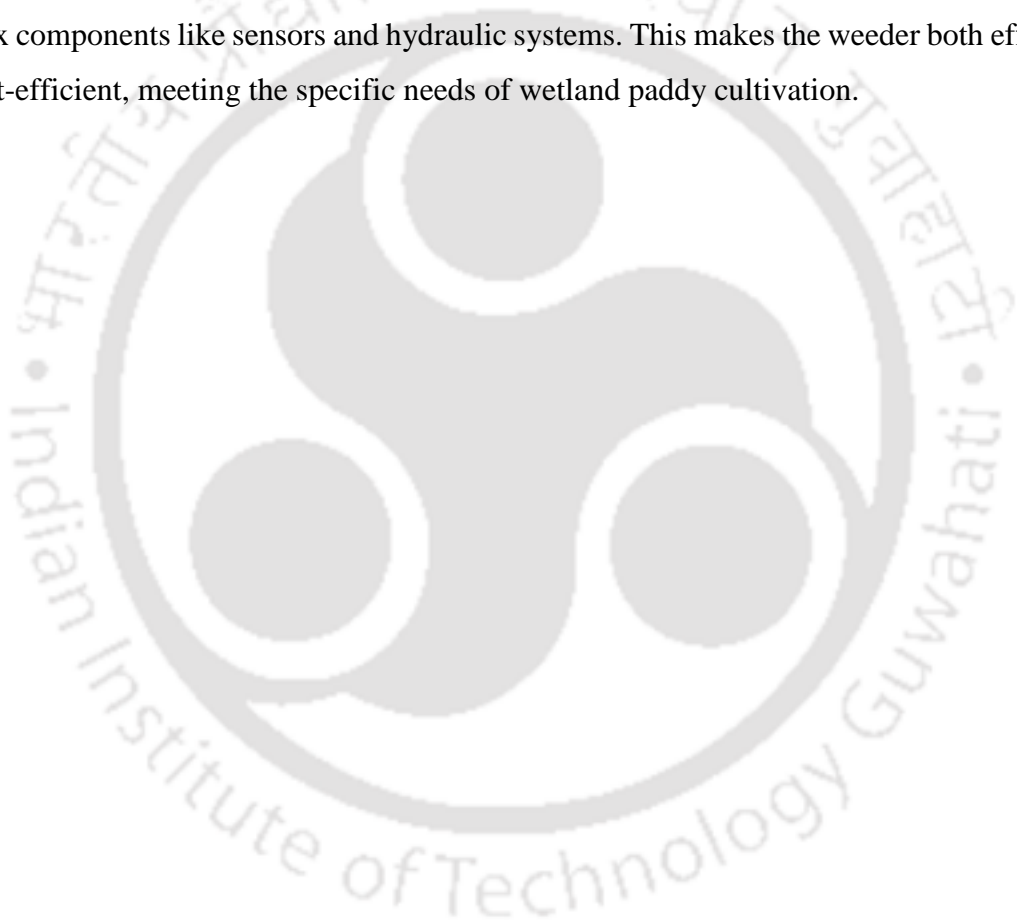
This chapter examines the several kinds of paddy weeders that have been used in India and abroad, the difficulties that the northeastern portion of the country has as a result of inadequate farm mechanization, and the necessity of intra-row weeding.

The study reveals that among the various types of weeders, the power-operated rotary weeder offers the lowest operating costs (1169.59 Rs. /ha) and the highest field capacity (0.0793 ha/h). While both the Ambika and Cono weeders perform well in various field conditions and are commonly in use, the Ambika weeder shows slightly better field capacity and efficiency (0.0276 ha/h and 78.05%) compared to the Cono weeder (0.0178 ha/h and 73.51%). However, both weeders have some drawbacks in uprooting and destroying the weeds and thus, there is still room for improving its weeding efficiency. Thus, there is a need to redesign those similar existing tools to enhance efficiency. A roller rake weeder (**Chapter Three**) has been proposed to meet the requirement for those drawbacks. Hand weeding, despite its high efficiency (up to 100% in some cases), has the lowest field capacity (0.00414 ha/h) and the highest operating costs (5104.14 Rs. /ha). However, most farmers in rural areas still followed hand weeding due to a lack of awareness of the use of machinery and resources.

The study also points out that the northeastern states of India suffer from significantly lower farm power availability compared to the national average. Assam, despite leading in tractor sales, and states like Arunachal Pradesh and Nagaland, where medium-sized land holdings are common, still face lower agricultural yields due to the limited availability of mechanized tools. The development of innovative small hand-held weeders and portable power weeders specifically designed for hilly regions holds the potential to significantly enhance farm mechanization in the northeastern states of India. These regions often have steep, uneven terrains, making traditional large-scale farming equipment challenging or impossible to use effectively. Compact, lightweight, and maneuverable weeders would be much easier to operate on slopes, allowing farmers to remove weeds more efficiently in areas with difficult terrain. In addition, these portable power weeders would save labor time and reduce the physical strain on farmers, especially beneficial in areas where manual labor is often the primary means of weeding. By increasing the efficiency and productivity of weed management, farmers in these regions could achieve better crop yields, reduce reliance on chemical weed control, and promote sustainable agricultural practices. Overall, these developments could transform the

agricultural landscape in India's northeastern states by making farming on hilly lands more viable, improving livelihoods, and contributing to food security.

Apart from inter-row weeds, intra-row weeds can reduce yields by 18–76%, making their removal critical for optimal crop production. Over the past decade, numerous studies have focused on weed control for high-value crops like vegetables. This study evaluates various weeders—mechanical, electrical, and automated—specifically designed for intra-row weeding. It proposes a weeder tailored to wetland paddy cultivation that addresses both inter-row and intra-row weeding challenges (**Chapters Four and Five**). The design prioritizes simplicity, efficiency, and affordability by utilizing an internal combustion (IC) engine and avoiding complex components like sensors and hydraulic systems. This makes the weeder both effective and cost-efficient, meeting the specific needs of wetland paddy cultivation.



## CHAPTER THREE

### 3 Design, development, and performance evaluation of Roller Rake Weeder

#### 3.1 Introduction

Weeds can reduce crop yield by up to one-third of the entire cost of production, depending on the crop and its location (Rangasamy et al., 1993), and therefore, their eradication is essential. Manual weeding by hand accounts for about 25% of total labor requirements during peak season (Nag & Datt, 1979). However, there is limited use of mechanical devices in the hilly remote areas and the trend of manual weeding continues. This is caused by several factors, such as uneven topography, a lack of awareness and technical expertise, and challenging economic situations. These barriers prevent mechanical weed extraction from being widely used in the area, despite the advantages it offers. Because the average farmer in our nation owns marginal-sized land (< 1 ha), using a heavy and large power weeder is both expensive and impracticable.

A commonly used manually operated mechanical paddy field weeder is a cono weeder. However, in it, there exist some disadvantages. In hardpan soil, there's a risk that the conical roller of the cono weeder just rolls over the soil's surface without uprooting any weeds (Sebastian & Kalita, 2022). Narwariya et al. (2016) and Remesan et al. (2007) reported that cono weeders perform well in the initial stage of weed growth. However, when the weeds are large enough, the weeder just rolls over the weeds with minimum uprooting and inversion. Thus, there is a need to redesign and develop a versatile weeder that could eliminate the problems faced by the current weeders.

The agricultural landscape in India is characterized by vast expanses of cultivated land, with rice cultivation occupying a significant portion. Out of the extensive gross cropped areas spanning 195 million hectares, a substantial 43.86 million hectares are dedicated to rice cultivation alone. This enormous area contributes to account for 116.48 million metric tons of rice produced annually in India, with a remarkable output rate of 2659 kg per hectare as of 2020 (Anon, 2020).

To maintain such extensive rice cultivation, a variety of paddy weeders have been developed to cater to the diverse agricultural conditions prevalent in India. These weeders serve both wet and dry land cultivation scenarios. For dry land intercultural operations, hoe-type weeders

emerge as the primary choice, effectively addressing weed infestations in these settings. In contrast, wetland paddy cultivation necessitates weeders such as rotary power weeders, cono weeders, and Ambika weeders, which have gained widespread adoption across Indian agricultural landscapes (Sebastian & Kalita, 2022).

The advent of mechanical weed control mechanisms has significantly transformed weed management practices in Indian agriculture. Mechanical weeders offer several advantages, including high output capacity, swift operation, and effectiveness in weed eradication. Research by Pannacci & Tei, (2014) underscores the efficiency of mechanical weed control, highlighting its potential to revolutionize weed management strategies.

While chemical methods, employing substances like Cyhalofop and Bysparibac-Na, are also utilized for weed control, concerns regarding their adverse impacts on human health and the environment persist. It elucidates the high risks associated with chemical weed control methods, prompting the exploration of alternative, eco-friendly approaches (Tewari et al., 2014).

In response to these concerns, mechanical weeders have emerged as a viable alternative, offering a safer and more sustainable weed management solution (Pannacci & Tei, 2014). Mechanical weeders not only mitigate health and environmental risks but also contribute to reducing labor requirements significantly. This reduction in labor demand aligns with India's agricultural landscape, characterized by a reliance on manual labor, and presents a compelling case for the widespread adoption of mechanical weeders.

Moreover, the utilization of mechanical weeders has been shown to enhance crop yields, benefiting both field crops and vegetables alike. The research carried out by Alizadeh (2011), provides empirical evidence supporting the efficacy of mechanical weeders in bolstering agricultural productivity. The adoption of these innovative technologies represents a paradigm shift in weed management practices, offering a promising pathway toward sustainable agriculture in India.

Furthermore, the affordability of manually operated mechanical weeders further enhances their acceptability among Indian farmers. Research conducted by Behera et al. (2007) emphasizes the cost-effectiveness of manual mechanical weeders, making them accessible to a broader spectrum of farmers across different socio-economic strata.

Thus, the integration of mechanical weed control methods into Indian agriculture heralds a new era of sustainable and efficient weed management practices. With their proven efficacy, environmental friendliness, and affordability, mechanical weeders stand poised to revolutionize weed control strategies, ultimately contributing to enhanced agricultural productivity and livelihoods for Indian farmers.

### 3.2 Methodology

This section discusses the overall structural design, estimation of various performance parameters, design methodology, and field evaluation of the weeder.

#### 3.2.1 Overall structural design consideration

For the overall structural design of the weeder, several parameters including the width of operation, handle height and length, soil-engaging components (roller drum with spikes and fixed rake), and float were taken into account. The detailed specifications of the weeder are given in Table 3.1.

**Table 3.1 Specification of the developed weeder**

Sl. No.	Particulars	Testing Center
1.	Name of the implement	Roller Rake Weeder (wetland paddy field weeder)
2.	Make	Prototype
4.	Type	Single row
5.	Mass	5.4 kg

6. Overall dimensions (at the middle setting of the angle regulator)
- a) Length, (mm) 1550
  - b) Width, (mm) 450
  - c) Height, (mm) 1080
7. Type of soil working part      Roller with spike and rake
8. Weeding roll
- a) Number and diameter of the drum      01 Nos. and 105 mm
  - b) Length of spike      31 mm
  - c) Number of spikes in one drum      42
  - d) Arrangement of spikes      8 and 6 spikes in alternate rows, 4 rows with 8 spikes/row and 3 rows with 6 spikes/row, rows are parallel and straight
9. Weeding rake
- e) Number of tynes      05
  - f) Length of tynes      50 mm
  - g) Width of rake      143 mm
10. Range of adjustment of depth and width      Depth, up to 50 mm, width up to 140 mm

11.	Type of handle	MS Pipe
12.	The optimum angle of inclination of the handle to the horizontal plane	30°- 41°
13.	Grip type	MS Pipe, Outer diameter: 25 mm, straight horizontal
14.	Grip clearance from the ground	840-1130 mm
15.	Grip clearance from ground settings	Three settings (840 mm, 1080 mm, and 1130 mm)
16.	Number of persons needed to operate	01
17.	Special features, if any (float, etc.)	Float (sleigh), angle regulator for height adjustment
18.	Adjustment of float angle	No provision

The plant spacing affects the movement of the weeder's soil-engaging components. Plant spacing varies from place to place depending on soil type, crop variety, temperature, etc. With a plant spacing of 23 cm × 23 cm, Asghar et al., (2021) reported the highest grain yield of 6.75 tonnes per hectare. On the other hand, Reuben et al., (2016) stated that rice transplanted at a spacing of 25 cm × 25 cm yields higher as compared to 30 cm × 30 cm and 35 cm × 35 cm. Further, Estorninos & Moody (1976) reported a yield loss of 52% and 29% with plant spacing of 25 cm × 25 cm and 20 cm × 20 cm respectively. It was reported that the yield loss is least with plant spacing of 15 cm × 15 cm (19%). Thus, the width of operation for the weeding roll and fixed rake was kept at 140 cm for free movement of the weeder when it is pushed and pulled.

The depth of operation of the weeder can affect the performance and efficiency of the weeder. The rotary weeder can exhibit optimal working performance at a weeding depth of 39 mm (Zhang et al. 2022). Weeders can exhibit a maximal weeding rate of 87.06% at a weeding depth of 56.8 mm which meets the requirement of weeding agronomy (Tang et al. 2021). Tian et al. (2022) stated that weeder shows a maximum weeding rate of 85% at a depth of 40 mm. In this design, a weeding depth of up to 50 mm was considered.

For manually operated tools and implements, the height of the handle can affect the performance of the weeders. The stature of the operators and handle height are proportionately related. The higher the stature of the operator the higher should be the height of the handle. According to Gite & Yadav (1990), the optimum handle height of 100 cm was recommended for a push-pull type weeder. It further states that the physiological cost and muscular fatigue are minimal with a handle height between 0.7 and 0.8 of the shoulder height of the operator. In this design, three settings (840 mm, 1080 mm, and 1130 mm) of handle height (grip clearance from the ground) were considered to accommodate the varying stature of the operators.

However, the overall dimensional parameters of the machine including the diameter of the roller, length of spikes, angle inclination of the handle, width of operation, etc were followed accordingly within the range of the Indian Standard (IS:7927 – 1975) (Anon, 1976).

### **3.2.2 Estimation of Various Performance Parameters**

Various performance parameters such as operating speed, draft, power requirement, theoretical and actual field capacity, field efficiency, and weeding efficiency were estimated as follows:

### **3.2.3 Operating Speed**

The time needed to cover a certain distance (here considered as 10 m row length) was measured to calculate the travel speed of the machines during the weeding operation. Each plot has four measurements, from which an average value was determined. The time it took the weeder to travel a distance of 10 meters was measured using a digital stopwatch. Thus, speed was calculated as

$$\text{speed (km/h)} = \frac{\text{distance (m)}}{\text{time (s)}} \times 3.6$$

### 3.2.4 Draft Requirement

The requirement of the draft for the operation of paddy weeders was calculated following Yadav & Pund, (2007),

$$D = W \times d_w \times R_s$$

where, D = Draft of a weeder, (kg), W= Width of cut, (cm),  $d_w$  = Depth of cut, (cm),  $R_s$  = Resistance of the soil, (kg/cm<sup>2</sup>).

### 3.2.5 Power Requirement

The power requirement of the paddy weeder was calculated as (Yadav & Pund, 2007)

$$\text{Power (Hp)} = \frac{\text{draft (kg)} \times \text{speed (m/s)}}{75}$$

### 3.2.6 Theoretical Field Capacity

The rate of field coverage that would be attained if the weeder was operating at its rated forward speed and covering 100% of its rated width for 100% of the time is known as its theoretical field capacity. It was calculated following Bainer et al. (1955)

$$\text{Theoretical field capacity (ha/h)} = \frac{\text{speed (km/h)} \times \text{width (m)}}{10}$$

### 3.2.7 Actual Field Capacity

The effective field capacity of a machine is the actual area covered by the machine, based on its total time taken and its width. Effective field capacity can be determined by the following relationship (Kepner et al. 1978). Thus,

$$\text{Effective field capacity, (ha/h)} = \frac{A}{T_p + T_n}$$

where, A = area covered, (ha),  $T_p$  = Productive time, (h),  $T_n$  = Non-productive time, (h)

### 3.2.8 Field Efficiency

It was calculated as the ratio of effective field capacity to theoretical field capacity (Kepner et al. 1978). Thus,

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

### 3.2.9 Weeding Efficiency

It is represented in percentage and was calculated as the ratio of the number of weeds eradicated by the weeder to the total number of weeds remaining in a unit area. It was determined following Tajuddin, (2006). Thus,

$$\text{Weeding efficiency (\%)} = \frac{w_1 - w_2}{w_1} \times 100$$

where,  $w_1$  = Number of weeds per unit area before weeding operation

$w_2$  = Number of weeds per unit area after weeding operation

## 3.3 Initial design of the prototype

The overall structure of the prototype was designed in SolidWorks (Figure 3.1). The soil-engaging components of the mechanism are comprised of two main parts: a roller with spikes positioned along its periphery and a fixed rake. Initially, the design featured a roller with straight spikes attached to its outer surface. The rake, on the other hand, was affixed to the frame and included pointed tips consisting of 5-7 tynes. For the prototype construction, locally

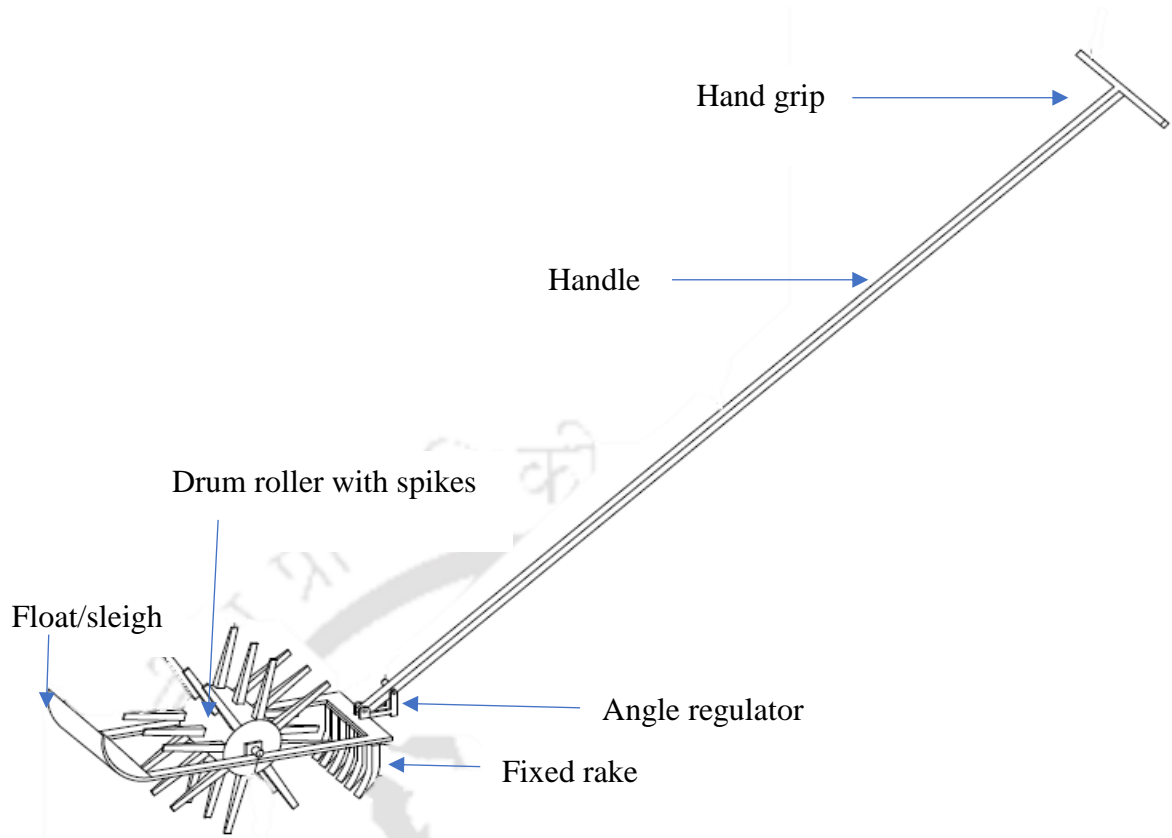
available materials such as PVC pipes for the roller, nails, wooden frame, and handle were utilized (Figure 3.2 and Figure 3.3).

Subsequently, modifications were made to the initial design during the later stages of development. The prototype underwent fabrication at a welding and fitting workshop. Notably, alterations were made to the spikes on the roller drum. Instead of straight spikes, a V-shaped cut flat bar was employed at the tip of each spike. These spikes were strategically curved backward and forward, arranged alternately in tandem. This design modification aimed to reduce jerking motions experienced during the operation of the mechanism, ensuring smoother and more efficient performance.

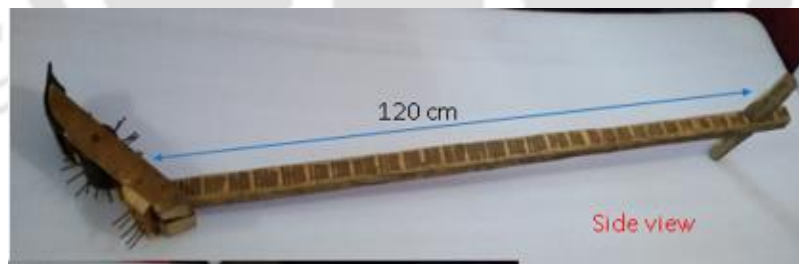
The decision to transition from locally available materials to a welding and fitting workshop for fabrication underscores a shift towards more durable and precise construction methods. By utilizing welded components, the prototype gains structural integrity and longevity, essential for withstanding the rigors of field use. Moreover, the alteration of the roller drum spikes from straight to V-shaped cut flat bars represents a deliberate effort to enhance the functionality and ergonomics of the mechanism.

Furthermore, the arrangement of the spikes in an alternating manner contributes to the overall efficiency of the mechanism. This configuration ensures consistent soil engagement across the entire width of the implement, maximizing its effectiveness in weed removal and soil cultivation tasks as compared to other similar tools (Figure 3.4). For the final prototype, a pen and sketch were drawn to incorporate all the missing components including the backward curved spikes and a depth limiter (Figure 3.5).

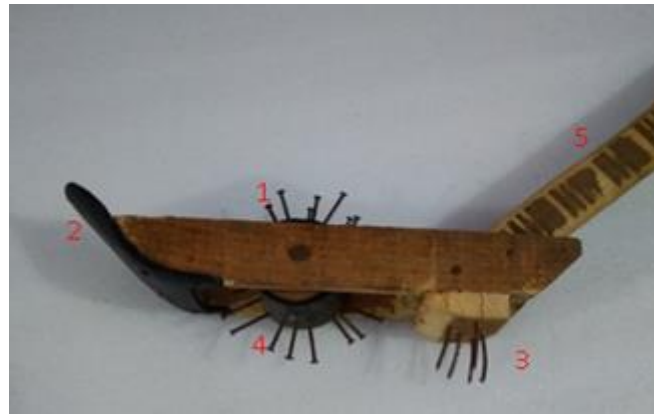
Overall, these modifications represent a significant evolution in the design of the soil-engaging components, aimed at improving the performance, durability, and user experience of the mechanism. Through thoughtful adjustments and modifications, the prototype has been designed to meet the demands of its intended application, promising enhanced efficiency and effectiveness in weed management and soil cultivation practices.



**Figure 3.1 A SolidWorks sketch of the initial design**



**Figure 3.2 Photographs of the initial stage prototype**

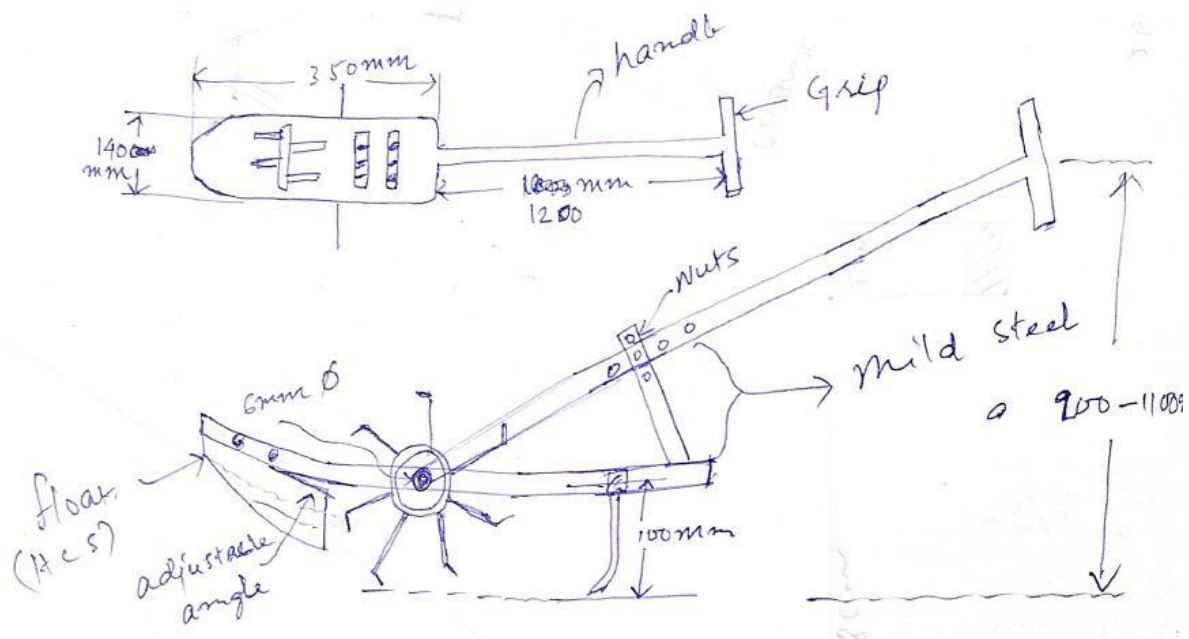


1. Spikes
2. Flaot/sleigh
3. Fixed rake
4. Drum roller
5. Handle

**Figure 3.3 Soil-engaging components**



**Figure 3.4 The initial developed prototype in the workshop**

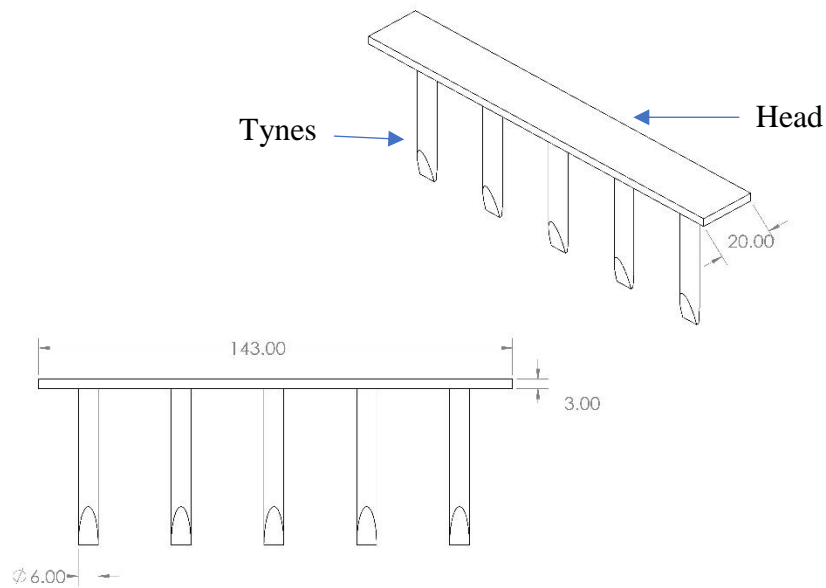


**Figure 3.5 Sketch of the prototype during the idea generation stage**

### 3.4 Finite Element Analysis of the Weeder Rake

The rake experiences a draft force when the weeder is pushed and pulled in the forward and backward direction. Soil resistance plays a significant role in estimating the draft of the weeder. As the soil resistance differs from place to place, silt loam soil resistance was considered in the study which is estimated to be between 0.034 and 0.049 N/mm<sup>2</sup> (Basavaraj et al., 2016). Thus, the draft force exerted by the weeder rake was estimated to be 350.35 N (using equation 2). The following assumptions were made in estimating the draft; the soil resistance = 0.049 N mm<sup>-2</sup>, the width of the rake as 143 mm, and the depth of operation as 50 mm. The soil contact element of the rake was modeled using SolidWorks and is presented in Figure 3.6. Boundary and loading conditions were used to accurately describe the dynamic interaction between the soil and the rake tines. The head of the rake was constrained and forces were applied to the tines in various directions. On applying the maximum draft force of 350.35 N on the weeder rake, the analysis results showed that the maximum stress induced was  $1.586 \times 10^6$  N/m<sup>2</sup> which

was less than the yield strength of the material of  $2.5 \times 10^8 \text{ N/m}^2$  indicating that the design is safe (Sebastian & Kalita, 2024; Upadhyay et al., 2017). The results also indicate a rake tyne displacement of  $2.066 \times 10^{-3} \text{ mm}$ , when forces were applied, which is negligible. The estimated designed specifications of the rake and tynes are given in Table 3.2. Analysis of stress and displacement of the rake under the applied force is presented in Figure 3.7 and Figure 3.8 respectively.



**Figure 3.6** Isometric and front views of the rake (All dimensions are in mm)

**Table 3.2** Specifications of the rake

Sl. No.	Particulars	Values
1	Overall width of rake, mm	143
2	Width of cut, mm	140
3	Height of tynes/spikes, mm	50

4	Diameter of tynes of rake, mm	6
5	Spacing between tynes, mm	28
6	Width and thickness of the rake head, mm	20, 3

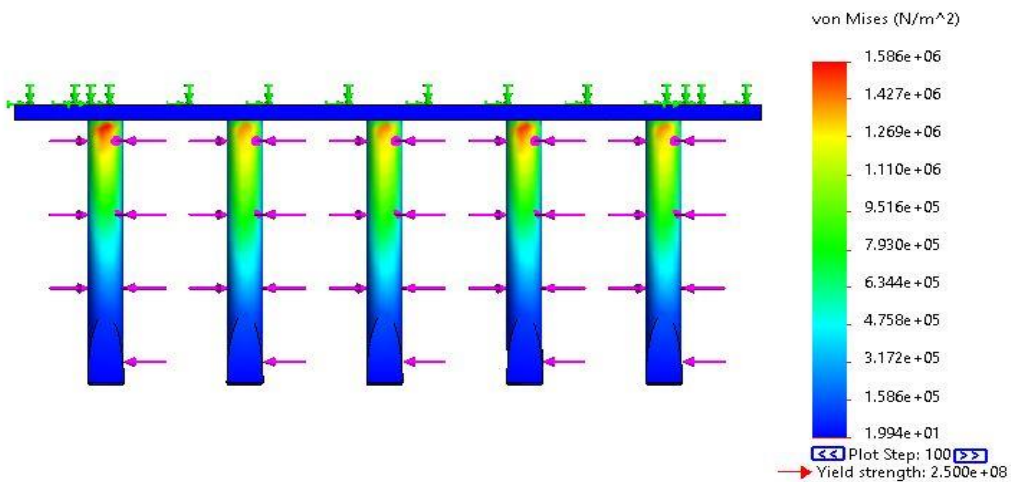


Figure 3.7 Stress analysis of the rake

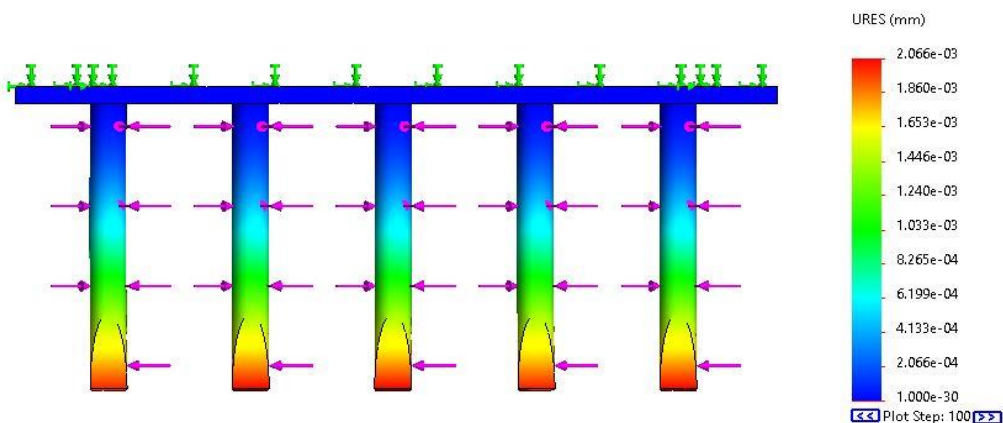


Figure 3.8 Displacement analysis of the rake

### **3.5 Design of the Weeder (Final Product)**

To accommodate the country's rough terrain, especially in the remote hilly region, a suitable manually operated weeder was designed. The design was influenced by several variables, including ease of manufacture, availability of replacement parts, cost of production, and operational safety. To make it easy for farmers to use, the operation and replacement parts of the weeder were simplified. The fabrication of the designed weeder involves metal cutting, bending, shaping, and welding.

The prototype end-users are directly impacted by the size and dimensions of the tools. The comfort level of the handgrip and handle height affect how well different hand-held implements work, especially manually operated paddy field weeders. Therefore, measurements for the handle grip, handle height, and soil-engaging component size were developed using anthropometric data that was gathered for Indian farmworkers by multiple researchers. The Indian Standard Code IS: 1976-1976 (Anon, 1976) served as the basis for the design of the working mechanism's dimensions and those of its related parts.

#### **3.5.1 Design of handle grip**

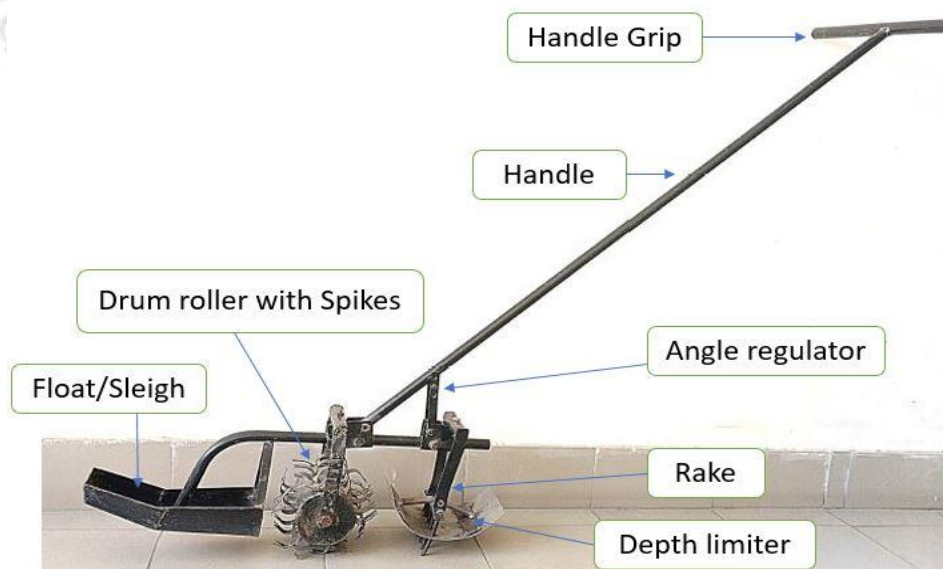
The 5<sup>th</sup>, 95<sup>th</sup>, and 50<sup>th</sup> percentile values of inside grip diameter of male and female Indian agricultural workers are 34, 54, and 44 mm; 32, 52, and 42 mm respectively (Tewari et al., 2007). Thus, the handle diameter of 34 and 32 mm for the male and female respectively, i.e. 5<sup>th</sup> percentile value of the inside grip diameter has been taken.

The 5<sup>th</sup>, 95<sup>th</sup>, and 50<sup>th</sup> percentile values of handbreadth at metacarpal III of males and females are 76, 85, and 77 mm; 61, 77, and 69 mm respectively (Tewari et al., 2007). The optimum value for the grip length should be such that the operator's widest palm should accommodate the handle. Therefore, the length of the handle grip will be 85 and 77 mm for males and females respectively.

### 3.5.2 Design of handle height

The 5<sup>th</sup>, 95<sup>th</sup>, and 50<sup>th</sup> percentile values of Metacarpal III height of male and female Indian agricultural workers are 680, 740, and 675 mm; 572, 686, and 629 mm respectively. The optimum holding height for the male and female population ranges from 630 to 677 mm and 534 to 630 mm respectively (Tewari et al., 2007). Gite & Yadav (1990) recommended a handle height of 100 cm for manually operated push-pull-type dryland weeders. Thus, the grip clearance from the ground was kept at the range of 84 to 113 cm.

A low-cost, gender-friendly paddy field weeder that works well for hill farming has been developed. Because of its straightforward design, even a layperson or any farmer could operate it with minimal instruction. The idea may also be helpful to cultivators in impoverished areas who cannot afford expensive machinery. Because of the country's undulating terrain, massive power-operated engines are also impractical in many areas of the northeast. Therefore, it would be useful to have hand tools that are compact and portable to get rid of tedious tasks. A photograph of the developed prototype is presented in Figure 3.9.



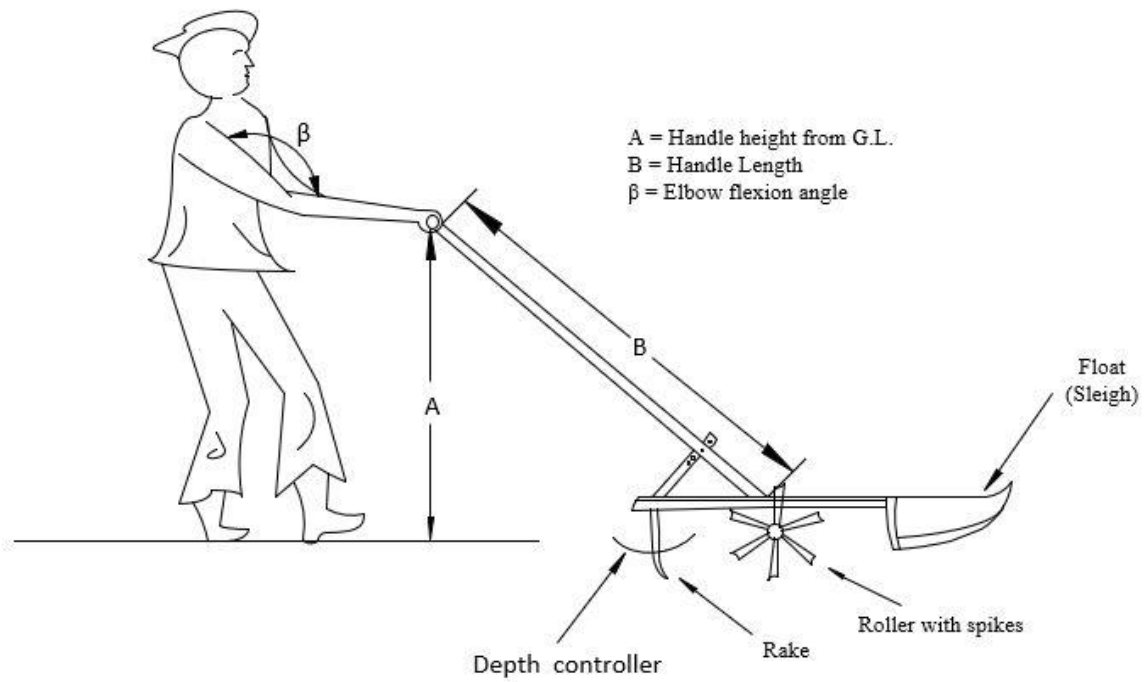
**Figure 3.9 Roller Rake Weeder**

### **3.6 The Working Principle of the Designed Weeder**

The machine is operated in a push-pull manner by holding the handle grip (Figure 3.10). Two soil-engaging components constitute the developed tool's operating mechanism: a stationary rake at the rear end, and a roller drum with V-shaped spikes on the periphery at the front end. The roller drum either uprooted the weeds or crushed them as it rolled back and forth over its surface. The weight of the weeder was 5.4 kg, designed for easy portability and maneuverability enabling farmers to effectively operate the plots without the need for cumbersome equipment. The roller's spikes are paired in twos and are positioned alternately in threes and fours in each line so that no weeds are left out in between the spikes. The spikes of the roller have forward and backward curves to provide a smooth experience without jerking when pushing or pulling. The function of the fixed rake ensures that every weed that the roller drum leaves behind is uprooted and destroyed. Thus, there is a high chance that the weeding efficiency could be improved as compared to the existing available tools. To prevent the machine from sinking into the ground while it is in use, a float has been affixed to the front end to keep it floating on the marshy water surface. A height-adjustable handle is attached to the soil-engaging mechanism that can accommodate operators of different statures.

### **3.7 Machine Performance and Evaluation**

To obtain accurate data on overall machine performance and work capacity under real-world field conditions, a study on field performance was conducted in farmers' fields at Makha and Rey Khola villages in Sikkim (Figure 3.11). Field testing of manually operated weeder was conducted following the test procedure of IS 7927: 1975 (Reaffirmed 1999). The test was conducted during the critical period of crop-weed competition for direct-seeded rice which is 15 to 45 days after sowing (Singh et al., 2008). The conditions of the field before the operation of the weeder and after its operation are shown in Figure 3.12. A range of instruments, including a timer, scales, recording notepad and pen, measuring tape, and load cell, were employed to measure different parameters.



**Figure 3.10 Schematic representation of an operator handling the weeder (After Sebastian & Kalita, 2023)**



**Figure 3.11 Photograph of an operator during testing of the weeder**



**Figure 3.12 Field conditions before and after the operation of the weeder** (the area inside the orange boundary indicates the field conditions before the operation of the weeder and the area inside the blue boundary indicates the field conditions after the operation of the weeder)

Test conditions such as soil type, bulk density of the soil, depth of cut, and density of the weeds were taken into consideration. Using depth limits, the weeder's maximum operating depth was set at 5 cm. The summary of crop, field, and weed conditions during the testing is provided in Table 3.3.

**Table 3.3 Summary of field, crop, and weed condition**

Sl. No.	Parameters	Observation				
		I	II	III	IV	V

28/07/23

26/08/23

27/08/23

**1 Condition of field & soil**

a) Location	Makha		Rey Khola		
b) Kind of field	Leveled, terrace land				
c) Type & character of the soil	Medium, Sandy loam soil				
d) Length of field, m	25.6	30.4	26.7	15.7	20.4
e) Width of field, m	2.5	4.6	5.5	6.2	3.5
f) Bulk density, gm/c.c	-	1.52	1.56	1.49	1.54

**2 Condition of weed**

a) Height of weed, cm	5.3	7.2	6.4	5.3	7.8
b) No. of weeds/m <sup>2</sup> before weeding	600	152	212	176	186

**3 Condition of crop**

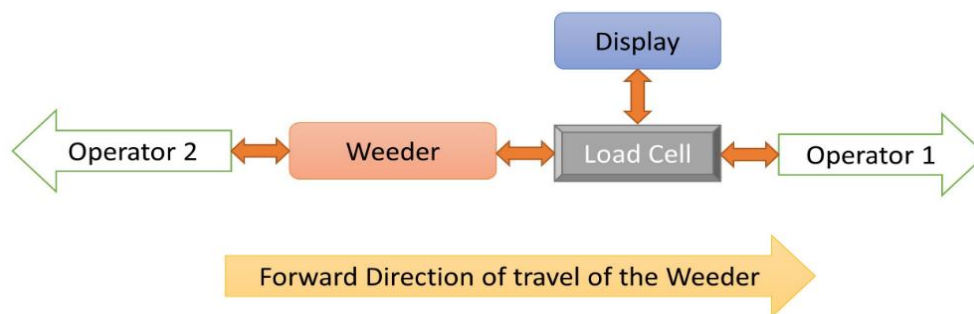
a) Name of crop	Rice	Rice	Rice	Rice	Rice
b) Variety	Local	Local	Local	Local	Local
c) Age of crop, days	31	26	26	27	27
d) Planting method	Direct seeding (20 cm row spacing)				
e) Height of plant, cm	26.4	31.5	28.4	35.3	31.6

**4 Condition of power source and weeder**

- |                                  |                                    |
|----------------------------------|------------------------------------|
| a) No. of power sources          | 1 manpower                         |
| b) Adjustment of weeder (if any) | Handle height adjustment provision |
- 

### 3.8 Draft Measurement of the Weeder

A schematic diagram of the weeder with load cell arrangement is given in Figure 3.13. A minimum of three operators were involved in measuring the draft. During the testing, Operator 1 pulls the machine in the forward direction and Operator 2 pulls the machine in the backward direction. The third operator reads and records the display readings from the load cell. Several readings of forward and backward strokes were recorded and their average value was considered for evaluation. A photograph of draft measurement in the field is shown in Figure 3.14.



**Figure 3.13 Schematic representation of arrangement for draft measurement**

### 3.9 Results and discussion

This section discusses the results of the field performance evaluation of the developed weeder that was carried out in the farmer's field at Makha and Rey Khola in Sikkim. The field experiment was conducted for about a month for 2.5 to 3.5 hours per day. This duration is crucial for evaluating the machine's endurance and suitability for daily farming routines. The range of 12–17 seconds turning time for each row was observed. In time-sensitive jobs like

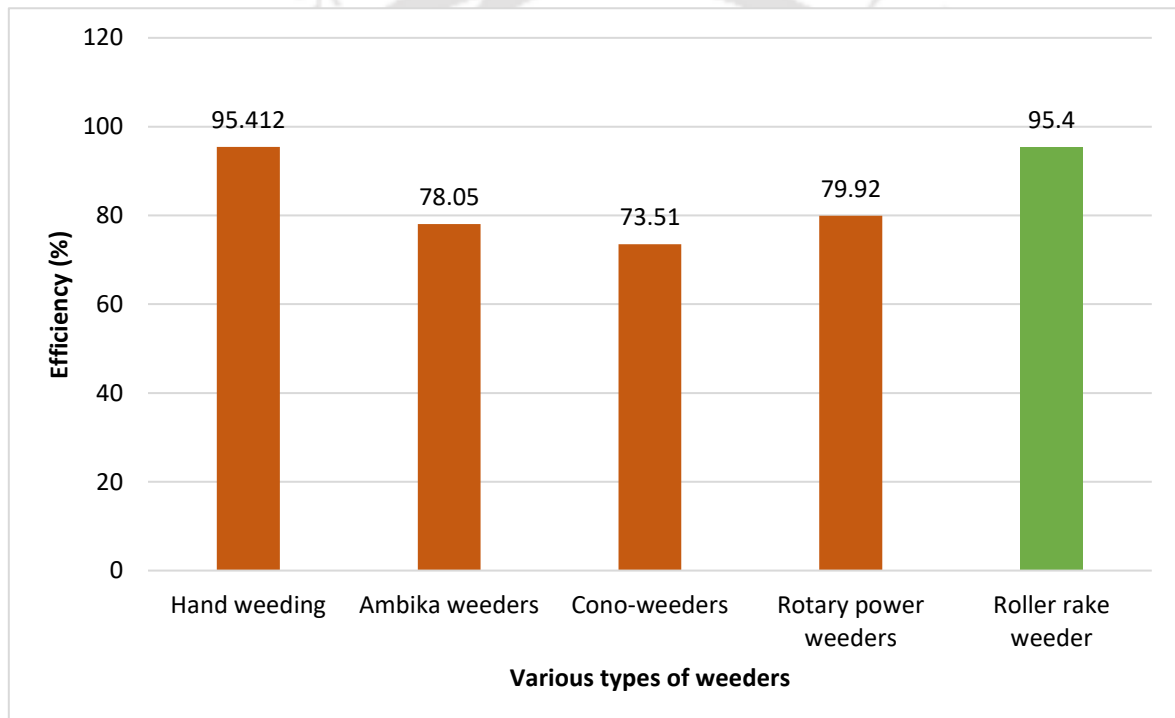
weeding, minimizing turning time is crucial to sustaining continuous operation and optimizing field coverage.



**Figure 3.14 Measurement of the draft**

Maintaining consistency in cutting width is essential to getting reliable outcomes and avoiding partial or uneven weed removal. It was observed that the weeding activities are executed with an effective width of a cut of 143 mm. The equipment stability and operational efficiency were found to be comfortable at the average travel speed of 1.9 to 2.1 km/h. With a reported actual field capacity ranging from 0.038 to 0.04 ha/h, the machine can effectively cover a sizable area in a predetermined amount of time. This measurement is essential for determining the weeder's productivity in actual farming situations. The test reports show that the actual field capacity was higher than the average actual field capacity of the similar existing tools (0.029 ha/h). It should be mentioned that the machine's cutting width affects the field capacity, i.e., the greater the width, the more the field capacity. A high weeding efficiency of 88.5% to 95.4% was observed which was higher than the average weeding efficiency of similar existing mechanical weeders (75.81%). This highlights how well the designed equipment eradicates weeds while keeping accuracy. High weeding efficiency may be due to the reason that when the drum roller failed to remove every weed, the fixed rake at the back end must have contributed to uprooting the weeds leading to the high weeding efficiency. A comparison of weeding efficiency with various other weeders is presented in Figure 3.15. It can be seen that the developed weeders

have a high efficiency comparable to hand weeding which has the highest efficiency. The absence of plant damage is a positive observation, indicating the machine can be utilized efficiently. However, it also depends upon the skill and expertise of the operator. The machine is lightweight, and the observed power requirement was 0.06 to 0.07 HP, where one person can be operated at ease. The labour requirement was found to be 28.6-34.5 man-h/ha. The time required to cover one hectare was recorded as 28.6 to 34.5 hours. No mechanical breakdown or clogging was observed during the operation of this weeder. The machine was operated in a push-pull manner and the corresponding average length of forward and backward strokes was 85.44 cm and 26.8 cm respectively. The average force required for forward and backward strokes was observed to be 68.4 N and 23.2 N respectively.



**Figure 3.15 Comparison of weeding efficiency with various weeders**

Various parameters were determined by analyzing the data gathered during field evaluation trials. A detailed summary of field performance test results is presented in Table 3.4.

**Table 3.4 Field Performance Test Results**

Sl. No.	Parameters	Test trials				
		I	II	III	IV	V
1.	Date of test	28/07/23	26/08/23	26/08/23	27/08/23	27/08/23
2.	Net test duration, h	3.5	2.5	3.0	2.5	3.5
3.	Type of soil	Sandy loam, medium land				
4.	Time lost due to turning, sec/row	16	14	12	17	14
5.	Effective width of cut of one row, mm	140	139	143	142	143
6.	Rated width of coverage, mm (same as crop row spacing)	200	200	200	200	200
7.	Average travel speed, km/h	2.1	2.1	2.0	1.9	2.1
8.	Field capacity, ha/h	0.034	0.035	0.032	0.029	0.034
	Theoretical	0.04	0.04	0.04	0.038	0.04
9.	Time required, h/ha	29.4	28.6	31.3	34.5	29.4
10.	Field efficiency, %	86.4	87.5	79.3	76.4	84.2
11.	Weeding efficiency, %	89.5	91.7	93.4	95.4	88.5
12.	Plant damage, %	Nil	Nil	Nil	Nil	Nil

13.	Length of the forward stroke, cm	87.4	86.2	78.2	86.1	89.3
14.	Length of the backward stroke, cm	24.4	20.5	30.6	27.2	31.3
15.	The force required for forward motion, N	72	64	68	73	65
16.	Force required for backward motion, N	21	26	27	24	18
17.	Number of forward and backward strokes per minute, min <sup>-1</sup>	44.6	42.4	41.1	46.7	44.1
18.	Power requirement, hp	0.07	0.06	0.06	0.07	0.06
19.	Labour requirement, man-h/ha	29.4	28.6	31.3	34.5	29.4

---

### 3.10 Conclusions

The month-long field trial conducted on the newly developed weeding tool provided valuable insights into its performance and effectiveness. The results demonstrated that the design of the weeder is not only efficient but also user-friendly and reliable, making it a practical solution for managing weeds in agricultural operations.

During the field test, the weeder operated at speeds between 1.9 to 2.1 km/h, showcasing its capability for steady performance. The force measurements revealed that the push force required to operate the weeder was 68.4 N, while the pull force was significantly lower at 23.2 N. These values indicate that the weeder can be operated with a manageable level of effort, which is essential for ensuring user comfort during extended periods of use.

The actual field capacity and weeding efficiency of the developed tool were impressive, achieving rates of 0.038 to 0.04 ha/h and an efficiency range of 88.5% to 95.4%. These figures

are notably superior to those of existing weeding tools, such as cono weeders, which have lower capacities (0.029 ha/h) and efficiencies (75.81%). This comparison underscores the potential of the new weeding tool to enhance weed management practices, particularly in hilly regions where traditional methods may be less effective.

Overall, the findings from the trial suggest that the developed weeder is a feasible and high-performing option for agricultural applications, particularly in challenging terrains. The ability to effectively address inter-row weeds through the use of this tool could significantly alleviate the labor-intensive nature of weed management for farmers.

However, in addition to inter-row weeds, the issue of intra-row weeds remains a concern, as these weeds can still pose a challenge to crop yields and overall field health. While the weeder offers substantial benefits for inter-row weed management, further efforts are needed to tackle the intra-row weed problem. This aspect is expected to be explored in greater detail in the subsequent chapter (**Chapter Four**), indicating a comprehensive approach to weed management that acknowledges the complexities of various weed types and their locations within crop rows.

In conclusion, the field trial has validated the potential of the newly developed weeding tool as an effective solution for managing weeds in agricultural fields. Its superior performance metrics compared to existing tools highlight its capability to significantly improve operational efficiency and ease of use for farmers, especially in hilly areas. As the agricultural sector continues to seek innovative solutions to enhance productivity and sustainability, tools like this weeder represent a promising advancement. However, addressing the challenges posed by intra-row weeds will be essential for achieving comprehensive weed management and maximizing crop yields. Future research and development efforts will be crucial in refining the tool further and expanding its application to tackle all types of weed issues effectively.

## CHAPTER FOUR

### 4 Design and analysis of wetlands inter cum intra-row paddy field weeder

#### 4.1 Introduction

To control weeds, mechanical, chemical, and biological methods can be combined with manual weeding. Manual weeding with bare hands or hand-held power tools is considered the most efficient method, despite being time-consuming, difficult, and costly (Datta et al., 2017). After that, this technique progressed to hand tools, such as a hand hoe instead of a stick. Field rotations, stale seed beds, planting dates, seeding rates, and other cultural techniques are examples of pre-emergence weed management strategies that can be useful in lowering weed populations before they get entrenched in the crop. In light of recent government regulations regarding the use of herbicides and the connection between ecologically friendly farming practices and subsidies, non-chemical management is becoming increasingly important and is the main focus of this study. Non-chemical control can be divided into two primary categories: soil-engaging and non-soil-engaging. Weeds in and along the row can be controlled by either category. Mechanical weeding is advised because chemical weeding is usually more costly, hazardous, and selective. Moreover, by generating soil mulch, mechanical weeding preserves a loose soil surface and enhances aeration and moisture retention.

India has become self-sufficient in the production of food grains and is presently the world's largest exporter of rice, with 12.7 MMT valued at \$7.7 billion in 2017–18. The development and uptake of enhanced production technology, such as weed management technologies, in India, made these advancements possible (Rao et al., 2014; Rao & Chauhan, 2015). Researchers have been working on weed management technologies over the past 50 years, and they have evolved and been handed on to farmers through various means (Rao et al., 2014) where farmers benefitted (Rao et al., 2014). However, because weeds are ever-changing, they still pose a significant threat (Rao, 2018). Therefore, ongoing efforts are required to keep an eye on the constantly evolving weeds in various ecosystems and to create weed management methods that are appropriate for a variety of environments.

Inter-row and intra-row weeds, or weeds between the rows and along the row, respectively, are the two sorts of weed positions that are dangerous. To keep interrow weeds under control, mechanical hoes are used, moving between the rows to snip and bury the weeds. The most difficult weeds to remove are those that are growing between the rows of crops i.e., intra-row

weeds (Klooster, 1982; Kouwenhoven, 1992). According to Kouwenhoven (1992), 60–70% of the surface is treated when using inter-row weed management. He observes that weeds that are tightly around the crop are nearly hard to control with the current intra-row weeding procedures, such as brushing or ridging.

Currently, inter- and intra-row weeding activities are typically carried out separately, resulting in inefficiencies and high energy consumption, especially in both dryland and wetland environments. Thus, the study endeavors to address this inefficiency by designing an all-in-one system capable of performing both inter and intra-row weeding operations in a single pass. The proposed mechanism, powered by an IC engine and devoid of sensors and hydraulic systems, presents a novel approach to weed control in wetland paddy field cultivation. Through the creation of a CAD model, the study aims to analyze the strength and functions of various components, while also delineating a suitable path for intra-row weeding.

The motivational concepts that inspired the weeder's design are expounded upon in the following reasons.

1. Weeds in the intra-row zone can significantly lower crop yields in the range of 18–76% (Alba et al., 2020; Chandel et al., 2015; Gharde et al., 2018), hence eliminating them is essential.
2. While many prototypes exist for inter-row weeding, there are comparatively few available for intra-row weed management (Sebastian & Kalita, 2022).
3. Wet-land paddy cultivation has not been known to employ intra-row weeders, despite research and tests on mechanical weeders, such as finger weeders and torsion weeders, having been examined and analyzed for dry-land vegetable crops (Sebastian & Kalita, 2022).
4. Although intra-row weeders have been implemented in a variety of dryland crops, intelligent intra-row weeders have not been able to outperform non-intelligent equipment (Chandel et al., 2021; B Melander et al., 2015; Pérez-Ruíz et al., 2014).
5. Furthermore, additional resources are needed for sensors, processors, and control systems in intelligent weeders (Chandel et al., 2021).

Thus, in this study, a unique mechanism (as discussed in Chapter 2, Section 2.5.4) that runs on an IC engine and can perform intra- and inter-row weeding in a single pass without the need for hydraulic systems or sensors is presented.

The integration of Finite Element Analysis (FEA) into the design process of machine components is imperative, serving as a crucial step before prototyping. By conducting stress analyses of materials, manufacturers can ensure the reliability of their products, particularly when operating under challenging dynamic conditions. Traditional techniques for determining the size and weight of components often yield unreliable results, underscoring the necessity of FEA in optimizing design parameters.

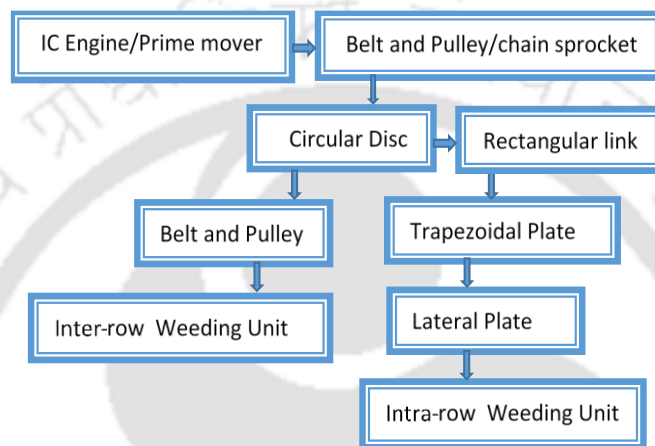
The use of Finite Element Analysis in designing machine components is necessary before the actual prototyping which could benefit the manufacturer in saving time and more economically. Stress analyses of materials are required to offer a particular level of reliability for products that must operate well in challenging dynamic conditions. It is challenging to determine the optimum size and weight of different components, and the dimensions calculated using conventional techniques are unreliable. Furthermore, accurate force analysis on various soil-engaging units is crucial during the machine serving life. Applications of the finite elements approach and three-dimensional (3D) modeling are becoming increasingly common in industry nowadays. Numerous examples of 3D modeling and finite element applications may be found across several engineering specialties (Gunay, 1993). Inadequate technical expertise, the application of new technology, and novel design elements can result in issues like malfunctions and breakdowns during field operations, particularly in the small- and medium-sized agricultural machinery sector (Tarighi et al., 2011). One of the primary concerns in engineering is machinery failure (Tarighi et al., 2011; Upadhyay et al., 2017). Another effective technique for delving into intricate engineering issues is the finite element approach, particularly when dealing with dynamic systems that exhibit significant deformation and failure (Li et al., 2015; Upadhyay et al., 2017; Upadhyaya et al., 2002).

In summary, this study presents a novel idea that could address some of the problems with traditional weeding methods. The work contributes to the development of agricultural technology by creating an integrated weeding system that can function well in wetland environments, offering increased productivity and sustainability in paddy field farming.

## **4.2 Functions of various components**

To illustrate the clarity of functions of various components, a power flow diagram (Figure 4.1) and a technical route (Figure 4.2) were devised. The major components necessary for the

functioning of the weeder comprise a prime mover (IC engine), circular disk, rectangular link, trapezoidal plate, lateral plates, sliding rod, shank attachment for intra unit, cutting blades, and float (sleigh). A pen and paper sketch (Figure 4.3) was devised during the idea generation stage. A schematic diagram of the flow of power from the prime mover to the weeding units is shown in Figure 4.4. The initial design sketched in SolidWorks is shown in Figure 4.5. The function of each component is described below.



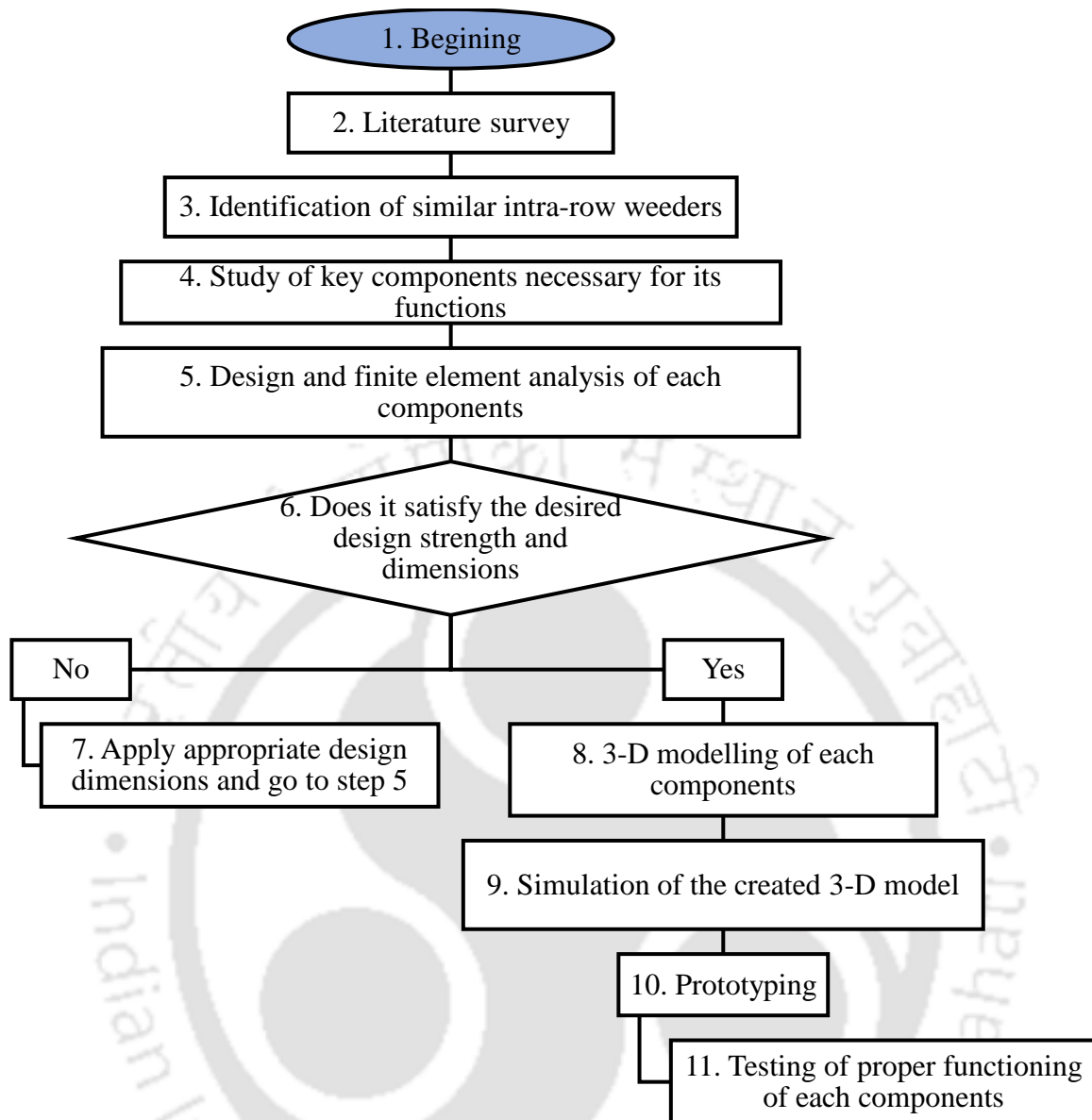
**Figure 4.1 Power flow diagram**

#### 4.2.1 Source of power requirement

The power source is derived from an IC engine (Figure 4.6a). Its main function is to provide the power required for inter and intra-row weeding.

#### 4.2.2 Circular disk

The round disk that rotates (Figure 4.6o) has been incorporated to serve as a crank. At a distance offset from the disc's center, the trapezoidal plate is connected to the circular disk via a rectangular link. Because of this configuration, the trapezoidal plate provides a reciprocating motion.



**Figure 4.2 Technical route involved in the process of designing the weeder**

#### 4.2.3 Rectangular link

The rectangular link (Figure 4.6p) serves as a connecting link and transfers the motion between the circular disk and the trapezoidal plate.

#### **4.2.4 Trapezoidal plate**

The function of the trapezoidal plate (Figure 4.6d) is to provide reciprocating motion. The side angle of the plate is inclined at 45° to provide lateral motion. The trapezoidal plate is connected laterally to two adjacent lateral plates on both sides. As the trapezoidal plate reciprocates, the two side lateral plates move sideways laterally outward and inward as per the design.

#### **4.2.5 Sliding rod**

A smooth round circular rod (Figure 4.6h) is provided for the lateral plates to slide inward and outward for lateral motion of the intra-row unit.

#### **4.2.6 Rotor blade**

Weeds in the inter-row zone are removed by the rotor equipped with an L-type blade (Figure 4.6e). The belt and pulley system transfer the engine's motion to the rotor.

#### **4.2.7 Lateral plate extension**

The platform for connecting the intra-row weeding unit's shank is provided by the lateral plate extension (Figure 4.6c). The weeds can be uprooted by using the spikes at the tip of the intra-row weeding unit. As a result of the scraping action, the spikes pull out the weeds in the intra-row zone as they move inward and outward.

#### **4.2.8 Float**

The float (Figure 4.6i) prevents the machine from sinking into the muddy soil while operating. It provides an upward thrust and thus the machine can be moved forward without much friction.

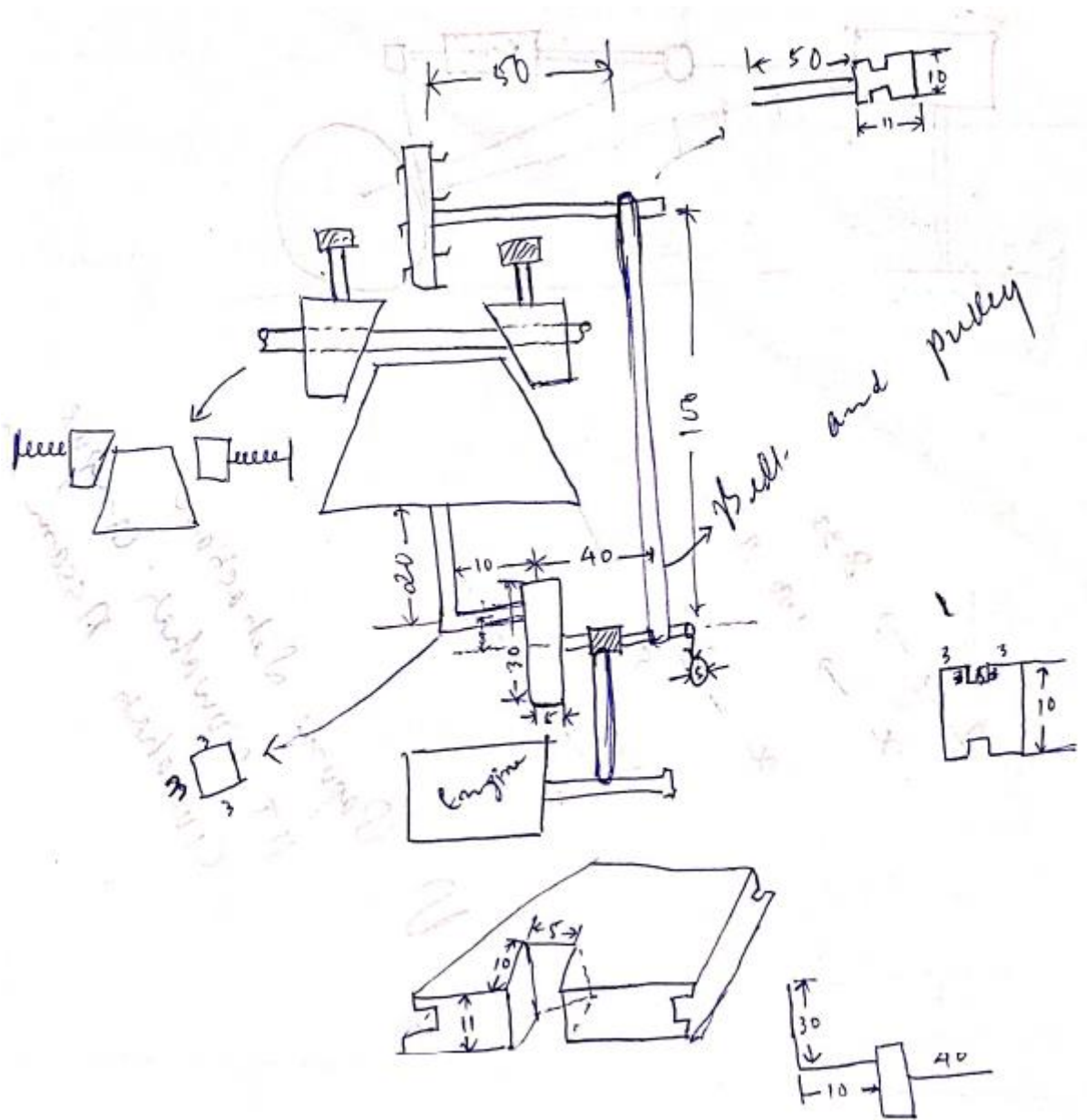


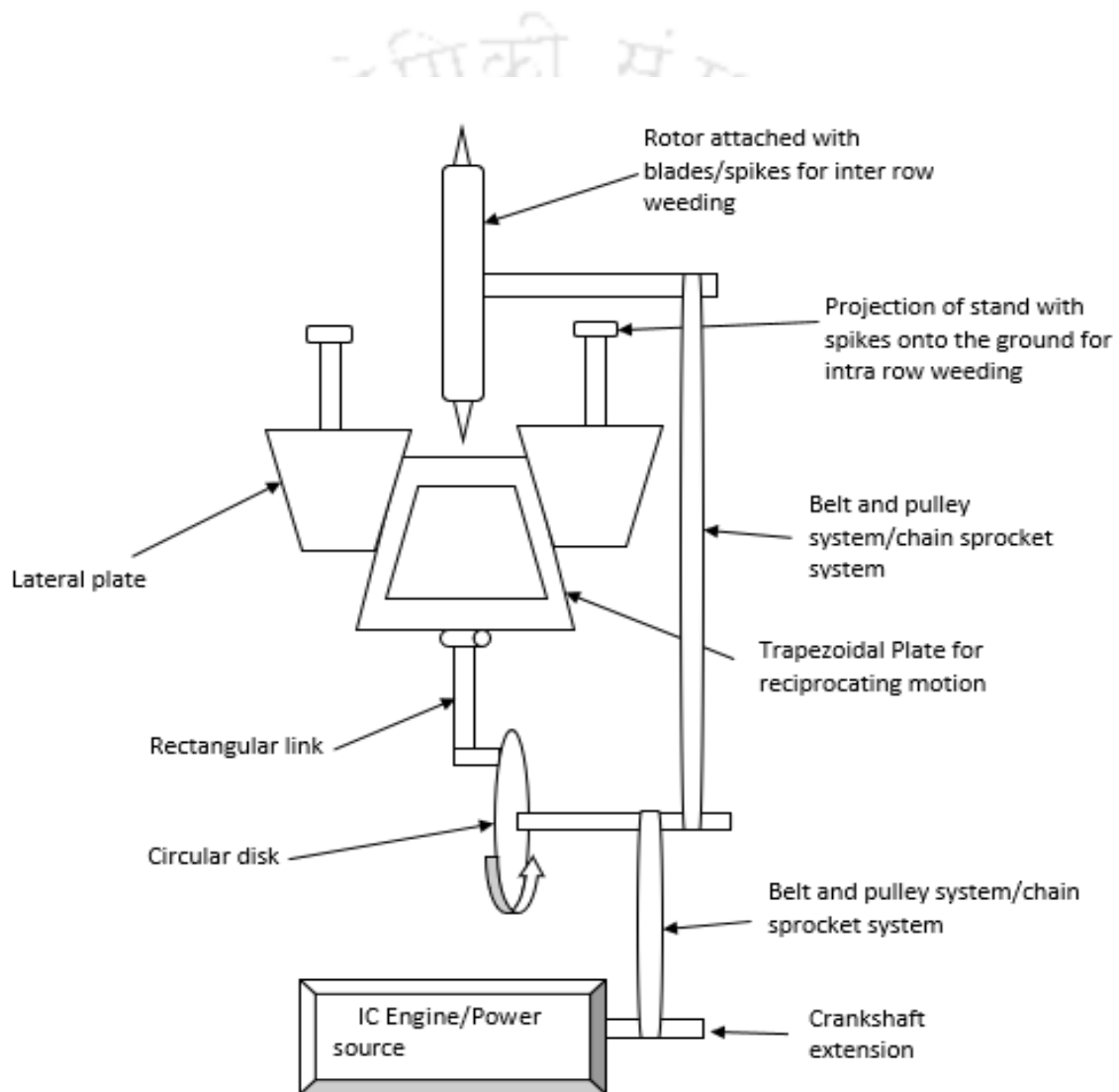
Figure 4.3 Pen and paper sketch of the prototype during the idea generation stage

#### 4.3 The working principle of the designed mechanism

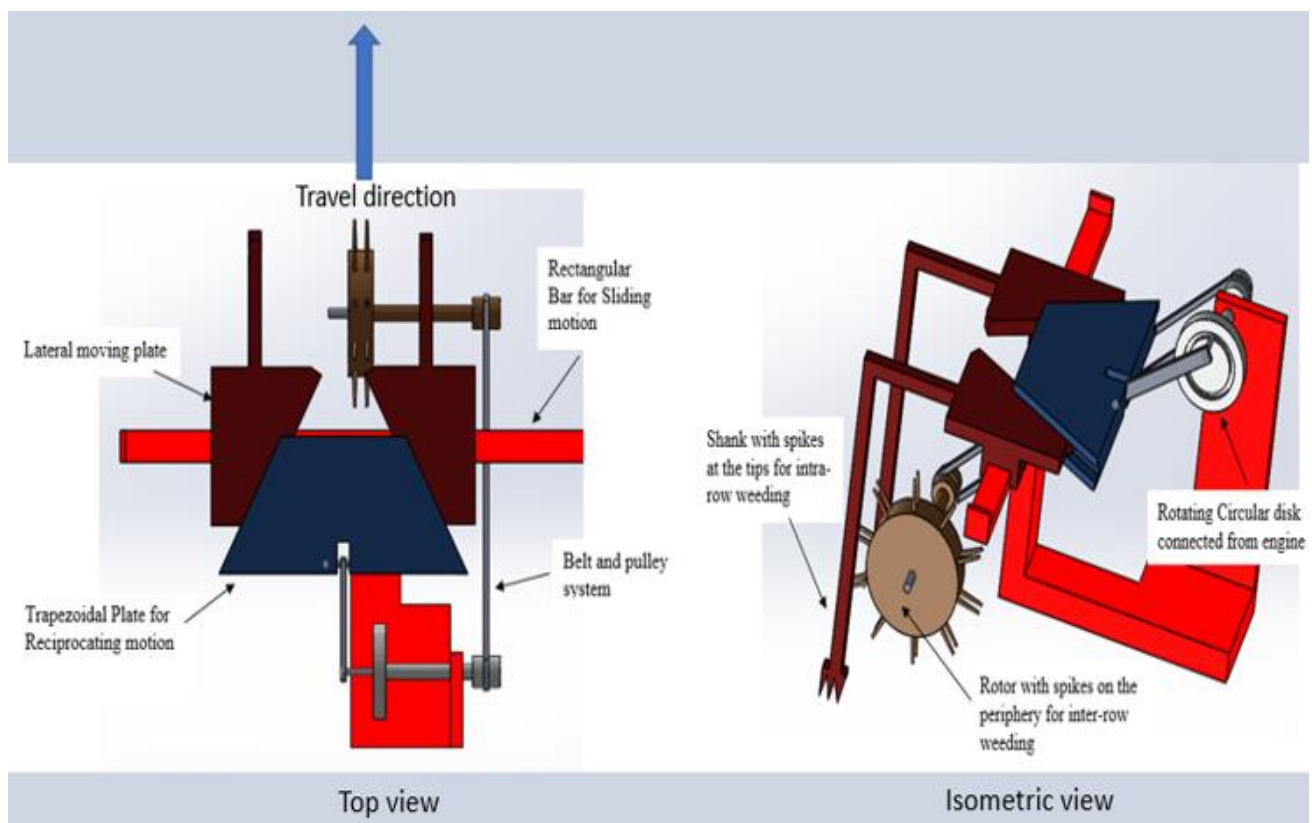
An IC engine serves as the prime mover's source. It powers a circular disc using a belt and pulley system, with a rectangular link connecting the circular disc to a trapezoidal plate. The trapezoidal plate has two lateral plates linked to the grooves on either side. For intra-row weeding, a shank that emerges from the two lateral plates and has spikes at the tip is utilized.

A belt and pulley system is used to transfer the drive for inter-row weeding from the circular disc's shaft extension to the rotor shaft.

The theoretical analysis and FEA of the individual components were carried out based on the agronomic requirement of the paddy which includes the row-to-row spacing, plant-to-plant spacing, and the height of the crop. The design of various components and their analysis are described below.



**Figure 4.4 Schematic diagram depicting the power flow from the IC engine to the units**

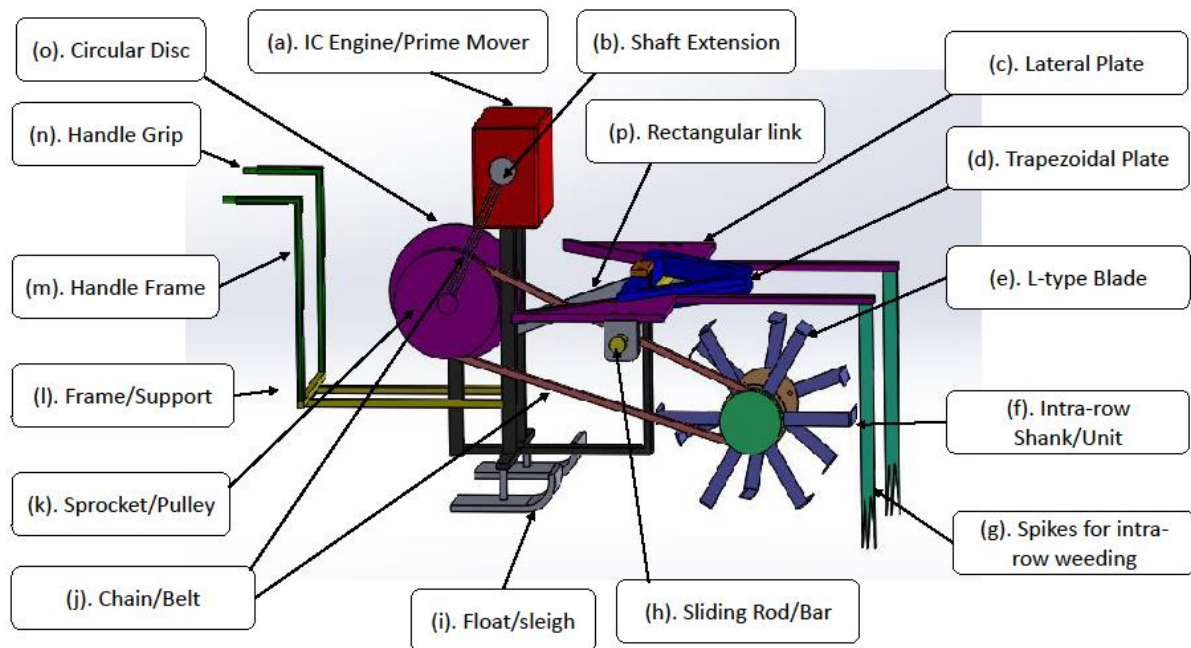


**Figure 4.5 Various views of the initially designed weeder**

#### **4.4 Theoretical analysis of various parameters**

##### **4.4.1 Calculation of power requirement**

The total power required for operation was calculated by summing up the power required for inter and intra-row weeding. Soil resistance plays an important role in calculating the weeder's power requirements. Due to the uneven distribution of soil in the same plot, soil resistance also varies, thus silt loam soil's resistance was considered in the study and estimated to be between 0.034 and 0.049 N.mm<sup>-2</sup> (Basavaraj et al., 2016). Therefore, the maximum soil resistance of 0.049 N.mm<sup>-2</sup> was considered for the study. The maximum working speed of the weeder was considered to be 1 km/h to 2 km/h. The width of coverage of the rotor blade was taken as 120 mm. The lateral extension coverage of each intra-row weeding unit was 150 mm in both sideways directions.



**Figure 4.6 A 3-D model of the designed paddy field weeder**

The depth of operation was considered as 50 to 80 mm. The power requirement of intra-row weeding of the designed weeder was calculated following Sirmour & Verma, (2018). Thus, the power required for intra-row weeding was estimated as

$$P_a = \frac{S_r \times d \times w \times v}{75} \quad (1)$$

where,  $P_a$  = Power requirement for intra-row weeding (kW),  $S_r$  = Soil resistance, ( $N.m^{-2}$ ),  $d$  = Operation depth (m),  $w$  = Effective width of operation (m),  $v$  = Speed of operation ( $m.s^{-1}$ ). Hence, the power required for intra-row weeding ( $P_a$ ) was estimated to be 0.22 kW. According to Gupta & Visvanathan (1993), the power requirement of a rotary tiller in saturated lateritic clay loam soil consists of 0.34 to 0.59% for cutting the soil slices, 30.5 to 72.4% for throwing out soil slices by the centrifugal action of rotary blades, 0.96 to 2.45% for overcoming soil metal friction, 0.62 to 0.99% for soil-soil sliding friction and 23.1 to 64.6% for idle power. They have experimented and shown that the power requirement of a rotary tiller in saturated lateritic sandy clay loam soil at 200 rpm of the rotor blade was 1.1 kW. Further, the power requirement of L-shaped blades in supersaturated soil at 162 rpm and 243 rpm is 1.12 kW and

1.68 kW respectively (Beeny & Khoo, 1970). Hence, the power required for inter-row weeding ( $P_b$ ) at 200 rpm of the rotor blade can be considered in between the range of 1.1 to 1.4 kW. Thus, the total power required for inter and intra-row weeding ( $P_a + P_b$ ) can approximated to be 1.5 kW.

#### 4.4.2 Torque transmitted by the engine shaft

The torque transmitted by the engine shaft was calculated as

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

where,

$P$  = power, kW;  $T$  = torque transmitted by the shaft, Nm;  $N$  = revolutions per minute

Considering the engine speed as 6500 rpm and the engine power as 1.5 kW, the torque value was calculated as 2.20 Nm. Similarly, the torque required at the rotor shaft was calculated as 71.62 Nm (the rpm of the rotor shaft was taken as 200).

#### 4.4.3 Design of rotor shaft

For designing the rotor shaft, the maximum tangential force that can be sustained by the rotor was considered. The maximum tangential force occurs at the minimum blade tangential speed and was calculated as (Bernacki, H., Haman, J., and Kanafojski, 1972)

$$K_s = \frac{75 \times C_s \times N_c \times \eta_c \times \eta_z}{U_{\min}} \quad (3)$$

where,

$K_s$  = Maximum tangential force, kg,

$C_s$  = Reliability factor (1.5 for non-rocky soils and 2 for rocky soils),

$N_c$  = Power of engine, Hp,

$\eta_c$  = Traction efficiency for the forward rotation of the rotor shaft as 0.9,

$\eta_z$  = Coefficient of reservation of engine power (0.7-0.8),

$U_{min}$  = Minimum tangential speed of the blades,

The minimum tangential speed of the blade was calculated as  $3.14 \text{ m.s}^{-1}$  using the following equation,

$$U_{min} = \frac{2 \times \pi \times N \times R}{6000} \quad (4)$$

Now, the maximum tangential force that occurs at the minimum blade tangential speed is 593.11 N.

The maximum moment on the rotor shaft was calculated as

$$M_s = K_s \times R \quad (5)$$

where  $M_s$  is the maximum moment in kg.mm; R is the rotor radius in mm. Therefore,

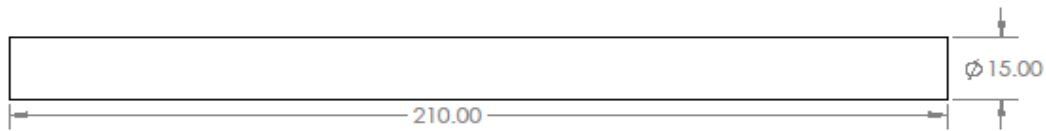
$$M_s = 90690 \text{ kg mm}$$

The rotor shaft diameter was calculated as 13.5 mm by using the following equation as

$$D = \sqrt[3]{\frac{16 \times M_s}{\tau_{all} \times \pi}} \quad (6)$$

where, D = diameter of rotor shaft;  $\tau_{all}$  = allowable stress on the material (taken as 250 MPa for mild steel)

Thus, a rotor shaft of 15 mm diameter (Figure 4.7) was selected for its torque analysis.



**Figure 4.7 Rotor shaft (all dimensions are in mm)**

#### 4.4.4 Design of cutting blades

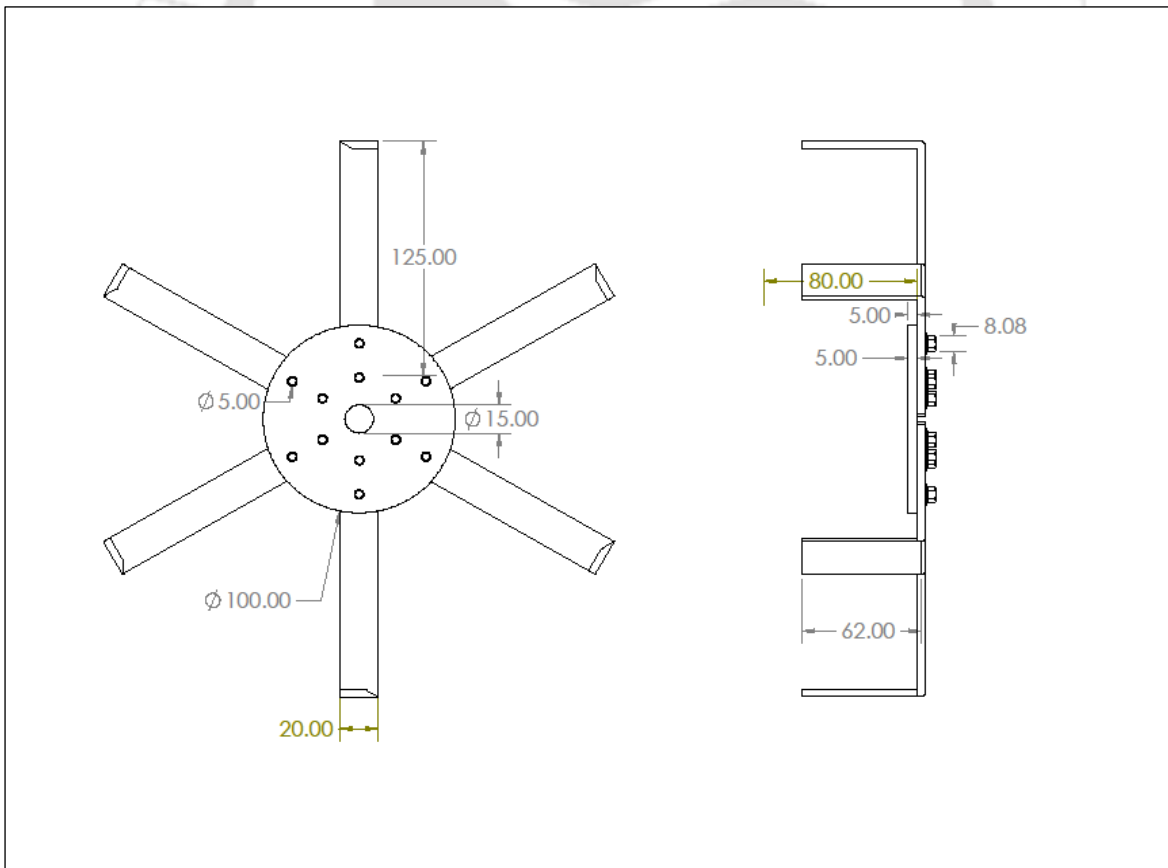
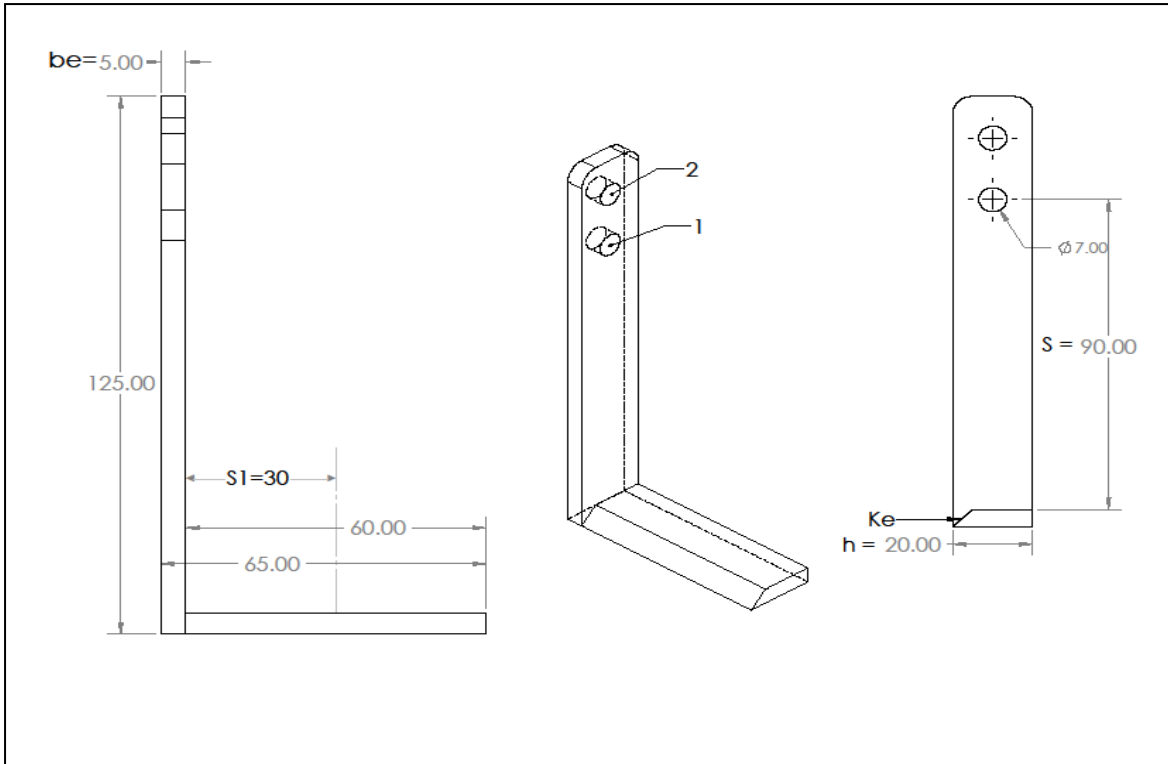
To provide safe strength and bending values for manufacturing blades during weeding operation, different parameters were employed in the study and taken into consideration. The rotary tillage blade is one of the most critical functioning sections of the rotary tiller and one of the portions that put the most stress on it. The deformation of soil by the cutting blade can be divided into three stages (Du et al., 2013). It states that the first stage is the cutting stage, which involves simply cutting into the soil with the blade, and in the second stage, the blade holds the chopped soil on its scooped surface which is called the holding stage. Furthermore, it states that the third stage is the no-load stage of deformation in a rotary tiller where, the tilled dirt is thrown into the air, where it loses contact with any materials. To design the cutting blade, the parameters employed were assumed based on the Textbook of Agricultural Machines, Theory and Construction (Bernacki et al., 1972).

The assumption considered includes as follows; Number of blades in one working set = 6; Length of blade = 124 mm; Width of blade = 20 mm. To calculate the design strength of the blade; the revolution per minute of rotor shaft (N) = 200 r.p.m; the radius of the engine output rotor (R) = 150 mm. The soil force acting on the blade ( $K_e$ ) was calculated by the following equation,

$$K_e = \frac{K_s \times C_p}{i \times Z_e \times n_e} \quad (7)$$

where,

$C_p$  = overload factor of an individual working element ( $C_p = 1.5$ , for stoneless soil;  $C_p = 2$ , for stony soil);



**Figure 4.8 CAD model of the designed blade (All dimensions are in mm)**

$i$  = Number of working sets in the machine = 2;

$Z_e$  = number of blades on each side of the flange = 6;

$n_e$  = fraction determining the number of working elements that operate simultaneously.

In general, it is considered that one-fourth of the knives and blades in rotating cultivators and hoes, as well as one-half of the elements in rotary plows, cut the soil simultaneously. Therefore, the maximum force of the entire machine is divided by this number of functioning elements. Because the loads on each of the different functioning elements are not equal, the overload factor ( $C_p$ ) is introduced. Thus, the soil force ( $K_e$ ) was calculated to be 296.56 N. As the blade rotates in the direction of travel, this amount of force will pull the machine forward while operating it.

The bending stress ( $\sigma_{zg}$ ), shear stress ( $\sigma_{skt}$ ), and equivalent stress ( $\sigma_{zt}$ ) can be estimated as follows (Bernacki, H., Haman, J. and Kanafojski, 1972). The analytical force  $K_e$  is assumed to act at a distance  $S_1 = 30$  mm from the shank.

$$\sigma_{zg} = \frac{6 \times K_e \times S}{b_e \times h_e^2} \quad (8)$$

$$\sigma_{skt} = \frac{3 \times K_e \times S_1}{\left(\frac{h_e}{b_e} - 0.63\right) \times b_e^3} \quad (9)$$

$$\sigma_{zt} = \sqrt{\sigma_{zg}^2 + 4\sigma_{skt}^2} \quad (10)$$

where,

$\sigma_{zg}$  = bending stress,  $\text{N.mm}^{-2}$ ;  $\sigma_{skt}$  = shear stress,  $\text{N.mm}^{-2}$ ;  $\sigma_{zt}$  = equivalent stress,  $\text{N.mm}^{-2}$ .

Now, the values of bending stress, shear stress, and equivalent stress were calculated as  $99.96 \text{ N.mm}^{-2}$ ,  $90.92 \text{ N.mm}^{-2}$ , and  $215.29 \text{ N.mm}^{-2}$  respectively.

Considering the allowable stress of mild steel as  $250 \text{ N.mm}^{-2}$  the obtained equivalent stress value i.e.,  $215.29 \text{ N.mm}^{-2}$  is less than the maximum permitted equivalent stress for M.S. material. Thus, the design was secure. The CAD model of the designed blade is shown in Figure 4.8.

#### 4.4.5 Shank for intra-row weeding

The shank is subjected to bending stress while in operation. The length and thickness of the shank play an important role in overcoming the stresses. The draft force exerted by the shank may be calculated as

$$\text{Draft} = \text{Area displaced by shank} \times \text{soil resistance} \quad (11)$$

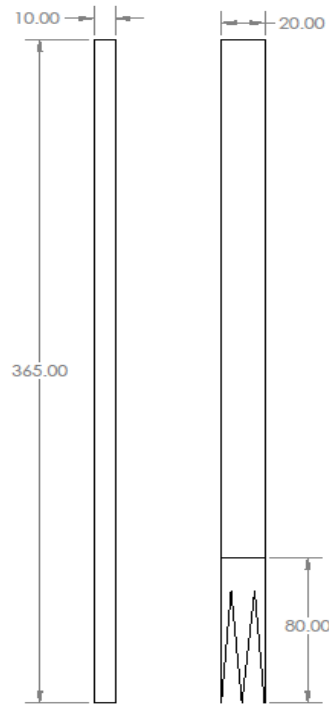
where,

Draft in N,

Area = width of shank  $\times$  depth of operation,  $\text{mm}^2$

Soil resistance =  $0.049 \text{ N.mm}^{-2}$

Considering the maximum width of the shank as 80 mm and the depth of operation as 50 mm, the draft exerted by each shank of the intra-row unit (Figure 4.9) was calculated as 196 N.



**Figure 4.9 Intra-row weeding unit (All dimensions are in mm)**

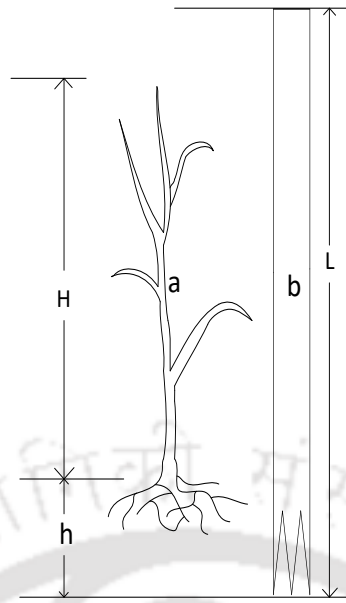
#### 4.4.6 Height of intra-row weeding shank

The intra-row shank is derived from the extension of lateral plates. To ensure smoothness of operation, the height of the intra-row shank  $L$  should be greater than the sum of the rice seedling's height  $H$  and depth of operation  $h$  (Figure 4.10); that is,

$$L \geq H_{\max} + h_{\max} \quad (12)$$

The height of paddy seedlings grown with vermicompost, farmyard manure, and coir pith after two weeks ranges from 156.9 to 170.6 mm (Dhananchezhiyan et al., 2013). The critical period of crop-weed competition for direct-seeded rice is 15 to 45 DAS (Days After Sowing) (Singh et al., 2008). Furthermore, the height of the rice seedlings was within the range of 100-150 mm 7-10 days after transplanting, and the height of the seedlings was within the range of 200-300 mm 15-20 days after transplanting (Li et al., 2015; Tian et al., 2022; Wu et., 2009). Thus, considering the operating depth of 50 mm, the minimum vertical height of the intra-row unit should not be less than 350 mm. Hence from eqn. (12),

$$H_{\max} + h_{\max} \leq 350 \text{ mm} \quad (13)$$



**Figure 4.10 Schematic diagram of paddy seedling along with the intra-row weeding unit**

[H is the height of the seedling; h is the depth of operation; L is the vertical height of the intra-row weeding unit (height of shank); a indicates the paddy plant; b indicates the intra-row weeding unit]

The dimensions of various components considered for the design are presented in Table 4.1.

**Table 4.1 Dimensions of various components**

Sl. No.	Components	Parameters (mm)				
		Length	Height	Width	Thickness	Diameter
1	Rotor shaft	210				15
2	Blade	64	124	20	4	272
3	Intra-row shank		360	20	10	

4	Rectangular link	246	25	10
5	Sliding rod	792		20
6	Circular disc		8	200

#### 4.5 Finite element analysis of various components

SolidWorks is a software enabling finite element analysis (FEA), that facilitates the analysis of structural properties including stress, displacement, natural frequency, etc (Glodová et al., 2014). Hence to analyze the stress and deformation (Mohamed et al., 2018) of various components of the weeder, finite element analysis was carried out using the SolidWorks software. The results of generated Von Mises stress and total deformation were examined, and appropriate design changes in dimensions were incorporated into the 3-D model to attain the optimal part dimensions for product development. Furthermore, kinematic analysis and the path to be traced by the intra-row weeding unit were also achieved by using the SolidWorks software.

ASTM A36 (as available in SolidWorks software) has properties similar to mild steel with a yield strength of  $2.5 \times 10^8 \text{ Nm}^{-2}$  and hence was selected for the analysis of various components.

Material properties selected for the analysis of various components are presented in Table 4.2.

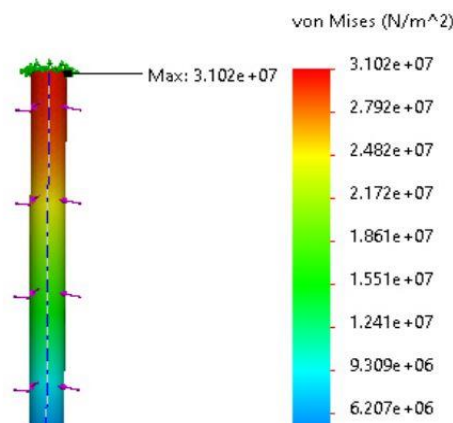
**Table 4.2 Material properties used for FEA (ASTM A36)**

Sl. No.	Property	Value	Units
1	Elastic Modulus	$2 \times 10^{11}$	$\text{N.m}^{-2}$
2	Poisson's Ratio	0.26	NA
3	Shear Modulus	$7.93 \times 10^{10}$	$\text{N.m}^{-2}$

4	Mass Density	7850	$\text{Kg.m}^{-3}$
5	Tensile Strength	$4 \times 10^8$	$\text{N.m}^{-2}$
6	Yield Strength	$2.5 \times 10^8$	$\text{N.m}^{-2}$

#### 4.5.1 Finite Element Analysis of Rotor Shaft

The rotor shaft carries the two flanges on which the blades are mounted. Under operation, it experiences torque due to unequal force distribution in different soil conditions. To analyze its strength, mesh was created throughout the rotor shaft body and a torque of 71.62 Nm (94) was applied. Figure 4.11 shows the torque analysis of the rotor shaft.



**Figure 4.11 Analysis of the rotor shaft**

From the study, the maximum and minimum stress values were found to be  $3.102 \times 10^7$   $\text{N.m}^{-2}$  and  $3.282 \times 10^3$   $\text{N.m}^{-2}$  respectively. The maximum stress value induced due to the applied force (i.e.,  $3.102 \times 10^7$   $\text{N.m}^{-2}$ ) was less than the yield strength of the selected material ( $2.500 \times 10^8$   $\text{N.m}^{-2}$ ) which indicates that the design was safe. This result is in agreement with Upadhyay et al. (2017), and hence the designed dimensions were selected for the rotor shaft.

#### 4.5.2 Finite Element Analysis of Cutting Blade

To analyze the stress and deformation due to cutting action, finite element analysis was carried out. The parameters considered for the analysis are presented in Table 4.2. A soil force of 296.56 N (96) was applied on the blade cutting edge and its deformations and stresses were studied.

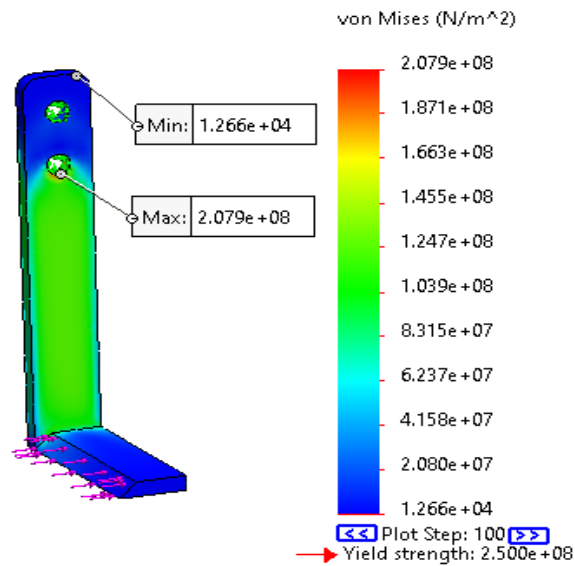


Figure 4.12 Stress distribution on the blade

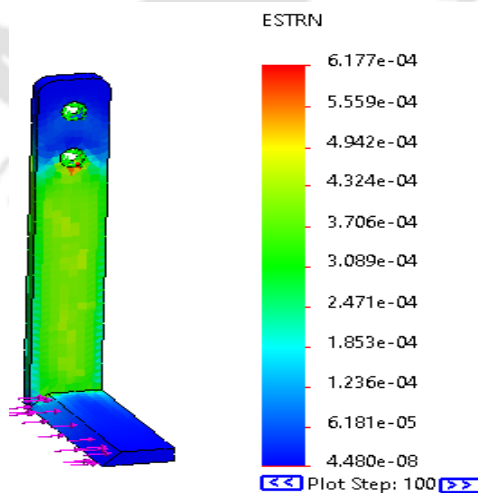
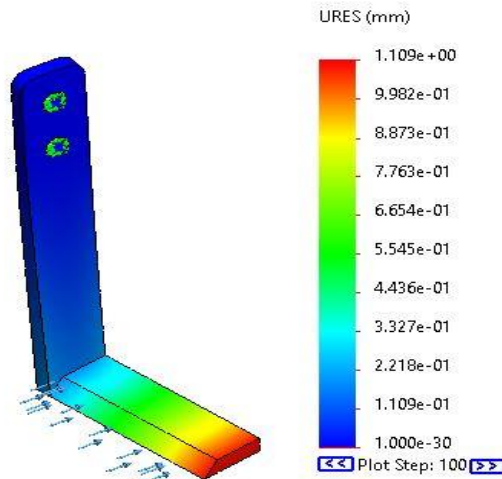


Figure 4.13 Strain distribution of the blade



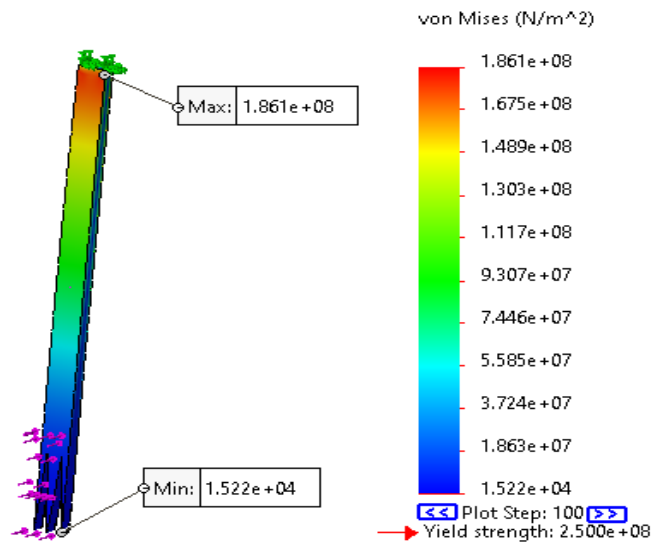
**Figure 4.14 The resultant displacement of the blade**

The study indicates that the maximum stress value of  $2.079 \times 10^8 \text{ N.m}^{-2}$  and minimum stress value of  $1.266 \times 10^4 \text{ N.m}^{-2}$  were obtained. It was found that the maximum stress value (i.e.,  $2.079 \times 10^6 \text{ N.m}^{-2}$ ) induced was less than the yield strength of the selected material (i.e.,  $2.500 \times 10^8$ ) (Figure 4.12). The result is consistent with Upadhyay et al., (2017) which indicates that the design was safe. Hence, the designed dimensions of the blade were selected for the cutting blade. The results indicate that the blade component closest to the assembly hole has the most stress, indicating that designers should pay more attention to this area, whereas the area around the blade tip has the most deformation. Du et al. (2013), performed finite element analysis on rotary tillage blades using SolidWorks and have shown similar results. The maximum and minimum strain values were found to be  $6.177 \times 10^{-4}$  and  $4.48 \times 10^{-8}$  respectively (Figure 4.13). The maximum deformation occurs at the hole of the blade end provided for nut and bolt assembly. Hence, to avoid failure of the blade, proper attention needs to be paid to that location by the designers. The maximum displacement of the blade at the cutting edge was found to be 1.109 mm (Figure 4.14).

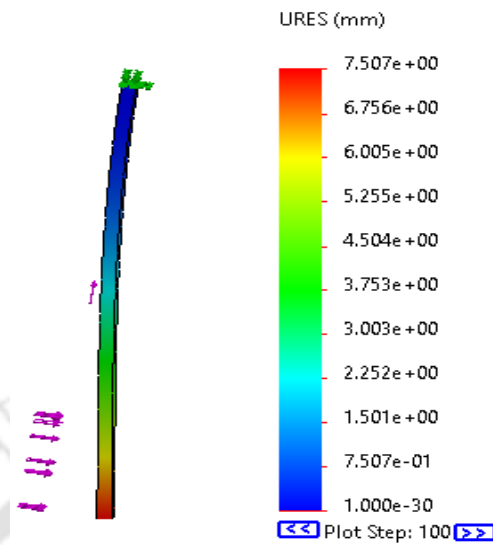
#### **4.5.3 Finite Element Analysis of Intra-row Shank**

The finite element analysis of the intra-row shank was carried out to analyze its strength and deflection. A force of 196 N (99) was applied at the soil-engaging spiked tip. The study shows

that the maximum stress value was  $1.861 \times 10^8 \text{ N.m}^{-2}$ , and the minimum stress value was  $1.522 \times 10^4 \text{ N.m}^{-2}$ . It was observed that the yield strength of the chosen material ( $2.5 \times 10^8 \text{ N.m}^{-2}$ ) is greater than the stress induced by the applied force ( $1.861 \times 10^8 \text{ N.m}^{-2}$ ) indicating that the design is safe (Upadhyay et al., 2017). The highest stress value occurs at the end extension of the lateral plate where the shank was attached (Figure 4.15). This is the point where designers and manufacturers need more attention to avoid breakage. On the other hand, the highest deflection (Figure 4.16) was shown at the bottom part of the spikes around where soil engagement takes place, and the point at the adjoining end of the lateral plate shows the least deflection. According to the experience gained from the study, increased deflection of the intra-row shank may induce machine instability during operation. As a result, it may be suggested that a hollow frame structure be used instead of the current solid structure. This could decrease the deflection.



**Figure 4.15 Stress distribution on the shank**

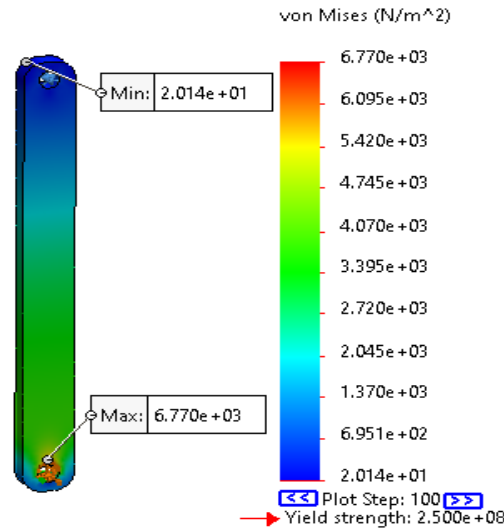


**Figure 4.16 Deflection of shank upon the force application**

#### 4.5.4 Rectangular link

The rectangular link provides the required movement for intra-row weeding via a trapezoidal plate and lateral plate. The required force required by a single intra-row unit was 196 N (99). As the rectangular link supports both the intra-row units, it needs to provide a total force of 392 N for two intra-row units.

According to the study, the maximum stress value was  $6.770 \times 10^3 \text{ N.m}^{-2}$ , and the minimum stress value was  $2.014 \times 10^4 \text{ N.m}^{-2}$ . The highest stress value, which was found to be  $6.770 \times 10^3 \text{ N.m}^{-2}$ , was less than the yield strength of the chosen material, which was found to be  $2.5 \times 10^8 \text{ N.m}^{-2}$ , indicating that the design was safe. This is in agreement with Upadhyay et al. (2017), and the designed dimensions were chosen for the rectangular link. It was observed that the highest stress occurs at the adjoining point of the circular disk (Figure 4.17). This applies at the other connection point to the trapezoidal plate. Hence, care must be taken while designing to overcome the failure at the two adjoining points.



**Figure 4.17 Analysis of rectangular link**

## 4.6 Kinematic Analysis of the Designed Mechanism

### 4.6.1 Creation of individual components and assembly

Each of the individual components required for the functioning of the weeder was designed and saved. Using the *insert components* command, the individual components were inserted into the *Assembly* section. The desired components were then selected or browsed from the saved folder for assembly. Based on the row-to-row and plant-to-plant spacing of the paddy (here taken as 200 mm for both spacings), the dimensions of the major components (trapezoidal plate, length of connecting bar, diameter of the circular disc) were decided. The length of the connecting bar was decided based on a trial and error method using the SolidWorks software so that free reciprocating motion could be played between the circular disc and trapezoidal plate. The extent of the movement of the two lateral plates was kept at 150 mm.

### 4.6.2 Stages of the motion study


The stages of the motion study were conducted following Nedelcu et al. (2020). It includes the following stages.





- a. Activation of the SolidWorks Motion module;
- b. Creation and specification of the study's options;
- c. Specify *Rotary Motor*;
- d. Specify *Force*;
- e. Specify *Gravity*;
- f. Specify *Motion Mates*;
- g. Running the design study

The *Rotary Motor* was activated to the face of the circular disc and the *constant speed* was set to *125 rpm* for operating the intra-row weeding unit. The operating rotational speed of the rotor blade for the paddy field weeder however varies from 180 to 250 rpm. The difference in the variation of the rpm can be adjusted by changing the gear ratio.

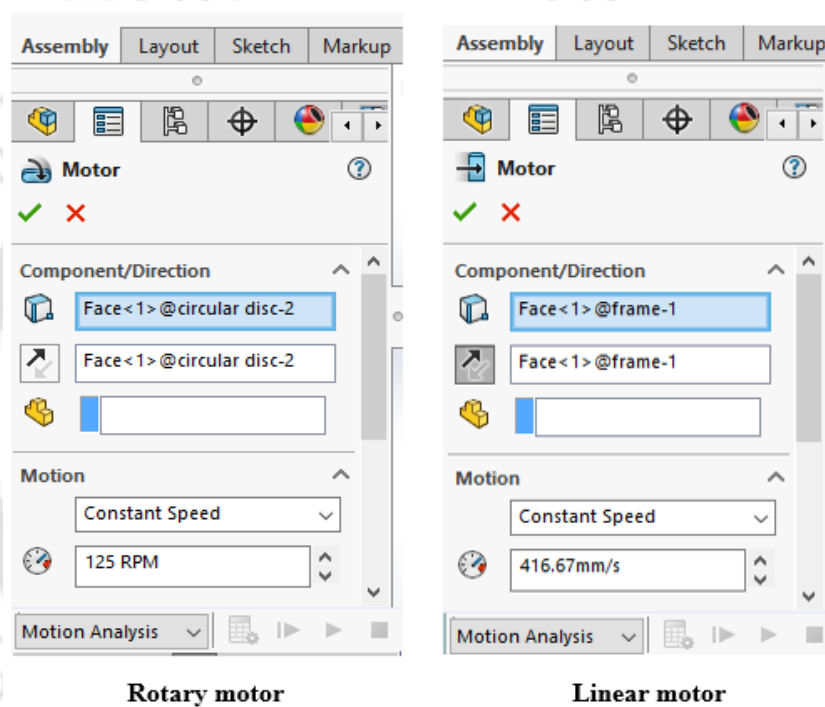
A *Linear Motor* was applied to the base of the frame to propel the machine in the forward direction. The speed of the *Linear Motor* was set at *416.67 mm/s* to match the usual operating speed of the paddy field weeder (i.e., 1.5 km/h). The activation of the *Rotary* and *Linear Motor* for simulation is shown in Figure 4.18.

#### 4.6.3 Running the design study

The study was run following Nedelcu et al. (2011). On clicking the *Calculate*  button, it initiates to run the study. During the computing period, the *Motion Analysis Messages* window displays specific information. At the end of the computing period, the following options were available:

- the  button – to play the animation starting from the beginning;
- the  button - to play the animation starting from the current point;
- the  button - to stop the animation;
- The  slider – to set the animation to a current point;

- the **1x** list – to select the speed of the animation;
- the **→** list – to select the type of animation: **→** Normal (display at normal speed), **↻** Loop (display in a continuous loop), **↔** Reciprocate display forward, the reverse in a continuous loop);
- the **📁** button – to save the animation as avi or another file type;
- the **📄** button – to insert a view rotation or explode/collapse at the current time bar location.

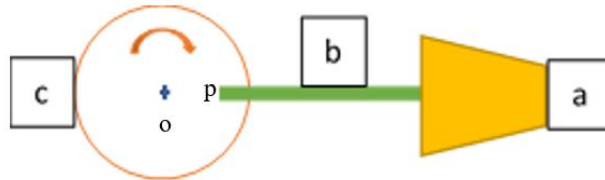


**Figure 4.18 Activation of rotary and linear motor**

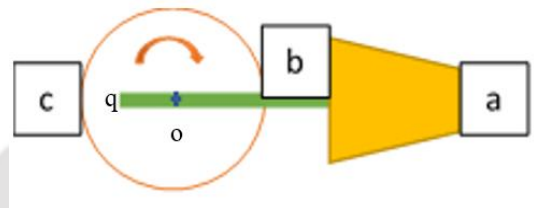
#### 4.7 Position analysis of the weeding units

The power derived from the IC engine was made to rotate the circular disc in a clockwise direction. The circular disc was made to rotate which provides reciprocating motion motion to the trapezoidal plate via a rectangular link. The two inclined sides of the trapezoidal plate in turn led to the lateral movement of the adjoining lateral plates when it reciprocated back and forth.

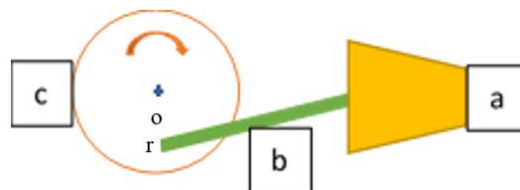
Figure 4.19 shows the maximum lateral position of the intra-row unit when the circular disc rotates in the clockwise direction. In other words, the lateral distance between the two intra-row units is farthest (Figure 4.22) when the connecting point of the rectangular link and circular disc acting as the crank is at point p. The distance between the center point o and the points p, q, r represents the length of the crank.



**Figure 4.19 Maximum lateral position**



**Figure 4.20 Minimum lateral position**




**Figure 4.21 Middle position (a: trapezoidal plate; b: rectangular link; c: circular disk)**

Figure 4.20 shows the minimum lateral position of the intra-row unit. This occurs when the connecting point of the rectangular link and circular disc is at point q. At this point, the distance between the two intra-row units is minimal.

Figure 4.21 is the position of the intra-row unit when it is exactly in between the two plants. This occurs when the connecting point of the rectangular link and circular disc is at point r. As the inter-row unit operates in the middle row among the three rows, the intra-row unit operates in the two adjacent rows when it is in the maximum lateral extension position. During the minimum lateral position, it operated within the rows of the inter-row unit. The intra-row unit traverses in the sinusoidal path along with the linear forward motion of the weeder. The maximum and minimum lateral extension of the intra-row unit is presented in Figure 4.21.

#### 4.8 Simulation of the intra-row path

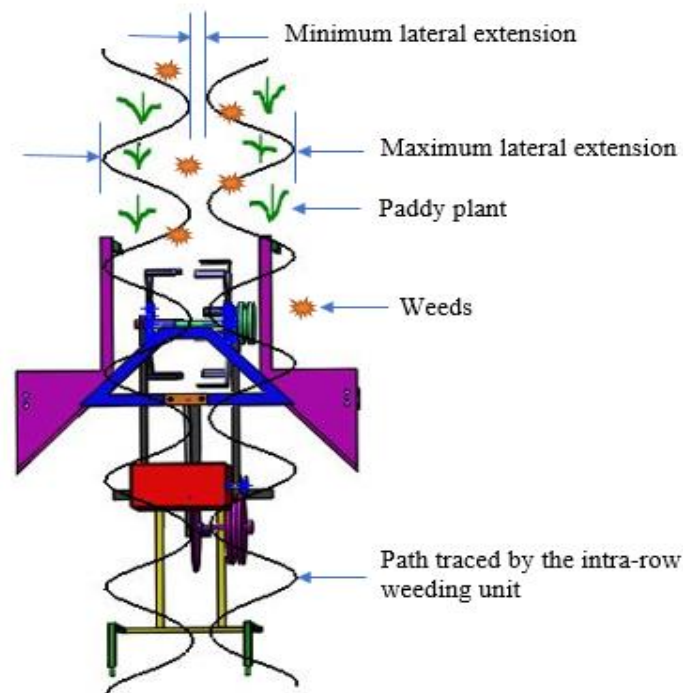
The *Motion Analysis* button was activated for tracing the path of the intra-row weeding unit. The *Timeline* for the simulation was set to run for 8 seconds.

The button *Results and Plots*  was used to view the path traced by the intra-row weeding unit. The plot was defined by the following steps.

- *Displacement/Velocity/Acceleration*;
- *Trace path*;
- Select the tip of the intra-row weeding unit;

The top view of the path traced by the intra-row unit is shown in Figure 4.22. A plot of land with an area of 5000×1000 mm was created to replicate the virtual paddy field. The assembled CAD model was placed on the virtual field and pre-set to travel in a straight direction. The velocity of the machine was set to travel at 1.5 kmph and the rotational speed of the rotor blade was kept at 200 rpm. The simulation was made to run for 8 seconds.

The sole interest in the simulation of the designed model lies in tracing a suitable path for the two intra-row weeding units. The result of the simulation shows a sinusoidal curve generated as per the design where the intra-row weeding units traverse around the paddy plants without disturbing them.



**Figure 4.22 Top view of the weeder in operation during simulation**

In the figure, a path of a single intra-row spike (out of three spikes) has been traced in the simulation. However, the number of spikes can be increased as per the requirement. During the operation, each of the two intra-row units passes to the neighboring adjacent rows in between the paddy plants so that the weeds are uprooted or destroyed by the intra-row weeding spikes.

The plant spacing affects the movement of the intra-row weeding units. The type of soil, water conditions, and varieties of rice also affect the spacing of the paddy plant. However, it is a very difficult task to decide the exact spacing as it varies from location to location. Asghar et al. (2021) reported the highest grain yield (6.75 tonnes per hectare) with a plant spacing of 23 cm  $\times$  23 cm. On the contrary, under the SRI practice, rice transplanted at a spacing of 25 cm  $\times$  25 cm yields higher as compared to 30 cm  $\times$  30 cm and 35 cm  $\times$  35 cm (Reuben et al., 2016). Estorninos & Moody (1976) reported that yield loss from weeds is least with a spacing of 15 cm  $\times$  15 cm (19%) as compared to 25 cm  $\times$  25 cm (52%) and 20 cm  $\times$  20 cm (29%). China's rice planting agronomy recommends 30 cm row spacing and 13 cm plant spacing in paddy fields (Tian et al., 2022). Thus, in this study, a plant spacing of 20 cm  $\times$  20 cm was considered for tracing the path of the intra-row weeding unit and its rotor blades. The rotor with blades

was intended to be 160 cm wide, allowing it to travel between the rows without disturbing the plants. Furthermore, as the intra-row weeding units were designed to travel in a sinusoidal path, the width was kept at 80 cm, which is fairly adequate for passing through the plants in between the intra-row zones.

#### 4.9 Motion analysis of the inter-row weeding unit

The inter-row weeding device makes a circular motion around the axis and a uniform linear motion along the forward direction with the weeder when powered by the IC engine. The motion of the inter-row weeding device can be characterized by a combination of uniform linear and uniform circular motion around the axis.

As illustrated in Figure 4.23, the rotating radius of the blade is  $R$ , the rotation angular velocity is  $\omega$ , and the weeder's forward speed is  $V_m$ . The coordinate system's origin is set to the initial rotation center of the inter-row weeding device, the weeder's forward direction is X-axis positive, and the vertical downward direction is Y-axis positive. When the initial position of point P coincides with the x-axis, point P being the endpoint of the blade, the coordinate of point P at any time is:

$$\begin{cases} X = V_m t + R \cos \omega t \\ Y = R \sin \omega t \end{cases} \quad (14)$$

where  $R$  is the radius of the working set, mm;  $V_m$  is the weeder's forward speed,  $m \cdot s^{-1}$ ;  $\omega$  is the rotation angular velocity of the weeder,  $rad \cdot s^{-1}$ ;  $t$  is the weeder's operating time, s. The rotational speed of the end point P of the blade is

$$\begin{cases} V_x = \frac{dx}{dt} = V_m - R\omega \sin \omega t \\ V_y = \frac{dy}{dt} = R\omega \cos \omega t \end{cases} \quad (15)$$

The instantaneous speed of point P is,

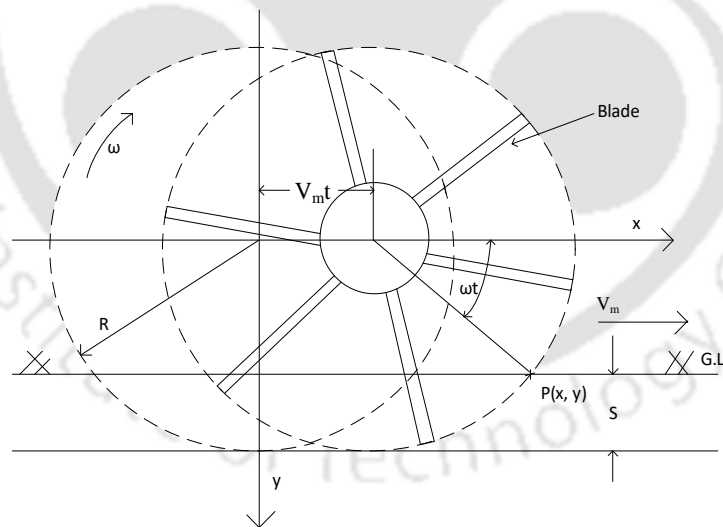
$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{v_m^2 + R^2\omega^2 - 2v_mR\omega\sin\omega t} \quad (16)$$

Let  $\gamma$  denote the weeding speed ratio, that is  $\gamma = \frac{v_p}{v_m}$ , where  $v_p = \omega R$  is the circumferential speed of the weeding device. Therefore,  $\gamma = \frac{\omega R}{v_m}$ .

By substituting the value of  $\gamma$  in equation (15),

$$v_x = v_m(1 - \gamma \sin\omega t) \quad (17)$$

Since,  $\sin\omega t \leq 1$ ,  $v_x \geq 0$  is constant when  $\gamma \leq 1$  that is, the forward speed of the weeding rake tooth's endpoint will always be greater than zero, and the weeding rake tooth pushes forward throughout the operation. When  $\gamma > 1$ , the endpoint of the rake teeth moves to some other position, and thus,  $v_x < 0$ , and hence, the rake teeth press the soil backward. The value of  $\gamma$  has a direct impact on the weeding rake teeth' movement track in the soil and the condition of operation of the weeding equipment.



**Figure 4.23 Schematic analysis of the movement of the rotor blades**

$R$  is the rotation radius of the weeder, mm;  $\omega$  is the rotation angular velocity of the weeder, rad/s;  $V_m$  is the forward speed of the weeding device,  $m.s^{-1}$ ;  $t$  is the time of operating, s;  $S$  is the depth of operation, mm; G.L. indicates the ground level.

#### 4.10 Motion analysis of the intra-row weeding unit

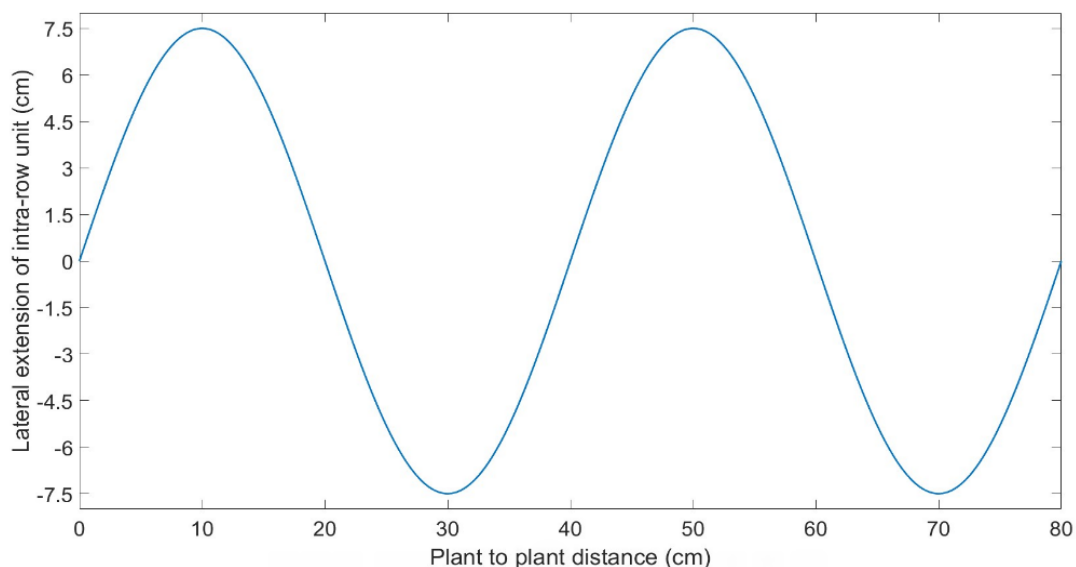
The intra-row weeding unit's primary objective is to travel around the paddy plant without interfering with it. Thus, the weeds around paddy plants in an intra-row zone are eradicated and uprooted. A sinusoidal wave curve (Figure 4.24) was traced by an intra-row unit during operation. In this study, a check row planting of  $200 \times 200$  mm plant-to-plant and row row-to-row spacing was considered. Thus, the paddy plants are supposed to be located at the coordinates, (10,0); (30,0); (50,0); (70,0), etc, which maintains a gap of 20 cm in between them. A schematic diagram representing the field plot is given in Figure 4.25. The plotted curve of the intra-row unit path is depicted below which follows the equation as

$$y(x) = y_0 \times \sin\left(2 \times \pi \times \frac{x}{20}\right) \quad (18)$$

where,  $y$  = lateral extension of intra-row unit, cm

$y_0$  = half of the lateral extension of the intra-row unit, cm

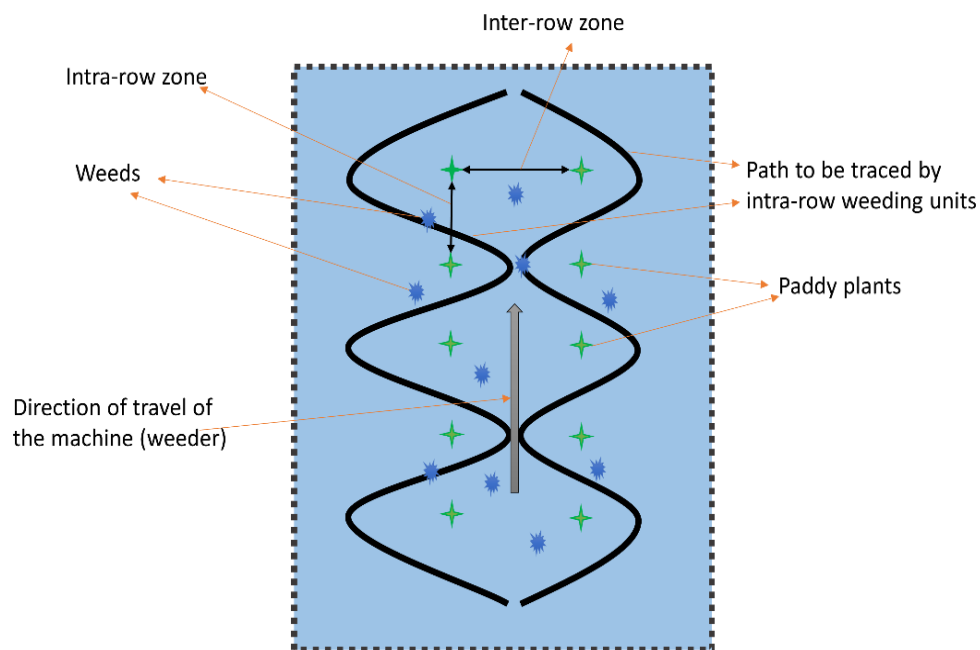
$x$  = plant to plant distance, cm



**Figure 4.24 Path traced by an intra-row weeding unit**

#### 4.11 Assumptions and limitations

1. The row-to-row and hill-to-hill spacing of the paddy was assumed to be planted maintaining an equal distance i.e.,  $200 \times 200$  mm. In reality, it would be difficult to maintain a constant spacing of the paddy plant during planting. However, the machine was designed in such a way that it is flexible to handle some variability up to some extent.
2. The travel speed of the machine was assumed to be constant as per the simulation travelling at 1.5 km/h.
3. The tyne/spikes movements of the intra-row weeding unit were considered moving in a perfect sinusoidal curve without any obstacles such as rocks. This condition made it easier to model.
4. The operating depth of the weeder was assumed to work at 50 mm.



**Figure 4.25 Schematic diagram depicting the field plot**

## 4.12 Conclusions

A novel mechanism aimed at eliminating weeds in both inter-row and intra-row zones has been introduced. The study involved a strength analysis of various machine components, including circular discs, rectangular links, trapezoidal and lateral plates, a sliding rod, L-type blades, and the shank of the intra-row weeding units. Power for the mechanism is supplied by an internal combustion engine, and the functions of each component were detailed. The components were designed and assembled using SolidWorks, followed by a simulation of the 3-D model to assess the effectiveness of the design in producing the necessary output motion.

The proposed weed eradication mechanism shows promise through its comprehensive design and strength analysis of critical components. By utilizing SolidWorks for modeling and simulation, the project ensures that each part operates effectively within the system. This innovative approach could enhance weed management practices, contributing to more efficient agricultural operations. The development and laboratory testing of the designed weeder are presented in the next chapter (**Chapter Five**).

## CHAPTER FIVE

### 5 Development of inter cum intra-row weeder

#### 5.1 Introduction

The fabrication process of a weeder is a complex endeavor that involves the assembly and integration of various components aimed at optimizing its performance in agricultural fields. At the core of this process lies the design and construction of the major components necessary for the functioning of the weeder. These components include a prime mover, circular disk, rectangular link, trapezoidal plate, lateral plates, sliding rod, shank attachment for intra unit, cutting blades, and float (sleigh). Each component plays a crucial role in the overall operation of the weeder, contributing to its efficiency and effectiveness in weed management.

The selection and acquisition of the required materials and components constitute the initial stage of the fabrication process. Selecting a suitable internal combustion (IC) engine to act as the primary mover is part of this. The weeder's power source is the IC engine, which supplies the energy needed to run its numerous moving parts and carry out its essential field duties. To guarantee optimum performance, careful analysis must be given to the IC engine's power output in providing the desired motion, and suitability for the other weeder parts.

#### 5.2 Fabrication of various components

The fabrication of various components for the designed weeder is a critical process that encompasses several stages and considerations. This weeder is aimed at improving the efficiency of intra-row weeding, which is essential for enhancing crop yield and reducing competition from unwanted plants. The materials selected for the prototype construction predominantly consist of mild steel (MS), which is favored for its strength, malleability, and cost-effectiveness. The choice of mild steel also extends to various structural forms, including channel types, angle bars, square tubes, rectangular sections, circular discs, and MS flats, which serve multiple functions within the weeder's design, such as providing structural support and facilitating specific movements.

A pivotal aspect of the weeder's design involves the trapezoidal and lateral plates, which are integral to its lateral motion capabilities. The design of these plates was driven by the need for

effective intra-row weeding, allowing the weeder to navigate closely alongside the crops without causing damage. The design parameters for the trapezoidal plate are crucial; specifically, the angle of inclination on both sides and the lengths of the sides were carefully calculated. These factors directly influence the amount of lateral extension the weeder can achieve, thereby determining its overall efficacy in removing weeds between rows of crops.

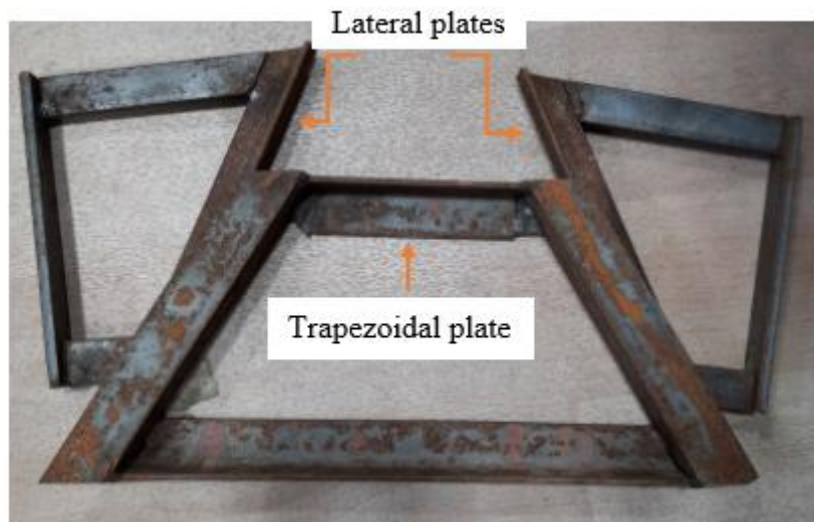
Initially, a straightforward structure for the trapezoidal and lateral plates was created using MS angle bars and rectangular sections. This early prototype aimed to explore the basic functionality and applicability of the design in real-world conditions (as illustrated in Figure 5.1). However, after thorough observation, it became evident that the lack of precise tolerances and smooth surfaces on these plates may led to significant resistance during operation. Such resistance could hinder the weeder's performance, making it less effective at efficiently displacing weeds.

Recognizing these challenges, subsequent fabrication efforts focused on refining the design and enhancing the manufacturing processes. The trapezoidal plates were subjected to various machining techniques, including wire electric discharge machining (wire EDM), which allows for greater precision and smoother finishes (as seen in Figure 5.2). This advanced machining technique is particularly advantageous for creating intricate designs and achieving the tight tolerances necessary for reducing friction during the weeder's operation.

In addition to enhancing the design, specific modifications were made to facilitate smoother movement. A rectangular groove was incorporated on both sides of the trapezoidal plates, enabling the lateral plates to slide freely during operation. This design adjustment is crucial, as it significantly reduces the friction and resistance experienced by the weeder while in motion, allowing for more efficient weeding. The combination of improved material choice, precise machining, and thoughtful design changes culminates in a prototype that not only meets functional requirements but also enhances operational efficiency.

Overall, the meticulous approach taken in the fabrication of the weeder's components highlights the importance of precision engineering in agricultural tools. The careful consideration of material properties, design parameters, and machining techniques demonstrates a comprehensive understanding of the challenges faced in intra-row weeding and reflects a commitment to developing effective solutions that can lead to better agricultural practices. As this prototype undergoes further testing and refinement, it holds the promise of

significantly improving the effectiveness of weeding in crop production, thereby contributing to more sustainable farming practices.



**Figure 5.1 A typical structure of trapezoidal and lateral plates**



**Figure 5.2 Trapezoidal and lateral plates fabricated with sliding grooves**

To enhance the overall efficiency and functionality of the weeder prototype, significant modifications were made to the design of the trapezoidal and lateral plates. One of the primary considerations was the weight of these components. Initially constructed from heavy-weight materials, the trapezoidal and lateral plates contributed significantly to the overall mass of the

machine, which could negatively impact maneuverability and ease of operation. To address this issue, strategic cutouts were made in the middle portion of both the trapezoidal and lateral plates. This innovative approach effectively reduced the weight of the machine without compromising the structural integrity required for efficient weeding.

The decision to cut out sections from these plates was not merely about weight reduction; it also aimed to enhance the machine's balance and stability during operation. A lighter machine is not only easier to handle but can also move more freely through rows of crops, minimizing the risk of damaging plants while maximizing the effectiveness of the weeding process. By decreasing the bulk of the plates, the design could achieve a more agile prototype that could better navigate tight spaces between rows, which is crucial for intra-row weeding.

Despite the initial success in reducing weight, it became clear that the trapezoidal plates still retained considerable mass due to their thick frame design. Consequently, a further redesign was undertaken, wherein the trapezoidal plates were replaced with a simpler MS rectangular section frame. This adjustment provided a substantial reduction in weight while maintaining adequate strength and stability, thus optimizing the overall design of the weeder. The rectangular frame is inherently lighter than the original trapezoidal structure, allowing for improved performance without sacrificing functionality.

In addition to the modifications in the plates, the integration of a linear guide system significantly enhanced the operational efficiency of the weeder. This system comprises bearings and a slider rod, which work in concert to facilitate smooth and precise lateral movement of the machine. By employing this linear guide arrangement, the weeder can glide more effortlessly during operation, thereby reducing friction and wear on the components. The addition of lubrication, including grease and oil, further contributes to the smoothness and quietness of the machine's motion. This attention to detail ensures that the weeder operates efficiently and quietly, which can be particularly advantageous in agricultural settings where noise reduction is desirable.

The culmination of these design improvements and modifications led to a refined arrangement that was ultimately used in the final prototyping stage of the machine. This stage is crucial as it incorporates all the lessons learned from previous iterations and testing, allowing for a comprehensive evaluation of the weeder's performance. By focusing on weight reduction, structural efficiency, and operational smoothness, the design team aimed to create a prototype

that meets the demands of modern agriculture while ensuring ease of use and effectiveness in weed management.

In summary, the thoughtful approach taken in modifying the trapezoidal and lateral plates, alongside the implementation of a linear guide system, illustrates a commitment to optimizing the weeder's design for better performance. These enhancements not only contribute to a more lightweight and agile machine but also ensure that it operates smoothly and efficiently, which is essential for achieving the desired outcomes in agricultural practices. As the weeder advances through the prototyping phase, these innovations position it as a valuable tool in the pursuit of sustainable and effective farming solutions.



**Figure 5.3 Photograph of the prototype during the assembly stage**

### 5.3 Problems encountered during the fabrication process

In the development of the weeder prototype, several challenges, particularly concerning the precise dimensions of various components occurred. While minor issues related to measurements were manageable, a more significant concern arose regarding the attachment of the trapezoidal and lateral plates to the frame of the machine. The trapezoidal plate needed to be securely positioned yet capable of reciprocating back and forth during operation. This movement is essential for providing the proper motion of the adjoining components.

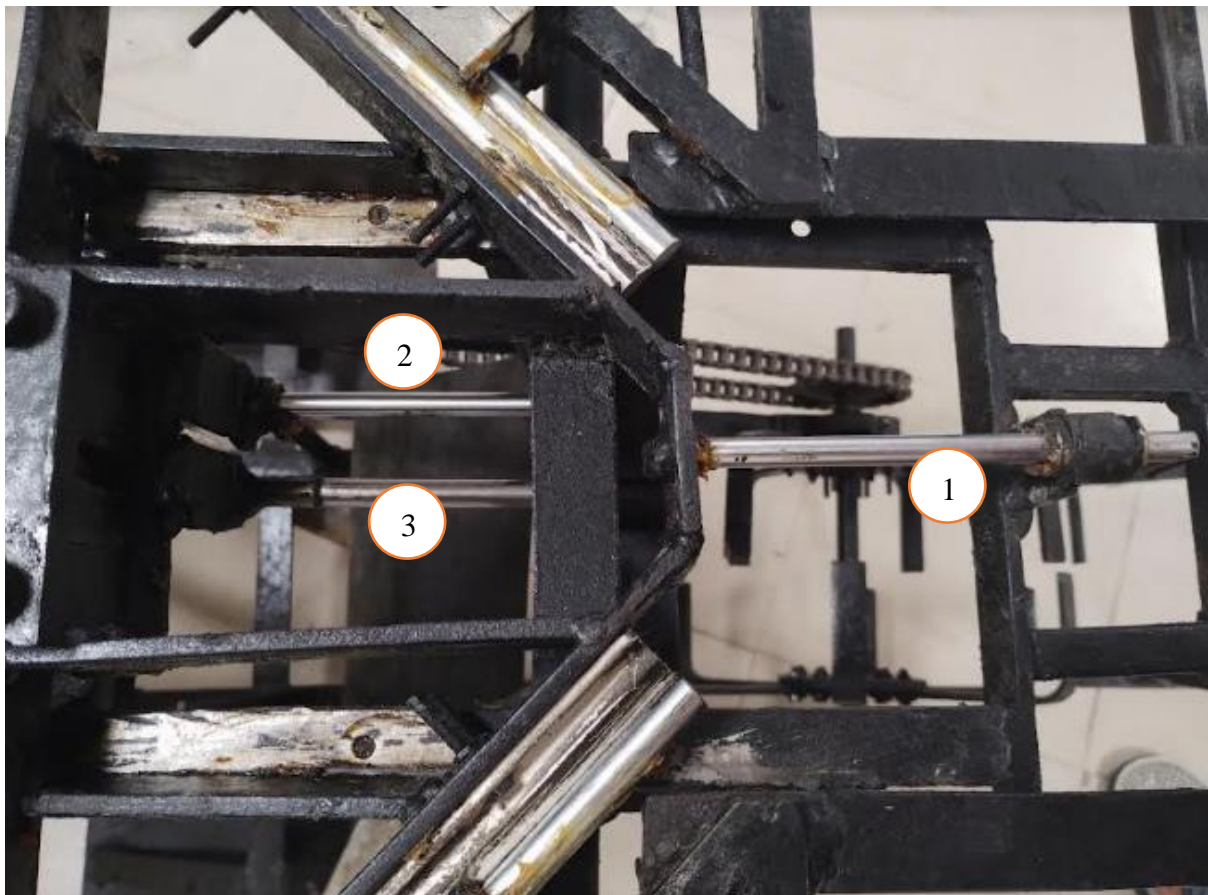
To address this need, a pair of mild steel (MS) channel sections was strategically placed beneath the trapezoidal plate. This design choice enabled the plate to slide smoothly forward and backward while maintaining stability. The incorporation of these channels ensured that the trapezoidal plate could operate effectively without excessive friction or resistance, thereby enhancing the machine's overall performance.

As the work progressed further, it became apparent that the trapezoidal plate needed to travel in a perfectly straight line. This requirement was critical for preventing any misalignment that could hinder the machine's functionality. If the trapezoidal plate deviated from its intended path, it could become wedged between the trapezoidal and the two lateral plates. Such a situation would not only obstruct the movement of the weeder but could also cause wear and tear on the components, leading to potential failure of the machine during operation.

To mitigate this risk, a linear guide system was implemented. Three linear guides were strategically installed in front of and below the trapezoidal plates, as shown in Figure 5.4. These guides play a pivotal role in facilitating smooth and straight-line motion for the trapezoidal plate. By providing a defined pathway, the linear guides prevent any lateral movement that could lead to entanglement or misalignment. This adjustment not only enhances the operational reliability of the weeder but also extends the lifespan of its components by reducing unnecessary wear.

The incorporation of linear guides is a significant engineering solution that exemplifies the attention to detail necessary in machinery design. By ensuring that the trapezoidal plate operates in a straight trajectory, the weeder can perform its intended function more efficiently, resulting in better weed control and improved crop yield. The overall design refinement reflects a deeper understanding of the mechanical dynamics at play in agricultural machinery, emphasizing the need for precision and reliability in the development process.

While the initial stages of the weeder prototype's design encountered challenges related to component dimensions and alignment, the strategic solutions of implementing linear guides have significantly improved the machine's functionality. As the prototype advances toward the final stages, this innovative arrangement of the trapezoidal plate and lateral plates lays the groundwork for a robust and efficient mechanism that meets the demands of modern agricultural weeding practices.



**Figure 5.4 Linear guides**

#### **5.4 Assembly of various components**

With the proper arrangement of the trapezoidal and lateral plates as discussed in the previous section, the assembly continues with the arrangement of a circular disk with the prime mover. A chain and sprocket system was used to connect the circular disk to the IC engine, making this operation easier. The engine can transfer its rotational motion to the disk through this

method, allowing the disk to revolve in the appropriate direction and at the desired speed while operating.

In addition to the circular disk, the fabrication process also involves the assembly of the rectangular link with the trapezoidal plate. These components are essential for connecting the circular disk to the lateral plates and providing stability and support during operation. The rectangular link serves as a linkage mechanism between the circular disk and the trapezoidal plate, while the trapezoidal plate acts as a mounting platform for the lateral plates and its associated bushing for lateral motion on the sliding rod.

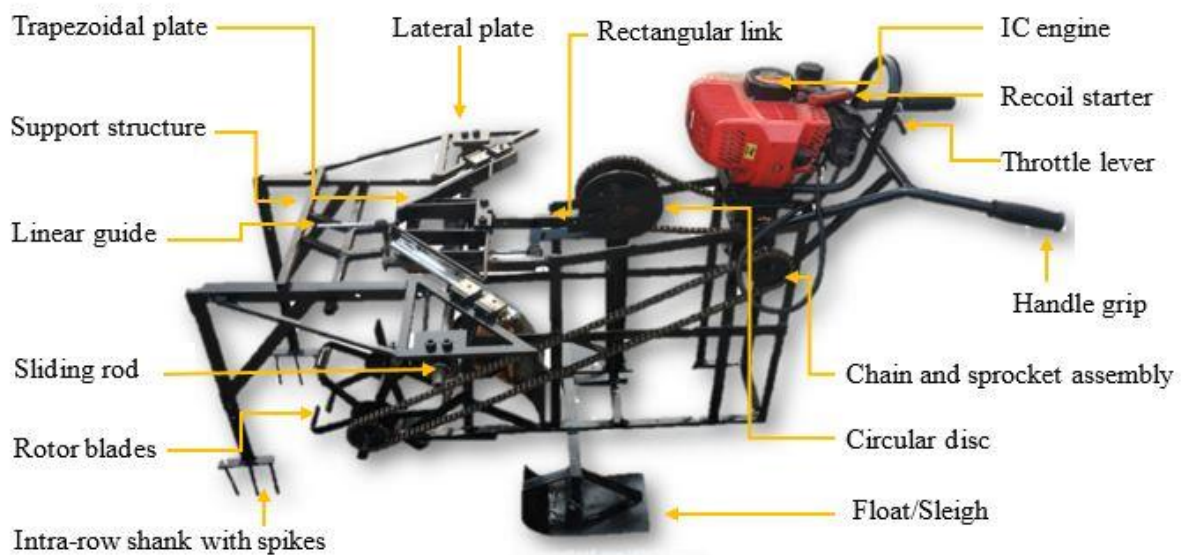
Another essential part of the weeder is the lateral plates, which support and direct the shank attachment used for intra-row weeding. They were fastened and grooved to the trapezoidal plate via a linear guide. The extension of the lateral plates was connected to the shank of the intra-row weeding unit.

In addition to the main components described above, the fabrication process also involves the assembly of other accessories and features designed to enhance the performance and functionality of the weeder. This includes the integration of a sliding rod mechanism with the two lateral plates as well as the incorporation of a float or sleigh attachment to ensure smooth operation over the muddy water. The fully developed model is shown in Figure 5.5 and Figure 5.6.

**Table 5.1** Specification of the engine

<b>Sl. No.</b>	<b>Particulars</b>	<b>values</b>
1.	Power, kW	1.7
2.	Displacement, cc	52
3.	Engine type	2 stroke
4.	Number of cylinders	1

5.	Fuel ratio	25:1
6.	Fuel type	Gasoline
7.	Fuel tank capacity	1.2 litres
8.	Starter type	Recoil starter



**Figure 5.5 Isometric view of the fabricated prototype**

### 5.5 Laboratory testing of the developed model

After every component of the manufactured weeder has been carefully assembled and integrated, the device enters a crucial phase of rigorous testing within the workshop environment. This comprehensive evaluation is essential to ensure that the weeder meets all specified requirements in providing the desired motion.



**Figure 5.6 Top view of the prototype**

As the testing progresses, any discrepancies or shortcomings identified are promptly addressed through necessary alterations or adjustments. This involves fine-tuning various mechanical components and their associated features. The goal is to optimize its functionality, ensuring that it operates seamlessly in real-world agricultural settings.

The testing phase also serves as a verification process, confirming that each component of the weeder works harmoniously in accordance with the original design specifications. The outcomes are found to be satisfactory, instilling confidence that the weeder is ready for practical use and capable of meeting the demands of modern farming. This thorough approach underscores the commitment to quality and innovation in agricultural technology particularly for weeding purposes.

## **5.6 Conclusions**

In conclusion, a specialized weeder designed for both inter-row and intra-row weeding in wetland paddy cultivation has been successfully developed. The weeder's design features

several key components aimed at improving efficiency and effectiveness in weed removal. The main structure consists of a circular disc, a rectangular link, a trapezoidal plate, two lateral plates, a rotor fitted with L-type blades, floats, and an IC engine as a source of power. The trapezoidal plate is equipped with two lateral plates on either side, which are extended to handle intra-row weeding, allowing the device to target weeds within the crop rows without damaging the plants. Additionally, an L-type blade is mounted on the rotor specifically for inter-row weeding, effectively clearing weeds between crop rows.

The weeder underwent lab testing to ensure the proper functionality of each component. These tests were conducted to evaluate the durability, precision, and performance of the weeder during operation. The results showed that all components worked as expected, meeting the design objectives. The satisfactory lab performance indicates that this weeder could be a reliable and efficient tool for farmers engaged in wetland paddy cultivation, providing a practical solution for both inter and intra-row weed management.



## CHAPTER SIX

### 6 Summary and conclusions

#### 6.1 Summary

In India, the development and utilization of various types of paddy weeders have significantly contributed to enhancing agricultural productivity, particularly in both dry and wetland conditions. In wetland paddy cultivation, several types of weeders have been widely adopted to address the challenges posed by weed infestation. Among these, the rotary power weeder, cono-weeder, and Ambika weeder stand out as commonly utilized tools. Each of these implements offers distinct advantages tailored to the specific requirements of wetland rice cultivation, providing farmers with effective solutions for weed management.

The rotary power weeder represents a notable innovation in mechanized weed control, offering efficient and versatile operation in wetland conditions. Its rotating blades effectively cut through weeds while minimizing damage to the rice crop, thereby ensuring optimal weed control without compromising crop health. This weeder's adaptability to varying field conditions and its ability to cover large areas efficiently make it a preferred choice for many farmers engaged in wetland paddy cultivation.

Similarly, the cono-weeder has gained popularity for its effectiveness in weed removal while promoting soil aeration and moisture retention. Its cone-shaped weeding attachment allows for precise and targeted weed removal, minimizing disturbance to the surrounding rice plants. By maintaining a healthy soil environment and reducing competition from weeds, the cono-weeder contributes to improved crop growth and yield in wetland rice fields.

The Ambika weeder, another widely used implement, offers a combination of reliability and affordability, making it accessible to a wide range of farmers across India. Its simple yet effective design enables efficient weed removal while minimizing labor requirements, thereby reducing the overall cost of weed control operations. The Ambika weeder's ease of use and maintenance further enhance its appeal to farmers seeking practical solutions for weed management in wetland paddy fields.

Among the various types of paddy weeders, the two-row power-operated rotary weeder stands out as a common and effective tool, particularly in wetland cultivation scenarios. With a field

capacity of 0.0793 ha/h, this weeder offers a balance between efficiency and operational speed, enabling farmers to cover significant areas within a reasonable timeframe. Moreover, its power-operated design reduces the physical strain on operators, thereby enhancing productivity and work efficiency in weed control operations.

Despite the effectiveness of existing paddy weeders, challenges persist in terms of cost and weeding efficiency. The average cost of operation for these weeders is reported at Rs. 1,668.04/ha, highlighting the financial burden associated with mechanized weed control. Additionally, while the weeding efficiency of existing paddy weeders is commendable at 79.92%, there is room for improvement to further optimize weed management practices and minimize yield losses attributable to weed competition.

The development and utilization of various types of paddy weeders have revolutionized weed management practices in both dry and wetland rice cultivation in India. By offering efficient, cost-effective, and environmentally sustainable solutions, these implements play a crucial role in enhancing agricultural productivity and livelihoods for farmers across the country. However, continuous research and innovation are needed to address existing challenges and further improve the efficiency and effectiveness of paddy weeders in meeting the evolving needs of Indian agriculture.

Efforts have been focused on innovation because existing weeders have limitations. A potential answer is the 'Roller Rake Weeder,' which consists of a roller with spikes to engage the soil and a stationary rake. The purpose of this suggested substitute is to rectify the inadequacies of the current weeders and provide a more effective and useful option. Promising results from testing the "Roller Rake Weeder" showed a field capacity of between 0.038 and 0.04 ha/h and weeding effectiveness ranging from 88.5% to 95.4%. These numbers indicate the possibility for major advancements in weed control techniques, as they outperform the performance of weeders that are now controlled manually. The introduction of the Roller Rake Weeder represents a notable advancement in agricultural technology, promising to revolutionize weed management strategies. By offering enhanced efficiency and productivity, this innovative weeder addresses the pressing need for sustainable and cost-effective solutions in weed control. Furthermore, its compatibility with diverse agricultural landscapes, including rural and hilly regions, makes it a valuable asset for small-scale farmers facing resource constraints. Beyond its immediate benefits, the 'Roller Rake Weeder' signifies a broader shift toward mechanization and innovation in agriculture. As traditional labor-intensive practices become

increasingly unsustainable, technological advancements offer a path toward greater efficiency and productivity. By harnessing the potential of mechanized weed control methods, farmers can optimize resource utilization and improve overall agricultural output. However, the successful adoption of the 'Roller Rake Weeder' hinges on several factors, including affordability, accessibility, and ease of use. Addressing these challenges will require concerted efforts from stakeholders across the agricultural sector, including policymakers, researchers, and agricultural extension services. By fostering collaboration and investment in innovative technologies, the agricultural community can unlock the full potential of mechanized weed control and pave the way for a more sustainable and productive future.

While numerous inter-row weeders have been developed and commercialized, research on intra-row weeding, particularly in wetland paddy cultivation, remains limited. Therefore, this study assesses various intra-row weeders, identifies their limitations, and proposes a conceptual weeder capable of effectively eliminating weeds in both inter and intra-row areas, specifically tailored for wetland paddy fields. The research synthesizes and examines recent advancements in intra-row weeders, encompassing tractor-operated finger weeders, torsion weeders, ECO weeders, brush weeders, and sensor-driven devices designed for controlling intra-row weeds. Additionally, the study underscores the significance of uniform crop planting, particularly in paddy fields, to facilitate efficient operation during the weeding process. Despite the development of several intra-row weeders, only a limited number have been practically implemented. As a result, ongoing efforts are dedicated to developing intra-row weeders specifically tailored for wetland paddy cultivation. The study meticulously evaluates the performance parameters of various intra-row weeders, aiming to identify strengths and weaknesses in their design and functionality. Drawing from this analysis, a conceptual design for a versatile weeder capable of effectively targeting weeds in both inter and intra-row areas within wetland paddy fields has been proposed. This conceptual design integrates insights from existing intra-row weeders while addressing the unique challenges posed by wetland paddy cultivation. Key considerations in the design process include ensuring adaptability to the varying terrain and soil conditions encountered in wetland paddy fields, as well as optimizing the weeder's efficiency and ease of operation. By addressing these factors, the proposed weeder aims to streamline weed control efforts in wetland paddy cultivation, ultimately enhancing crop yields and reducing labor requirements. Overall, this study fills a critical gap in research by focusing on intra-row weeders for wetland paddy cultivation, an area that has received limited attention in existing literature. Through comprehensive analysis and innovative design

proposals, this research contributes to the advancement of weed control technologies tailored to the specific needs of wetland paddy farmers, promoting sustainable agricultural practices and improving overall productivity in the sector. The proposed design was fabricated in the workshop. Laboratory testing shows that all the components function satisfactorily as per the design.

## 6.2 Conclusions

The following conclusions can be drawn from this research.

1. Although the northeastern region states of India have low farm power availability (0.63 kW/ha) which is below the national average of 2.205 kW/ha, there is still room for improving the farm power availability with the application of small hand tools and equipment in hilly terrain region. The need to create awareness of the utilization of farm machinery could enhance farm power availability.
2. The roller rake weeder (as discussed in Chapter 3) can be used effectively for weeding in wetland paddy cultivation. It is more convenient in hilly terrain conditions as it is a lightweight machine.
3. The efficiency of the roller rake weeder is higher as compared to similar existing tools (i.e., Cono weeder, Ambika weeder, etc.) as all the weeds that are left out by the roller are destroyed by the rake when it is pushed and pulled. While the other tools consist of only rollers with spikes/blades on the periphery.
4. There is a possibility that the intra-row weeds can be removed effectively without the use of sophisticated instruments like hydraulic systems, sensors cameras, etc, with the similarly developed weeder as discussed in Chapter 4 and Chapter 5.

## 6.3 Future scope of the work

The present study, in conjunction with the produced prototype, exhibits significant potential for further development towards the creation of a functional prototype intended for intra-row weeding in wetland paddy farming. Based on the experience gained from this research, a few improvements and modifications may be suggested to improve the usability of inter cum intra-row weeder.

1. A cage wheel/ground wheel can be attached at the rear end for better propelling during operation.
2. The performance of the prototype in terms of the lateral speed of the intra-row unit may be assessed using different settings such as travel speeds and different rotational speeds of the blades.
3. For the intra-row weeding unit, two vertical rotary shafts fitted with blades may be attached in place of fixed tynes of the shank. This could probably enhance the weeding efficiency of the machine.



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## Publications

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## Communicated manuscript

Sebastian, S., & Kalita, K. (2024). Challenges and Opportunities in Agricultural Mechanization in Northeastern India. *Agricultural Research Journal*. (**under review**)

Sebastian, S., & Kalita, K. (2024). Mechanization in Intra-Row Weeding: A Critical Review and Conceptual Design of Inter Cum Intra-Row Weeder for Wetland Paddy Cultivation. *Discover Agriculture*. (**under review**)

## Book chapter

Sebastian, S., Kalita, K. (2023). An Improved Gender-Friendly Paddy Weeder Suitable for Hill Agriculture. In: Patra, S., Mitra, S., Singha, S., Kalita, P. (eds) *Technologies for Rural Development*. NERC 2022. Springer, Singapore. [https://doi.org/10.1007/978-981-19-8513-3\\_7](https://doi.org/10.1007/978-981-19-8513-3_7)

Sebastian, S., Kalita, K. (2024). Kinematic Analysis of a Mechanism of an Integrated Inter and Intra Row Paddy Field Weeder Using Solidworks. *Research and Industrial Conclave-*

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### **Conference (Proceedings)**

Sebastian, S., Kalita, K. (2022). A modified gender-friendly paddy weeder suitable for hill agriculture. *North East Research Conclave (NERC 2022)*, IIT Guwahati (**Oral Presentation**)

Sebastian, S., & Kalita, K. (2023). Design and finite element analysis of paddy field weeder blade suitable for wetland cultivation. *57<sup>th</sup> Annual Convention of Indian Society of Agricultural Engineers on Agri-Food Systems' Transformation through Engineering Innovations and International Symposium on Engineering Interventions for Making Millets a Global Food* during 6<sup>th</sup> to 8<sup>th</sup> November 2023, UAS Raichur, Karnataka (**Oral Presentation**).

Sebastian, S., Kalita, K. (2024). Design and performance evaluation of Roller Rake Weeder. *Research and Industrial Conclave-Integration'24* organized by Students' Academic Board, IIT Guwahati & Research Park, IIT Guwahati (**Best Poster Award**).

Sebastian, S., Kalita, K. (2024). Design and Kinematic Analysis of Inter Cum Intra-row Paddy Field Weeder. *Research and Industrial Conclave-Integration'24* organized by Students' Academic Board, IIT Guwahati & Research Park, IIT Guwahati (**Oral Presentation**).

### **Patents**

1. Inter Cum Intra Row Paddy Weeder For Wetland Cultivation. Application Number: 202331034628; Status: **Granted** 30.04.2024; Patent Number: **536164**
2. Apparatus for Weed Extraction. Application No. 202131026647. Status: Published, **FER filed**

**Cover page of the test report (Roller Rake Weeder)**

Report No: CAEPHT/04/2023

December, 2023

**Confidential Test Report**



**Roller rake Weeder (Manually Operated)  
(Prototype)**

Tested at



**Farm Machinery Testing Center**  
**College of Agricultural Engineering and Post-Harvest Technology**  
**(Central Agricultural University Imphal), Ranipool-737135, East Sikkim**  
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