

**DEVELOPMENT AND EVALUATION OF SEMI
AUTOMATIC INTER AND INTRA ROW WEEDER
FOR WIDER ROW SPACED CROPS**

**BY
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2021**

DECLARATION

I, **Mr. ARIGELA KISHORE**, hereby declare that the thesis entitled **“DEVELOPMENT AND EVALUATION OF SEMI AUTOMATIC INTER AND INTRA ROW WEEDER FOR WIDER ROW SPACED CROPS”** submitted to the **Acharya N.G. Ranga Agricultural University** for the degree of **Master of Technology in Agricultural Engineering** in the major field of **Farm Machinery and Power Engineering** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

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CERTIFICATE

Mr. A. KISHORE has satisfactorily prosecuted the course of research and that the thesis entitled **“DEVELOPMENT AND EVALUATION OF SEMI AUTOMATIC INTER AND INTRA ROW WEEDER FOR WIDER ROW SPACED CROPS”** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any university.

Date:

Chairperson

CERTIFICATE

This is to certify that the thesis entitled “**DEVELOPMENT AND EVALUATION OF SEMI AUTOMATIC INTER AND INTRA ROW WEEDER FOR WIDER ROW SPACED CROPS**” submitted in partial fulfilment of the requirements for the degree of “**Master of Technology in Agricultural Engineering**” in the major field of “**Farm machinery and power Engineering**” of the Acharya N. G. Ranga Agricultural University, Lam, Guntur is a record of the bonafide original research work carried out by **Mr. ARIGELA KISHORE** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

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LIST OF SYMBOLS AND ABBREVIATIONS

Unless otherwise stated, the abbreviations and symbols in the text shall have the following meaning

%	=	Per cent
°C	=	Degree Celsius
°	=	Degrees
&	=	And
/	=	Per
Rs.	=	Indian currency rupée
cm	=	Centimeter
DAS	=	Days after sowing
DAT	=	Days after transplanting
Db	=	Dry basis
DSR	=	Direct seeded rice
<i>et al.</i> ,	=	and others people
<i>etc.</i> ,	=	and so on
Fig.	=	Figure
g	=	Gram
h	=	hour
ha	=	hectare
HP	=	Horse Power
HW	=	Hand weeding
<i>i.e.</i> ,	=	That is
kg	=	Kilogram
kg ha ⁻¹	=	Kilo gram per hectare
kN	=	Kilo Newton
kW	=	Kilo Watt
l	=	Litre
M ha	=	Million hectare

MJ	=	Mega Joules
MJ ha ⁻¹	=	Mega Joule per hectare
MPa	=	Mega Pascal
MT	=	Million tonnes
m ²	=	Meter square
mm	=	millimetre
N	=	Newton
No.	=	Number
q	=	Quintal
RPM	=	Revolutions per minute
t	=	Tonne
vs.	=	Against
yr	=	year

ABSTRACT

Name of the Author : **ARIGELA KISHORE**
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Weeds are unwanted and undesirable plants which interfere with the utilization of land and water resources and thus adversely affect crop growth. They can also be referred as plants out of place. Weeds compete with the beneficial and desired vegetation in crop lands, forests, aquatic systems etc. Weeding is an essential requirement to enhance crop growth. Handling the weeds nearby crop plants needs more attention and operation of machine is difficult along with crop. Hence, it is weeds grow mostly carried at present by engaging manual labor and become a labor intensive agricultural operation. Weeding accounts for about 25 % of the total labour requirement during a cultivation season. Whereas on the other hand machines can perform weed control when the crops are well-rooted, because if the intra-row weeders mentioned above have contact with the crops, the crops will not be damaged. This requirement causes a difficulty in controlling weeds at very early planting stage.

The crop parameters those influence the weeding operation are row to row spacing, intra row spacing between the plants and also the crop physical parameters. Generally, the row to row spacing in wider spaced crops varies from 60 to 90 cm or 60 to 120 cm. while plant to plant spacing varies from 30 to 60 cm. The height of the plant, number of branches and crop canopy varies at different stages of weeding also influence the design of the weeding machine. Clearance required between the rows and also from ground to chassis of the power source, in case of power operated weeding equipment also effect the weeding efficiency. The height of the plant as well as the canopy of the plant at different stages are to be taken into consideration to improve weeding efficiency and to reduce the plant damage, particularly, while working between the plants with in the row.

A study was therefore undertaken on “development and evaluation of semi-automatic inter and intra row weeder for wider row spaced crops” at Dr. NTR College of Agricultural Engineering, Bapatla. The tractor mounted implement was evaluated by varying forward speeds i.e., 0.6, 0.8 and 1.0 km h⁻¹ at constant RPM of 180, 220 and 290 respectively and 2, 4 and 6 cm depth of operation levels in chilli crop.

Lower weeding efficiencies were obtained at all depth of operation levels at forward speed of 0.6 km h⁻¹. The rate of increase in weeding efficiency was more when forward speed increased than increase in depth of operation. The weeding efficiency was almost constant for further increase of forward speed from 1.0 to 1.8 km h⁻¹. It was clear that the percentage of plant damage was zero or constant above 45 cm plant to plant distance. Below 45 cm plant to plant distance, the percentage of plant damage was found to be from 0 to 100 %. Draft increased with the increase in forward speed at all levels of depth of operation. It was observed that the field capacity increased with the increase of forward speed at all levels of depth of operation in all the crops both at 45 cm intra row spacing. It was observed that the fuel consumption was almost constant for further increase of forward speed from 1.0 to 1.8 km h⁻¹. Cost of operation with developed inter and intra row weeder was observed to be low when compared with traditional method of weeding operation. The saving in cost was about Rs. 5,220 ha⁻¹ over traditional method of weeding.

keywords: Semi-automatic, inter and intra row, depth, weeding efficiency, plant damage, draft, field capacity.

Chapter I

INTRODUCTION

Weeds are unwanted and undesirable plants which interfere with the utilization of land and water resources and thus adversely affect crop growth. They can also be referred as plants out of place. Weeds compete with the beneficial and desired vegetation in crop lands, forests, aquatic systems etc. and poses great problem in non-cropped areas like industrial sites, road/rail lines, air fields, landscape plantings, water tanks and water ways etc.,

Weeds are important factor in the management of all land and water resources, but their effect is greatest on agriculture. The losses caused by weeds exceed the losses caused by any other category of agricultural pests. Weeds account for 45% of total annual loss in agriculture when compared to insects (30%), disease (20%) and other pests (5%).

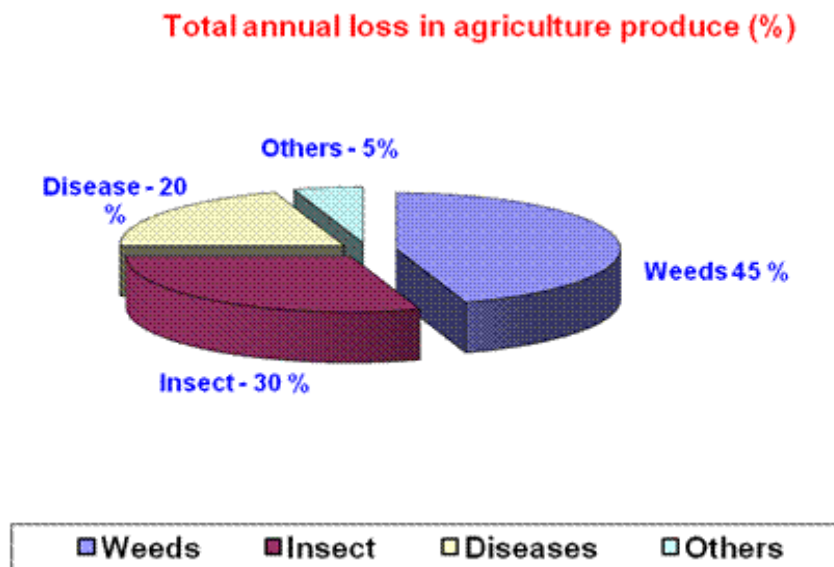


Fig 1.1: Total annual loss in agriculture produce (%)

Interest in using mechanical methods for weed control has increased rapidly during the last decade. Several countries in Europe have developed regional or national plans for reducing herbicide use in various crops or increasing the percentage of organic farms. To fulfil these goals several studies on mechanical weed control methods have been initiated, with the main focus on solving weed problems in row-grown crops.

Until recently, herbicides contributed 20 % to the total use of active ingredients in biocides and 40 % of the costs of biocides in the Netherlands. To reduce the risk of harming the environment, the farmer and the crop, and to reduce spending on herbicides and prevent the development of herbicide resistant or tolerant weed populations, the Dutch government defined various targets to be achieved before the year 2000 in its Long-term Plan on Crop Protection. These are reduction of the dependence on chemicals; systematic reduction of the use of chemicals by 50 % and a reduction of nematicides to 10-20 % of the amount applied in 1988. In response to this plan, a large variety of studies on the possibility of increasing the contribution of mechanical weed control were conducted by graduate students at the Tillage Laboratory of Wageningen Agricultural University during a five-year period. The research focused on various possibilities of increasing the area treated by intra-row mechanical weed control and guided tactile hoeing, combined with planting systems and with full width weeder harrows.

Weeding is an essential requirement to enhance crop growth but handling the weeds nearby crop plants needs more attention and difficult to operate as bulk because it grows along with crop. So, it is mostly carried out at present by engaging manual labor and become a labor intensive agricultural unit. Weeding accounts for about 25 per cent of the total labour requirement during a cultivation season (Basavaraj *et al.*, 2016).

To achieve high yield of crop, good agricultural practices are required. One of the most important practices is to properly manage the weeds. Weeds affect crop yield due to competition to acquire plant nutrients and resources (Slaughter *et al.*, 2008; Weide *et al.*, 2008). Weeds have very fast growth rates compared to crops, and if not treated and managed, they may dominate the field.

There are various methods for controlling weed infestation in crop production. Some farmers adopt agronomic practices that improve crop competitiveness such as planting vigorous crop seeds at relatively shallow depths and planting right after a weed control operation. This method is used to prevent the weed seeds from germinating before the crop is planted and to ensure that crop plants emerge before the weed plants. This practice will not only ensure a maximized crop yield and reduce weed infestation, but also minimize any economic losses (Maxwell and Donovan, 2007). The above practice should be applied for controlling weeds if the canopy closes and does not allow much light onto the ground surface where weeds will germinate and grow. However, weed control is still required during the crop production cycle.

Another weed control method that is practiced is to increase the crop density in the field. By filling the field with crops, weed seed germination rates are reduced (Blackshaw *et al.*, 2007). However, the distance between plants are reduced and might affect other field operations such as fertilizer spraying or harvesting. Weed management is a strategy that a desired plant population successful in a particular agro ecosystem using knowledge of the ecology of the undesired plants, that is the weeds (Ghersa *et al.*, 2000). The most effective method of weed management is by making physical contact with the weeds themselves, which is weed control.

Currently, there are several ways of controlling weeds, either of using manual, chemical, mechanical or biological means. The earliest and the simplest weed control method is manual weed control. This method was and is accomplished by a person bending down and using their hands to pull weeds out of the soil. This method then advanced to hand tools, from using a stick to using a hand-hoe. The labor required for weeding is expensive, time consuming and difficult to organize (Weide *et al.*, 2008). Gianessi and Reigner (2007) reported that manual labor costs have increased from Rupees 50/day in 1940s to Rupees 150/day in 1960s. As of 2015, the rate had further increased to rupees 450/day.

Furthermore, problems such as back pain due to frequent repetitive bending caused manual weed control to be avoided. In areas such as California, hoe weeding and hand weeding was banned due to permanent back damage in workers. Before the existence of chemical weed control, mechanical weed control was the best option to solve issues related to manual weeding. In mechanized agriculture, there were times when weeding tools were pulled by draft animals such as buffaloes and horses, which now in the developed world have generally been replaced by tractors. There are various types of mechanical weeding implements in the market that use three main techniques: burying weeds, cutting weeds and uprooting weeds. The burial of weeds through the action of tillage tools, and is usually done during land preparation. For cutting and uprooting weeds, there are two types of machinery available: inter-row weeders and intra-row weeders. Inter-row weeding is a weeding method that accomplishes between-planting row weeding, while intra-row does within-plant-row weeding.

Mechanical inter-row weeders such as inter-row cultivators, rotary cultivators and basket weeders are available in the market (Cloutier *et al.*, 2007). Inter-row cultivators and rotary cultivators are agriculture implements that consists of suspended cutting blades that perform weed control action. The basket weeder is an implement

consisting several rolling rectangular-shaped wires, forming a round basket. The efficacy of the weeding operation often depends on factors such as plant height, rooting depth and forward speed. More aggressive operations generally result in higher weed control efficacy, but often increase the risk of damaging crop plants.

There are also a wide range of mechanical intra-row weeders available. Cloutier *et al.* (2007) and Weide *et al.* (2008) reported the usage of finger weeders and torsion weeders. A finger weeder is a simple mechanical intra-row weeder that uses two sets of truncated steel cone wheels with rubber spikes, or 'fingers' that point horizontally outwards. Torsion weeders use flexible spring tines connected to a rigid frame and bent so that two short segments work close together and parallel to the work surface. They concluded that these machines will work effectively when precise and accurate steering is used. This was the reason for these weed attachments being integrated with precision cultivators. Furthermore, these machines can only perform weed control when the crops are well-rooted, because if the intra-row weeders mentioned above have contact with the crops, the crops will not be damaged. This requirement causes a difficulty in controlling weeds at very early planting stage.

One of the most promising technologies for intra-row weeding is the brush weeder. Cloutier *et al.* (2007) reported that the brushes of the brush weeders are made of fiberglass and are flexible. These brushes can be vertically-rotated or horizontally rotated. These weeders mainly uproot, but also bury and break weeds. A protective shield or cover can be installed to cover the crop from damage. An operator can also be added to steer the brushes to cultivate as close as possible to the crop but without damaging the crops.

In modern agricultural systems, chemical-based weed control is widely used. The implementation of conservation tillage practices to promote soil quality, to minimize soil erosion, or to simplify crop management has increased reliance on herbicides (Weaver *et al.*, 2007). The appearance of herbicides in the mid-20th century contributed to a decreased reliance on mechanical weeders (Cloutier *et al.*, 2007). Gianessi and Reigner (2007) reported that during those years, labor became scarce and more expensive especially after World War II.

Currently, however, it is becoming increasingly difficult to ignore the usage of herbicides in weed management because of its effectiveness to accomplish weed control and at the same time reduce yield loss. However, renewed interests in mechanical weeding have grown due to environmental concerns, the growing demand for pesticide free produce and also the growth of herbicide-resistant weeds (Upadhyaya & Blackshaw,

2007). Biological weed control is a weed control method using specialized herbivorous natural enemies of problematic plants in agricultural or natural environments (Blossey, 2007). Héraux *et al.* (2005) used allelochemical-releasing organisms to control weeds in transplanted vegetable fields. Hakansson (2003) also reported several well-known examples of biological control of weeds, such as the control of an Australian weed, prickly pear cactus using a moth that originated in South America. The biological approach has its success and failures and some inconsistencies make this method rarely practiced.

Advances in computers and sensors have contributed in the use of automation for agriculture machinery generally and for weeding machines specifically. With automation, the weeding is performed electronically which reduces human intervention and optimizes the power provided by the machine. Automated machines also offer the possibility to determine and differentiate crop from weeds and at the same time, remove the weeds with a precisely controlled device (Bakker, 2009). Several researchers have attempted to use automation for intra-row weed control. Tillett *et al.* (2008) tested an automated weeding machine using computer vision to detect plants and a rotating half circle disc for the weed control.

Astrand and Baerveldt (2002) developed an agricultural mobile robot using a perpendicular rotating weeding tool for weed control and two cameras – one near-infrared filter camera to locate crop row position and another color camera to identify crop plants were used. Cloutier *et al.* (2007) reported on the “Sarl Radis” hoe developed in France. This automated weeder used light interception for crop detection and a control system that controlled the lateral motion of a hoe relative to the crop row and around the crop plants. Griepentrog *et al.* (2006) developed an autonomous intra-row weeder based on RTK (Real-time Kinematics) GPS. This rotary weeder was controlled with an electrohydraulic motor system to power eight rotating tines that could be controlled individually to follow two different tine trajectories. This machine has the same concept as the brush weeder, using rotating tines or brushes to perform weed control. Automation should be the next step ahead for the rotating tine concept since it has produced very good weed control efficacy. In addition, automation can help reduce issues such as labor, human intervention and time consumption associated with manual weed control. Current automated weeding machines have not employed electrical power for the rotating tine weeding mechanism. Electronic control could provide more precise and reliable response with low maintenance.

The research documented in this thesis investigated inter and intra row weeding using a rotating tine weeding mechanism that was PTO powered. Different parameters that could affect weed control efficacy were studied. This research will be useful for researchers who would like to further investigate automated inter and intra row weed control. Crop growers can use the information in this thesis to identify the correct settings for intra-row weed control, specifically when using rotating tines mechanisms for weed removal. Agricultural machine manufacturers can also benefit from the research to produce better inter and intra row weeders.

To overcome the problems as discussed above, ‘development and evaluation of semi-automatic inter and intra row weeder for wider row spaced crops’ is necessary which has an advantage mechanical control of intra-row small weeds and those close to crop plants can be carried out successfully uprooting of weeds, and without damage to the crop.

Keeping these points in view, a research on development and evaluation of semi-automatic inter and intra row weeder for wider row spaced crops was taken up with the following objectives.

1.1 OBJECTIVES

1. To study the existing practices mechanical weeding both for inter and intra row weeding operations.
2. To develop semi-automatic, inter and intra row weeder for wider row spaced crops.
3. Performance evaluation of developed machine in wide row spaced crops.
4. To analyze cost economics of developed, inter and intra row weeder.

Chapter II

REVIEW OF LITERATURE

In this chapter, the comprehensive review of the research work carried out by different researchers relevant to the present study is presented and summarized in the following sub heading.

- 2.1 Types of weeding methods in India
- 2.2 Types of inter and intra weeders
- 2.3 Influence of parameters in design of inter and intra weeder
- 2.4 Effect of yield for wider row spaced crops
- 2.5 Performance evaluation of weeder in field conditions
- 2.6 Cost economics of developed weeder

2.1 TYPES OF WEEDING METHODS IN INDIA

Weed control methods are categorized into manual, animal drawn, mechanical, chemical and self-propelled weed controls. Each category has been summarized below particularly of chemical, manual and mechanical weed control methods.

2.1.1 Manual weeder

Khan and Diesto (1987) reported a push type cono-weeder which uproots and buries weeds in a single pass without requiring a back forth movement, especially suitable for rice. Manual weeding of rice in one hectare requires on an average of 120-man h. The cono weeder was about twice as far as to operate as that conventional rotary weeder.

Kumar *et al.* (2013) reported that two types of manual weeder cono-weeder and Mandava weeder for shallow water conditions and evaluated for different age group of workers 25 to 30, 30 to 35, and 35 to 40 years at different day timings T1 = 8.00 to 11.00 AM, T2 = 12.00 to 2.00 PM, and T3 = 4.00 to 6.00 PM. The weeding operations by different age group of workers at different working hours showed that the heart rates corresponding to cono-weeder and Mandava weeder were 154.54 beats/min and 140.17

beats/min, respectively. Oxygen consumption rate were 1.76 l/min and 1.47 l/min respectively. Working during 12:00 to 2:00 PM with both weeders developed maximum heart rate and oxygen consumption rate as compared to 8:00 to 11:00 AM and 4:00 to 6:00 PM. The study also revealed that, agricultural workers of 25 to 30 years age group developed maximum working heart rate and oxygen consumption rate, during weeding operations, which were higher than the age groups of 30 to 35 years and 35 to 40 years.

2.1.2 Animal Drawn Weeder

To control the weed by animal drawn technique many type of weeders have been developed depending upon the power source, soil type, and crop. These weeders generally cut, uproot and burry weeds.

Beeny and Khoo (1970) developed three blade shapes with different radius of curvature i.e., C-shape, I-shape and L-shape. They reduced the cutting force by reducing ratio of blade surface to contact with soil to volume and the soil cut by the blade. They also compared to the performance of optimized rotary blades are the basis of specific work. The specific work requirement of the L-shape blade was found comparatively higher than the other two types of blades in operating conditions.

Lukyanov (1978) studied the parameters of rotary tiller blades with the view of decreasing energy requirements. The design of the cutting blades mounting on the rotor should guarantee free movement in the soil being cut loose. It was found that decrease in the speed, angle of cutting length, and the forward face of the blade reduced energy requirements.

Sakai (1978) conducted rotary tools of rotary tiller was equivalent to share of moldboard plough and use of rational shape of rotary tool is indispensable for effective tillage. It was found that on the rotary tiller the external soil forces, i.e. driving forward force and lifting up force were presumed to be affected by the radial suction force of the blade. It was caused by the shape of the scoop surface of the blade and by the knife factor which depended upon the shape of knife edge.

Yadav and Anderson (1980) conducted study on the serrated blade for hoe and harrow, bullock drawn blade cum tine hoe for weeding and intercultural operations in dry land farming. The serrated blade of different size may be fitted in to the traditional blade hoe or blade harrow (bakhar). The serrated blades easily penetrated into the soil and help in moisture conservation.

Biswas *et al.* (1999) reported that animal drawn weeder worked between crop row spacing, the weeds left over a long rows might be removed manually. The straight blades in traditional hoes tend to remove weeds up to the working width of the blades. However, due to clogging of the straight edges, the output was adversely affected. So, they concluded there was need to study and use improved blades.

2.1.3 Chemical weeding

Chemical weed control was done by the use of herbicides. Selective herbicides kill certain targets while leaving the desired crop relatively unharmed. These act by interfering with the growth of the weed and are often based on plant hormones. Contact herbicides destroy only plant tissue that contacts the herbicide. Systemic herbicides are foliar-applied and move through the plant where they destroy a greater amount of tissue.

Singh and Tsuchiya (1982) found that the highest net return chemical weed control was obtained with two weeding done at 15 and 30 DAS of rice. When herbicide application was combined with hand weeding, the highest net return was obtained with thiobencarb at 2 kg ha⁻¹ followed by butachlor at 2 kg ha⁻¹ and thiobencarb at 1.5 kg ha⁻¹ each combined with one hand weeding at 45 DAS.

Biswas *et al.* (1984) reported that advanced countries had mostly switched over to chemical control. The use of chemicals for weed control was quite low in India. However, a large number of herbicides were now available to control different types of weeds in rice crop. The reasons for the limited use of herbicides in India were high-cost of herbicides, lack of knowledge on the available herbicides and most of the actions. Effective chemical weed control required different herbicides and management practices in various systems of rice cultivation.

Cheema *et al.* (2005) Conducted field trial in cotton crop with chemical, mechanical and manual methods for controlling weeds. Weed biomass was significantly reduced from 75 to 95 % in all the weed control treatments and seed cotton yield was increased by 46 to 61 %.

Channappagoudar and Biradar (2007) conducted experiments in soybean and red gram intercropping systems with fives pre-emergence herbicides and in combination with cultural practices inter cultivation and hand weeding along with the weed-free plot and

unweeded plot to control the weed. A significant reduction in the weed biomass was noticed by all the herbicides application plot over the unweeded control plot. The plant height of soybean was significantly highest in weed-free plots.

Khan *et al.* (2009) reported that potato plant growth in chemically treated weeding plots with manual weeding was significantly improved as compared to the growth in the unweeded plot. It was observed that all the weed management plots produced significantly improved marketable yield as compared to unweeded plots.

Nalini *et al.* (2011) conducted experiments in cotton crop to evaluate weed management practices with chemical weed control application of pre-emergence and early post-emergence herbicides, cultural practices mulching with straw and hand weeding once in twice and weed-free situation hand weeding 10 times of for unwanted weed control. A combination of manual and chemical weeding gave a higher seed cotton yield of 58 % compared to manual weeding treatment.

Hussain *et al.* (2013) conducted experiments in potato crop with a total of nine treatments including eight herbicides and an unweeded plot for comparison. The results revealed that all the herbicides had a significant effect on weed density and also on the tuber yield of potato. Herbicidal treatment significant reduced the weed population as compared to control treatments, with 104 weed. All the treatment resulted in more than 80 % mortality of weed that infested the field before the application of the herbicides. No crop injury was observed in any of the herbicides used in the experiment. The herbicides combination gave the highest potato tuber yield 15,910 kg/ha, which was 36% higher than the without herbicides treatment.

Chauhan *et al.* (2014) suggested that, in Asian countries, weed in rice, like unwanted plants like weed cultivated with rice, these plants produce damaged grains reduced rice yield from 16% to 74%.

Ali and Abdulai (2014) suggested that weed control was the biggest challenge to conservation agriculture adoption. Weed ecology and management was different in conservation agriculture than in conventional agriculture. In conservation agriculture, weeds expression, seed bank status, distribution, dispersal mechanisms, diversification, growing patterns, and competition trends were complex and differ from conventional systems. It was due to reduced tillage of the soil and the flora that thrives in conservation agriculture. Reduced tillage systems affect the efficacy of herbicides and mechanical

weed control measures. So, it was an important task to find out the differences and to formulate new management options.

2.1.4 Mechanical weed control

To control the weed mechanically many types of weeders have been developed depending upon power source, soil type, and crops. These weeders generally cut, bury or uproot weeds. The different types of weeding tools to be attached to the weeder have been developed by many researchers.

Biswas *et al.* (1984) reported that the control of weeds was the oldest method of weed control. It received less scientific attention as compared to the other methods of weed control. The tools and implements for mechanical weed control were mostly used. Mechanical control of weeds involves use weeders operated by humans, animal-drawn or tractor drawn weeders, self-propelled weeders or power weeders.

Quadri (2010) reported that the mechanical weeder was made of two implements attachment i.e. the primary cutting edge which was in front to loose soil above and the secondary cutting edge which was behind to do cutting and lifting of weeds. The weeding efficiency manually operated weeder on loamy soil was 81.14%, clay soil was 93.75% and sandy soil was 94.29%. The overall machine field efficiency was 98.67%.

Veerangouda *et al.* (2010) reported that weeding usually performed by manually with traditional hand tools Khurpi in upright bending posture inducing back pain for majority of labour and required considerable time. It was very costly and many times, availability of the required number of labour during peak season of the year was a problem. In India, diverse farm mechanization scenario prevails in the country due to varied size of the farm holdings and socio-economic disparities. At present, small capacity power weeder was available in market whose field capacity normally 0.07 ha h⁻¹.

Bhuvanewari and Chinnusamy (2010) conducted the field experiments in non-chemical weed management methods for organically grown maize and sunflower cropping system. Twin wheel hoe weeding at 20 DAS + hand weeding at 40 DAS registered the higher weed control efficiency in maize 92.4 and 93.5 % and in sunflower 91.9 and 94.7 % during 2007-2008 and 2008-2009, respectively. Higher yield was obtained with twin wheel hoe weeding at 20 DAS + hand weeding at 40 DAS in maize

58.2 and 61.8 % and sunflower 49.4 and 61.1 % over unweeded control during first and second year, respectively.

Chaudhary *et al.* (2011) reported that hand hoeing gave higher weed control, of 95.77 and 98.12 % of broad and narrow leave weeds, respectively and produced lowest weed dry matter 6.086 g cm⁻¹ crop. Significantly highest grain yield of 1,519.56 kg ha⁻¹ was obtained by hand hoeing with an increase in yield of 117.46 % over weeding. The weed gave lowest yield 698.78 kg ha⁻¹. The highest additional return of Rs. 41,247 ha⁻¹ with a cost benefit ratio (CBR) of 1:5.16 was obtained by hand hoeing twice.

Shiru (2011) designed, a push-pull type of mechanical manual weeder. The weeder consisted of main frame, handle, soil cutter (wedge), spikes, wheel bearing, bicycle chain and sprockets. It was quite simple and effective. Tests result showed a weeding index of 74.53%, efficiency of cutting blades of 88% and field capacity of 0.02 ha h⁻¹. Small scale farmers could take advantage of the improved weeder to control weeds on their farms.

Muhammad and Attanda (2012) developed a hand push mechanical weeder that consisted of two set of cone rotor blades, adjustable main frame and a float. The effective field capacity of 0.357 ha h⁻¹ were observed 64.87 N draft and overall width and depth of cut of 180 mm and 20 mm respectively. With a single run of cut in between the rows on the field at a soil moisture content of 40.8%, the optimum weeding efficiency was 84.5% while weeding efficiency at 10.5% soil moisture content was 15%. Consequently, the highest plant damage of 8.33% was recorded at the 10.5% soil moisture content and the 0.058 HP power was required by a single person to push the prototype weeder.

Gongotchame *et al.*, (2014) conducted study on participatory approaches to examine the suitability of six mechanical weeders i.e., ring hoe, fixed-spike weeder, curved spike floating weeder, twisted-spike floating weeder, straight-spike weeder and two row spike-and-blade. Weeders were compared in order of preference with weed management practices. The ring hoe had the highest rank with 97 % farmer's preference in the fields of non-ponded water.

Merfield (2016) said that weeder working in sandy soils performed well in clay soils at optimum soil moisture contents, but performed poorly at other moisture contents. This variability in weeder performance might lead to requirements of different weeders for clay soils at high and low moisture contents. Stones are another complicating factor

for mechanical weeding, leading to damage or reduced effectiveness of some weeders, while others may be mostly unaffected. To control the weeds mechanically many types of weeder having different weeding tools has developed, depending upon power source, crop and soil, etc. These weeders generally uproot the weeds.

2.1.5 Self-Propelled Weeder

Zareiforush *et al.* (2010) presented a new theoretical approach to design main tillage components of rotary tillers. The rotary tiller shaft, it was revealed that in addition to the torsional moment, the flexural moment was also effective on the system and safety. It was known that in designing a rotary tiller, blades are subjected to fracture by incoming stresses. The optimum value of rotor diameter considering the values of maximum tangent force was about 39.4 mm.

Alizadeb (2011) conducted performance evaluation of four types of mechanical weeders, single row conical weeder (W1), two rows conical weeder (W2), rotary weeder (W3) and power weeder (W4) and also compared with control (W5) in rice. The results among the mechanical weeders, the highest weeding efficiency 84.33 % was obtained with (W4) power weeder and the lowest value 72.80 % was measured with the rotary weeder (W3). The average damaged of plants in mechanical weeders was obtained 3.83 % as compared to 0.13 % in control. The weeding cost was reduced by 15.70 %, 38.51 %, 22.32 % and 48.70 % for W1, W2, W3 and W4, respectively as compared to W5.

Ratnaweera *et al.* (2013) designed and fabricated a power weeder. The weeding ability was optimized by weeding three rows simultaneously. The double-action weeding drum was driven by a small 1.3 kW gasoline engine, which can enable removal of weeds, while facilitating the forward motion of the machine. In addition, the conical shaped weeding drums designed to lose the soil without harming the rice. A novel row changing mechanism was helpful for operating the machine by single person without destroying rice. A helical shaped tooth was designed in the weeding drums to enhance the shearing effect for weeding while losing up the soil.

2.2 TYPES OF INTER AND INTRA WEEDERS

2.2.1 Finger weeder

Sogaard, H. T (1997) finger weeders were used for weed control, the treatment effect will vary, depending on the state of the soil. In 1995, a pilot project was carried out

to examine the possibility of using sensor/control technology to reduce variations in the weed control caused by variations in soil conditions. The object was to verify that weed covering depends on working depth and that reduction of this variation could be achieved by controlling the tine angle on the basis of working depth measurements. A finger weeder was equipped with a sensor for measuring the working depth, and the signal from this sensor was transmitted to a control system. The purpose of the control system was to maintain a fixed working depth by controlling the angle of the harrow tines. Experiments were carried out in experimental plots sown with “weed plants”. The experiments showed a clear relationship between the working depth and the weed covering achieved. Furthermore, the experiments showed that the sensor/control system is able to keep the working depth almost constant and so minimize variations in weed covering by soil.

Bleeker et al. (2002) observed that the European finger weeder killed up to 95% of weeds. They concluded that like most weeding tools, the efficacy of the finger weeder is greatly reduced when used in soil which has a crusted surface. Also, similar to other tools, the finger weeder worked better in lighter sandy soils than heavier clay. Between 36% and 71% weed control, and between 5.9% and 15% crop plant reduction has been achieved in 2-leaf drilled onion.

Van der Schans and Bleeker (2006) recommend that a direct-seeded crop be at the 2-leaf stage to tolerate the finger weeder, while the ideal weed stage is from cotyledon to 2-leaf. They found the appropriate speed was 4-12 km h⁻¹. Like many other in-row weeding tools (including the flextine harrow), efficacy was improved when finger weeders were coupled with between-row knives run simultaneously and working as close to the row as possible in front of the finger weeders

2.2.2 Torsion weeder

Ascard & Bellinder (1996) Torsion weeders can be highly effective. Two passes with the torsion weeder gave good overall results in direct-sown onions halving the time required for subsequent hand-weeding with no significant yield reduction compared to inter-row weed control alone two in-row cultivations gave 51-57% in-row weed control and 48-64% reduction in subsequent hand-weeding, compared with between-row cultivation alone. Others have found that torsion weeders reduce hand-weeding by two-thirds compared to flame weeding coupled with subsequent between-row cultivation.

Smith and Silva (2008) also found that the torsion weeder caused greater yield reduction in transplanted lettuce and brassicas than the finger weeder. However, in an earlier study in onions, torsion weeding at the one-leaf stage caused considerable stand reduction, but still gave good weed control and yield, as following cultivation the remaining onion plants enlarged in size due to the increased space created by the decreased stand.

Hitchcock Tilton (2017) Torsion weeders are spring-steel of varying length in diameter from approximately 0.7 cm to 1 cm. They are bent into a loop that allows the metal tine to flex or vibrate under tension. Pairs are set-up on either side of the crop so that their tips cross, or nearly cross, making a 'V' shape. According to manufacturers, as they are pulled through the soil they vibrate, uprooting small weeds.

2.2.3 Brush weeder

Kouwenhoven (1997) gives a detailed explanation of the types and modes of action of the brush weeder as well as the possible adjustments. The axis of brush rotation is either perpendicular or parallel to the ground and in both cases the rotating brushes either uproot small weeds or throw soil to bury them. He describes the findings of earlier research by Van Duijin and De Haar (1991) that the first brush cultivation should move soil into the crop row to bury in-row weeds; in this way in-row weeds can be killed while keeping the brushes from coming into contact with the tender young crop. For the second cultivation, when the crop is bigger, brushes could work the in-row area, moving soil outward. Maximum working speed was given as 2.9 km h⁻¹. One must remember that working speed and efficacy differ greatly by type of crop and crop growth stage. Working depth was between 2 and 3 cm.

Melander (1998) used the opposite strategy for brush weeding; during the first cultivation he worried that throwing soil into the row could bury the crop, and so he pulled soil from the row and then in the second cultivation threw soil into the row to bury weeds. This difference in approach is likely explained by differences in crop and development – whereas Van Duijin and De Haar were cultivating sugar beet and maize at canopy closure, Melander was cultivating onion 38 days after planting. The difference in crop size likely also explains Melander's lower working speed of 1.5 km h⁻¹ and shallower working depth of 1.5 cm.

Cirujeda et al. (2007) used a brush weeder on processing tomatoes and found it gave effective control when used at 1.5 km h⁻¹.

2.3 INFLUENCE OF PARAMETERS IN DESIGN OF WEEDER

2.3.1 Machine and operational parameters

Craig (1956) designed oscillating weeder and cultivator for tractors. This invention related to an improved apparatus mounted on a tractor for cultivating and weeding relatively small plants, particularly cotton plants in the early stages of their growth. To overcome the difficulties in the cultivation and weeding of cotton plants, the machine consisted of two parallel resilient tines. Tines were driven by a wheel contacting the ground over which the apparatus was moved to cause the tines to oscillate in an accurate path across the row of plants. These tines were driven to oscillate at a speed conforming to the rate of movement of the implement over the ground and movement of the tines was such that they miss the cotton plants while cultivating and weeding.

Tewari and Datta (1985) reported that cutting force for weeding increased linearly with the width of cut of the blade and the working time to operate the weeders decreased with the increased width of blades.

Melander (1997) studied on adjustments of a vertical axis rotary brush weeder for intra-row weeding in row crops. In brush weeder, brushes were in pairs, so one brush works either side of the crop row. Results showed that the peripheral speed of brushes and tractor speed had no clear effect on weeding performance for either uprooting or covering. Narrowing the distance between the pairs of brushes to 30 mm for uprooting increased the level of intra-row weed control without negative yield responses. Increasing the working depth of the brushes increased percentage crop soil cover and ridge height when the machine was covering.

Pullen and Cowell (1997) studied on working width and forward speed of the blade hoe. Authors concluded from study that cutting action of blade hoe was efficient when it operated at shallow depth and increasing the working depth does little to improve weed kill but a higher forward speed increases soil covering of weeds and may reduce their survival.

Gobor and Lammers (2007) developed a hoeing tool, which could be used in different plant spacing systems, various plant intra-row distances and growth stages. Hoeing tool consisted of an arm holder and three or more integrated arms rotating around a horizontal axis above the crop row. Length of the arm estimated to be in the range of 350-550 mm for positioning the trajectory between plants for wide hoeing. Kinematical behavior of the hoes was simulated to optimize the hoeing process. Equal intra-row area covering could be realized with the invariable setting of the arm length and with an angular adjustment of front and rear duck-feet. It was observed that the soil type, previous tillage, forward speed of the carrier, rotational speed of hoe and hoeing depth had significant influence on the torque.

Akhijahani *et al.* (2011) investigated the effect of vehicle and rotational speeds of mechanical inter-row weeder on the performance of the system and mechanical damage. Results showed that the performance of the weeder increased by increasing of rotational speed at a constant vehicle speed and decreased by increasing of vehicle speed at a constant rotational speed. Statistical analysis indicated that the influence of vehicle and rotational speeds on the performance of the system were significant. More mechanical damages were observed at higher rotational speeds at constant vehicle speed. Vehicle speed of 5.4 km h⁻¹ and rotational speed of 134 rpm were found as the optimal speeds for weeding, considering the maximum performance of the system and minimum damage to the plants.

Cordill and Grift (2011) developed a system for identifying the maize stalk locations, allowing a soil engaging tool to mechanically remove weeds in the row. This system consisted of a sensing arrangement, control algorithm and dual mechanical end effectors. Implement was drawn through the field whilst sensing corn plants and moving the mechanism along its intended path. Damaging the roots caused by the tines could be prevented by leaving a 50 mm diameter circle surrounding the maize stalk. They concluded that the weeding implement was more effective at locating maize stalks and moving the end effector in the broadleaf weed plots than in the grassy weed plots because fewer plants were damaged. Overall functionality of the machine was proven but the percentage of fatally damaged plants was 8.8 % in the absence of weeds and reaching 23.7 % in heavy weed infested areas with hundreds of weeds per m².

Chavan *et al.* (2015) carried out a structural analysis on developed weed removal machine to determine the effects of loads on physical structures and their components.

Computer Aided Design (CAD) was used to create 3D model of weed removal machine and Finite Element Method (FEM) technique was used for analyzing. .

Rabcewicz *et al.* (2017) designed and tested implements for mechanical weeding. Designed implements were hoe, rotating ring blade, oscillating edge, rotating multi-edged ring and orchard rotavator tested in the apple orchard. The best weed control effect of a single treatment was obtained with the rotavator (96.5 %). Rotary multi-edged ring was not quite as efficient (85.0 %) while the efficacy of the hoe was only 59.4 %. Tools on vertical axis shallowly penetrating soil seem to be most promising due to working with a low rotating velocity.

Melander (2017) used the opposite strategy for brush weeding; during the first cultivation he worried that throwing soil into the row could bury the crop, and so he pulled soil from the row and then in the second cultivation threw soil into the row the bury weeds. This difference in approach is likely explained by differences in crop and development – whereas Van Duijn and De Haar were cultivating sugar beet and maize at canopy closure, Melander was cultivating onion 38 days after planting. The difference in crop size likely also explains Melander's lower working speed of 1.5 km h⁻¹ and shallower working depth of 1.5 cm.

2.4 EFFECT OF YIELD FOR WIDER ROW SPACED CROPS

Fufa and Etagegnehu (2016) studied Weed Control Practices and Inter-Row Spacing Influences on Weed Density and Grain Yield of Finger Millet (*Eleusine Coracana* L. Gaertn) in the Central Rift Valley of Ethiopia. Weeds are one of the major constraints limiting finger millet productivity and production. Field experiment was conducted on weed control practices and inter-row spacing influences on weed density and grain yield of finger millet at Arsi Negelle during 2011 and 2012 cropping seasons. The objective of the study was to determine the influences of weed control practices, inter-row spacing and their interactions on weed density and grain yield of finger millet. The experiment was laid out in randomized complete block design in factorial arrangement using three replications. The treatment combination was four levels of inter-row spacing (30 cm, 40cm, 50 cm and 60 cm) and four levels of weed control practices (no weeding, one hand weeding (at 20 days after emergence), two hand weeding (at 20 and 40 days after emergence) and post-emergence herbicide (2, 4-D at 0.72 kg ha⁻¹) + hand weeding (at 40 days after emergence). *Galinsoga parviflora* was found to be the

most dominant weed species affecting finger millet yield. Significant differences were observed at 5% probability among weed control practices and inter-row spacing on total weed density, weed biomass, grain yield, and plant height, finger per plant and crop biomass. The study indicated that 82% yield reduction was recorded from weedy plot. Twice hand weeding at 20 and 40 days after emergence resulted in the highest grain yield (3.42 t ha⁻¹) of finger millet. The highest yield was obtained from 40 cm inter row spacing; while the lowest grain yield was obtained from 60 cm inter-row spacing. There was no significant interaction effect of weed management practices by inter-row spacing. The narrower inter-row spacing resulted in reduced weed density and weed biomass as compared to wider inter row spacing. Therefore, the combination of twice hand weeding at 20 and 40 days after emergence and 40cm inter-row spacing was found to be good to manage weed problem and prevent significant yield loss. Moreover, the application of post-emergence herbicide (2, 4-D at 0.72 kg ha⁻¹) + hand weeding at 40 days after emergence with 40 cm inter-row spacing also reduce weed infestation and give good yield.

Gezahegn, A. M and Tesfaye, K. (2017) Conducted a field experiment was at Haramaya university research site to determine optimum inter and intra row spacing for faba bean production under Fluvisol. Three inter row spacing (30, 40 and 50 cm) and three intra row spacing (8,10 and 12 cm) were arranged in 3 x 3 factorial combination in Randomized Complete Block Design (RCBD) with three replications. The results revealed that inter and intra row spacing had a significant effect on growth, yield and yield components of faba bean, except 100 seed weight. However, interaction effect of inter and intra row spacing was not significant. An increase in inter and intra row spacing significantly increased seed germination percentage, the number of branches per plant, pod length, number of pods per plant, number of seeds per pod and seed yield per plant. However, an increase in inter and intra row spacing reduced plant height, lodging, seed yield (kg ha⁻¹) and dry matter yield (kg ha⁻¹). The highest seed yield of faba bean was obtained in 40 cm inter and 10 cm intra row spacing. Therefore, 40 cm inter and 10 cm intra row spacing is recommend for obtaining high yield of faba bean under Fluvisols.

Andrea Peruzzi *et al.* (2017) Conducted experiments to study machines for non-chemical intra-row weed control in narrow and wide-row crops, Intra-row weed control in organic or low-input cropping systems was more difficult than in conventional agriculture. The various mechanical and thermal devices available for intra-row weed control were reported in this review. Low-tech mechanical devices such as cultivators,

finger-weeders, brush weeders, and torsion weeders tend to be used in low density crops, while spring-tine harrows are mainly applied in narrow-row high-density crops. Flame weeding can be used for both narrow and wide-row sown crops, provided that the crop is heat-tolerant. Robotic weeders are the most recent addition to agricultural engineering and only a few are available in the market. Nowadays, robotic weeders are not yet used in small and medium sized farms. In Europe, high income niche crops are often cultivated in small farms and farmers cannot invest in high-tech solutions. Irrespectively of the choice of low- or high-tech machines, there are several weeders that can be used to reduce the use of herbicides, making of them a judicious use, or decide to avoid them.

Mohammed Y. E *et al.* (2018) Studied on New Narrow Inter-Row Spacing for Maximizing Groundnut Yield under Rain-Fed Conditions of North Kordofan State, Sudan. The experiment was conducted for three consecutive seasons (2013, 2014 and 2015) at Elobeid Research Station research farm (12⁰ -13⁰ N, 3⁰-14⁰ E), under rain fed conditions to study the effect of plant spacing on hay and pod yield of groundnut variety Geibish. Six treatment combinations (60, 40 and 30 for inter-row and 20 and 15 for intra-row spacing) were laid out in a randomized complete block design (RCBD) factorial with four replications. Days to fifty percent flowering were significant in season 2014 and 2015. The earliest flowering days were recorded for the spacing of 30×20 cm. reducing plant spacing from 60×20 cm to 30×20 cm decreased the number of weeds before first and second weeding to 50 %. High significant difference ($P \leq 5$) among treatments in hay and pod yield of 2643.5 kg ha⁻¹ and 2065.0 kg ha⁻¹ were recorded for the spacing of 30×20 cm, respectively, the treatment combination of 30×20 cm increased the pods 66.1% and hay yield 52.2% on average across all season. Significant differences ($P \leq 5$) were showed between treatments in number of pods per plant and number of seeds per pod for enter row. No significant differences ($P \leq 5$) were observed between treatments in shelling percent, maturity, harvest index.

2.5 PERFORMANCE EVALUATION OF WEEDERS IN FIELD CONDITIONS

Tiwari *et al.* (1993) evaluated the performance of manually operated push pull weeder under field conditions and reported that 85 to 90 % of human energy utilized per cycle of push for cutting of weed roots and about 10 to 15.5 % of energy was spent on penetration of a push pull weeder in to the soil. Also found that output efficiency of push pull weeder was four times more than the manual weeding.

Padole (2007) conducted performance evaluation of rotary power weeder. This experiment was conducted in three trial plots of 20 m × 10 m cotton field for evaluating the weed efficiency, plant damage and field efficiency of the power weeder. It was revealed that the working depth of weeder varies with the moisture content of the field and rotational speed of cutter wheel. Field efficiency of weeder was found to be 90 %. Weeding efficiency and plant damage were 92.76 % and 10 %, respectively.

Bi *et al.* (2014) evaluated performance of self-propelled rotary power weeder in wide row line sown vegetable crops of tomato, yard long bean and okra. From the study, it was observed that no stem damage was found in whole weeding operation due to higher row-to-row spacing of crop. Plant damage was higher in yard long bean crop due to more branches and tilted crop. Plant damage was to be 2.3 % in long yard bean and minimum in tomato (1.65 %) crop. It was also observed that during operation the weed became entangled in end of shaft and obstructed clean weeding. In the same time there was no clogging of weeds observed in middle portion. The machine was found to be ideal and effective in carrying out the weeding operation in vegetable crops.

Keshavalu *et al.* (2017) evaluated performance of power weeder in wet land conditions and compared with conventional method of hand weeding. The data collected were analyzed and the major findings of the field evaluation for actual field capacity of manual weeding and power weeding observed was 0.005 and 0.15 ha h⁻¹, respectively. The maximum value of weeding index of 99 % was observed in manual method compared to that of power weeder i.e. 93.7 %. The plant damage of power weeder and manual weeding was observed as 8 and 2 %, respectively.

Mallikarjuna (2017) developed a rotary weeder matching to mini tractor. Rotary weeder was tested with different type of blades viz., J and L-type, rotary speeds of 300 and 440 rpm and 1.5 and 2.5 km h⁻¹ forward speed of operation.

Padole (2018) conducted performance evaluation of rotary power weeder. This experiment was conducted in three trial plots of 20 m × 10 m cotton field for evaluating the weed efficiency, plant damage and field efficiency of the power weeder. It was revealed that the working depth of weeder varies with the moisture content of the field and rotational speed of cutter wheel. Field efficiency of weeder was found to be 90 %. Weeding efficiency and plant damage were 92.76 % and 10 %, respectively.

2.6 COST ECONOMICS OF WEEDERS

Remesan *et al.*, (2007) Reported that the cost of weeding for female labors could be reduced by 4.85 times and 5.2 times by using rotary weeder and cono weeder respectively, compared to hand weeding. While for male labors the weeding cost could be reduced by 6.6 times and 7.6 times by using rotary weeder and cono weeder, respectively as compared to hand weeding.

Islam *et al.* (2017) compared the cost efficiency of mechanical weeding over traditional hand weeding. They reported that highest weeding cost was involved in hand weeding (Tk. 4287 ha⁻¹) compared to BEERI weeder (Tk. 1103 ha⁻¹) and BRRRI power weeder (Tk. 950 ha⁻¹). BW (BRRRI weeder) and BPW (BRRRI power weeder) reduced 74 and 78 % weeding cost compared to HW (hand weeding). Weed control methods exerted insignificant effect on grain yield. BRRRI (Bangladesh Rice reseach Institute) power weeder and BRRRI weeder reduced weeding cost, enhanced weed control and improved the labor efficiency without sacrificing grain yield.

Keshavalu *et al.* (2017) studied the cost economics of power weeder. The maximum value of cost operation of Rs. 3750 per ha was observed with manual weeder while power weeder recorded minimum value of Rs. 2386 per ha. This difference may be due to high initial cost of power weeder and less actual field capacity.

Chapter III

MATERIAL AND METHODS

The chapter describes briefly the methodology used for development and evaluation of semi-automatic inter and intra row weeder, suitable for wider row crops like chillies, red gram and cotton. The measurement of various machine and operational parameters and the procedures followed to determine the weeding efficiency, Plant damage were described. Experimental methodology and measurement techniques adopted during the course of investigation were described in the following sections.

3.1 EXPERIMENTAL STUDY AREA

Fabrication and evaluation of the inter and intra row weeder was conducted at Dr. NTR College of Agricultural Engineering, Bapatla. The college is located at 15.54° N latitude and 80.30° E longitude at an altitude of 5 m above sea level. The texture of the experimental site is sandy loamy soils.

3.2 WEED CONTROL PRACTICES IN WIDER ROW SPACING CROPS

The crop parameters those influence the weeding operation are row to row spacing, intra row spacing between the plants and also the crop physical parameters like, height of the crop, type of branching and crop canopy. Generally, the row to row spacing in wider spaced crops varies from 60 to 90 cm or 60 to 120 cm. while plant to plant spacing varies as 30, 45 and 60 cm. The height of the plant, number branches and crop canopy varies at different stages of weeding and also are important parameters which influence the design of the machine.

Clearance is required between the rows and also from ground to chassis of the power source. In case of power operated weeding equipment, the height of the plant as well as the canopy of the plant at different stages are to be into consideration to improve weeding efficiency and to reduce the plant damage, particularly, while working between the plants within the row.

The period for weed control in wider spacing crops varies between 20 to 70 days after sowing, depending the crop in dryland agriculture. In dryland agriculture, the weeding operation is carried out between the rows after sowing. The first weeding is done between 15 to 20 days and second and third weeding may be done every 15 to 20 days after first weeding.

3.3 DEVELOPMENT OF TRACTOR DRAWN INTER AND INTRA ROW WEEDER

Among different agricultural operations, inter and intra row weeding operation consumes maximum energy. There are different methods employed to remove the weeds between the rows. The intra row weeding is done manually. So far there is no equipment developed in India, which can be operated between the plants within a row.

Hence a tractor drawn inter and intra row weeder was developed to remove the weeds in wider spaced crops like cotton and chillie. The unit mainly consist of the following components.

- I. Frame
- II. PTO-Universal joint
- III. Gear box (bevel gears)
- IV. Bearings
- V. Pneumatic tires with rim and axle
- VI. V-belt and pulleys
- VII. Disc with blades
- VIII. Seat with frame
- IX. Handles

I. Frame

A rectangular angular frame section made of MS square pipe of length X breadth 1500 mm X 1000 mm and 4 mm thickness was used to give required strength to the frame to with stand all type of load driving operation. The entire frame was attached to the prime mover by means of three-point linkage. A 20 HP four-wheel drive tractor (mini) was used as power source to operate the inter and intra row weeder.



Plate 3.1 Developed Frame

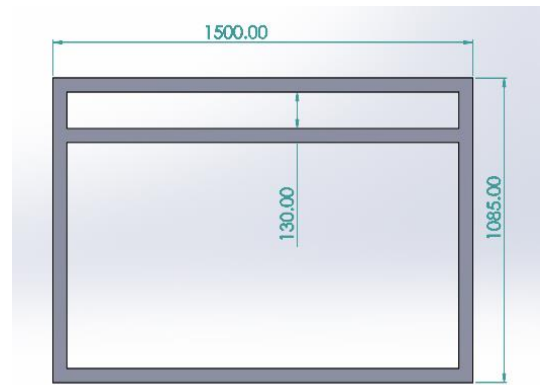


Fig. 3.1 CAD view of developed frame

II. PTO-Universal joint

A universal joint (universal coupling, U-joint, Cardan joint, Spicer or Hardy Spicer joint, or Hooke's joint) is a joint or coupling connecting rigid rods whose axes are inclined to each other, and is commonly used in shafts that transmit rotary motion. It consists of a pair of hinges located close together, oriented at 90° to each other, connected by a cross shaft. The universal joint is not a constant-velocity joint.



Plate 3.2 PTO-Universal joint

III. Gear box (bevel gears)

In the field of power transmission, Bevel Gearboxes have a special place because of their ability to change direction of power transmission, usually by 90° . Bevel gearboxes can also transmit high torque at high speed with low power loss unlike worm gearboxes. The power is transmitted to the weeding tool through belt and pulley arrangement from the output shaft of the gearbox. Speed reduction ratio 2:1, number of teeth on pinion and crown gear is 16 and 32 respectively.

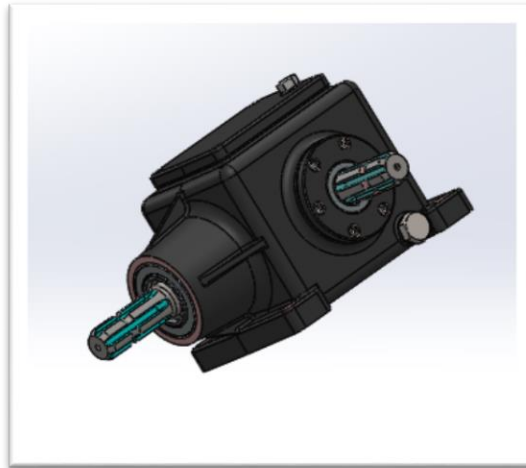


Fig. 3.2 CAD view of bevel gear box

IV. Bearings

A bearing is a device used to support and guide a rotating, oscillating, or sliding shaft, pivot or wheel. Whenever a shaft rotates, it needs a bearing for smooth, effective operation.



Plate 3.3 Pillow block bearing



Plate 3.4 Flange bearing

V. Pneumatic tires with rim and axle

The portion of the frame is supported by two pneumatic tires. The depth of operation of the weeder is controlled by raising and lowering the height of the frame through screw arrangement provided with a handle. To raise or lower the frame from the round, MS bracket are provided on either side of the frame. To wheel pneumatic tires are fixed along with adjustable arrangement system as shown in plate 3.5

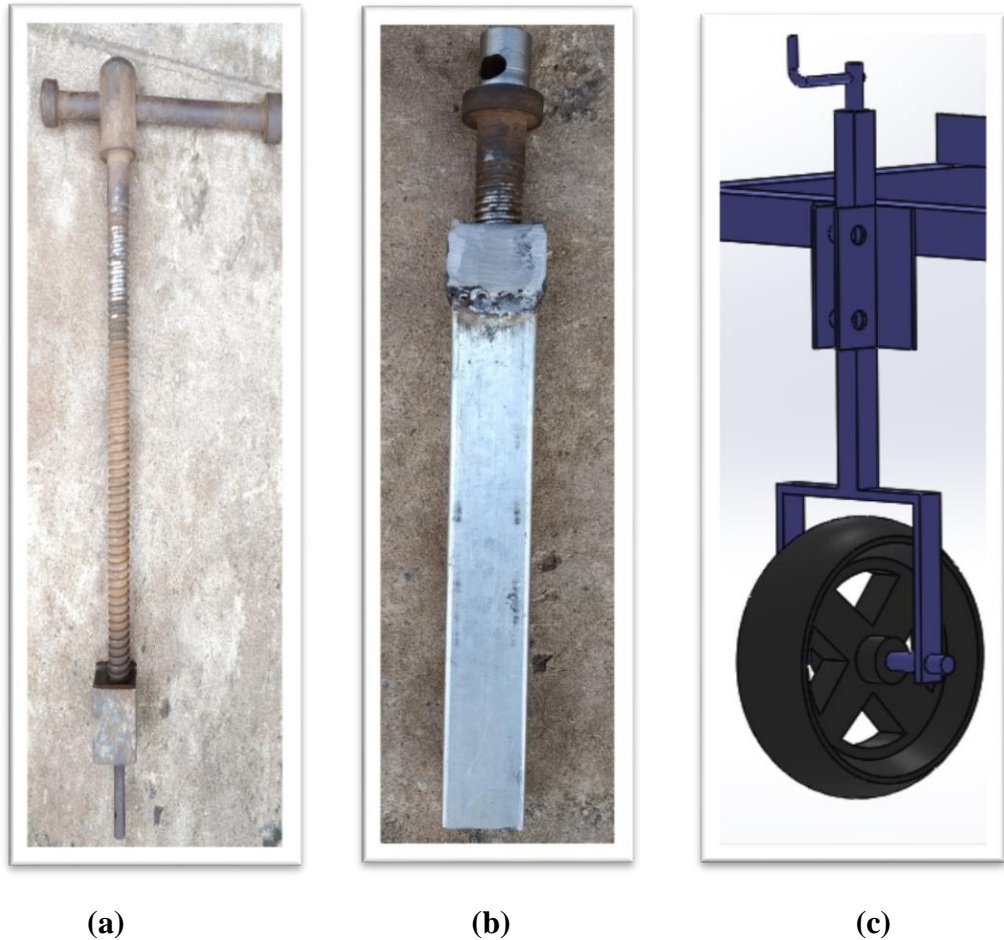


Plate 3.5 (a) (b) (c) Screw mechanism of tire adjustment (up and down)

VI. V-belt and pulleys

A belt is a flexible loop system used to link two or more rotating [shafts](#) mechanically, most often parallel. Belts may be used as a source of motion. Belts are looped over pulleys and may have a twist between the pulleys, and shafts need not be parallel.

In a two pulley system, the belt can either drive the pulleys normally in one direction (the same if on parallel shafts), or the belt may be crossed, so that the direction of the

driven shaft is reversed (the opposite direction to the driver if on parallel shafts). As a source of motion, a [conveyor belt](#) is one application where the belt is adapted to carry a load continuously between two points. The belt drive can also be used to change the speed of rotation, either up or down, by using different sized pulleys.



(a)



(b)

Plate 3.6 (a) (b) V- belt (B 1313 Lp / B 50)

A pulley is a [wheel](#) on an [axle](#) or [shaft](#) that is designed to support movement and change of direction of belt, or transfer of power between the shafts. The power from PTO of the tractor was transferred to the gear box. From gear box the power was transmitted to the weeding unit through V-belt and pulleys. From the output shaft of gear box to the input shaft of weeding unit, the V- belt drive was used.



Plate 3.7 Pulley (101mm dia)

VII. Disc with spikes

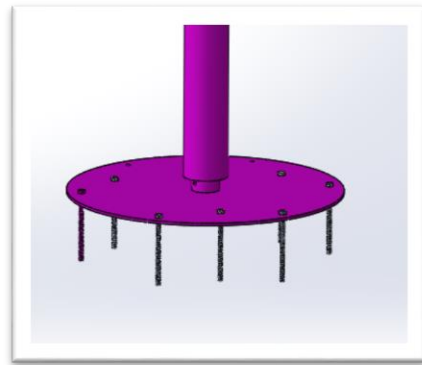


Plate 3.8 Rotating disc with cutting spikes (2, 4 and 6) Fig3.3 CAD view of rotating disc

The weeding unit was mainly consisting of rotating disc made of MS plate of 5 mm thickness and 150 mm diameter over which the cutting spikes were mounted. Arrangement was made on the rotating disc to increase or decrease the number of spikes from 2 to 6 spikes.

VIII. Seat with frame

Seat was made of plastic for seating arrangement on the main frame. This weeder semi-automatic so sitting on seat he/she control and remove the weeding between the plants.

At rear end of the main frame and at the center point of the near rectangular beams of the mainframe, seating arrangement. Disc weeder in between the plants with to and fro motion arrangement.



Plate 3.9 Seat arrangement

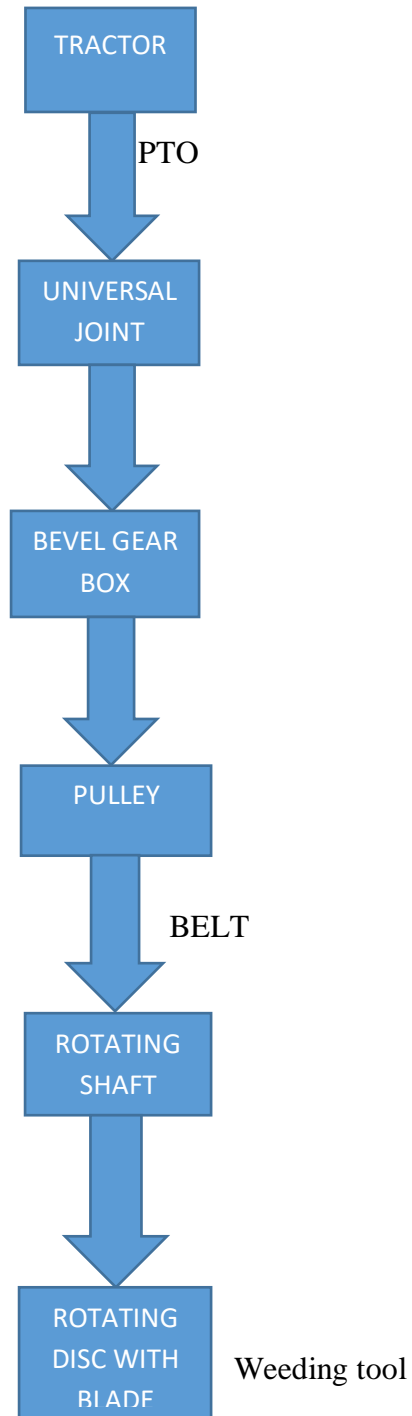


Fig 3.4 Power transmission from tractor PTO to weeding tool (intra row)

3.3.1 Prototype design

The weeder prototype is represented with a CAD software in order to define the component dimensions, verify the feasibility of parts movement. The software used was Solid works 2018.

The system dimensions are restrained. The whole unit representing the maximum longitudinal length equal to 1500 mm, maximum width equal to 1085 mm and height 800 mm.



Fig. 3.5 – CAD representation of prototype (isometric view)

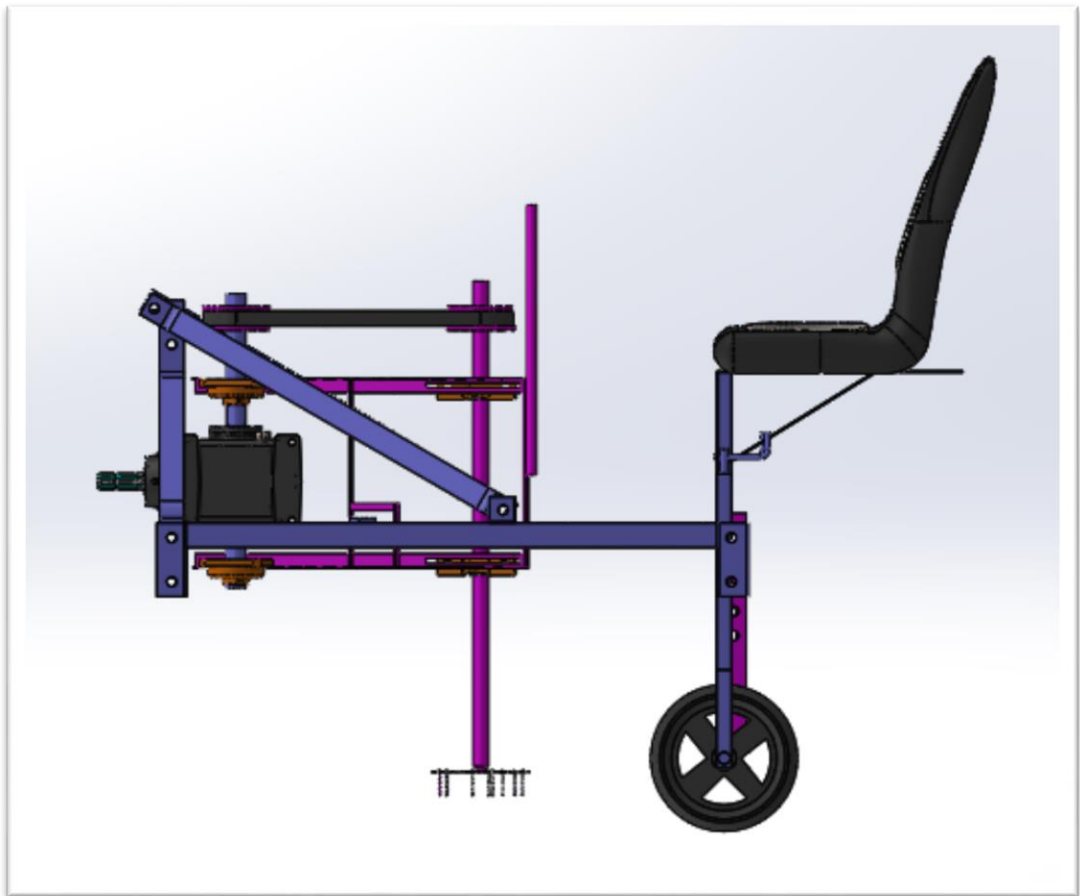


Fig. 3.6 – CAD representation of prototype, (side view)

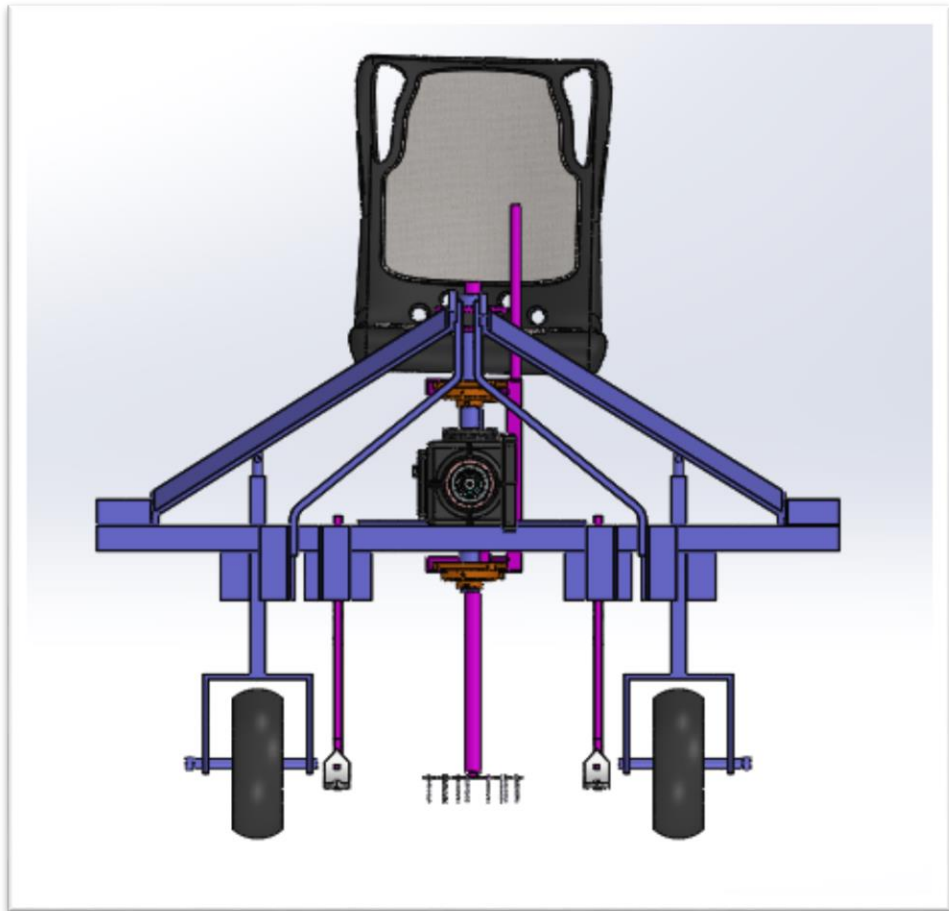


Fig. 3.7 - CAD representation of prototype, (front view)



Plate 3.10 Front view of developed inter and intra row weeder



Plate 3.11 Side view of developed inter and intra row weeder

3.3.2 Pivoting Arm Design Requirements

The pivoting arm concept was designed and attached to the prototype frame. Before deciding the best position to place the new actuation system, it was determined that the future machine vision system will be located between the gear box and the cutting tool system. This location was important so that the assembly area inside the frame could be specified that would determine the crucial location of the pivot point. This pivot point was actually the rotation point of the pivot arm and everything attached to it including the weeding mechanism and the rectangular frame, which is where the integrated gear box and the weeding mechanism tool were mounted. Based on the pulley size selected, the width of the belt drive system of the pivot arm could be estimated. Since the limit of the lateral movement is the prototype frame width, which was 87.63 cm, a targeted working area of crop canopy radius, 15.24 cm was to be achieved.

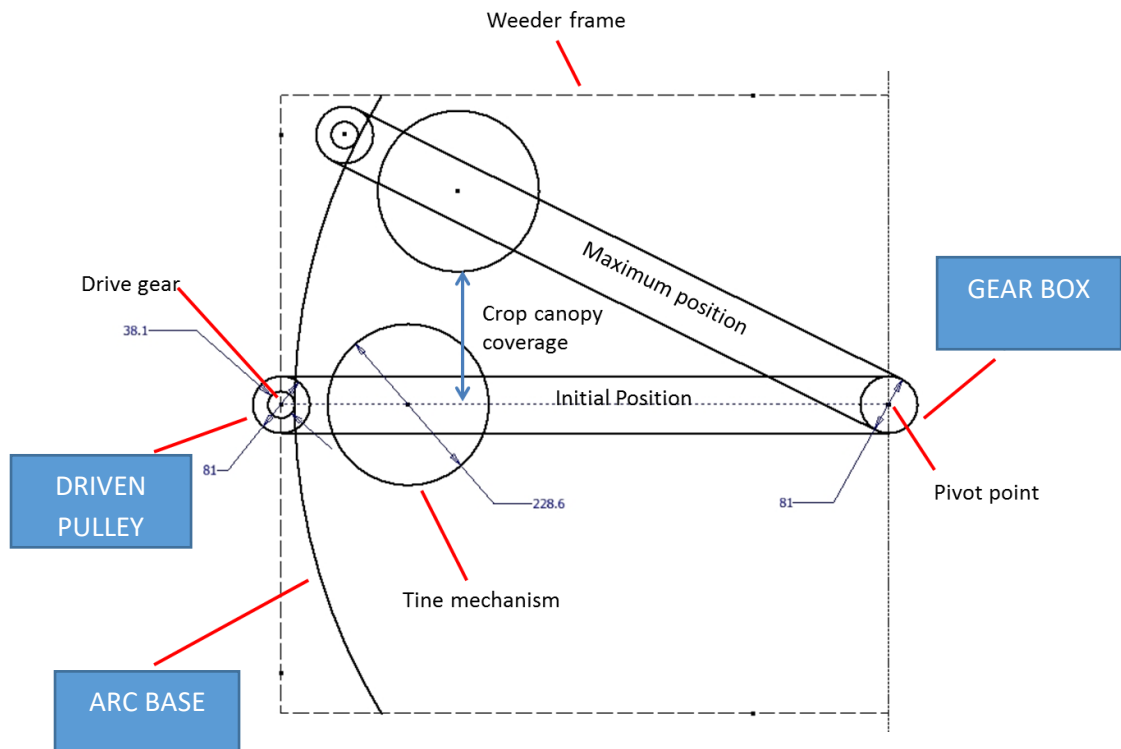


Fig 3.8: The pivoting arm concept to determine the crop canopy coverage using different arc radius of the weeding tool.

With the target set, the most suitable arc radius for the weeding tool was determined. This was investigated by a manual operator sitting on back side frame to determine the position of the weeding mechanism shaft on the pivot arm to achieve the targeted coverage area (Fig. 3.8). The targeted coverage area defined for the design was the crop canopy diameter, which was 30.5 cm. This targeted coverage area was the area where the weed control would be accomplished. Many trials using different arc radii were tested to obtain the targeted coverage area. The best coverage area of 18.8 cm was obtained when using an arc radius of 64.1 cm. It was a good technique to design the crop canopy coverage to be bigger than the targeted value, since it would be very difficult to achieve a large crop canopy during actual operation because of the effect of the forward travel speed of the prototype. In addition, it would require large torque and acceleration to move the pivot arm from one end to the other.

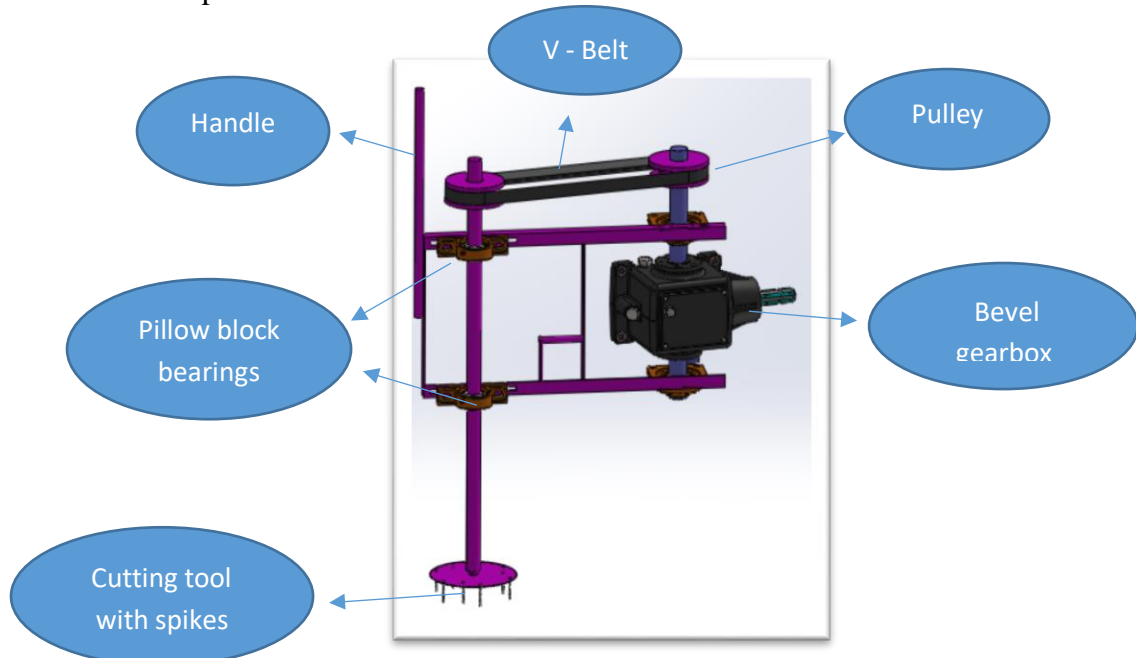


Fig.3.9 View of power transmission of intra row of weeding mechanism.

After the arc radius was determined, the length of the pivot arm was determined because all of the components position attached to the pivot arm had been decided.

The pulley was assembled on top of the gear box using a shaft. The reduction ratio of of gear box was 2:1 and provide with same size of the pulley on gear box shaft and another pulley on weeding tool shaft, that gives same rpm. However, a higher torque was produced from the pinion of gear box. Since the belt drive system of the pivot arm would generate the torque to move the weeding tool, it was found sufficient.

The size of the rectangular frame that accommodates the weeding mechanism tool and the pivot point was determined by the height the weeding mechanism tool with the gearbox.

Adequate space was needed to install these two components to the frame. The length is determined by the location of the weeding mechanism shaft, because at one end of the frame, two pillow block bearings were fixed in a special housing so that the weeding mechanism shaft would easily rotate, and at the same time resist any axial and thrust loads.

I. Tine kinematic model

The time t , in seconds, taken for the tine to move forward at a certain travel speed is given by

$$t = \frac{d}{v} \quad \dots\dots\dots (i)$$

where d = Travel distance, m

and v = Forward speed of the weeder, $m\ s^{-1}$.

At the same time, the tine will move in an angular distance, φ , in radians, given by

$$\varphi = \omega t \quad \dots\dots\dots(ii)$$

where ω = the angular velocity, $rad\ s^{-1}$.

To determine the working zone for a certain number of rotating tines, it was necessary to use predefined values for the equations mentioned above. Using a weeding mechanism with six tines, three different travel speeds ($0.6\ km\ h^{-1}$, $0.8\ km\ h^{-1}$ and $1.0\ km\ h^{-1}$) were tested. As indicated above, the aim was to obtain the minimum angular velocity of the tine weeding mechanism required to achieve acceptable working zones, which was either overlapping or touching between each tine.

Table 3.1: Levels of different travel speeds, different rotational speeds and different working depths used for the experiment.

Factor	First Level	Second Level	Third Level
Working Depth, cm	2	4	6
Travel Speed, Kmh^{-1}	0.6	0.8	1.0
Mechanism Rotational Speed, rpm	180	220	290

3.3.3 Experimental details

The cutting disc can be operated in two ways (Fig. 3.10 (a) (b)) When the direction of rotation was as shown in *Fig.3.10 (a)*, soil was moved away from the crop row, although a small amount was thrown into the crop row at the back of the blades. This is called ***uprooting***, because weeds were primarily uprooted by the blades and then thrown sideward.

In *Fig .3.10 (b)*, the direction of rotation was changed so that soil is thrown into the crop row creating a small ridge. This way of operation is called ***covering***. Here, weeds were primarily controlled by soil coverage, although some are uprooted by the blades. The size of the ridge can be changed by adjusting the working depth and by angling the spikes either forward, backwards, or sideward.

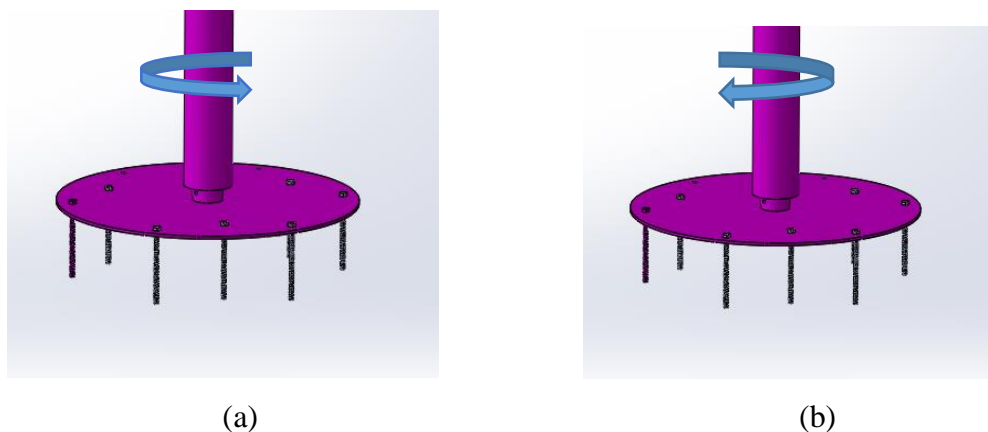


Fig. 3.10 (a) (b) Drawings to illustrate the working principles of intra row weeding

3.4 TRAJECTORY OF INTRA ROW WEEDING

It provides a weeding operation just to one side to the crop row. The disadvantage of this trajectory is the abrupt deceleration and acceleration that the bevel gear of the slider is forced to execute; moreover, the non-negligible inertia of the slider system impedes, practically, to instantaneously stop the slider and restart it. Hence the inversion of direction must be preceded and followed by a deceleration and acceleration phase respectively; this additional phase would worsen the weeding efficiency because the tool would follow a smoothed trajectory, remaining farther to the crop row and thus, missing to remove weeds present along the row.

However, this alternative trajectory was the only suitable solution if the canopy radius is bigger than the semi-distance between two following crop plants. In this situation the weeding would be limited to an inter-row weeding and to follow the canopy region boundaries. But the intra-row system in objective would lose sense and a classic inter-weeding system can be used more efficiently.

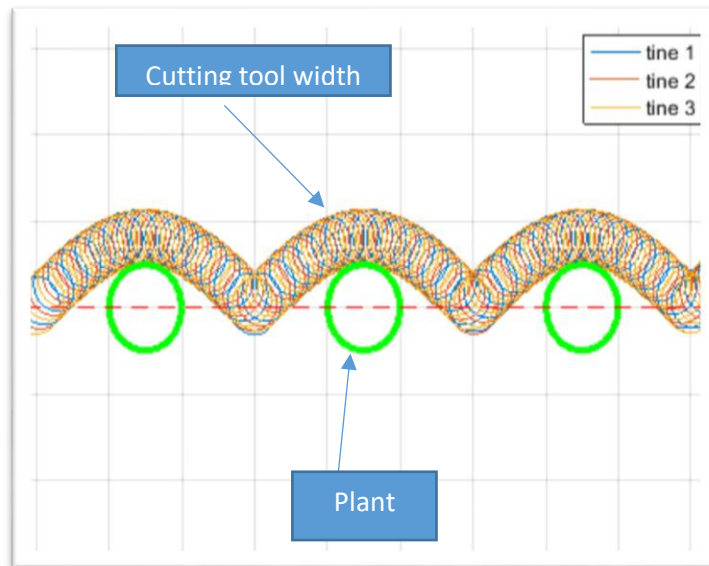


Fig. 3.11 Region of soil covered by the tool when is approaching plants.

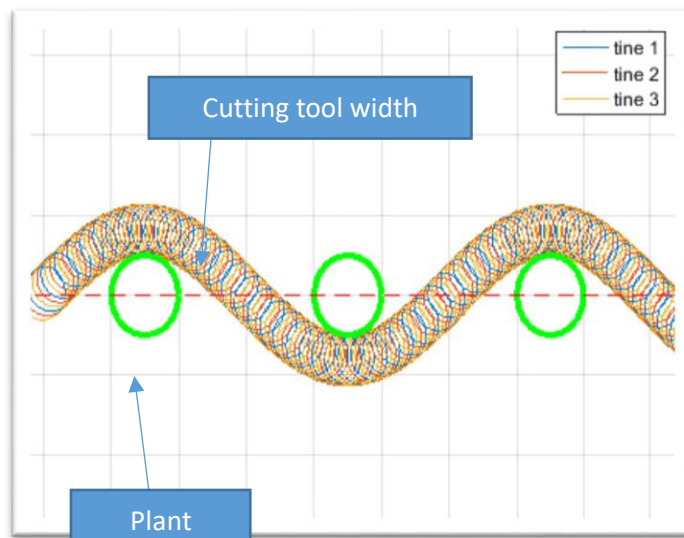


Fig. 3.12 Region of soil covered by the tool when is approaching plants.

An alternative trajectory is shown in fig 3.11. It is possible to notice from Fig. 3.12 that the weed control takes place only to one side of the crop row, being the weeding system provided of just one tool. In order to compute a correct weed operation, it is hence necessary that the vehicle passes two times on the same row so to compute the weeding also to the other side of crop row. This additional operation doubles the weeding time, making the weed control longer, less productive, more difficult to manage. The alternative was the use an intra-row weeding system provided of two tools instead of one, in this manner the system would became more complex, heavier, it would require more power source.

The system designed in this study was provided with just one tool being the vehicle just a prototype, with the main task the design of a good mechanism more than the optimization of weeding performances.

It is now presented the kinematics of weed operation in real situation, in which the system must react to interaction with the crop plants that are disposed along the row at a certain inter-plant distance.

The disposition of the chillie plants (plot -2) is the following:

- Distance between two row: 60 & 60 cm
- Distance between plants along the row: 45 & 60 cm
- Radius of canopy: from 0 to 40 cm or even 45 cm

Considering to work with continuity of motion this specific type of crop field, the trajectory followed by the tool could be the one shown in Fig. 3.12.

The preferential trajectory was the one depicted in Fig.3.12 because, it gives continuity of movement, avoids abrupt change in directions, provides a good coverage of the canopy area hence it is the one adopted for the study. The alternative trajectory (Fig.3.11) was instead abandoned. If the distance between two crop plants is higher, it is possible to distinguish two trajectories patterns.

3.4.1 Inter row weeding

One sense of the name refers to frames with teeth (also called shanks) that pierce the soil as they are dragged through it linearly. Shanks stir and pulverize the soil, either

before planting (to aerate the soil and prepare a smooth, loose seedbed) or after the crop has begun growing (to kill weeds—controlled disturbance of the topsoil close to the crop plants kills the surrounding weeds by uprooting them, burying their leaves to disrupt their photosynthesis, or a combination of both). Unlike a harrow, which disturbs the entire surface of the soil, this shank is designed to disturb the soil in careful patterns, sparing the crop plants but disrupting the weeds.

The main function of the shank is weed control between the rows of an established crop. Row crop cultivators are usually raised and lowered by a three-point hitch and the depth is controlled by gauge wheels.

Sometimes referred to as *cultivators*, these commonly have two center blades that cut weeds from the roots near the base of the crop and turn over soil, while two rear sweeps further outward than the center blades deal with the center of the row, and can be anywhere from 1 to 2 rows for this project.

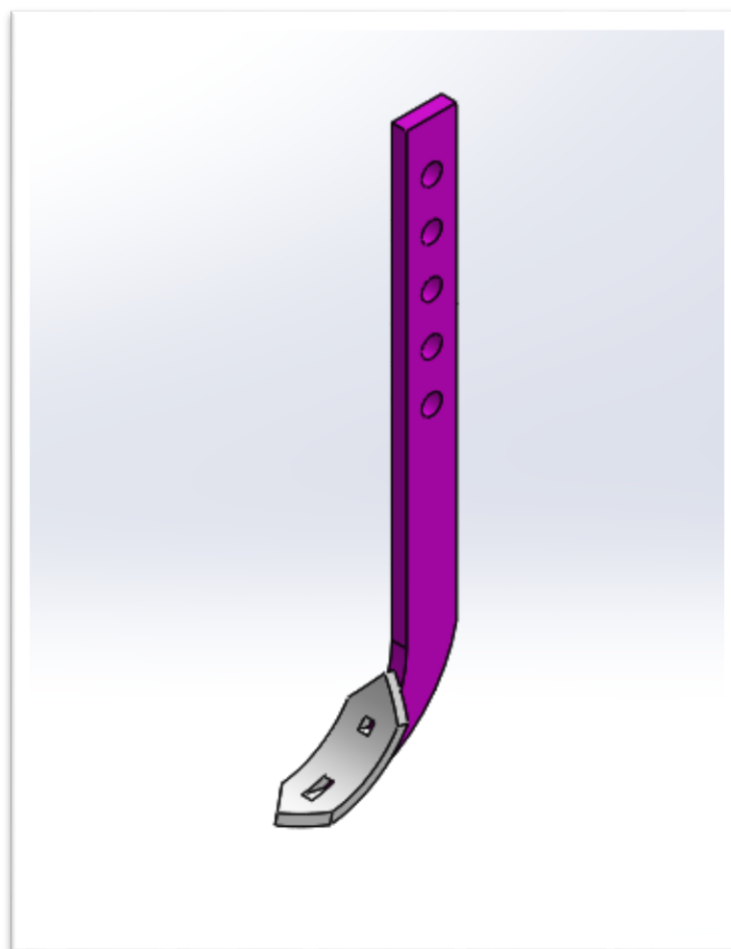


Fig. 3.13 Shank with shovel

Table 3.2 Specifications of tractor drawn inter and intra weeder

S. No.	Particular	Specification
1.	Name of machine	Inter and Intra Row Weeder
2.	Make	ANGRAU
3.	Model	Prototype
4.	Type of machine	Mini-tractor and tractor operated
6.	Overall width of machine, mm	1500
7.	Overall length of machine, mm	1085
7.	Overall height of machine, mm	1000
8.	No. of rows covered	1 (intra) 2 (inter)
9.	Type of transmission system	Bevel gear box
10.	No. of pillow block bearings	2
11.	No. of flange bearings	2
12.	Diameter of rotary disc, cm	15
13.	Type of linkage system	3-point linkage

3.4.2 Type of Power Unit

There are various types of power units available for operating the weeder at various depths and situations. Some of the power units are human, animal, power tiller and tractor drawn. In this project a 20 hp tractor is taken as power unit and weeder is designed suitable for that tractor. Output cutting weeding tool rpm required was 220- 290 so minimum 20 HP above tractor selected.

3.5 CROP CULTIVATION

Chillies are raised as per recommended agronomical practices. Accordingly, plot of 30 m x 10 m at the Dr. NTR College of Agricultural Engineering, Bapatla was prepared. The soil of the experimental farm is classified as alluvial soil group having sandy loam texture. Seedbed was prepared by single pass of plough, double pass of cultivator and single pass of rotavator for obtaining good tilth. The details of crop cultivated in test plot are as follows.

3.5.1 Chillies

Chillies plants were transplanted manually on the ridges at row-row distance of 0.60 m and plant to plant distance of 0.45 m. and another plot is 0.60 x 0.60 m The recommended rate of fertilizers (N: P: K) was applied in 3 splits at the time of transplanting, 30 days after transplanting. Proper irrigation was applied to crop during its life period. During vegetative growth, irrigation was applied after every 10 days. Weeding was done with developed weeder in chillies at 20 DAT as shown in plate 3.13.



Plate 3.12 Manually method of chillie transplanting



Plate 3.13 After 20 days of chillie

3.5.2 Forward Speed of Operation

The forward speed operation of tractor of 0.6, 0.8 and 1.0 km h⁻¹ were selected for optimizing the best forward speed of the tractor along with the intra row weeding equipment.

3.5.3 Plant to Plant Distance

Generally, in wider row spaced crops the row to row spacing varies from 60 to 120 cm and the intra row spacing i.e., between the plant with in the row varies from 30 to 60 cm. Hence three spacing of 30, 45 and 60 cm between the plant to plant were selected for optimizing the intra row weeder.

3.5.4 Depth of Operation

Generally, in dryland agricultural the weeding equipment are operated up to depth of 2 to 6 cm for better removal weeds and soil pulverization. Hence three depths of 2, 4 and 6 cm were selected for ptimising the best depth of operation of intra row weeding equipment.

3.5.5 Rotational Speed of Cutting Spike

The rpm of the PTO shaft of tractor was 540 rpm. For better churning of the soil. Three levels of rpm of cutting blades were selected. The designed rpm were obtained by changing suitable pulley and belt drive from gear box to cutting blade unit The rpm from PTO shaft of tractor was reduce to in two stages in between the PTO and the counter shaft of the gear box. The second reduction was between the counter shaft of the gear box to the rotary cutting blade unit through belt and pullies. In the first stage the rpm was reduced from 540 to 180 rpm by mounting 1:3 reduction gears on the gear box. In the second stage, the required rpm was obtained by providing selected size pullies to obtain 180, 220 and 290 rpm on the cutting blade unit.

3.5.6 Levels of variables

The interaction effect of variables on weeder performance was conducted for chillies. The experiment was conducted at 30 days after transplanting i.e. 30 DAT. The levels of variables selected for investigating the interactive effect of depth of operation and speed of operation on performance of weeder are furnished (Table 3.3).

Table 3.3 Details of variables and its levels considered for field evaluation

Parameters	Levels	Symbols
INDEPENDENT VARIABLES		
Machine forward speed (S)	3	S ₁ S ₂ S ₃
Plant to plant distance (P)	3	P ₁ P ₂ P ₃
Depth of operation (D)	3	D ₁ D ₂ D ₃
Rpm of cutting blade (R)	3	R ₁ R ₂ R ₃
DEPENDENT VARIABLES		
Weeding Efficiency (%)	.....	WE
Plant Damage (%)	.....	PD
Draft, (kg)	.....	D
Fuel Consumption, (l h ⁻¹)	.....	FC
Field capacity (ha h ⁻¹)	.....	EFC

3.5.7 Optimization of Variables

Selected levels of variables were optimized for achieving the best performance in terms of evaluation of parameters. Parameters selected were weeding efficiency, plant damage and performance index of weeder. The treatment with the combination of selected variables that resulted in maximum value of weeding efficiency, fuel consumption and minimum plant damage was selected as optimized combination level of variables for the field evaluation prototype weeder.

3.6 LABORATORY PERFORMANCE OF INTER AND INTRA ROW WEEDER

After fabrication of weeder laboratory performance was conducted. Sticks were used instead of plants as shown in plate 3.14. Intra row of sticks to stick maintained distance 30, 45 and 60 cm



Plate 3.14 laboratory model developed in the field for intra row (sticks instead of plants)



Plate 3.15 Side view of inter and intra row testing in laboratory model



Plate 3.16 After testing of inter and intra row weeder in laboratory

After testing stick to stick (plant to plant) distance and below 30 cm was stick (plant) damage is more. there was no damage at 45 and 60 cm. So more than 30 cm was most suitable.

It was also find out machine forward speeds at 3 levels that is, 0.6, 0.8 and 1 km h⁻¹ rpm of weeding tool is 180, 220 and 290 respectively. This levels are finalized testing for field performance of inter and intra weeder.

3.7 FIELD PERFORMANCE OF THE PROTOTYPE INTER AND INTRA ROW WEEDER

The performance evaluation of prototype tractor drawn inter and intra row weeder was conducted in sandy loam soils of Dr. NTR College of Agricultural Engineering, Bapatla. The prototype inter and intra weeder was mounted to the tractor through three-point hitch system operated at a forward speed of 0.6, 0.8 and 1.0 km h⁻¹. The observations

on weeding efficiency, plant damage, field capacity, draft and fuel consumption were recorded.

A test length of 30m for crop at all three forward speeds were recorded for all the parameters and each test was replicated thrice to eliminate experimental bias. The same procedure was followed at D₁, D₂ and D₃ depth of operation levels and evaluated for all the parameters. Thus, a total number of 27 runs with 9 runs in the crop is completed and performance data was recorded. Following performance parameters were calculated from the field data.

3.7.1 Weeding Efficiency

Weeding efficiency is a ratio between the number of weeds removed by a weeder to the no. of weeds present in a unit area and expressed as percentage (Anonymous, 1983). Number of weeds before and after each test was counted and replicated thrice and average was calculated at all forward speeds of 0.6, 0.8, 1.0 km h⁻¹ at D₁, D₂ and D₃ depth of operation levels for chillie crop.

$$\text{Weeding efficiency (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \dots(i)$$

where,

W₁ = Number of weeds before weeding

W₂ = Number of weeds after weeding



Plate 3.17 Counting weeds before weeding and after weeding in m²

3.7.2 Plant Damage

It is the ratio between the number of damaged plants in a row to the number of plants present and expressed in percentage. Number of plants in a 20 m row length were recorded before and after operation and replicated thrice and average plant damage percentage was calculated at all forward speeds of 0.6, 0.8 and 1.0 km h⁻¹ at D₁, D₂ and D₃ depth of operation levels for chillie crops.

$$\text{Plant damage, (\%)} = \left\{ 1 - \frac{q}{p} \right\} \times 100 \quad \dots\dots(\text{ii})$$

where,

q = Number of plants left in a 20 m row length after weeding

p = Number of plants in a 20 m row length before weeding

3.7.3 Field Capacity

Field capacity is defined as the ratio of the field coverage by weeder. Turning time at the end of the field operation was added with the actual operating time for effective field capacity determination.

I. Theoretical field capacity

Theoretical field capacity was determined by the following equation (Verma and Dewangan., 2006).

$$\text{Theoretical field capacity, ha.hr}^{-1} = \frac{S \times W}{10} \quad \dots\dots(\text{iii})$$

Where,

TFC = Theoretical field capacity, ha. h⁻¹

S = forward speed, km. h⁻¹

W = width of coverage, m

II. Effective field capacity

Effective field capacity is the actual average rate of field coverage by the Machine, based upon the total field time and it is given as (Verma and Dewangan , 2006).

$$C_{\text{eff}} = \frac{A}{T} \quad \dots\dots \text{(iv)}$$

Where,

C_{eff} = effective field capacity, ha. h⁻¹

A = Field coverage, ha

T = Actual time of operation, h

III. Field efficiency

Field efficiency represents the ratio of effective field capacity to theoretical field Capacity and was expressed as percentage. The field capacity was calculated by using the following formula.

$$\text{Field efficiency } E_f = \frac{EFC}{TFC} \times 100 \quad \dots\dots\dots \text{(v)}$$

Where,

E_f = Field efficiency, %

EFC = Effective field capacity, ha. h⁻¹

TFC = Theoretical field capacity, ha. h⁻¹

IV. Fuel consumption measurement

Experiments were conducted in selected plot to measure the fuel consumption of tractor with test implement. Before operation, the fuel tank of tractor was filled with fuel up to brim. Tractor was operated with the developed equipment in the selected plot. The amount of fuel added to fill the fuel tank up to the brim was noted as fuel consumed by the tractor was expressed as follows.

$$\text{Fuel Consumption } F_t = \frac{V}{t} \quad \dots\dots\dots \text{(vi)}$$

Where,

F = fuel consumption rate, $l\ h^{-1}$

V = volume of fuel consumed, l

t = total operating time, h

3.7.4 Draft of Inter and Intra Weeder

The drawbar pull (draft force) was measured using 1 ton S-type load cell which was attached to the front of the test tractor mounted with implement. Another auxiliary tractor was used to pull test tractor through a load cell based dynamometer in load and no load condition. The average draw bar pull is taken while in neutral gear without implement in operating condition and the towing force while the implement is in weeding operation as shown in Plate 3.18 (Nkakini *et al.*, 2008).



Plate 3.18 Measurement of draft in the field

3.8 COST ECONOMICS OF INTER AND INTRA WEEDER OPERATION

Any agricultural equipment should be designed, taking into consideration of its cost economics. A machine designed should have minimum cost with better field performance. Therefore, cost economics of tractor drawn inter and intra weeder was determined by straight line method. Total cost of inter and intra weeder was determined by adding both the net cost of material used for fabrication and labour cost for fabrication.

Similarly, total cost of operation was calculated on the basis of fixed and variable cost and shown in Appendix. The estimated cost of operation was compared with manual weeding method.

3.8.1 Fixed Cost

Fixed cost is the total cost of depreciation, interest on investment, tax, insurance and housing. Straight-line method was used for calculating the depreciation of the machine.

I. Depreciation

Depreciation is the reduction in value of a machine with the passage of time. Among the various systems employed in calculating depreciation, the straight line method is the most practical and most common. It is the simplest method and gives a constant annual charge for depreciation throughout the life of the machine. The following equation is used for calculating the depreciation. The salvage value in this equation assumed equal to 10 % of the initial cost. (Alizadeh *et al.*, 2007).

$$\text{Depreciation (Rs/h)} = \frac{C-S}{L \times H} \quad \dots\dots \text{(ix)}$$

Where,

D = Depreciation cost h⁻¹, Rs/-

C = Purchase price of the machine, Rs/-

S = Salvage value of the machine, Rs/-

L = Useful life of the machine, years

H = Working hour per year, h

II. Interest on investment

Interest on the investment in a farm machine is a legitimate cost, since money spent in buying a machine cannot be used for other productive enterprises. The following equation is used for calculating the interest (Alizadeh *et al.*, 2007).

$$\text{Interest (Rs/h)} = \frac{C+S}{2} \times \frac{i}{H} \quad \dots\dots \text{(x)}$$

Where,

$I = \text{Interest per hour, Rs h}^{-1}$

$i = \text{rate of Interest, \%}$

III. Insurance, taxes and housing costs

These are minor items in the total fixed costs, but should be included. These are wide variations among states in regard to property taxes. This amount was paid at the time of purchase and this may be distributed over the life of the machine. It depends on the type of machine/implement. Generally, each one was taken 1% of initial cost of the implement (Alizadeh *et al.*, 2007).

3.8.2 Variable Cost

Variable costs are directly related to the amount of use and include repairs and maintenance, fuel and lubricants and wages for man power. The various costs are calculated as discussed below.

I. Repair and maintenance

The cost for repairing and maintenance was taken 10 % of purchase price of the tractor (Alizadeh *et al.*, 2007).

II. Fuel cost

Tractor operated inter and intra weeder with 20 hp. For calculating cost of fuel per hour, fuel consumption to operate and present cost of the fuel per litre were considered.

III. Lubrication costs

The cost of engine oils and lubricants was estimated as 30 % of fuel consumption cost (Alizadeh *et al.*, 2007).

IV. Wages and labour charges

To operate the tractor man power is required. The existing rates for tractor driver was taken to calculate wages. The working hours per day was considered as 8 hours. (Alizadeh *et al.*, 2007).

The total cost of operation per hour of the implement was calculated by using above mentioned procedure is summarized below.

$$1. \text{Fixed cost} = \text{Depreciation} + \text{Interest} + \text{Insurance} + \text{Taxes} + \text{Housing}$$

2. Variable cost = Fuel + Lubricant + Repair and maintenance + wages

3. Total cost of operation = Fixed Cost + Variable Cost

Chapter IV

RESULTS AND DISCUSSION

In this chapter, the design calculations of development and evaluation of semi-automatic inter and intra row weeder for wider row spaced crops were presented. The developed machine was tested to optimize the operating parameters to achieve the desired performance and also performance evaluation of the unit was carried for different treatments. The results of weeding efficiency, plant damage and other parameters were analyzed and narrated. The performance evaluation of prototype inter and intra row weeder is presented.

The technical specifications of the tractor drawn inter and intra row weeder are shown in Table 4.1

Table 4.1. Specification of inter and intra row weeder

S. No.	Particular	Specification
1.	Name of machine	Inter and Intra Row Weeder
2.	Make	ANGRAU
3.	Model	Prototype
4.	Type of machine	Mini-tractor and tractor operated
6.	Overall width of machine, mm	1500
7.	Overall length of machine, mm	1085
7.	Overall height of machine, mm	1000
8.	No. of rows covered	1 (intra) 2 (inter)
9.	Type of transmission system	Bevel gear box
10.	No. of pillow back bearings	2
11.	No. of flange bearings	2
12.	Diameter of rotary disc (cm)	15
13.	Type of linkage system	3-point linkage

4.1 CROP PARAMETERS INFLUENCING THE WEEDING OPERATION

4.1.1 Plant to plant spacing

In wider spaced crops, the plant to plant spacing varies from 30 to 60 cm. Hence two spacing's of 45 and 60 cm were selected for present evaluation. The chilly crop seedlings were transplanted in the field manually at the age of 35 days.

4.1.2 Plant Height

In normal practice, the weed removal and intercultural operations have to be performed at different stages of the crop growth period. In chilly crop, the critical weed control period ranges from 30 days after transplanting (DAT). The crop height in this period would define the height of the intercultural equipment and ground clearance of the power source. Keeping the importance of crop parameters, the plant height was measured randomly in five selected locations for a sample of 10 plants of the crop of the experimental field at 45 days after transplanting.

Table 4.2. Plant height at 30 and 45 DAT (G-3, 425)

Parameter	DAT	Overall field values (cm)
Mean, cm	30	37.54
S.D.		2.56
C.V.		0.068
Mean, cm	45	61.30
S.D.		3.78
C.V.		0.061

The data pertaining to each sample means and overall field mean observed values of G-3(425) chilly variety were presented in Table 4.2. The chilly plant heights were observed in the range of 34 to 41.0 cm with a overall field mean of 37.54 cm. and 57.3 to 66.0 cm with a overall field mean of 61.30 at 30 and 45 days after DAT respectively. The plant height differences among the highest and lowest values of replications were also

very low which was also supported by the statistical parameter coefficient of variation. The overall plant mean height values at 30 and 45 DAT were 37.54 and 61.30 respectively.

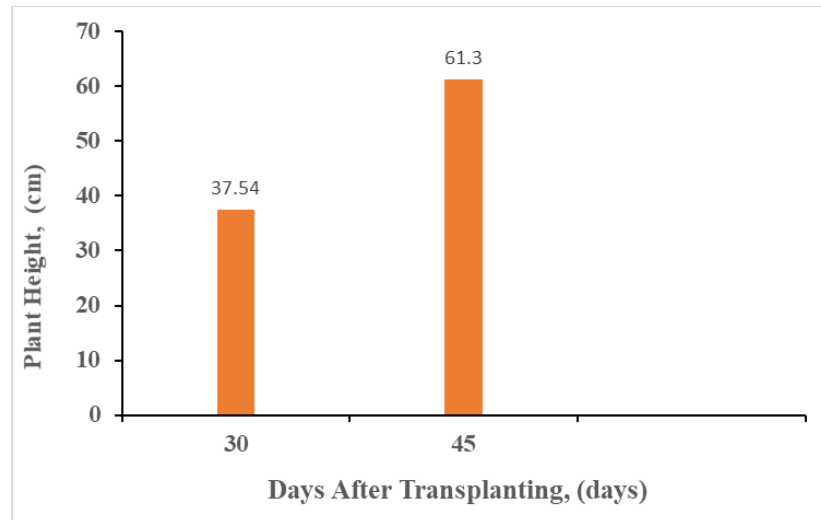


Fig. 4.1 Plant height vs Days after transplanting

4.1.3 Speed of cutting blades

The rpm of the PTO shaft of tractor is 540 rpm, for better churning of the soil, three rpm of cutting blades were selected. The designed rpm was obtained by changing suitable pulley and belt drive from gear box to cutting blade unit. The rpm from PTO shaft of tractor was reduce to in two stages in between the PTO and the counter shaft of the gear box. The second reduction was between the counter shaft of the gear box to the rotary cutting blade unit through belt and pullies. In the first stage the rpm was reduced from 540 to 180 rpm by mounting 1:3 reduction gears on the gear box. In the second stage, the required rpm was obtained by providing selected size pullies to obtain a range of 220 to 240 rpm on the cutting blade unit for all the treatment combinations.

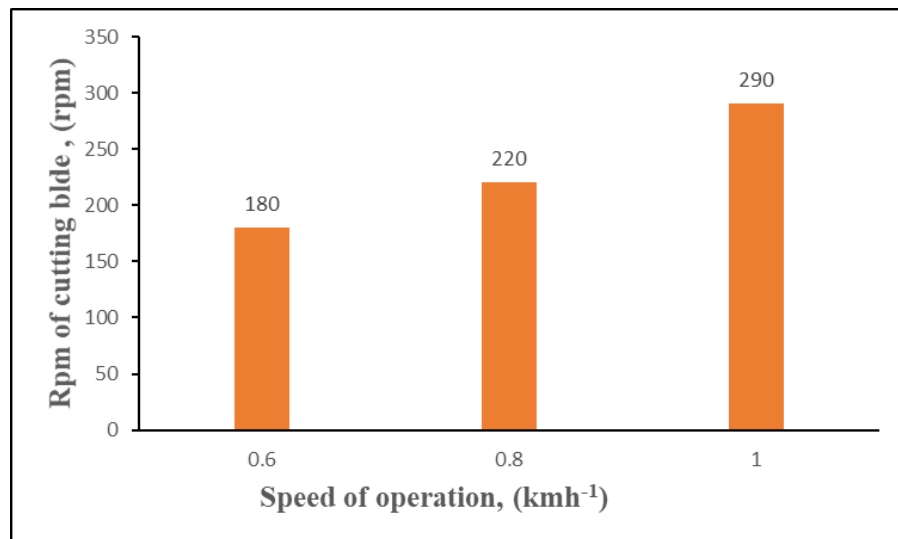


Fig. 4.2 Speed of operation vs rotation speed of cutting blade

4.2 PERFORMANCE EVALUATION OF INTER AND INTRA ROW WEEDER

The performance evaluation of developed inter and intra row weeder was conducted in chillie crop. Performance indicators and economics of the weeder were presented.

4.2.1 Effect of Selected Levels of Variables on Weeding Efficiency

Generally, the weeding operation is performed in chillie crop at 30, 45 and 60 DAT. However, to reduce number of experiments were conducted at different depths of operation on weeding efficiency at 45 DAT of chillie crop.

4.2.1.1 Effect of depth and machine operational parameters on weeding efficiency in chilly crop at 45 cm intra row spacing

The influence of depth and machine operational parameters on weeding efficiency at 45 cm intra row spacing in chilly crop was presented in table 4.3. The weeding efficiency for different treatment combinations is shown in fig 4.3 to 4.5.

Table 4.3. Effect of D x N x S interaction on weeding efficiency for 45 cm intra row spacing

Forward Speed (S)	Number of Blades (N)			F-Mean
	N ₁	N ₂	N ₃	
D= D₁				
S ₁	61	64	72	65.7
S ₂	58	61	68	62.3
S ₃	56	58	64	59.3
N-Mean	58.3	61.0	68.0	
D= D₂				
S ₁	70	79	83	77.3
S ₂	67	76	81	74.7
S ₃	66	72	80	72.7
N-Mean	67.7	75.7	81.3	
D= D₃				
S ₁	68	71	76	71.7
S ₂	65	68	71	68.0
S ₃	62	65	69	65.3
N-Mean	65.0	68.0	72.0	

It was observed that the weeding efficiency increased with increase in depth of the cutting blades and number of blades per assembly at all forward speeds. This was due to reduction in bite length (Beeny and Khoo, 1970; Chamen, 1979 and Patnaik, 1982). It was observed that the weeding efficiency decreased when the forward speed increased for all levels of variables. A maximum weeding efficiency of 83 % was obtained at 4 cm blade depth and at 6 number of blades per assembly at forward speed of 0.6 kmh⁻¹.

At depth D₁(2 cm), weeding efficiency increased as number of blades increased. The rate of increase is higher when no of blades increased from 2 to 6 nos. However, the weeding efficiency decreased as the speed increased from S₁ to S₃. The main reason for obtaining low weeding efficiency at 2 cm depth of operation is due to non-contacting of the blades to the soil when the field is uneven during operation. At depth D₂(4 cm), weeding efficiency increased as number of blades increased. The rate of increase is higher

when no of blades increased from 2 to 6 nos. However, weeding efficiency decreased as the speed increased from S_1 to S_3 .

At depth D_3 (6 cm), weeding efficiency increased as number of blades increased from 2 to 6 nos. However, the weeding efficiency decreased as the speed increased. Due to increase of speed from S_1 to S_3 , the weeding efficiency decreased at all depths of operation, as the time for operating the intra row weeding unit manually reduced considerably. The highest weeding efficiency of 83% was obtained for $D_2S_1N_3$ combination followed by 81 and 80% were obtained for $D_2 S_2 N_3$ and $D_2 S_3 N_3$ combination respectively.

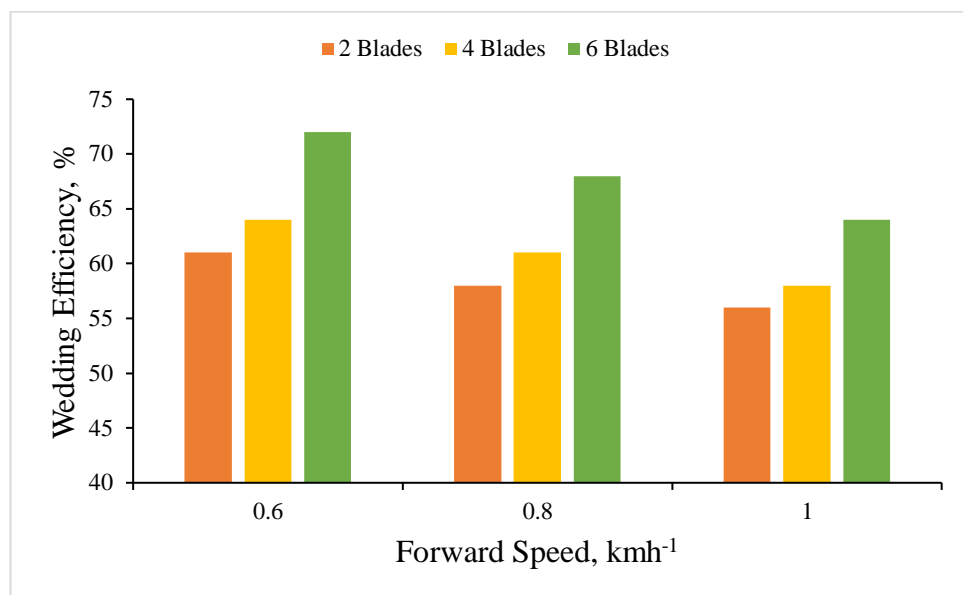


Fig. 4.3 Effect of number of blades and forward speed (S) on weeding efficiency at 45 cm intra row spacing for depth (D_1)

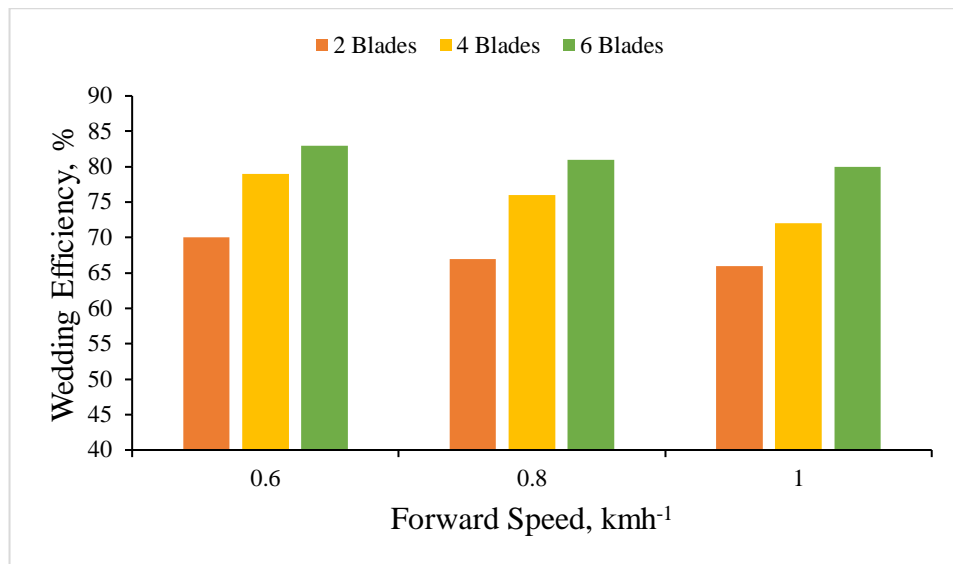


Fig. 4.4 Effect of number of blades and forward speed (S) on weeding efficiency at 45 cm intra row spacing for depth (D₂)

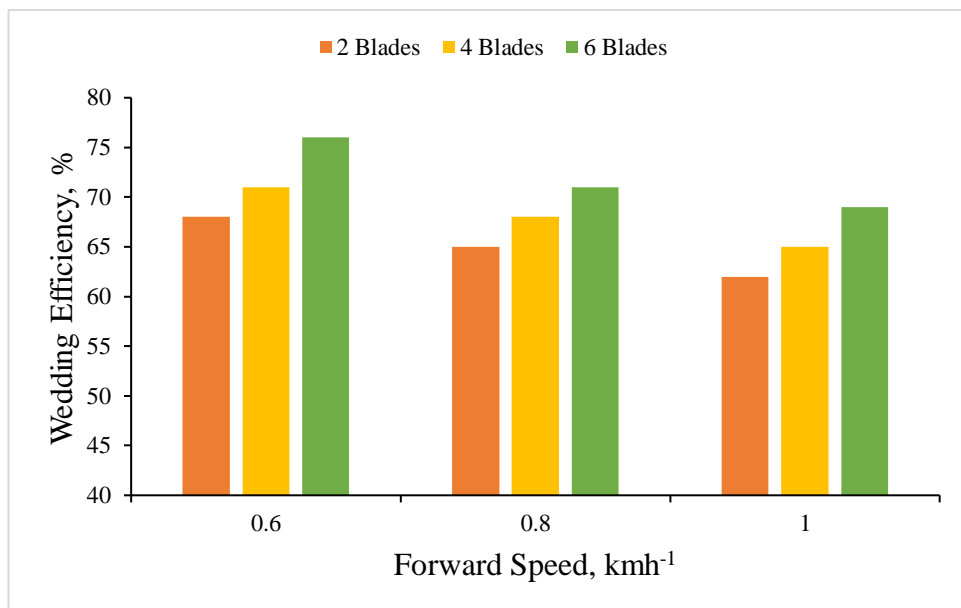


Fig. 4.5 Effect of number of blades and forward speed (S) on weeding efficiency at 45 cm intra row spacing for depth (D₃)

Table 4.4. ANOVA for weeding efficiency at 45 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	900.65	100.07	44.88	< 0.0001	significant
A-Depth	1	84.10	84.10	37.71	0.0001	
B-Speed	1	108.90	108.90	48.83	< 0.0001	
C-Number of blades	1	230.40	230.40	103.32	< 0.0001	
AB	1	0.00	0.00	0.00	1.0000	
AC	1	2.00	2.00	0.90	0.3659	
BC	1	2.00	2.00	0.90	0.3659	
A²	1	275.00	275.00	123.32	< 0.0001	
B²	1	2.75	2.75	1.23	0.2928	
C²	1	0.69	0.69	0.31	0.5909	
Residual	10	22.30	2.23			
Lack of Fit	5	19.47	3.89	6.87	0.0271	significant
Pure Error	5	2.83	0.57			
Cor Total	19	922.95				

cv = 1.8%, ** = significant at 1% level

The analysis of variance for individual and interaction effect of variables on weeding efficiency is summarized in Table 4.4. The analysis of variance showed that there was significant difference among the treatments. The individual effect of the variables viz., cutting blade depth, number of blades per assembly and forward speed were highly significant. This confirmed that these three variables had influenced the weeding efficiency. The interaction effect of D x N x S was not significant implying that they are independent variables and the three factor interaction does not influence the weeding efficiency (Table 4.4).

4.2.1.2 Effect of depth and machine operational parameters on weeding efficiency in chilly crop at 60 cm intra row spacing

The influence of depth and machine operational parameters on weeding efficiency at 60 cm intra row spacing in chilly crop was presented in table 4.5. The weeding efficiency for different treatment combinations is shown in fig 4.6 to 4.8.

Table 4.5. Means of D×N×S interaction for 60 cm intra row spacing

Forward Speed (S)	Number of Blades (N)			F-Mean
	N ₁	N ₂	N ₃	
D= D₁				
S ₁	65	69	75	69.7
S ₂	61	65	71	65.7
S ₃	59	63	69	63.7
N- Mean	61.7	65.7	71.7	
D= D₂				
S ₁	71	76	85	77.3
S ₂	69	75	84	76.0
S ₃	68	79	84	77.0
N- Mean	69.3	76.7	84.3	
D= D₃				
S ₁	71	69	78	72.7
S ₂	68	73	76	72.3
S ₃	66	76	73	71.7
N-Mean	68.3	72.7	75.7	

It was observed that the weeding efficiency increased with increase in depth of the cutting blades and number of blades per assembly at all forward speeds. This was due to reduction in bite length (Beeny and Khoo, 1970; Chamen, 1979 and Patnaik, 1982). When the forward speed increased, it was observed that the weeding efficiency decreased for all levels of variables. At 6 cm blade depth and at 6 number of blades per assembly the maximum weeding efficiency of 85 % was obtained at forward speed of 0.6 km h⁻¹.

At depth D₁ (2 cm), weeding efficiency increased as number of blades increased. The rate of increase is higher when no of blades increased from 2 to 6 nos. However, the weeding efficiency decreased as the speed increased from S₁ to S₃. The main reason for obtaining low weeding efficiency at 2 cm depth of operation is due to non-contacting of

the blades to the soil when the field is uneven during the operation. At depth D_2 (4 cm), weeding efficiency increased as number of blades increased. The rate of increase is higher when no of blades increased from 2 to 6 nos. However, weeding efficiency decreased as the speed increased from S_1 to S_3 .

At depth D_3 (6 cm), weeding efficiency increased as number of blades increased from 2 to 6 nos. However, the weeding efficiency decreased as the speed increased. Due to increase of speed from S_1 to S_3 , the weeding efficiency decreased at all depths of operation, as the time for operating the intra row weeding unit manually reduced considerably.

The highest weeding efficiency of 85% was obtained for $D_2 S_1 N_3$ combination followed by 84 and 84% were obtained for $D_2 S_2 N_3$ and $D_2 S_3 N_3$ combination respectively.

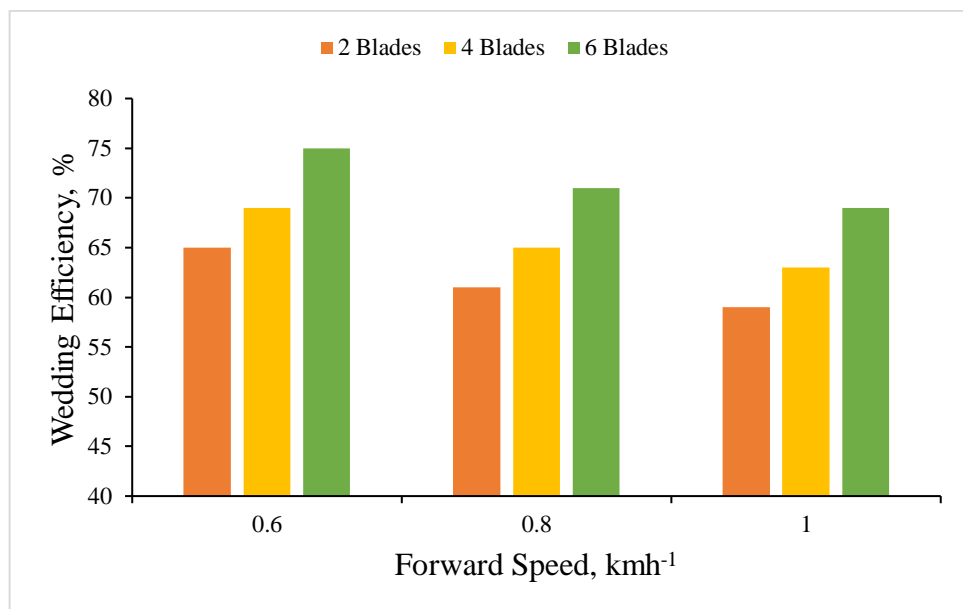


Fig. 4.6 Effect of number of blades and forward speed (S) on weeding efficiency at 60 cm intra row spacing for depth (D_1)

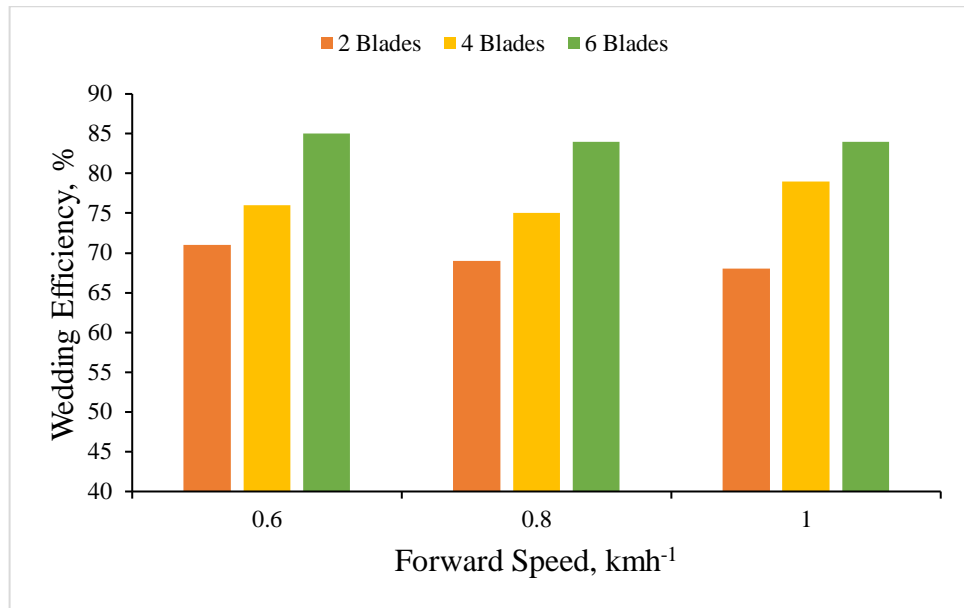


Fig. 4.7 Effect of number of blades and forward speed (S) on weeding efficiency at 60 cm intra row spacing for depth (D₂)

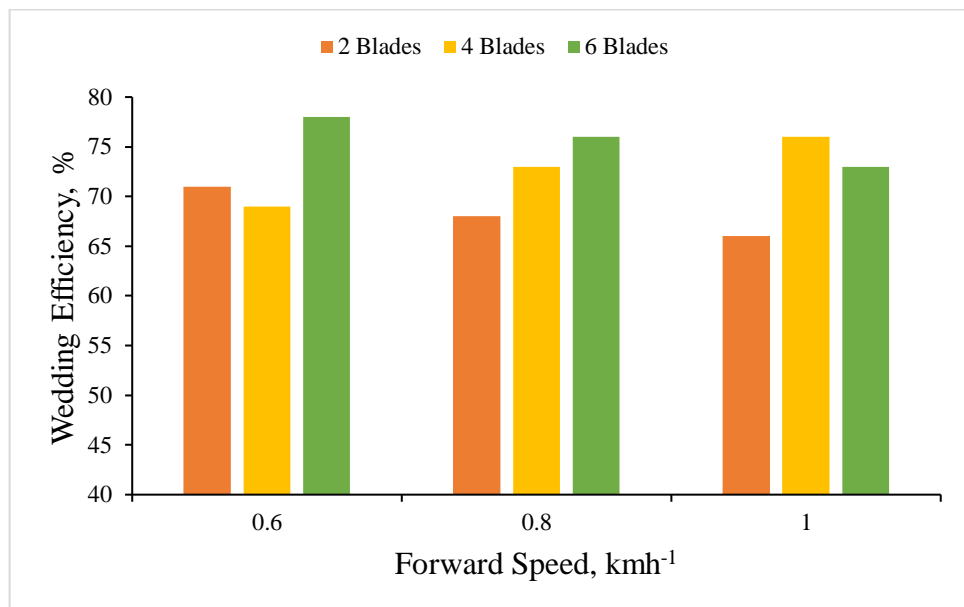


Fig. 4.8 Effect of number of blades and forward speed (S) on weeding efficiency at 60 cm intra row spacing for depth (D₃)

The analysis of variance for individual and interaction effect of variables on weeding efficiency is summarized in Table 4.6. The analysis of variance showed that there was significant difference among the treatments. The individual effect of the variables *viz.*, cutting blade depth, number of blades per assembly and forward speed were highly significant. This confirmed that these three variables had influenced the weeding

efficiency. The interaction effect of D x N x S was not significant implying that they are independent variables and the three-factor interaction does not influence the weeding efficiency (Table 4.6).

Table 4.6. ANOVA for weeding efficiency at 60 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	444.39	49.38	11.12	0.0004	significant
A-Depth	1	48.40	48.40	10.90	0.0080	
B-Speed	1	16.90	16.90	3.81	0.0456	
C-Number of blades	1	202.50	202.50	45.60	< 0.0001	
AB	1	2.00	2.00	0.45	0.5174	
AC	1	18.00	18.00	4.05	0.0718	
BC	1	4.50	4.50	1.01	0.3378	
A²	1	73.84	73.84	16.63	0.0022	
B²	1	30.28	30.28	6.82	0.0260	
C²	1	19.78	19.78	4.45	0.0610	
Residual	10	44.41	4.44			
Lack of Fit	5	44.41	8.88			
Pure Error	5	0.00	0.00			
Cor Total	19	488.80				

CV = 1.8%, ** = significant at 1% level

The R×N×S table of means indicated that the highest weeding efficiency of 84 % was obtained for the forward speed of 0.6 kmh⁻¹, blade depth of 6 cm and at 6 number of blades(S₁ D₃ N₃). Higher depth and number of blades and minimum forward speed led to finer soil breakup because of shorter bite length (Beeny and Khoo, 1970; Chamen, 1979 and Patnaik, 1982). However, it was observed that there is no significance difference in weeding efficiency at 0.8 and 1.0 kmh⁻¹ forward speeds compared to 0.6 for 60 cm plant to plant spacing. This may be due to sufficient space between the plants within the row.

4.2.1.3 Optimized operational parameters for maximum weeding efficiency

The experimental results of different treatment configuration that yielded the maximum weeding efficiency are presented in Table 4.7.

Table 4.7. Best treatment combination for maximum weeding efficiency

Intra row spacing	Best treatment combination	Maximum weeding efficiency (%)
45 cm	D ₂ S ₁ N ₃	83
	D ₂ S ₂ N ₃	81
	D ₂ S ₃ N ₃	80
60 cm	D ₂ S ₁ N ₃	85
	D ₂ S ₂ N ₃	84
	D ₂ S ₃ N ₃	84

4.3 Effect of depth and machine operational parameters on Plant damage in chilly crop at 45 cm intra row spacing

Table 4.8. Effect of D×N×S interaction on plant damage for 45 cm intra spacing

Forward speed (F)	Number of blades (N)			F-Mean
	N ₁	N ₂	N ₃	
D= D₁				
S ₁	1	1	2	1.3
S ₂	1	2	2	1.7
S ₃	1	2	2	1.7
N-Mean	1	1.7	2	
D= D₂				
S ₁	1	1	2	1.3
S ₂	1	2	2	1.7
S ₃	1	2	2	1.7
N- Mean	1	1.7	2	
D= D₃				

S₁	4	6	7	5.7
S₂	5	6	8	6.3
S₃	5	7	9	7
N-Mean	4.6	6.3	8	

The plant damage obtained at 45 cm intra plant row spacing by varying the number of blades per assembly, depth of operation and at different forward speeds were analyzed and presented.

The plant damage obtained at 45 cm intra plant row spacing for the different treatment combination is shown in Fig 4.9- to 4.11. It was observed that the plant damage increased with the increase in number of blades per assembly at all selected levels of forward speeds. The plant damage obtained at operating depths of 2 and 4 cm was almost similar when the speed increased from S₁ to S₃ when number of blades increased from 2 to 6 nos. This is may be due to no change in the force required in operating the intra row weeding unit manually and also maneuverability during operation. However, the plant Damage was comparatively higher when the depth of operation increased from 4 to 6 cm at all forward speeds of operation. This is may be due to change in the force required in operating the intra row weeding unit manually and also maneuverability during operation.

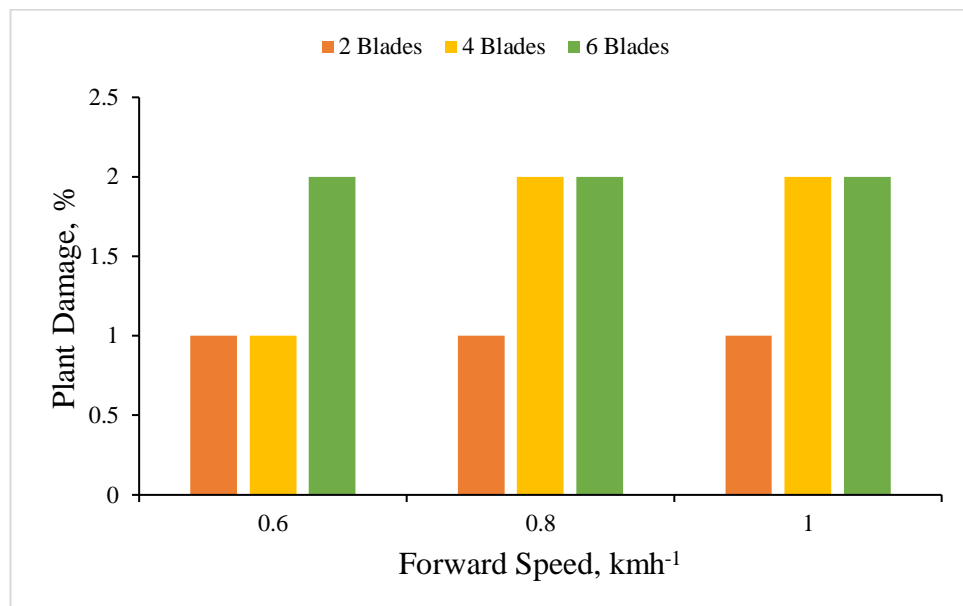


Fig. 4.9 Effect of number of blades and forward speed (S) on plant damage at 45 cm intra row spacing for depth (D₁)

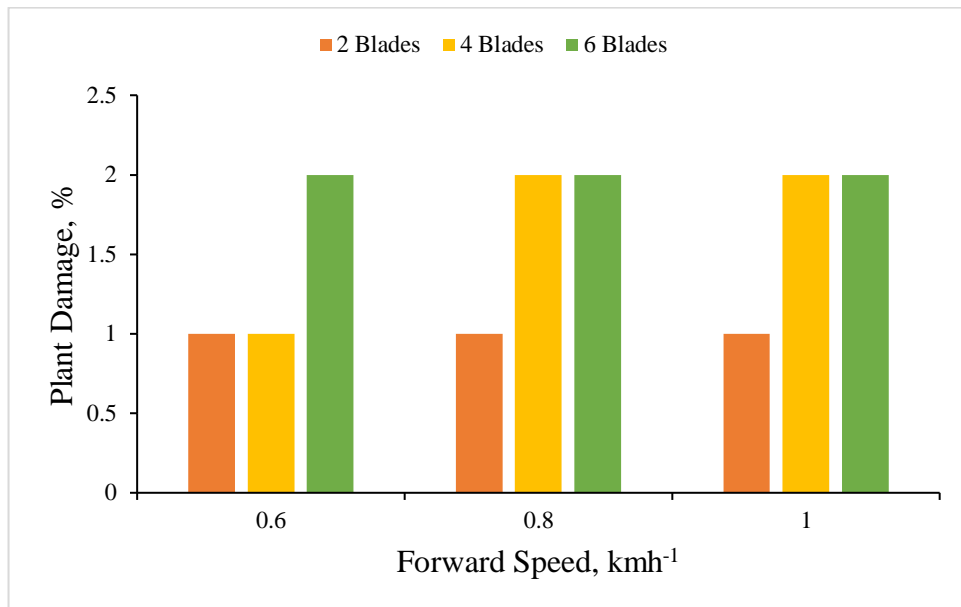


Fig. 4.10 Effect of number of blades and forward speed (S) on plant damage at 45 cm intra row spacing for depth (D₂)

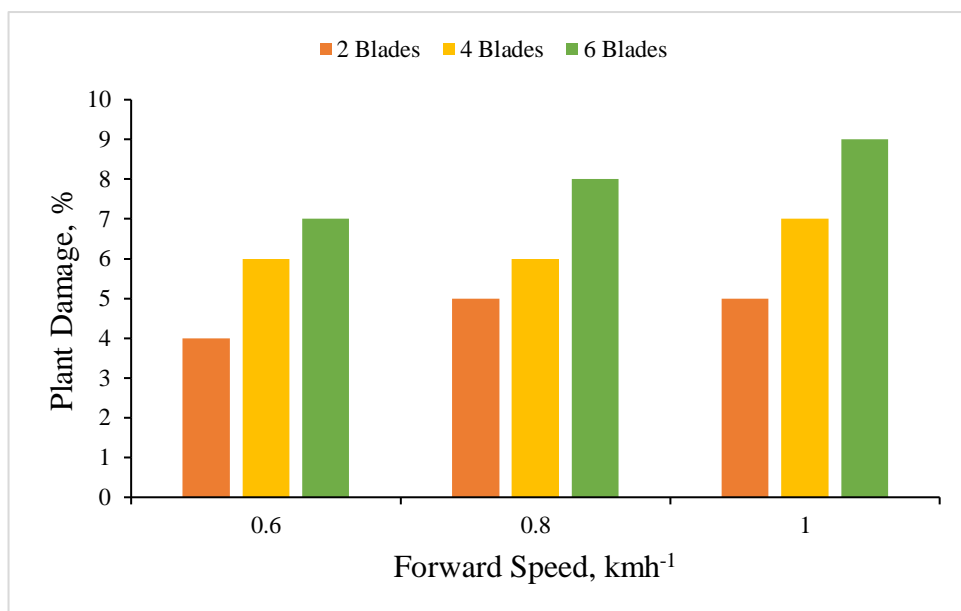


Fig. 4.11 Effect of number of blades and forward speed (S) on plant damage at 45 cm intra row spacing for depth (D₃)

The analysis of variance showed that there was no significant difference among the treatments. The individual effect of the variables *viz.*, depth, number of blades per assembly and forward speed were also not significant. This confirmed that these three

variables have not influenced the plant damage. The interaction effect of $D \times N \times S$, were not significant. The lowest plant damage of 1-2.0% was obtained for all the treatment combination at depth D_1 and D_2 .

Table 4.9. ANOVA for plant damage at 45 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	111.13	12.35	21.20	< 0.0001	significant
A-Depth	1	72.90	72.90	125.15	< 0.0001	
B-Speed	1	0.00	0.00	0.00	1.0000	
C-Number of blades	1	3.60	3.60	6.18	0.0322	
AB	1	0.12	0.12	0.21	0.6531	
AC	1	0.13	0.13	0.21	0.6531	
BC	1	3.13	3.13	5.36	0.0431	
A²	1	17.19	17.19	29.51	0.0003	
B²	1	0.00	0.00	0.00	1.0000	
C²	1	0.00	0.00	0.00	1.0000	
Residual	10	5.83	0.58			
Lack of Fit	5	5.83	1.17			
Pure Error	5	0.00	0.00			
Cor Total	19	116.95				

4.3.1 Effect of depth and machine operational parameters on Plant damage in chilly crop at 60 cm intra row spacing

The plant damage obtained at 60 cm intra plant row spacing by varying the number of blades per assembly, depth of operation and at different forward speeds were analyzed and presented.

The plant damage obtained at 60 cm intra plant row spacing for the different treatment combination is shown in Fig 4.12 to 4.14. It was observed that the plant damage increased with the increase in number of blades per assembly at all selected levels of forward speeds. The plant damage obtained at operating depths of 2 and 4 cm was almost similar when the speed increased from S_1 to S_3 when number of blades increased from 2 to 6 nos. This is may be due to no change in the force required in operating the intra row weeding unit manually and also maneuverability during operation. However, the plant

Damage was comparatively higher when the depth of operation increased from 4 to 6 cm at all forward speeds of operation. This is may be due to change in the force required in operating the intra row weeding unit manually and also maneuverability during operation.

Table 4.10. Means of D×N×S interaction of plant damagefor 60 cm intra spacing

Forward speed (F)	Number of blades (N)			F-Mean
	N ₁	N ₂	N ₃	
D= D₁				
S₁	1	1	1	1
S₂	1	1	2	1.3
S₃	1	1	2	1.3
N- Mean	1	1	1.7	
D= D₂				
S₁	1	1	2	1.3
S₂	1	1	2	1.3
S₃	1	1	2	1.3
N- Mean	1	1	2	
D= D₃				
S₁	3	3	5	3.7
S₂	3	4	7	4.7
S₃	4	4	8	1.7
N-Mean	3.3	3.7	6.7	

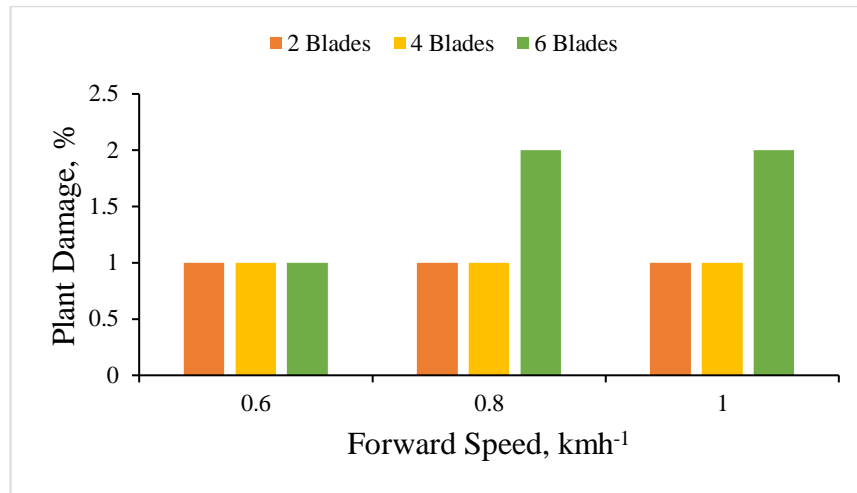


Fig. 4.12 Effect of number of blades and forward speed (S) on plant damage at 60 cm intra row spacing for depth (D₁)

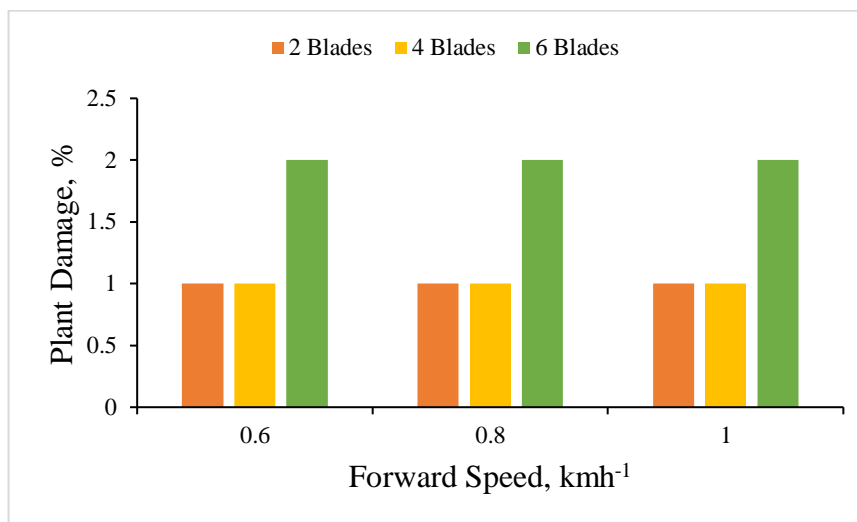


Fig. 4.13 Effect of number of blades and forward speed (S) on plant damage at 60cm intra row spacing for depth (D₂)

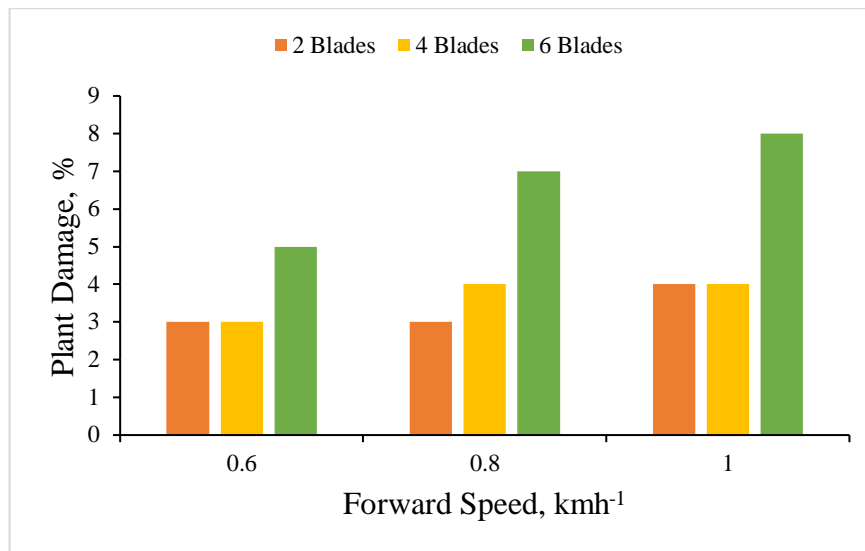


Fig. 4.14 Effect of number of blades and forward speed (S) on plant damage at 60 cm intra row spacing for depth (D₃)

The analysis of variance showed that there was no significant difference among the treatments. The individual effect of the variables *viz.*, depth, number of blades per assembly and forward speed were also significant. This confirmed that these three variables have not influenced the plant damage. The interaction effect of D×N×S, were also not significant. The lowest plant damage of 1-2.0 % was obtained for all the treatment combination at depth D₁ and D₂.

Table 4.11. ANOVA for plant damage at 60 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	65.74	7.30	60.53	< 0.0001	significant
A-Depth	1	32.40	32.40	268.47	< 0.0001	
B-Speed	1	2.50	2.50	20.72	0.0011	
C-Number of blades	1	6.40	6.40	53.03	< 0.0001	
AB	1	1.13	1.13	9.32	0.0122	
AC	1	3.13	3.13	25.89	0.0005	
BC	1	1.13	1.13	9.32	0.0122	
A²	1	6.57	6.57	54.43	< 0.0001	
B²	1	0.01	0.01	0.05	0.8326	
C²	1	0.82	0.82	6.78	0.0263	
Residual	10	1.21	0.12			
Lack of Fit	5	1.21	0.24			
Pure Error	5	0.00	0.00			
Cor Total	19	66.95				

4.3.2 Optimized operational parameters for minimum plant damage

The experimental results of different treatment configuration that yielded the minimum plant damage are presented in Table 4.12.

Table 4.12. Best treatment combination for minimum plant damage

Intra row spacing	Best treatment combination	Maximum plant damage (%)
45 cm	All combinations at D ₁ and D ₂ depths	1-2
60 cm	All combinations at D ₁ and D ₂ depths	1-2

4.4 Effect of depth and machine operational parameters on draft in chilly crop at 45 cm intra row spacing

The draft obtained at 45 cm intra plant row spacing by varying the number of blades per assembly, depth of operation and at different forward speeds were analyzed and presented.

The draft obtained at 45cm intra plant row spacing for the different treatment combination is shown in Fig 4.15 to 4.17. It was observed that the draft increased with the increase in number of blades from 2 to 6 nos and also with the increase of depth from 2 to 6 cm at all selected levels of forward speeds. The increase in draft was not significant for increase in number of blades and also increase of depth from 2 to 4 cm when forward speed increased. The main reason for obtaining low draft at 2 cm depth of operation is due to non-contacting of the blades to the soil when the field is uneven during the operation. However, there is significant difference in draft when depth increased from 4 to 6 cm as speed increased. This is mainly due to increase of contact area as depth of operation increased. Draft increased as speed is increased, indicates that draft is directly proportional to speed.

Table 4.13. Means of D×N×S interaction on draft for 45 cm intra row spacing

Forward speed (F)	Number of blades (N)			F-Mean
	N ₁	N ₂	N ₃	
D= D₁				
S₁	142	145	150	145.7
S₂	146	153	160	153.0
S₃	151	158	162	157.0
N- Mean	146.3	152.0	157.3	
D= D₂				
S₁	148	154	162	154.7
S₂	158	163	166	162.3
S₃	161	166	172	166.3
N- Mean	155.7	161.0	166.7	
D= D₃				

S₁	174	176	194	181.3
S₂	176	185	199	186.7
S₃	185	195	206	195.3
N-Mean	178.3	185.3	199.7	

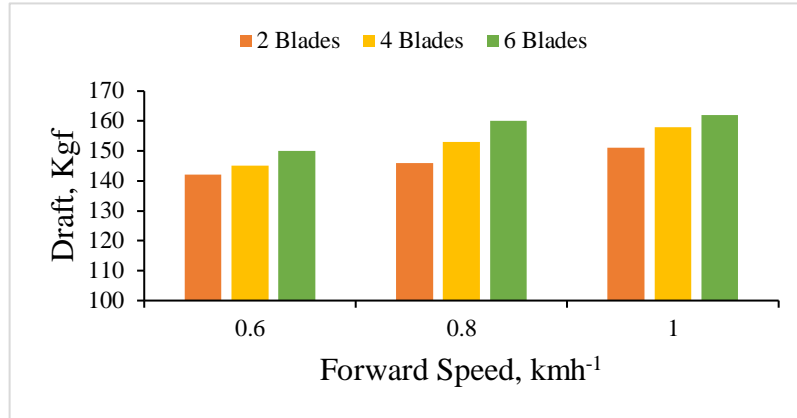


Fig. 4.15 Effect of number of blades and forward speed (S) on daft at 45 cm intra row spacing for depth (D₁)

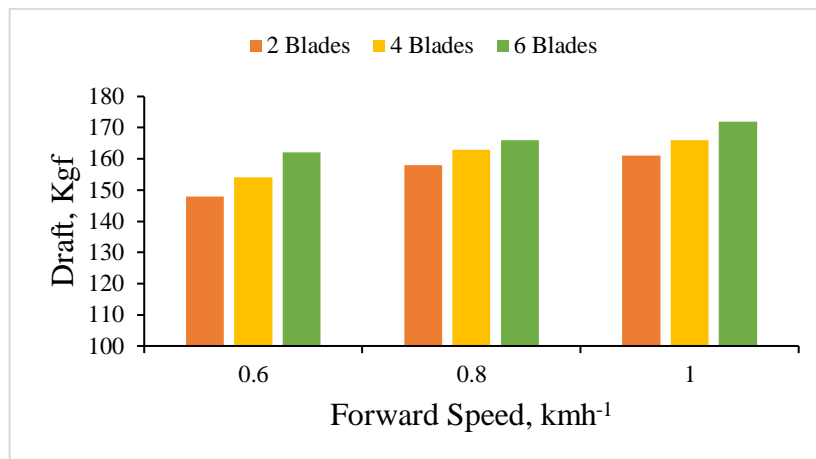


Fig. 4.16 Effect of number of blades and forward speed (S) on daft at 45 cm intra row spacing for depth (D₂)

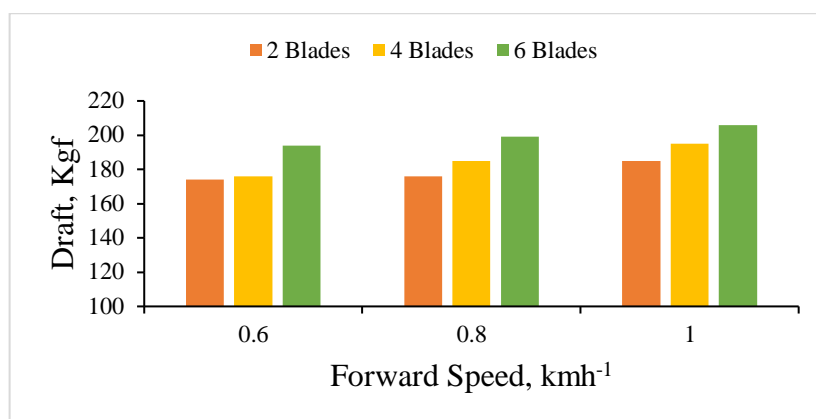


Fig. 4.17 Effect of number of blades and forward speed (S) on daft at 45 cm intra row spacing for depth (D₃)

The analysis of variance to assess the significance of the variables *viz.*, depth (D), number of blades per assembly (N) and forward speed (S) on draft is summarized in Table 4.14.

Table 4.14. ANOVA for draft at 45 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	4622.60	513.62	101.51	< 0.0001	significant
A-Depth	1	3459.60	3459.60	683.72	< 0.0001	
B-Speed	1	313.60	313.60	61.98	< 0.0001	
C-Number of blades	1	462.40	462.40	91.38	< 0.0001	
AB	1	0.50	0.50	0.10	0.7597	
AC	1	60.50	60.50	11.96	0.0061	
BC	1	2.00	2.00	0.40	0.5436	
A²	1	176.00	176.00	34.78	0.0002	
B²	1	2.75	2.75	0.54	0.4779	
C²	1	2.75	2.75	0.54	0.4779	
Residual	10	50.60	5.06			
Lack of Fit	5	50.60	10.12			
Pure Error	5	0.00	0.00			
Cor Total	19	4673.20				

The analysis of variance showed that there was no significant difference among the treatments. The individual effect of the variables *viz.*, depth, number of blades per

assembly and forward speed were significant. This confirmed that these three variables have influenced the draft. The interaction effect of $D \times N \times S$, were also not significant. The lowest draft of 141 kg was obtained for all the treatment combination at depth D_1 and D_2 .

4.4.1. Effect of depth and machine operational parameters on draft in chilly crop at 60 cm intra row spacing

The draft obtained at 60 cm intra plant row spacing for the different treatment combination is shown in Fig 4.18 to 4.20. It was observed that the draft increased with the increase in number of blades from 2 to 6 nos and also with the increase of depth from 2 to 6 cm at all selected levels of forward speeds at 60 cm intra row spacing. The increase in draft was not significant for increase in number of blades and also increase of depth from 2 to 4cm when forward speed increased. The main reason for obtaining low weeding efficiency at 2 cm depth of operation is due to non-contacting of the blades to the soil when the field is uneven during the operation. However, there is significant difference in draft when depth increased from 4 to 6 cm as speed increased. This is mainly due to increase of contact area as depth of operation increased. Draft increased as speed increased, indicates that draft is directly proportional to speed.

Table 4.15. Means of $D \times N \times S$ interaction for 60 cm intra row spacing

Forward speed (F)	Number of blades (N)			F-Mean
	N ₁	N ₂	N ₃	
D= D₁				
S ₁	142	145	154	147.0
S ₂	146	154	161	153.7
S ₃	154	158	164	158.7
N- Mean	147.3	152.3	159.7	
D= D₂				
S ₁	156	159	161	158.7
S ₂	160	163	168	163.7
S ₃	163	168	171	167.3
N- Mean	159.7	163.3	166.7	
D= D₃				
S ₁	175	179	193	182.3

S₂	178	182	198	186.0
S₃	184	196	207	195.7
N-Mean	179.0	185.7	199.3	

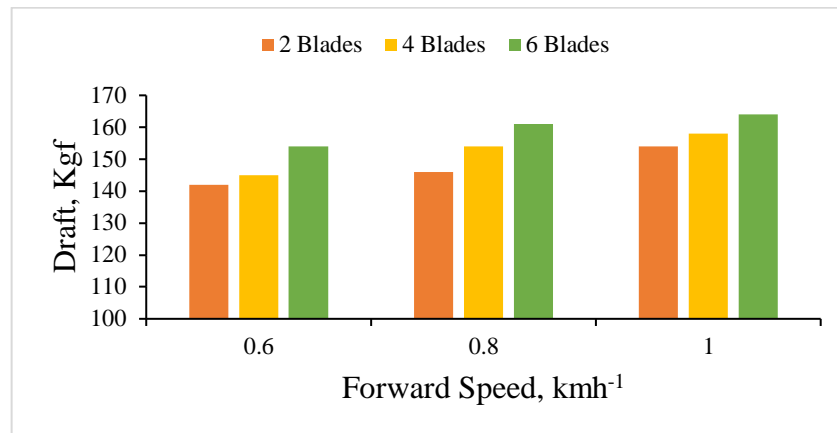


Fig. 4.18 Effect of number of blades and forward speed (S) on daft at 60 cm intra row spacing for depth (D₁)

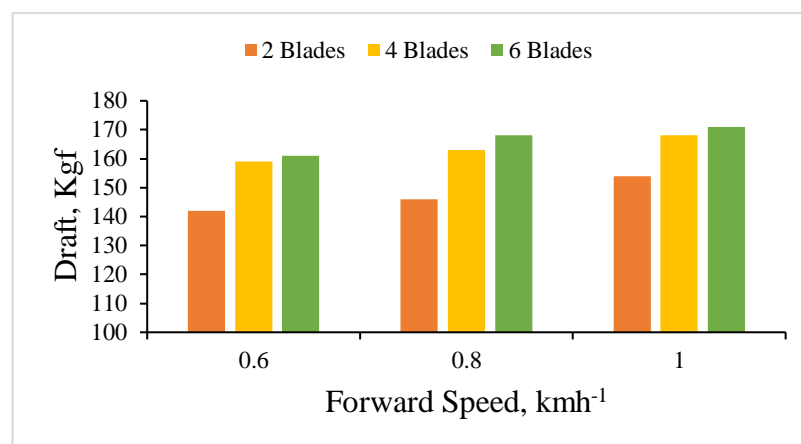


Fig. 4.19 Effect of number of blades and forward speed (S) on daft at 60 cm intra row spacing for depth (D₂)

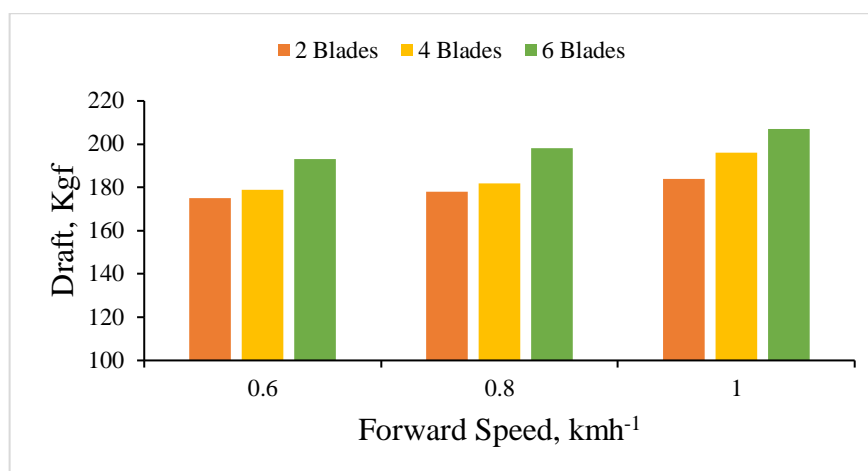


Fig. 4.20 Effect of number of blades and forward speed (S) on daft at 60 cm intra row spacing for depth (D₃)

The analysis of variance to assess the significance of the variables *viz.*, depth (D), number of blades per assembly (N) and forward speed (S) on draft is summarized in Table 4.16.

Table 4.16. ANOVA for draft at 60 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	4144.43	460.49	75.03	< 0.0001	significant
A-Depth	1	2992.90	2992.90	487.68	< 0.0001	
B-Speed	1	291.60	291.60	47.51	< 0.0001	
C-Number of blades	1	504.10	504.10	82.14	< 0.0001	
AB	1	0.13	0.13	0.02	0.8893	
AC	1	45.13	45.13	7.35	0.0219	
BC	1	1.13	1.13	0.18	0.6776	
A²	1	91.64	91.64	14.93	0.0031	
B²	1	4.45	4.45	0.73	0.4142	
C²	1	8.64	8.64	1.41	0.2628	
Residual	10	61.37	6.14			
Lack of Fit	5	61.37	12.27			
Pure Error	5	0.00	0.00			
Cor Total	19	4205.80				

The analysis of variance showed that there was no significant difference among the treatments. The individual effect of the variables *viz.*, depth, number of blades per assembly and forward speed were significant. This confirmed that these three variables have influenced the draft. The interaction effect of $D \times N \times S$, were also not significant. The lowest draft was obtained for all the treatment combination at depth D_1 and D_2 .

4.4.3 Optimized operational parameters for minimum Draft

The experimental results of different treatment configuration that yielded the minimum draft are presented in Table 4.17.

Table 4.17. Best treatment combination for minimum Draft

Intra row spacing	Best treatment combination	Minimum draft
45 cm	All combinations at D_1 and D_2 depths	142
60 cm	All combinations at D_1 and D_2 depths	142

4.5 Effect of depth and machine operational parameters on field capacity for 45 cm intra row spacing

The Field Capacity obtained at 45 cm intra plant row spacing for the different treatment combination is shown in Fig 4.21 to 4.23. It was observed that the Field Capacity decreased with the increase in number of blades from 2 to 6 nos and also with the increase of depth from 2 to 6 cm at all selected levels of forward speeds at 45 cm intra row spacing. The decrease in Field Capacity was significant for increase in number of blades and also increase of depth from 2 to 4 cm when forward speed increased from S_1 to S_3 . This is mainly due to increase of contact area as depth of operation increased.

Table 4.18. Means of $D \times N \times S$ interaction for 45 cm intra row spacing

Forward speed (F)	Number of blades (N)			F-Mean
	N_1	N_2	N_3	
D= D_1				
S_1	0.144	0.138	0.135	0.139
S_2	0.368	0.358	0.356	0.360
S_3	0.561	0.557	0.554	0.557
N- Mean	0.357	0.351	0.348	

D= D₂				
S₁	0.144	0.139	0.134	0.139
S₂	0.366	0.357	0.352	0.358
S₃	0.562	0.557	0.555	0.558
N- Mean	0.357	0.351	0.347	
D= D₃				
S₁	0.134	0.127	0.116	0.125
S₂	0.323	0.319	0.316	0.319
S₃	0.523	0.515	0.509	0.515
N-Mean	0.326	0.320	0.313	

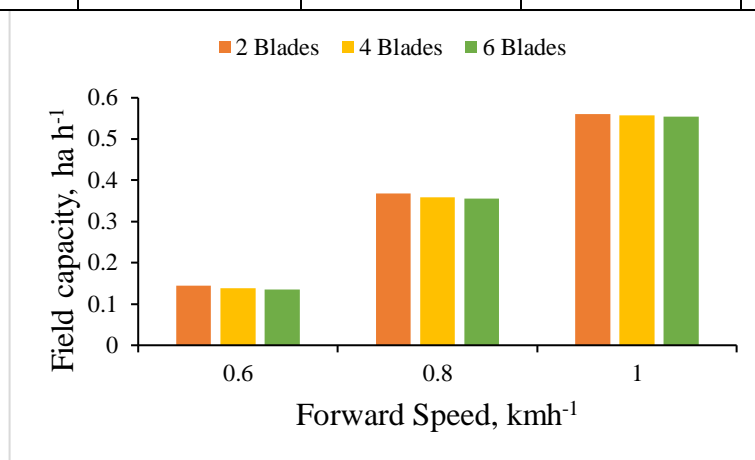


Fig. 4.21 Effect of number of blades and forward speed (S) on field capacity at 45 cm intra row spacing for depth (D₁)

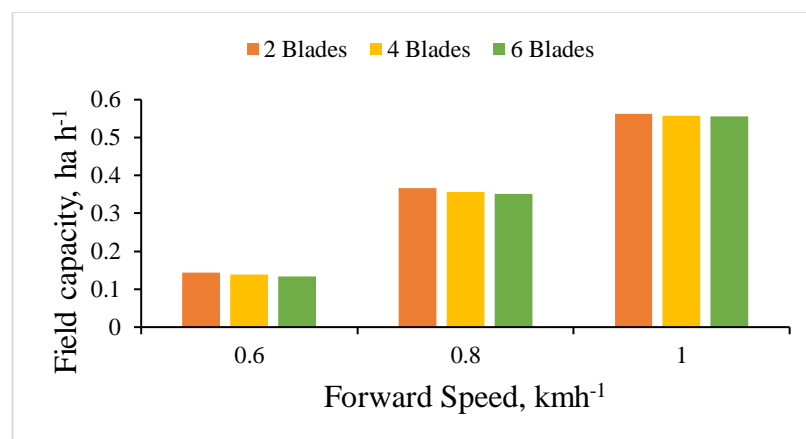


Fig. 4.22 Effect of number of blades and forward speed (S) on field capacity at 45 cm intra row spacing for depth (D₂)

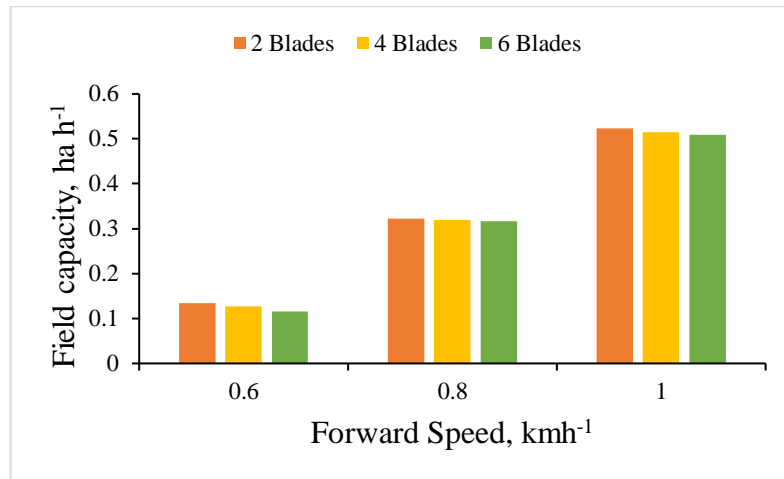


Fig. 4.23 Effect of number of blades and forward speed (S) on field capacity at 45 cm intra row spacing for depth (D₃)

The analysis of variance to assess the significance of the variables *viz.*, depth (D), number of blades per assembly (N) and forward speed (S) on Field Capacity is summarized in Table 4.19.

Table 4.19. ANOVA for Field Capacity at 45 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	0.42	0.05	3663.59	< 0.0001	significant
A-Depth	1	0.00	0.00	179.07	< 0.0001	
B-Speed	1	0.41	0.41	32556.23	< 0.0001	
C-Number of blades	1	0.00	0.00	30.19	0.0003	
AB	1	0.00	0.00	28.63	0.0003	
AC	1	0.00	0.00	2.51	0.1440	
BC	1	0.00	0.00	0.35	0.5654	
A²	1	0.00	0.00	65.46	< 0.0001	
B²	1	0.00	0.00	13.51	0.0043	
C²	1	0.00	0.00	2.06	0.1814	
Residual	10	0.00	0.00			
Lack of Fit	5	0.00	0.00			
Pure Error	5	0.00	0.00			
Cor Total	19	0.42				

The analysis of variance showed that there was no significant difference among the treatments. The individual effect of the variables *viz.*, depth, number of blades per assembly and forward speed were significant. This confirmed that these three variables have influenced the Field capacity. The interaction effect of $D \times N \times S$, were also not significant. The highest Field capacity of 0.562, 0.557 and 0.555 hah^{-1} were obtained for treatment combinations $D_2 S_3 N_1$, $D_2 S_3 N_2$ and $D_2 S_3 N_3$ at 60 cm for all the treatment combination at depth D_2 .

4.5.1 Effect of Depth and Machine Operational Parameters on Field Capacity for 60 cm intra row spacing

The Field Capacity obtained at 60 cm intra plant row spacing for the different treatment combination is shown in Fig 4.24 to 4.26. It was observed that the Field Capacity decreased with the increase in number of blades from 2 to 6 nos and also with the increase of depth from 2 to 6 cm at all selected levels of forward speeds at 45 cm intra row spacing. The decrease in Field Capacity was significant for increase in number of blades and also increase of depth from 2 to 4 cm when forward speed increased from S_1 to S_3 . This is mainly due to increase of contact area as depth of operation increased.

Table 4.20. Means of $D \times N \times S$ interaction for 60 cm intra row spacing

Forward speed (F)	Number of blades (N)			F-Mean
	N_1	N_2	N_3	
D= D_1				
S_1	0.145	0.138	0.136	0.139
S_2	0.369	0.359	0.357	0.361
S_3	0.529	0.522	0.557	0.536
N- Mean	0.347	0.339	0.350	
D= D_2				
S_1	0.146	0.143	0.135	0.141
S_2	0.368	0.360	0.353	0.360
S_3	0.561	0.555	0.553	0.556

N- Mean	0.358	0.352	0.347	
D= D3				
S₁	0.133	0.128	0.120	0.127
S₂	0.326	0.322	0.318	0.322
S₃	0.538	0.525	0.516	0.526
N-Mean	0.332	0.325	0.318	

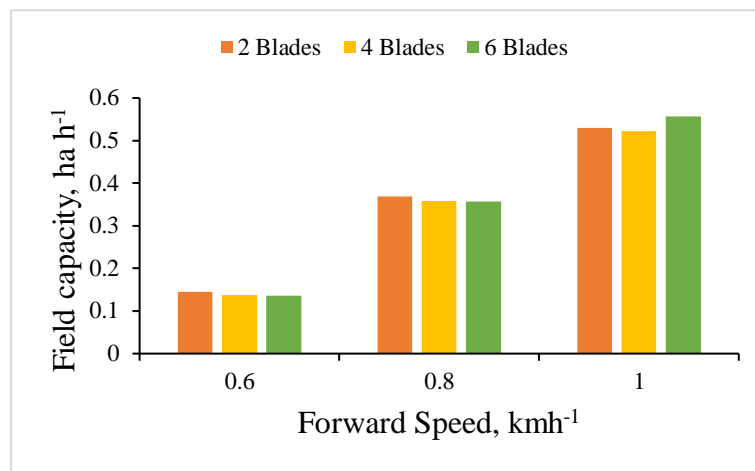


Fig. 4.24 Effect of number of blades and forward speed (S) on field capacity at 60 cm intra row spacing for depth (D₁)

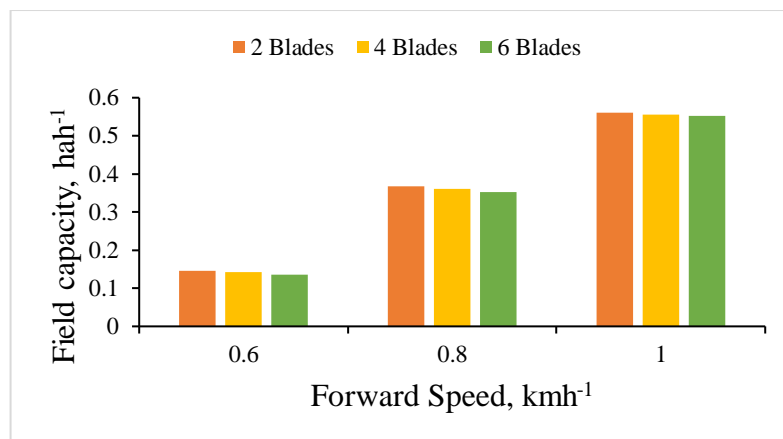


Fig. 4.25 Effect of number of blades and forward speed (S) on field capacity at 60 cm intra row spacing for depth (D₂)

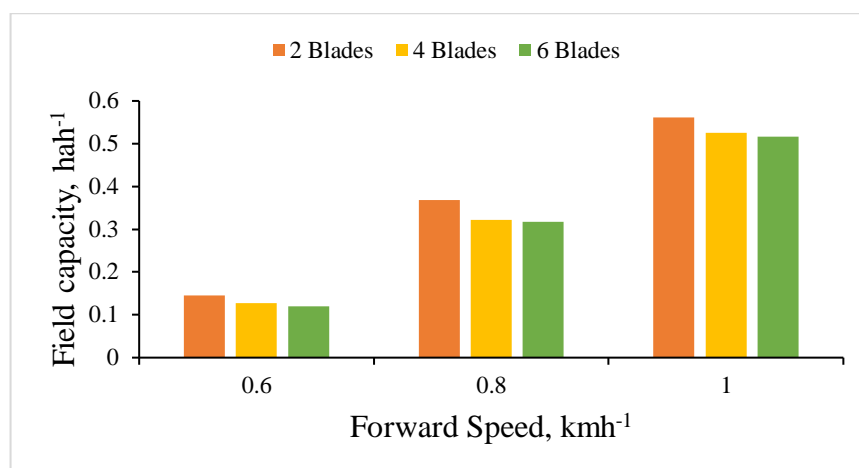


Fig. 4.26 Effect of number of blades and forward speed (S) on field capacity at 60 cm intra row spacing for depth (D₃)

The analysis of variance to assess the significance of the variables *viz.*, depth (D), number of blades per assembly (N) and forward speed (S) on Field Capacity is summarized in Table 4.19.

Table 4.21. ANOVA for Field Capacity at 60 cm intra row spacing

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	9	0.41	0.046	818.68	< 0.0001	significant
A-Depth	1	0.00	0.001	16.85	0.0021	
B-Speed	1	0.41	0.407	7291.78	< 0.0001	
C-Number of blades	1	0.00	0.000	1.72	0.2189	
AB	1	0.00	0.000	0.04	0.8537	
AC	1	0.00	0.000	6.53	0.0286	
BC	1	0.00	0.000	1.75	0.2148	
A²	1	0.00	0.001	15.87	0.0026	
B²	1	0.00	0.000	4.40	0.0623	
C²	1	0.00	0.000	0.21	0.6596	
Residual	10	0.00	0.000			
Lack of Fit	5	0.00	0.000			
Pure Error	5	0.00	0.000			

Cor Total	19	0.41				
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4.5.2 Optimized operational parameters for maximum Field Capacity

The experimental results of different treatment configuration that yielded the maximum Field Capacity are presented in Table 4.22.

Table 4.22. Best treatment combination for maximum Field Capacity

Intra row spacing	Best treatment combination	Maximum Field Capacity
45 cm	D ₂ S ₃ N ₁	0.562
	D ₂ S ₃ N ₂	0.557
	D ₂ S ₃ N ₃	0.555
60 cm	D ₂ S ₃ N ₁	0.561
	D ₂ S ₃ N ₂	0.555
	D ₂ S ₃ N ₃	0.553

4.5.3 Effect of depth and machine operational parameters on fuel consumption in chilly crop

It was also observed that the fuel consumption increased significantly from 1.8, 2.14 l h⁻¹, 1.9 to 2.44 l h⁻¹ and 2.12 to 2.73 l h⁻¹ when the forward speed increased from 0.6 to 1.0 kmh⁻¹ at D₁, D₂ and D₃ depth of operation levels, respectively, at 45 and 60 cm inter row spacing. It was observed that the fuel consumption was almost constant for further increase of forward speed from 1.0 to 1.8 kmh⁻¹. However, the increase in the rate of fuel consumption were 65%, 78% and 89% when forward speed increased from of 1.0 to 1.8 kmh⁻¹ at D₁, D₂ and D₃ depth of operation levels, respectively, at 45 and 60 cm intra row spacing. It has been found that fuel consumption increases with increasing the operating speed of the weeder, because if speed increases the draft force increases.

The results of individual and interactive effect of the selected variables were optimized to achieve a suitable treatment combination that would yield better performance in terms of higher weeding efficiency, minimum plant damage, draft and maximum Field Capacity. The individual effect of pertinent parameters showed significant difference between various treatments whereas the interactive effect did not

have the significance on the performance of weeding techniques. Hence, it is difficult to identify the best treatment combination among the selected levels of variables. Therefore, in order to identify a suitable combination that would yield better performance, the ranking method was performed.

Table 4.23. Ranking of combination based on the performance

Sl. No.	Quality Parameters	Intra row spacing cm	Ranking of weeding combinations		
			I	II	III
1	Weeding efficiency(%)	45	D ₂ S ₁ N ₃	D ₂ S ₂ N ₃	D ₂ S ₃ N ₃
		60	D ₂ S ₁ N ₃	D ₂ S ₂ N ₃	D ₂ S ₃ N ₃
2	Plant damage (%)	45	All combinations at D ₁ and D ₂ depths		
		60	All combinations at D ₁ and D ₂ depths		
3	Draft (kgf)	45	All combinations at D ₁ and D ₂ depths		
		60	All combinations at D ₁ and D ₂ depths		
4	Field capacity (ha h ⁻¹)	45	D ₂ S ₃ N ₁	D ₂ S ₃ N ₂	D ₂ S ₃ N ₃
		60			

From the Table 4.23, It is inferred that there is no difference in the ranking position of weeding efficiency in both the intra row spacing of 45 and 60 cm. It was observed that treatment combination D₂ S₃ N₃ found a place with in three ranks in all the parameters like Weeding efficiency, Plant damage, Draft and Field capacity both at 45 and 60 cm intra row spacing. Low Weeding Efficiency and draft obtained at depth D₁ (2 cm) is mainly due to non-contacting of blades to the soil during operation. Generally, for better weeding performance, the depth of operation ranges from 3 to 4 cm. Among all the treatments, weeding efficiency, plant damage are the pertinent parameters which influence the quality of weeding operation with a maximum field capacity. Hence, the

following optimized parameters were considered for the fabrication of the prototype intra row weeding equipment.

Best treatment combination for both 45 and 60 cm intra row spacing's is considered D₂ S₃ N₃ as it found a place with in three ranks in all the parameters like Weeding efficiency, Plant damage, Draft and Field capacity both at 45 and 60 cm intra row spacing. The overall performance found better at depth of operation D₂ (4cm) in all the quality parameters.

4.6 COST ECONOMICS OF INTER AND INTRA ROW WEEDER OPERATION

The tractor operated inter and intra row weeder developed was evaluated for its field performance for the estimation of cost of operation and compared with traditional method of weeding. The cost of weeding with developed inter and intra row weeder was Rs. 1,030 ha⁻¹.

The cost of weeding per hectare of Rs. 1,030 ha⁻¹ and Rs. 6,250 ha⁻¹ were obtained for inter and intra row weeding and traditional weeding, respectively. There was a saving of Rs. 5,220 ha⁻¹ over traditional method of weeding. The detailed calculations were mentioned in appendices IV (B) and (C).

Chapter V

SUMMARY AND CONCLUSION

Tractor operated weeding implements can save about 75 % time and 20 % cost as compared to bullock drawn methods. Usually tractor mounted cultivators are used for weeding and inter-culturing operations in farm. But these are not effective for soil pulverization. The rotating type weeder stirs the soil more accurately, disturb the weed root and remove them from the soil and pulverize the soil effectively. In addition, this helps in keeping the soil in loose condition for proper aeration and results in better aeration and runoff water conservation, especially for the wide row spaced crops, where the tractor can be run. A study was therefore undertaken on “development and evaluation of semi-automatic inter and intra row weeder for wider row spaced crops” at Dr. NTR College of Agricultural Engineering, Bapatla. A tractor drawn inter and intra row weeder suitable for row crops was developed and fabricated at Workshop, Department of Farm machinery and power, Dr. NTR College of Agricultural Engineering, Bapatla. Performance evaluation of developed weeder was conducted by varying different forward speeds of 0.6, 0.8 and 1.0 kmh⁻¹ at constant range of 220-290 rpm and 2, 4 and 6 cm depth of operation levels in chilly crop.

5.1 EFFECT OF DEPTH AND MACHINE OPERATIONAL PARAMETERS ON WEEDING EFFICIENCY

1. The weeding efficiency increased with the increase of depth of operation at all levels of forward speeds. The rate of increase in weeding efficiency was increased with the increase of depth of operation and also with the increase of forward speeds.
2. At intra row spacing of 45 cm, the weeding efficiency increased significantly from 61% to 68%, 70% to 83% and 68% to 84% when the forward speed increased from 0.6 to 1.0 kmh⁻¹ at D₁, D₂ and D₃ depth of operation levels respectively at 45 cm intra row spacing in chillie crop.
3. At intra row spacing of 60 cm, the weeding efficiency increased significantly from 65% to 69%, 71% to 84% and 69% to 81% when the forward speed increased from 0.6 to 1.0 kmh⁻¹ at D₁, D₂ and D₃ depth of operation levels respectively at 60 cm intra row spacing in chillie crop.

4. The weeding efficiency was low at 2 cm depth of operation due to non-contact of the working unit during operation at 45 and 60 cm intra row spacing.

5. Lower weeding efficiencies were obtained at all depth of operation levels at forward speeds of 0.6 kmh⁻¹.

6. The rate of increase in weeding efficiency was more when forward speed increased than increase in depth of operation.

7. The weeding efficiency was almost constant for further increase of forward speed from 1.0 to 1.8 kmh⁻¹.

5.2 EFFECT OF SOIL AND MACHINE OPERATIONAL PARAMETERS ON PLANT DAMAGE

1. In chillie crop at 45 cm intra row spacing, the plant damage increased from 1 to 2 %, 1 to 2% and 4 to 9% with the increase of forward speed from 0.6 to 1.0 kmh⁻¹ at D₁, D₂ and D₃ depth of operation level.

2. In chillie crop at 60 cm intra row spacing, the plant damage increased from 1 to 2 %, 1 to 2% and 3 to 8 % with the increase of forward speed from 0.6 to 1.0 kmh⁻¹ at D₁, D₂ and D₃ depth of operation level.

3. Highest plant damage of observed of 4 to 9 % was recorded at 1.0 kmh⁻¹ at 45 cm intra row spacing.

4. Highest plant damage of observed of 3 to 8 % was recorded at 1.0 kmh⁻¹ at 60 cm intra row spacing.

5. The plant damage was almost constant for further increase of forward speed from 1.0 to 1.8 kmh⁻¹.

5.3 EFFECT OF SOIL AND MACHINE OPERATIONAL PARAMETERS ON DRAFT

1. Draft increased with the increase of forward speed at all levels of depth of operation.

2. Draft decreased from 142 to 162 kg, 148 to 172 kg and 174 to 206 kg at forward speeds of 0.6, 0.8 and 1.0 kmh⁻¹, respectively, when the soil depth of operation increased from D₁, D₂ and D₃ depth of operation at 45 cm intra row spacing.

3. Draft decreased from 142 to 164 kg, 156 to 171 kg and 175 to 207 kg at forward speeds of 0.6, 0.8 and 1.0 kmh⁻¹, respectively, when the soil depth of operation increased from D₁, D₂ and D₃ depth of operation at 60 cm intra row spacing.
4. All combination at D₁ and D₂ minimum draft requirement is 142 kg.

5.4 EFFECT OF SELECTED LEVELS OF VARIABLES ON FIELD CAPACITY

1. It was observed that the field capacity increased with the increase of forward speed at all levels of depth of operation in all the crops both at 45 cm intra row spacing.
2. The field capacity decreased from 0.144 to 0.554, 0.144 to 0.555 and 0.134 to 0.509 ha h⁻¹ in chillie. when weeding operation performed at 45 cm intra row spacing.
3. The field capacity decreased from 0.145 to 0.557, 0.146 to 0.553 and 0.133 to 0.516 ha h⁻¹ in chillie. when weeding operation performed at 60 cm intra row spacing.

5.5 EFFECT OF SELECTED LEVELS OF VARIABLES ON FUEL CONSUMPTION

1. It was also observed that the fuel consumption increased significantly from 1.8, 2.14 l h⁻¹, 1.9 to 2.44 l h⁻¹ and 2.12 to 2.73 l h⁻¹ when the forward speed increased from 0.6 to 1.0 kmh⁻¹ at D₁, D₂ and D₃ depth of operation levels, respectively, at 45 and 60 cm inter row spacing.
2. It was observed that the fuel consumption was almost constant for further increase of forward speed from 1.0 to 1.8 kmh⁻¹. However, the increase in the rate of fuel consumption were 65%, 78% and 89% when forward speed increased from of 1.0 to 1.8 kmh⁻¹ at D₁, D₂ and D₃ depth of operation levels, respectively, at 45 and 60 cm intra row spacing.
3. It has been found that fuel consumption increases with increasing the operating speed of the weeder, because if speed increases the draft force increases.

5.6 COST ECONOMICS OF WEEDING OPERATION WITH INTER AND INTRA ROW WEEDER WEEDER

1. Cost of operation with inter and intra row weeder was observed to be low when compared with traditional method of weeding operation. The saving is about Rs. 5,220 ha⁻¹ over traditional method of weeding.

Suggestions for Future Work

1. Intensive field evaluation of the inter and inter weeder for optimization of depth and machine parameters has to be performed for different row crops for wider adoptability.
2. Design and study of a prototype with two rotating disc that translate opposite to one another.
3. Design and study of a prototype no. of intra row covered at a time may be performed.

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APPENDICE- IV (A)

ANOVA Tables for Standard Deviation, Mean and Coefficient variance (CV)

ANOVA for weeding efficiency in chilies at 45 cm intra row spacing

Std. Dev.	1.49	R-Squared	0.98
Mean	70.55	Adj R-Squared	0.95
C.V. %	2.12	Pred R-Squared	0.85
PRESS	141.51	Adeq Precision	23.49

ANOVA for weeding efficiency at in chilies at 60 cm intra row spacing

Std. Dev.	2.11	R-Squared	0.91
Mean	72.40	Adj R-Squared	0.83
C.V. %	2.91	Pred R-Squared	0.17
PRESS	407.07	Adeq Precision	12.69

ANOVA for plant damage at 45 cm intra row spacing in chilies at all levels

Std. Dev.	0.76	R-Squared	0.95
Mean	3.05	Adj R-Squared	0.91
C.V. %	25.02	Pred R-Squared	0.22
PRESS	91.06	Adeq Precision	14.08

ANOVA for plant damage at 60 cm intra row spacing in chilies at all levels

Std. Dev.	0.35	R-Squared	0.98
Mean	2.05	Adj R-Squared	0.97
C.V. %	16.95	Pred R-Squared	0.83
PRESS	11.30	Adeq Precision	28.76

ANOVA for draft at 45 cm intra row spacing in chilies crop

Std. Dev.	2.25	R-Squared	0.99
Mean	166.20	Adj R-Squared	0.98
C.V. %	1.35	Pred R-Squared	0.92
PRESS	353.23	Adeq Precision	38.98

ANOVA for draft at 60 cm intra row spacing in chilies crop

Std. Dev.	2.48	R-Squared	0.99
Mean	167.10	Adj R-Squared	0.97
C.V. %	1.48	Pred R-Squared	0.87
PRESS	564.97	Adeq Precision	34.02

ANOVA for field capacity at 45 cm intra row spacing in chillie crop

Std. Dev.	0.00	R-Squared	1.00
Mean	0.35	Adj R-Squared	1.00
C.V. %	1.03	Pred R-Squared	1.00
PRESS	0.00	Adeq Precision	178.27

ANOVA for field capacity at 60 cm intra row spacing in chillie crop

Std. Dev.	0.01	R-Squared	1.00
Mean	0.35	Adj R-Squared	1.00
C.V. %	2.16	Pred R-Squared	0.98
PRESS	0.01	Adeq Precision	83.93

APPENDICE- IV (B)

Cost economics of inter and intra row weeder

1. Tractor

Cost of the Tractor (C)	=	Rs. 4,00,000
Life of Tractor (L), years	=	10
Annual usage of Tractor, H (assumed)	=	1000
Actual working hours per day, h (assumed)	=	8
Salvage value(S) (10% of purchase value)	=	Rs. 40,000

A. Fixed cost

Depreciation	=	$\frac{C-S}{L \times H} = \frac{400000-40000}{10 \times 1000}$	=	36.00
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Interest	=	$\frac{C+S}{2} \times \frac{i}{H} = \frac{400000+40000}{2} \times \frac{0.10}{1000}$	=	22.00
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Housing, insurance and taxes	=	$0.03 \times 400000 / 1000$	=	12.00
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A. Total fixed cost (Rs. h ⁻¹)	=	70.00
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B. Variable cost

Repair and maintenance	=	10 % of initial cost	=	$0.1 \times 400000 / 1000$	=	40.00
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Fuel cost (3 lit h ⁻¹ , 1 liter = Rs. 80)	=	3×80	=	240.00
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Lubricants	=	30 % of fuel cost	=	0.3×240	=	72.00
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Labor wages (Rs. 500 per 8 h)	=	62.50
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B. Total variable cost (Rs. h ⁻¹)	=	414.50
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Total cost of tractor (Rs. h ⁻¹) = A + B	=	484.5
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2. inter and intra row weeder

Cost of the weeder (C)	=	Rs.
78,000		
Life of weeder (L), years	=	6
Annual usage of weeder, H (assumed)	=	300
Actual working hours per day, h (assumed)	=	8
Salvage value(S) (10% of purchase value)	=	Rs.
7,800		
Depreciation	= $\frac{C-S}{L \times H} = \frac{78000-7800}{6 \times 300}$	= 39.0
Interest	= $\frac{C+S}{2} \times \frac{i}{H} = \frac{78000+7800}{2} \times \frac{0.10}{300}$	= 14.3
Housing	= $0.01 \times 78000 / 300$	= 2.6
Repair and maintenance	= 10 % of initial cost = $0.1 \times 78000 / 300$	= 26
Total cost of inter and intra row weeder (Rs. h ⁻¹)	=	81.9
Operating cost (Rs. h ⁻¹) weeder	= Total cost of tractor + Total cost of oscillating weeder	
	= 484.5 + 81.9	
	= 566.4	
Effective field capacity of machine	= 0.55 ha h ⁻¹	
Total operating cost capacity (ha h ⁻¹)	= Operating cost (Rs. h ⁻¹) / Effective field	
	= 566.4/0.55	
	= Rs. 1,030 ha ⁻¹	

APPENDICE- IV (C)

Cost economics for manual weeding

In traditional method of weeding, 25 manual labors were required to cover a one hectare. Present labor wages were considered to calculate the cost of operation for manual weeding.

Labor required for one hectare	=	25
Labor wages per person, Rs. day ⁻¹	=	250
Cost of manual weeding, Rs. ha ⁻¹	=	25 x 250
	=	6250