DESIGN AND DEVELOPMENT OF WALK BEHIND TYPE SOLAR POWERED ROTARY WEEDER

A

THESIS SUBMITTED TO THE
SARDARKRUSHINAGAR DANTIWADA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY
(Agricultural Engineering)

IN

FARM MACHINERY AND POWER ENGINEERING

BY

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JUNE – 2022

[Registration No. 04-MTAGE-02379-2020]

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ABSTRACT

Weed control is one of the most difficult tasks on an agricultural farm. Four methods of weed control are commonly known in agriculture viz., manual, mechanical, chemical and biological control. Mechanical weeding is one of the effective methods of weeds removal. Smaller weeding machines commonly known as portable weeders are solely used for weed removal in agricultural fields, gardens, public parks etc. Like tractors, weeders are becoming conventional as the displacement of labours is major concern. But use of mechanical and power weeder is very limited amongst the farmers due to involvement of high cost. Looking to availability of solar energy and fragmented land holding of farmers near to their houses, a weeder operated by solar power may be appropriate to perform the weeding operation.

Presently, the power weeder which are available in the markets run on fossil fuels. The usage of fossil fuels in agriculture increases the cost of operation. In addition to this, they emit harmful gases which pollute the environment. Hence, there is a need to switch over for alternate fuels like solar energy and bio fuels which are eco-friendly and budget friendly. The walk behind type solar powered rotary weeder are to be designed and developed in the workshop of Centre for Resources Conservation Technology Cum-Farm Machinery and Power Engineering, College of Renewable Energy and Environmental Engineering, Sardarkruishinagar Dantiwada Agricultural University, Sardarkrushinagar. The developed power weeder was tested (as per RNAM test code) in maize crops and the relevant data were collected and statistically analysed using the standard methodology.

The weeding efficiency of 80, 100 and 120 rpm rotor speed were 68.54 76.13 and 77.14 per cent. The lowest plant damage was found (3.94 per cent) for 80 rpm rotor speed followed by 100 rpm (4.92 per cent) and 120 rpm rotor speed (9.79 per cent). The average depth of cut was found 43.57, 42.43 and 36.14 mm for 80, 100 and 120 rpm rotor speed, respectively.The maximum field capacity was found with 120 rpm rotor speed (0.072 ha/h) as compared to 100 rpm (0.066 ha/h) and 80 rpm rotor speed (0.054 ha/h).

The field efficiency of 80, 100 and 120 rpm rotor speed were found to be 78.89, 83.39 and 85.32 per cent respectively. The performance index of weeder was varies between 354.37 to 506.06. The total time taken for charging and discharging of battery was 4 hr and 2.27 hr, respectively. The cost of opearation was found Rs. 78.2 per hour and Rs. 1185 per hectare. The cost of saving of developed weeder were 84.06 per cent and 53.06 per cent over manual weeding and petrol run power weeder, respectively. The developed weeder saves times 91.03 per cent over manual weeding.

Thus, the research work was carried out according to the pre-decided objectives and the developed weeder was found to work satisfactorily.

I. INTRODUCTION

Agriculture is the backbone of Indian economy. There are several constraints in agriculture like climate change, insect and pestsbut weed is the one of the major reason for declined yield per unit agricultural area in India. A weed can be described as any unwanted plant growing where it is not required.Weeding is an important but equally labor incentive agricultural operation. Weeding accounts for about 25 per cent of the total labor requirement (900-1200 man h/ha) during it carried, (Babu and Rao, 2017).

Weed causes 10-80 per cent crop yield losses, deteriorate quality of product causing health problems and damage to the environment (Rao and Chauhan, 2015). Weeds which hamper the growth of specific crops are threat to cultivation which affects crop production, crop quality and income of the farmers. India suffers yearly loss of USD 11 billion due to weeds alone in 10 major crops of India *viz.,* groundnut, soybean, greengram, pearl millet, maize, sorghum, sesame, mustard, direct seeded rice, wheat and transplanted rice (Gharde *et al.* 2018). Hence it is necessary to control weeds. Delay and negligence in weeding operation affect the crop yield up to 30 to 60 percent (Yadav and Pund, 2007).

Weeds decrease the value of land, particularly perennial weeds, which tend to accumulate on long fallows; increase cost of cleaning and drying crops (where drying is necessary). Farmers generally express their concern for effective weed control measures to arrest the growth and propagation of weeds. Chemical method of weed control is more prominent than manual and mechanical methods. However, its adverse effects on the environment are making farmers to consider and accept mechanical methods of weed control. Today the agricultural sector requires non-chemical weed control that ensures food safety. Consumers demand high quality food products and pay special attention to food safety. These mechanisms contribute significantly to safe food production. Through the technical development of mechanisms for physical weed control, it might be possible to control weeds in a way that meets consumer and environmental demands.

Generally, weeding is done by manually with the help of hand tools, however during peak seasons labours are not easily available. In India, small farmers are using bullock drawn implement for weeding operation, which has low field capacity, high maintenance cost and less field efficiency. Therefore, it is not feasible to farmers.

Mechanical weeding is one of the effective methods of weed removal. Smaller weeding machines commonly known as portable weeders are solely used for weed removal in agricultural fields, gardens, public parks *etc.* Like tractors, such weeders are becoming popular as the displacement of labours is major concern. In promoting weeders, especially considering the fact that majority of farmers are having small land who can hardly afford costlier tractors. Therefore, the weeders become a useful machine for intercultural operation specially for narrow spacing crops like groundnuts, pigeon pea, potato, okra, cluster bean, maize in particular and other crops in general for the small farmers. Its main objective is to reduce the manpower as in today's scenario finding labours is very hard as well as it reduces the working time and cost of cultivation.

1.1 Status of Maize Crop

Maize (*Zea mays* L.) is the most versatile food crop of global importance. It ranks third most important food grain crop after rice and wheat in India providing food, feed, fodder and also serves as a source of basic raw material for number of industrial products for food (25%), animal feed (12%), poultry feed (49%), starch (12%), brewery (1%) and seed (1%). It is one of the most efficient crops which gives high biological yield as well as grain yield in a short period of time due to its unique photosynthetic mechanism owing to C_4 mechanism. The average maize yield in the developed countries is more than 7 t/ha while in the developing countries it is only around 3 t/ ha (Dass *et al.*, 2010).

Among the maize growing countries, India rank 4th in area and 7th in production, representing around 4% of the world maize area and 2% of total production. During 2018-19 in India, the maize area has reached to 9.2 million ha (DACNET, 2020). During 1950-51 India used to produce 1.73 million MT maize, which has increased to 27.8 million MT by 2018-19, recording close to 16 times increase in production. The average productivity during the period has increased by 5.42 times from 547 kg/ha to 2965 kg/ha, while the area increased nearly by three times. Though the productivity in India is almost half of the world the average per day productivity of Indian maize is at par with many lead maize producing countries.

In India, maize is principally grown in two seasons, rainy (*kharif*) and winter (*rabi*). *Kharif* maize represents around 83% of maize area in India, while *rabi* maize correspond to 17% maize area. Over 70% of *kharif* maize area is grown under the rain fed condition with a prevalence of many biotic and abiotic stresses. The stress prone ecology contributes towards lower productivity of *kharif* maize (2706 kg/ha) as compared to *rabi* maize (4436 kg/ha), which is predominantly grown under assured ecosystem. Among Indian states Madhya Pradesh and Karnataka has highest area under maize (15% each) followed by Maharashtra (10%), Rajasthan (9%), Uttar Pradesh (8%), Gujarat (5 %) and others. (Singh *et al.*, 2011).

1.2 Weed Control Methods

The removal of weeds from the fields, gardens or land with minimum damage to the desired plants is weed control. Various methods described below are used for removal of weeds from the fields.

1.2.1. Manual weed control

Manual control is the use of the hands or handheld tools to remove weeds. Extensive amount of cheap manual labour is necessary for manual weeding. Manual weeding is commonly employed by small Indian framers.

1.2.2. Chemical weed control

Chemical control involves the use of herbicides. Herbicides weed control plants either by speeding up, stopping or changing the plant's normal growth patterns; by drying out the leaves or stems; or by making it to drop its leaves. Chemical control with herbicide application can provide the most effective and time-efficient method of managing weeds. Numerous herbicides are available which provide effective weed control and are selective in nature. Chemical method of weed control is more prominent than manual and mechanical methods. However, its adverse effects on the environment are making farmers to consider and accept mechanical methods of weed control. Chemical weeding is the most extensively used method of weed removal. But these chemicals used for weeding are harmful to living organisms and toxic in nature.

1.2.3. Biological weed control

Biological control involves the use of insects or pathogens that affect the health of the weed. It includes the use of living organisms for suppressing or controlling the weeds. Plant, animal or micro-organisms are also used for destruction of weeds. The goal of biological control is not prevention, but the use of living agents to suppress vigour and spread of weeds. Such agents can be insects, bacteria, fungi, or grazing animals such as sheep, goats, cattle or horses. Grazing produces results similar to mowing, and bacteria and fungi are seldom available for noxious weed management. Biological control is most commonly thought of as insect bio control.

1.2.4. Mechanical weed control

Mechanical control is the use of powered tools and machinery to manage weeds. It is suitable for larger areas because it reduces the weed bulk with less manual effort. Mechanical control consists of methods that kill or suppress weeds through physical disruption. *i.e.*, pulling, digging, disking, ploughing and mowing.

Renewable energy plays an important role in reducing greenhouse gas emissions. Wind, solar and hydroelectric systems generate electricity with no associated air pollution emissions. Geothermal and biomass systems emit some air pollutants, though total air emissions are generally much lower than those of coal and natural gas-fired power plants. To ensure energy security and to reduce the dependency on oil import, work has initiated under Ministry of Non-Renewable Energy (2006) to develop and deploy alternative sources of energy such as solar energy, wind energy, bio-fuels *etc.* Solar energy is a clean, cheap and abundantly available renewable energy which is inexhaustible in nature. Solar energy is abundantly available across the globe, and it is easy to harvest and efficiently converted into energy for utilization either in heat or electrical form.

1.3 JUSTIFICATION

Presently, the power weeder which are available in the markets run on fossil fuels. The usage of fossil fuels in agriculture increases the cost of operation. In addition to this, they emit harmful gases which pollute the environment. Hence, there is a need to switch over for alternate fuels like solar energy and bio fuels which are eco-friendly and budget friendly. Thus, use of fossil fuels could be reduced gradually and this is how weeder could be environmentally friendly. In fodder and pulse crops, the row to row spacing is more and so offers more sunlight and aeration which increased weed population between the rows of crop. To have proper growth and propagation, little earth work is essential, thus weeder has been planned in such a way that it able to cut the weed and mix into soil for fertility. In other words, churning operation must be involved in developed weeder. Further, the energy demand of weeder may be fulfilled by solar energy. So that use of fossil fuels could be limited and clean and effective energy resources could be utilized. In this scenario, the solar powered walk behind type rotary weeder had met all the requirements of farmer and cost effective. It is expected that solar powered walk behind type rotary weeder could be a better viable option for the farmers on the cost basis. Keeping mentioned fact in mind, a research has been planned with following objectives:

1.4 Objectives

1. To design and develop walk behind type solar powered rotary weeder
2. To evaluate the performance of developed weeder
3. To study techno economic feasibility of the developed weeder

II. REVIEW OF LITERATURE

In this chapter, a brief review related to different weeders in reference to soil moisture content, weeding efficiency, plant damage and field efficiency have been discussed. This chapter deals with the review of the research work carried out by various workers related to different weeders. The review of research related to the present study has been arranged under the following headings.

2.1 Soil physical properties

2.2 Importance of weeding

2.3 Types of weeders

2.3.1 Manual weeders

2.3.2 Animal drawn weeder

2.3.3 Power operated weeder

2.4 Types of blades for mechanical weeder

2.5 Performance evaluation of weeders

2.6 Solar power cum battery operated machinery

2.7 Lithium ferro phosphate battery

2.8 Concluding remarks

2.1 Soil Physical Properties

Soil bulk density is an important factor in terms of soil-tool reactions, and indicates the extent of soil compaction at any period of time. Bulk density plays an important role in deciding the power requirement of any soil working tool or machinery.

Sahu and Raheman (2006) studied the draft requirements of tillage implement combinations and measured the draft requirements of a reference tillage tool (single disk) and two combinations (mould board plough with disc gang and cultivator with disc gang) of tillage implements at different depths (50, 75 and 100 mm), wet bulk densities (in the range of 1270 – 1850 kg/m^3) and speeds (1.2, 2.2, 3.2 and 4.2 km/h). It was reported that the draft of the implements increased with increase in soil compaction, depth and speed of operation.

Ahaneku *et al.* (2008) studied the soil strength properties, namely shear strength and cone index which decrease with increase in soil moisture content.

Olatunji and Davies (2009) noted that soil moisture is one of the important factors that affect draft requirements and depth of operation of any soil working tool. In case of disc plough operating in sandy loam soils, depth of operation was changed from 80 to 210 mm when the soil moisture changed from 4.9 to 9.4 per cent and draft changed from 3.39 to 7.45 kN.

Ojomo *et al.* (2012) studied the effect of moisture content (10, 13 and 16 per cent) and the type of cutting blades (flat blade, spike tooth blade and curved blade) on the machine efficiency, quality performance efficiency, percentage of uprooted weeds and percentage of partially uprooted weeds. Soil moisture content and type of cutting blades statistically affected the machine performance at 5 per cent level of significance using Duncan Multiple Range Test (DMRT). The machine was found to be influenced by the soil moisture content and type of cutting blades however, the machine using spike tooth blade gave the best machine efficiency of (94 %), quality performance efficiency of (84 %) and least percentage of partially uprooted weeds of (1.8 %) at 16 per cent soil moisture content.

Rajashekar *et al.* (2014) developed a three row weeder for weeding and inter culturing. The efficiency of the manually operated weeder on loamy soil, clay soil and sandy soil was 81.4, 86.5 and 88.82 per cent, respectively. The weeder had field capacity of 0.1 ha/h. For achieving ease of operation and increase in field capacity, petrol start kerosene engine was mounted on the base frame.

It is observed that soil properties (Bulk density, porosity, soil strength and moisture content) play and important role on performance evaluation of power weeder.

2.2 Importance of Weeding

Blasco *et al.* (2002) found that weeding is an important but equally labour intensive agricultural unit operation. There is an increasing interest in the use of mechanical intra- row weeders because of concern over environmental degradation and a growing demand for organically produced food. Today the agricultural sector requires non-chemical weed control that safeguards consumers demand for high quality food products and pay special attention to food safety. Through the technical development of mechanisms for physical weed control, such as precise inter-and intrarow weeders, it might be possible to control weeds. These mechanisms contribute significantly to safe food production.

Goel *et al.* (2008) studied the weed growth in dryland crops particularly in oilseed crops like groundnut and mustard causing a considerable lower yield. Manual weeding requires huge labour force and accounts for about 25% of the total labour requirement. The labour requirement for weeding depends on weed flora, weed intensity, time of weeding and soil moisture at the time of weeding and efficiency of worker. Often several weeding operations are necessary to keep the crop weed free. Reduction in yield due to weed alone is estimated to be 16-42% depending on crops and locations and involves 1/3rd of the cost of cultivation. Weeding and hoeing is generally done 15-20 days after sowing. The weed should be controlled and eliminated at their early stage. Depending upon the weed density, 20-30% loss in grain yield is quite usual which might increase up to 40% if adequate crop management practice is not observed.

Rathod *et al.* (2010) stated that weed control is one of the most expensive operationsin crop growth. Weeds increase cost of production and lower the quantity as well as the quality of the crop. Depending on the weed density 20-30% loss in grain yield is the quiteusual which may increase to 50%, when crop management practices are not properly followed. The yield losses in cotton due to weeds alone was assessed as 13.60% than that of insects and diseases which is about 18.60%, while the losses due to weeds alone was assessed to be 32.20%. Weeding is an important practice to be carried out during the initial stages of crop growth especially for controlling the weeds competing with the crop, stirring the soil for aerating the crop root zones and for burying the weeds into the soil.

Veerangouda *et al.* (2010) stated that weeding is usually performed manually withtraditional hand tools (Khurpi) in upright bending posture inducing back pain for majority of labour and require considerable time. It is costly and many times, availability of the required number of labours during peak season of the year is a problem. In India, diverse farm mechanization scenario prevails in the country due to varied size of the farm holdingsand socio-economic disparities. Status of land holding in contexts of Indian agriculture and Karnataka state is reveals that about 80% of land holdings were below 2 hectare (small and marginal land holding). At present, small capacity power weeder are available in market whose field capacity normally 0.07

ha/h, which is greater than bullock operated weeders having field capacity is 0.058 ha/h.

Rao and Chauhan (2015) reviewed the weeds and weed management in India. Weeds cause 10-80 per cent crop yield losses besides impairing product quality and causing health and environmental hazards. Invasive alien weeds are a major constraint to agriculture, forestry and aquatic environment. Crop-specific problematic weeds (weedy rice in rice) are emerging as a threat to cultivation, affecting crop production, quality of product and income of farmers. Traditionally, weed control in India has been largely dependent on manual weeding. However, increased labour scarcity and costs are encouraging farmers to adopt labour and cost saving options. These include herbicides whose market grew at an annual rate of 15 per cent. Integrated weed management (IWM) is being practiced by Indian farmers, with the level of adoption varying from one farm to the other.

Babu and Rao (2017) studied the manually operated dry land weeder. Weeding and hoeing is generally done 15 to 20 days after sowing. The weed should be controlled and eliminated at their early stage. Depending upon the weed density, 20 to 30 percent loss in grain yield is quit usual which might increase up to 80 per cent if adequate crop management practice is not observed. Rice and groundnut are sensitive to weed. Competition in the early stage of growth and failure to control weeds in the first three weeks after seeding, reduce the yield by 50 per cent. Manual weeding requires huge labor force and accounts for about 25 per cent of the total labor requirement which is usually 900 to 1200 man h/ha. Functional efficiency the weeder is 87% and, Theoretical field capacity 0.0375ha/hr, Effective field capacity 0.03ha/hr, Field efficiency 81% Soil inversion 87% One man can weed 1 acre area in 42 days.

Gharde *et al.*(2018) studied the yield and economic losses in agriculture due to weeds in India. The study revealed that potential yield losses were high in case of soybean (50–76%) and groundnut (45–71%). Greater variability in potential yield losses were observed among the different locations (states) in case of direct-seeded rice (15–66%) and maize (18–65%). Three factors viz. location (state), crop, and soil type significantly ($p < .0001$) explained the variability in actual yield losses due to weeds at farmers' fields. Significant differences were also observed between different locations, crops and soil types. Actual economic losses were high in the case of rice (USD 4420 million) followed by wheat (USD 3376 million) and soybean (USD 1559 million). Thus, total actual economic loss of about USD 11 billion was estimated due to weeds alone in 10 major crops of India viz. groundnut (35.8%), soybean (31.4%), greengram (30.8%), pearlmillet (27.6%), maize (25.3%), sorghum (25.1%), sesame (23.7%), mustard (21.4%), direct-seeded rice (21.4%), wheat (18.6%) and transplanted rice (13.8%).

Devojee *et al.* (2020) stated that India is a vast country with 329 million hectares of geographical area with agriculture still as a main occupation of 70 per cent of Indian population. Weeding is an essential operation in agriculture to prevent undesired species from growing and consuming the key resources (i.e. water, minerals, soil and sunlight) and thereby compromising crop yield. Farmers spend a large amount of time and money to managing weeds. Weeds are always associated with human endeavors and because huge reductions in crop yields, increase cost of cultivation, reduce input efficiency, interfere with agricultural operations, impair quality, act as alternate hosts for several insect pests, diseases and nematodes. At a conservative estimate, an amount of Rs.100 billion is spent on weed management annually in India, in arable agriculture alone.

Kamaraj *et al.* (2020) stated that globally, groundnut is the sixth important commercial crop. It is a 'food-income-industrial-commercial' crop. Groundnut contains 48- 50 % oil and 26-28 % nitrogen. High in fiber, it has many nutrients necessary for the humanbody. Around the world, about 26.4 million hectares are under groundnut cultivation. Totalproduction is 37.10 million tonnes. Its average yield is 14 quintal per hectare (World Food and Agriculture Union, 2003). About 94% of the total production is in developing countries. But the yield is low. Yield varies from one country to another, from one state to another, and from one province to another. Weed control is one of the most difficult tasks in agriculture that accounts for a considerable share of the cost involved in agricultural production. Manual weeding requires huge labor force and accounts for about 25 percent of the total labor requirement which is usually 900 to 1200 man h/ha. Farmers generally expressed their concern for effective weed control measures to arrest the growth and propagation of weeds. Chemical method of weed control is more prominent than manual and mechanical methods. However, its adverse effects on the environment are making farmers to consider and accept mechanical methods of weed control.

2.3 Types of Weeders

Biswas *et al.* (1984) classified the weeder according to their source of power as follows:

2.3.1 Manual weeders

- Small tools or aids
- Chopping hoes
- Pull type hoes
- Push type weeder
- Push-pull weeder

2.3.2 Animal drawn weeders

- Triangular and straight blades hoes
- Shovels, sweeps and duck foot sweeps type
- Animal drawn rotary weeders
- Rotary tines hoes

2.3.3 Power operated weeders

2.3.1 Manual Weeders

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

Muhammad and Attanda (2012) designed and developed a hand push mechanical weeder consisting of two set of cone rotor blades, adjustable main frame and a float. The overall width and depth of cut of weeder were 180 mm and 20 mm respectively. It was observed that in a single pass between the rows on the field at a soil moisture content of 40.8% and 10.5%, the optimum weeding efficiency was 84.5% and 53.1% respectively. Highest plant damage of 8.33% was recorded at the 10.5% soil moisture content and effective field capacity of 0.035 ha/h at 64.87 N draft. Power requirement of weeder was 0.058 hp by a single person to push the weeder.

Singh *et al.,* (2016) designed and developed a weeder for wide-row crops using swinging handle, four-wheel concept and slicing action. Soil bin study on push force revealed the significant effect of compaction levels and handle angles on the performance of operator in terms of high force. The minimum area coverage with the weeder was 0.0206 ha/h with more than 95% weeding efficiency. The push force requirement per cm cutting width was lowest among cited other mechanical weeders. The ergo-mech approach of design enabled operators to complete the weeding work timely with reduced drudgery and increased productivity as compared to conventional practice

2.3.2 Animal Drawn Weeders

Sims (2000) studied the elements of design for animal drawn weeders. An angle of attack of approximately 15° was ideal to lift and separate the weeds from the soil. At greater angles the tine starts to act like a bulldozer, which tends to leave the weeds mixed with soil. An angle of less than 15° may not have sufficient lifting action and would leave the weedsin their original positions. Approach angle of 30° - 50° were recommended. The angle canbe greater in loose soil with a low weed population.

Balachand (2006) designed and developed an animal drawn weeder considering the functional requirements and its required strength to bear soil forces acting on it. The performance of animal operated weeder having three types of blade *viz*., straight blade, curved blade, and sweep blade were compared with the Ambika paddy weeder and Hand weeding. Weeding by animal drawn weeder with sweep blade gave higher field capacity (0.0759 ha/h), field efficiency (73.87 per cent) and performance index (738.75) then the other two blades.

2.3.3 Power Weeder

Victor and Verma (2003) designed and developed a power operated rotary weeder for wetland rice cultivation and fabricated at the faculty of agriculture engineering workshop, IGKVV, Raipur, India during 1999-2000 and tested in the experiment field. A 0.5-hp petrol driven engine was used for power weeder with a reduction gear box. The power transmission from engine to traction wheel and to the cutting unit was provided by means of a belt, pulley and chain sprocket. For cutting four L shaped standard blades were used on the hub, and in turn fitted on rotary shaft. With 200 mm spacing, the field capacity of the machine varied between 0.04 to 0.06 ha/h with field efficiency of 71 per cent. The weeding efficiency of the machine was 90.5 per cent. The machine was simple, easy to fabricate by local artesian.

Tajuddin (2006) performed plan and improvement of a motor worked weeder with 2.2 kW (3hp) petroleum turned over lamp fuel run motor and tried it. Belt –

pulley and sprocket – bind system were utilized to lessen appraised speed of 3300 rpm at burden to 60 rev/min of ground wheel. A sweep type weeding cutting edge was connected for strength. The effective field capacity of machine was 0.10 ha/h, had fuel utilization of 0.60 to 0.75 l/h, while depth of operation was 37 mm,35 mm, 39 mm and field efficiency 85.71%. It was additionally discovered that weeding efficiency was 85.85% while starting expense of weeder was Rs. 20,000 with cost of operation Rs. 580/ha.

Yadav and Pund (2007) developed and ergonomic evaluation of manual weeder. Delay and negligence in weeding operation affect the crop yield up to 30 to 60 per cent. With regard this, a manually operated weeder was developed and tested ergonomically. The developed weeder could work up to 30 mm depth with field capacity of 0.048 ha/hr and higher weeding efficiency was obtained up to 92.5 %. During weeding operation, the peak heart rate of the subjects was found to range from 142 to 150 beats per min. In case of heavy work and dense grass infested field, the rest pause of 14 min was required by the subjects to come to the normal heart rate.

Niyamapa and Chertkiattipol (2010) planned three model rotating sharp edges to diminish the tilling torque, impact force and specific tilling energy, and tried in a research facility soil canister with flat tilling surface. Examinations with the model rotary blades and Japanese C-formed cutting edge were done at forward speeds of 0.069 and 0.142 ms-1 and at rotational speeds of 150, 218, 278 and 348 rpm (or 3.30, 4.79, 6.11 and 7.65 ms-1) by down-cut cycle in clay soil.

Nkakini *et al.* (2010) developed weeder comprises of main frame, handle, rotary blades, shaft, sprocket and chain, chassis, cutting depth hint rear cutting depth adjuster, wooden engine seating, engine and ground wheel. The developed machine had a theoretical field capacity was 0.047 ha/h with a effective field capacity 0.034 ha/h, this was around multiple times more than that of manual weeding. Performance index of weeder was 1,700 while fuel utilization was 3.2 l/day and weeding efficiency was 71%.

Ratnaweera *et al.* (2010) developed a power weeder with the capacity to perform weeding three rows at the same time. A 1.3 kW gasoline engine was utilized to drive double action weeding drum which was able for evacuation of weeds and provide forward movement to weeder. The cone shaped weeding drums were also design to free up soil without harming the rice crop. Row changing system was also developed which helps in working the machine by single individual without harming the rice. A helical shaped tooth was incorporated in the weeding drums to improve the shearing impact for productive weeding.

Srinivas *et al.* (2010) evaluated the performance of three commercially available weeder blades in the sweet sorghum crop. The weeding efficiency of power weeder using L-shaped blade was 91 per cent, while that for C-shaped blade and sweep type blade in power weeder was 87 % and 84 %, respectively. L-shaped, sweep type and C-shaped blade in power weeder had performance index of 169.84, 153.23 and 114.30, respectively. Field capacity of power weeder using sweep type blade was 0.12 ha/h, which was more than C-shaped and L-shaped blade. Plant damage in sweep type was least when compared with other two. In conclusion, power weeder with L-shaped blades was very economical and easy to use as it saved weed removal costs by 10.88 percent and achieved effective weed control.

Thorat *et al.* (2013) designed and developed a ridge type weeder for potato crop. The principle highlights of the weeder were cutting blades and the rotor shaft. Three sorts of cutting edges (type L, type C and Flat sort) were chosen with length, width and thickness of 100 mm, 25 mm and 6 mm, respectively, working with a rotor shaft 18 mm in diameter. C-type cutting blades were most appropriate at a gang speed of 200 rpm and 15.26 ± 0.96% (d.b) soil moisture with weeding efficiency, plant damage, field capacity were, 89.37%, 2.66%, and 0.086 ha/h , respectively. It was also observed that 92.7 per cent of time saves with ridge profile power weeder compared with manual weeding.

Kankal (2013) developed a self-propelled weeder on the ground of ergonomics and machine parameters. The weeder consists of, a 4 hp petrol start kerosene run engine, power transmission system, weeding blade (sweep) and cage wheel. The engine runs at 360 rpm reduce to 23 rpm at cage wheel by using three steps chain-sprocket mechanism.

Mahilang *et al.* (2013) design and fabricated a rotary weeder runs on petrol engine. The developed rotary weeder consist of a 1.4 hp petrol start/kerosene engine and belt pulley power transmission system. The power was transmitted by means of belt, pulley from engine to traction wheel and to cutting units. L-shaped blades were used for cutting action fitted to hub interned fitted to rotor shaft. The study shows the developed weeder hast the weeding efficiency and field efficiency of 91% and 60% , respectively and operational cost of weeder was Rs. 808.42.

Kumar *et al.* (2014) conducted an experiment to evaluate the filed performance of different weeders namely khurpi, push type cycle weeder and power weeder. The efficiency of *khurpi,* push type cycle weeder and power weeder were 91.5 per cent, 85.4 per cent and 71.25 per cent respectively. Field capacity was highest for power weeder i.e., 0.065 ha/h followed by khurpi and push type cycle weeder which was 0.025 and 0.035 ha/h respectively. The cost of operation was minimum in push type cycle weeder and maximum for khurpi.

Sirmour (2017) designed and developed single row power weeder and found that average speed of operation was found as 2.45 km/h. The average fuel consumption of power weeder was found as 0.55 l/ hr. The maximum field capacity was found 0.054 ha/h. The working width of the developed machine may be adjustable between140 mm to 250 mm. The weeding efficiency was observed as 88.62 per cent under single row active power weeder. The saving in cost of weeding was 60 per cent and saving in time was 65 per cent compared to manual weeding.

Kumar *et al.* (2018) evaluated the performance of power weeder, wheel hoe and star weeder on maize crop with row to row spacing of 60 cm under dry land condition. The actual field capacity was found to be 0.0494 ha/h, 0.022 ha/h and0.021 ha/h, respectively for power weeder, wheel hoe and star weeder. Weeding efficiency for power weeder, wheel hoe and star weeder were 78.4 percent, 74.0 per cent and 75.4 per cent, respectively. Field efficiency and operational cost was highest in case of power weeder and was lowest in case of wheel hoe. Drudgery involved during weeding operation was more in wheel hoe when compared with the power weeder and star weeder.

Ragesh *et al.* (2018) studied the performance of power weeder for paddy crop at 20 and 45 days after sowing (DAS) and the performance was compared with traditional hand weeding and *ambika* paddy weeder. The weeding efficiency was found to be 74.22% and 86% for 20 and 45 DAS respectively. The highest field efficiency was shown by paddy power weeder as 70% for 45 DAS and no significant variation in field efficiency was found in *ambika* paddy weeder at 20 and 45 DAS. The cost of operation per hectare with power weeder was Rs.928 and Rs.850 against ambika paddy weeder as Rs.2617 and Rs.2346 for 20 and 45 DAS.

Srinivas *et al.* (2020) evaluated a walking type multi crop power weeder. Machine worked at varying width of 15-45 cm so that it can be used for multi crops. Weeding efficiency was found 85.6 per cent and 86.2 per cent for okra and chili respectively. Plant damage was 2.29 per cent and 2.61 per cent and field capacity of the weeder was 0.0309 ha/h and 0.0302 ha/h, respectively for okra and chili crop working at 25 cm width. Optimum performance was found for maize crop at 45 cm cutting width.

Raosaheb *et al.* (2020) A rotary power weeder was designed and developed. The developed weeder consisted of frame, engine, tyne, wheel and handle. Weeding efficiency, field efficiency and plant damage of developed rotary weeder was 70.5%, 65% and 3.2%, respectively. The fuel consumption and field capacity of developed rotary power weeder was 0.8 l/h and 0.09 ha/h, respectively.

2.4 Types of Blades for Mechanical Weeder

Bernacki *et al.* (1972) Various types of cutting blades are used for manually operated weeder. Where weeders are continuously pushed, V–shape sweep is preferred and tool geometry of these cutting blades is based on soil-tool-plant interactions.

Kotov *et al.* (1977) studied the parameters of sweep design and showed that sweeps cleanthemselves best in heavy conditions with a swept angle of approximately 57°; and the condition of the cutting edge is the major factor in the accumulation of plant material on the sweep. Further studies showed that soil tended to pile up in front of the shank increasingsoil movement problems.

Tewari *et al.* (1993) calculated the field performance of weeding blades of a manually operated push-pull weeder. It was found that the overall performance of straight blade was the best as it gives the highest field efficiency and least plant damage. Also, it removes more weeds per unit area. In this push-pull type weeder, more amount of human energy is consumed in cutting soil and weed roots and a very less amount of energy is consumed in penetration of blade into the soil. On an average, the power required during this operation was 21.3 W. Push-pull weeding method when compared with manual weeding gives four times more work output.

Gajjar (2000) determined best combination of weeding blade. Three different width of blade (300, 375 and 450) mm. Rake angle (20°, 25° and 30°) and approach angle (120°, 150° and 180°) were selected for the experiment and design and concluded that twin straight blade for all rake angles and width 375 mm could be recommended for first intercultural operation and twin sweep type blade with a rake angle of about 20° and 300 mm could be used for second intercultural operation in groundnut crop sown at row to rowspacing of 600 mm.

Biswas and Yadavs (2004) studied four basic shapes of weeding tools, namely straight blade, curved blade, triangular blade and sweep. They concluded that for straight blades, optimum rake angle should lie between 20.6° to 22.5° and blade thickness, width and sharpness angle should be least. For curved blades of 200 mm working width optimum radius of curvature was 136.4 mm and rake angle ranged from 22.0° to 22.4°. For triangular blades, optimum rake angle ranged from 76.9° to 81.6°. Optimum values of rake angle for straight, curved and triangular blades were close, within the range of 20.6° to 22.5°. The average value of the optimum rake angle for all these blades was 21.93°. For sweeps, optimum values for tool parameters were approach angle in the range 74.7° to 75.0°, wing width of 50 mm and below and blade thickness less than 4 mm.

Balachand (2006) designed and developed an animal drawn weeder considering the functional requirements and its required strength to bear soil forces acting on it. The performance of animal weeder having 3 types of blade viz. Straight blade, curved blade, and sweep blade was compared with the Ambika paddy weeder and Hand weeding. Weeding by Animal drawn weeder with sweep blade results higher field capacity (0.0759 ha/h), field efficiency (73.87%) and performance index (738.75) then the other two blade.

Shrinivas *et al.* (2010) reported that L shaped blade can be recommended for inter row crops weeding in crops as it churns the soil by uprooting weeds. The weeding efficiency was found to be 91, 87 and 84 per cent, plant damage was found to be 5.1, 3.4 and 1.2 per cent, field capacity was found to be 0.059 ha/h, 0.068 ha/h and 0.12 ha/h, The operating cost was found to be Rs. 580/- per hectare, Rs. 550/- per hectare and Rs. 429/- per hectare and performance index was found to be 169.84, 114.30 and 153.23 for L type, c type and sweep type blade, respectively.

Khodabakhshi *et al.* (2013) studied the effect of design parameters of rotary tillers on unevenness of the bottom of the furrows. One of the widely used tillage implements in gardens and paddy fields is rotary tiller, which can prepare the seed bed in a single step. However a special consideration in using rotary tillers is the unevenness of the bottom of the furrows due to the consecutive intersection of two adjacent trochoids, *i.e.*, blade trajectories, yielding roiling and displacement of a seed inside the furrow in precision planters. Precision planting is possible when furrow unevenness is reduced to a minimum and meanwhile planting depth remains constant. This is especially important when the distance between two neighbor seeds in a row is low. This paper studies analytically the effect of design parameters of the rotary tiller on the quality of the furrows. The obtained results indicate that height of unevenness of the furrows decreases with increasing the number of blades on each flange, increasing the rotor speed and decreasing the forward velocity. Whereas L-shaped blades are the most common widely used for the fields with crop residue, removing weeds.

Mohankumar and Anantha (2014) developed a hydraulic test rig for evaluating weeding blades. The different types of weeding blades were evaluated by using hydraulic test rig. The L-type blade was recorded higher weeding efficiency (91 %) when compared to J-type and C-type blades. The J-type blades consumed less power (0.65 hp) when compared to L-type and C-type blades.

Thorat *et al.* (2014) designed and developed ridge profile power weeder. Three types of blades *i.e.*, L-type, C-type and Flat type were selected having length, width and thickness of 100 mm, 25 mm and 6 mm, respectively. During cutting, blade would be subjected to shearing as well as bending stresses. Total working width of weeder was 400 mm having two rotor shafts, each of length 200 mm. Highest and lowest weeding efficiency obtained for L-type blade and flat type was 86.23 and 83.93 per cent, respectively. The highest and lowest plant damage obtained for flat type and L-type blade was 4.96 and 3.29 per cent, respectively.

Singh (2017) evaluated field performance of four different types of manually operated weeders namely push pull weeder with five tines, push pull weeder with sweep blade, peg type dry-land weeder and straight blade hand hoe. The average effective field capacity of 0.0185, 0.022, 0.016, and 0.017 ha/h, respectively were for wheel hoe with five tine, wheel hoe with sweep blade, peg type dry-land weeder and straight blade hand hoe at forward speed of 0.285, 0.338, 0.290 and 0.270 m/s respectively. The result revealed that maximum weeding efficiency of 79.72% was recorded for sweep type followed by straight blade (78.19%), tine type (75.71%) and peg type dry-land weeder (72.50%).

2.5 Performance Evaluation of Weeders

Yadav and Anderson (1980) gave details of 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 orblade harrow (bakhar). It was found that serrated blades penetrate easily into the soil which helps in moisture conservation.

Rangaswamy *et al.* (1993) developed a power weeder and compared its performance with conventional method of manual weeding i.e., hand hoe and dry land weeder. The results shows the field capacity of 0.04 ha/h with weeding efficiency of 93 %for removing shallow rooted weeds. The performance index of weeder was 453. The cost of operation with power weeder amounted to ₹ 250 as against ₹ 490 by dry land weeders and ₹ 720 by manual weeding with hand hoe. The saving in cost and time amounted to be 65% and 93%, respectively.

Murthy and Gowda (1996) evaluated the performance of a bullock drawn blade hoefor 3 different approach angles which is 120°, 130° and 140°. The performance was carried out to determine the most effective angle with respect to implement draught, soil moistureconservation, weeding efficiency and crop (finger millet) yield under dry land conditions. The blade hoe gives the best overall performance at an approach angle of 140° with respectto the formation of ridges and furrows, soil moisture conservation and yield but the draft was significantly higher (19.5 kg).

Ramchandra and Gowda (1998) studied the effects of different manual weeders forweeding. Two different weeders i.e., varvari (hand hoe) and varvancruddali (long handle blade hoe) were tested and compared with each other. Weeding operation was carried out at 30 and 45 days of sowing. The result showed that varvari was best for the removal of weeds while varvancruddali required less draft per unit area.

Sthool and Shinde (2004) evaluated a peg tooth weeder in dry land agriculture and compared it with sickle. The result was found that field capacity of Peg tooth weeder was 0.02872 ha/h which was higher than that of sickle i.e., 0.004695 ha/h. The total savings wasfound to be 83.65% of man hours in peg tooth weeder. The weeding efficiency of the manual weeding by sickle was found 93.70% which is more than peg tooth weeder which was found 88.37%.

Padole (2007) evaluated the performance of rotary power weeder and compared it with bullock drawn blade hoe. The result showed that the working depth of rotary power weeder was 5.67 cm which was 16.67% more than the bullock drawn blade hoe, effective field capacity for rotary power weeder was found to be 0.14 ha/h which was 40% more than bullock drawn blade hoe and the field efficiency for rotary power weeder was 90% which was 34.11% more than bullock drawn blade hoe. There were savings of 10.77% of weedingcost, reduction in plant damage was up to 54.23% and the weeding efficiency up to 92.76% was achieved when the operation was carried out using bullock drawn blade hoe. It was concluded that rotary power weeder was more suitable than bullock drawn blade hoe.

Tekade and Dhaliwal (2007) evaluated power operated weeder in sugarcane and maize. A four row rotary weeder was developed to carry out studies on rotary weeding forsugarcane and maize crop. It was found the field capacity, plant damage, weeding index and fuel consumption varies from 0.062-0.214 ha/h,1.56-4.13%, 65.54-89.96%, 3.26-6.93 l/ha, respectively for sugarcane and 0.039-0.168 ha/h, 1.34-3.84% 65.91-90.76%, 2.96-6.92l/ha, respectively for maize crop with C and L types of blades. The optimum moisture content was 16.15% and 14.36%, respectively for sugarcane and maize with rotary speed of 190 rpm, depth of operation 9.4 cm for both the crops.

Veerangouda *et al.* (2010) evaluated weeders in cotton. The actual field capacity of0.005, 0.009, 0.092 and 0.07 ha/h, respectively were observed for hand khurpi, peg type dry land weeder, animal drawn blade hoe and power weeder. Among all the treatments, themaximum value of weeding index of 98.00% was observed in case of weeding operation by hand khurpi. The maximum value of cost of operation of ₹ 1666.00/ha was observed with hand khurpi while the animal drawn blade hoe recorded minimum value of ₹398.60/ha. The savings in cost of weeding operation using peg type dry land weeder, animaldrawn blade hoe and power weeder when compared to manual weeding by hand khurpi was 22.17, 76.07 and 42.28%, respectively.

Gavali and Kulkarni (2014) performed a comparative study on the analysis of potable weeders and power tillers in the Indian market. The main aim of the study was to focus on various equipments used for mechanical weeding. This study revealed that most of the small scale farmers do not use mechanical weed control methods because of some constraints and are mostly relied up on chemical and manual weed control methods. A veryfew of them can afford only portable weeders because of its low cost and maintenance. Power tillers on the other hand were comparatively more expensive but it was more versatile than portable weeder and can be operated on different soil conditions.

Kumar *et al.* (2014) conducted an experiment to evaluate the field performance of different weeders namely khurpi, push type cycle weeder and power weeder. It was found that the weeding efficiency of 91.5%, 85.4% and 71.25% was obtained for khurpi, push type cycle weeder and power weeder, respectively. The field capacity observed was highestfor power weeder, which was 0.065 ha/h, followed by khurpi and push type cycle weeder which is 0.025 and 0.035 ha/h, respectively. The cost of operation when calculated was highest for khurpi while it was calculated minimum for push type cycle weeder.

Hegazy *et al.* (2014) developed and evaluated a small-scale power weeder. The results showed that, the minimum value of fuel consumption was 0.546 l/h and highest fieldefficiency was 89.88% when recorded by using two blades with 1.8 km/h weeder forwardspeed, depth of operation ranged from 0-2 cm and soil moisture content was 16.18%.

Kankal *et al.* (2014) developed self-propelled weeder and studied that the highest cost of weeding contributes more losses due to various reasons. Three ranges of approach angles 60°, 70° and 80°, forward speeds viz. 0.28 m/s, 0.42 m/s and 0.56m/s and moisture contents 13%, 15% and 18% were optimized on the basis of lowest specific draft and highest weeding efficiency. An approach angle of 70 degree at a forward speed of 0.42 m/s at 15% moisture contents of soil was optimized as it resulted in lowest specific draft as 0.619 N/mm and highest weeding efficiency as 89.58%.

2.6 Solar Power Cum Battery Operated Machinery

Govardhini and Reddy (2017) developed a solar powered operated multi crop weeder. The drive mechanism includes one solar panel, two electrical dc motors, two batteries, rotary blade and chain sprocket mechanism. J-type rotary blade are used. The motor speed was varied through the speed controller by altering the operated voltage. The solar panel produced a DC output power ranges from 100 W to 360 W. Two 12V DC motor were used to supply the power to equipment. Speed controller was used to control the speed of the motor which was done by the knobs linked to the potentiometer provided in the circuit. Maximum field capacity and weeding efficiency was found to be 0.175 ha/day and 68.03 per cent, respectively. Minimum plant damage was 1.96 per cent.

Kumari *et al.,* (2019) developed a solar operated power weeder. The developed weeder was tested on maize crop having row to row spacing of 600 mm. The three different width of cutting blade viz. 50 mm, 60 mm and 70 mm were selected with two, three and four number of blades per flange. 150 W DC motor used to run the weeder shaft powered by 160 W solar panel. The maximum field capacity of 0.175 ha/day was found and weeding efficiency of 88.03% was obtained. The observation showed that the maximum and minimum plant damage by the developed weeder for maize crop was 3.03 and 1.961 per cent respectively for 2 blades 60 mm width and 4 blades 70 mm width respectively. The maximum and minimum performance index were 895 with 2 blades and 773 with 4 blades per flange with an average performance index of 841.

Singh *et al*., (2019) developed a battery assisted four-wheel weeder to reduce drudgery of farm workers. The weeder was developed on the concept of mechatronics. The developed weeder was driven by 250 W- 24 V DC motor powered by 24V-14Ah battery. The working width of weeder was 30 cm and a sweep type weeding tool was used for the weeding operation. The weeding capacity and weeding efficiency were 0.0554 ha/h and 97.5 per cent at walking speed of 2.52 km/h.

2.7 Lithium Ferro Phosphate Battery

Marongiu et al., (2010) done the test examination of lithium ferro phosphate battery to explore its possible application to electric vehicles and half-breed electric vehicles. The examination of dumping and stacking qualities and the energetic analysis of storage process efficiency have been developed. Dumping and stacking qualities, temperature affectability in a range of - 15o C to +50oC was determined under dynamic load variation test. The battery has been tried for 100 hours and 50 charge/discharge cycles. It was also observed that Li-fe-Po4 battery is reasonable to work in various surrounding conditions and shows more terrible execution at low burden current and low encompassing temperature.

Wang *et al.,* (2012) investigated the characteristics and efficiency of lithium ferro phosphonate (LiFePO4) batteries for standalone photovoltaic (PV) applications. Specific volume of battery is 65% than lead-acid battery and one-third of its weight. It indicates that battery efficiencies decrease with increasing charge and discharge currents. At a current density used for 100 hours charge duration, the efficiencies are found to be as high as 99%. The study also discussed that the battery is eco-friendly and does not get damage in low charge and thus it can be utilized for longer time.

Tseng *et al.*, (2018) performed a research on electrical characteristics of lithium ferro phosphates power pack battery of 12 V and 10 AH capacity. The experiment aims at to investigate the parameters such as internal resistance, actual value of internal voltage and discharge characteristics of the battery and done comparative study with the other batteries. Compared with other lithium family batteries packs, Li-fe-Po4 battery packs have high efficiency energy conversion up to 95 percent and have the more cycle up to 2000 times than the other lithium family battery which have cycle life up to 400 to 500 times.

2.8 Concluding Remarks

The chapter highlights the work so far done on different aspects of physical properties of soil, weeding methods and performance of manual, animal and power operated weeders under different conditions. Presently, the power weeder which are available in the markets run on fossil fuels. The usage of fossil fuels in agriculture increases the cost of operation. In addition to this, they emit harmful gases which pollute the environment. Hence, there is a need to switch over for alternate fuels like solar energy and bio fuels which are eco-friendly and budget friendly. In some crops, the row to row spacing is more and so offers more sunlight and aeration which increased weed population between the rows of crop. To have proper growth and propagation, little earth work is essential, thus weeder has been planned in such a way that it able to cut the weed. It is expected that solar operated weeder could be a better viable option for the farmers on the cost basis. It has been reported in many articles that solar energy could be harvested and utilized effectively for selected agricultural operations including weeding, In view of all these facts an attempt is required and so planned to work on solar power cum electric operated weeder for crops.

III. MATERIAL AND METHODS

In this chapter the description of the experimental materials used and the techniques employed for design and development of solar powered walk behind type rotary weeder are presented. The design criteria and power requirement at different rotor speed of blades were explained. This sequence was followed by the development of the prototype solar powered walk behind type rotary weeder based on the optimized parameters and the procedure adopted for the field evaluation of prototype were also discussed.

3.1 Location of Experiment

Fabrication work was carried out in the workshop of Centre for Resources Conservation Technology Cum-Farm Machinery and Power Engineering, College of Renewable Energy and Environmental Engineering, Sardarkruishinagar Dantiwada Agricultural University, Sardarkrushinagar. Field experiments were conducted at Main Research Farm of Agronomy Research Station Sardarkrushinagar Dantiwada Agriculture University, during the academic year 2021-2022.

3.2 Climate

Dantiwada is situated at 24°20’38” North latitude and 72°20’19” East longitude with an altitude of 252 meter above mean sea level. The climate is arid to semi-arid, and featured by hot dry summer and cool dry winter. The mean annual rainfall of Dantiwada, is 668 mm, from southwest monsoon rainfall occurred in mid-June to end of September with little occasional rainfall of 75 mm during other months (based on 20-year data, *source:* Department of Meteorological, C. P. College of Agriculture, SDAU). The mean monthly minimum temperature varies between 8.2 to 8.7 ^{0}C during December and January and maximum temperature varies between 45.5 to 46.4 ^{0}C during May and June, respectively. The mean humidity of tract ranges between 15.6 per cent in summer to 83.7 per cent during rainy season.

3.3 Design Consideration

Attention was given on the following aspects while designing and fabrication of solar powered walk behind type rotary weeder.

1. Physical and economical consideration
2. Functional requirement

3.3.1 Physical and Economical Consideration

Following points were considered.

1. Machine should be simple in design and should be easy to operate.
2. Cost of the machine should be low.
3. It should be easily repairable at local level.
4. It should save not only the labour engaged in, but also the time of weeding.

3.3.2 Functional Requirements

1. The machine should be used to remove weed from inter row.
2. Weeder should not damage crops in row.
3. It would have capability to meet all the required function with good efficiency.

3.4 Preparation of conceptual design by using Pro-E wildfire 2.0 software

The conceptual design of walk behind type solar powered rotary weeder was prepared by using Pro-E wildfire 2.0 software. Pro/ENGINEER (Pro-E for short) is a commercial CAD/CAM package that is widely used in industry for CAD/CAM applications. The model that was created by Pro-E should be feasible. Pro-E not performed task that may not lead to a solid model.

3.5 Design Procedure

3.5.1 Selection of Motor Power

The soil resistance has a considerable effect upon the power requirement of weeder. Also, width of cut and speed of operation influences power requirement. Since the weeding operation offer less soil resistance due to soil moisture and tilled condition soil resistance were kept as 0.6 kg/cm^2. Since operator has to walk behind the weeder, so speed of operation of the weeder was considered as 0.27 ms^{-1} to 0.33 ms^{-1}. Most of pulses and fodder crops like maize, green pea *etc*., the spacing between two rows 60 cm and hence width of operation was considered same. The depth of operation was considered as 3 to 5 cm and transmission efficiency is 82 per cent (Sharma and Mukesh, 2013).

$$P = \frac{SR \times d \times w \times v}{75} \quad \text{…………(3.1)}$$

Where,

P = Power, hp

SR = Soil resistance, kg/cm^2

d = Depth of cut, cm

w = Effective width of cut, cm

v = Speed of operation, ms^{-1}

Hence, power requirement is estimated as

$$P = \frac{0.6 \times 5 \times 55 \times 0.33}{75}$$

$$P = 0.726 \text{ hp} = 0.541 \text{ kW}$$

Total Power Required

The total power required is estimated as follows

$$P_t = \frac{P}{\eta} = \frac{0.541}{0.82} = 660 \text{ W} = 0.66 \text{ kW} \quad \text{……………..(3.2)}$$

Where,

P = Power required for digging the soil, kW

η = Transmission efficiency, per cent

Thus, a DC motor of above 660 W should be used. On the basis of availability of DC motor in the market, a 750 W DC motor would be suitable for this weeder.

3.5.1.1 Selection of Motor Torque

A force that produces or tends to produce rotation is called torque. The formula is used for the calculation of the torque transmitted though the shaft. (Khurmi & Khurmi, 2019).

$$T = \frac{60 \times P}{2 \times \pi \times N} \quad \text{………..………..(3.3)}$$

Where,

P = power, W

T = torque transmitted by the shaft, N-m

N = revolutions per minute

Considering the motor speed as 2000 rpm and motor power be 0.66 kW, we get torque

$$T = \frac{0.66 \times 60 \times 10^3}{2 \times \pi \times 2000}$$

$$T = 3.15 \text{ N-m}$$

Thus, the torque of 3.15 N-m was obtained

3.5.2 Design of Rotor Blade Shaft

The axle is a rotating member which transmits power from one point to another point. (Sharma and Mukesh, 2013).

Assumptions:

Maximum power actually required = 1 hp

rpm of the axle = 120

Maximum permissible shear stress = 550 kg/cm^2

$$hp = \frac{2\pi NT}{4500} \qquad \text{.............................. (3.4)}$$

Where,

hp = Horse power

N = Revolution per minute

T = Torque in kg-cm

$$T = \frac{1 \times 4500}{2 \times 3.14 \times 120}$$

$$T = 5.97 \text{ kg-m}$$

$$T = 597 \text{ kg-cm}$$

$$T = \frac{\pi \times F_s \times d^3}{16} \qquad \text{...................... (3.5)}$$

Where,

T = torque

F_s = Maximum permissible shear stress

d = Diameter of rotor shaft

$$d^3 = \frac{T \times 16}{\pi \times F_s}$$

$$d^3 = \frac{597 \times 16}{3.14 \times 550}$$

$$d^3 = 5.53 \text{ cm}^3$$

$$d = 1.75 \text{ cm}$$

In view of availability and work to be performed, the diameter selected for fabrication was 3 cm.

3.5.3 Design of Power Transmission System

The power transmission system was designed to reduce motor output shaft speed from 2000 rpm to 120, 100 and 80 rpm on rotor shaft. The power reduction was designed in 2 stages. Motor power is first transmitted from motor pulley to intermediate shaft through V-belt and pulley system and then from intermediate shaft to rotor shaft through chain sprocket system.

3.5.3.1 Design of Belt Drive

"V" type **A** section belt was selected on the basis of motor safety and as per requirements. Other properties of **"A"** type belt for Agricultural machinery (Sharma and Mukesh, 2013) are as follows;

Power range : 0.70 - 3.50 KW

Top width of belt (w) : 13 mm

Belt thickness (t) : 8 mm

Weight : 1.06 N/m

V-belt drive had been selected for the initial reduction stage because it has following advantages,

- Speed variation is obtained easily
- No lubrication required
- Alignment is not difficult
- It is smooth running
- It works as a safety clutch due to slippage on overload
- It is made-up of nylon or other material embedded in rubber, the whole being encased in fabric

The RPM on motor pulley was measured with the help of digital tachometer 2000 (N_1). For transmitting power from motor pulley (D_1, 5.5 cm) to intermediate shaft pulley, we take velocity ratio as 5. Diameter of driven pulley (D_2) fixed on intermediate shaft was calculated as (Sharma and Mukesh, 2013)

$$VR = \frac{D_2}{D_1} \qquad \text{……………………….. (3.6)}$$

$$D_2 = D_1 \times VR$$

$$D_2 = 5.5 \times 5$$

$$D_2 = 27.5 \text{ cm}$$

Therefore, RPM on the intermediate shaft (N_2) is given by

$$N_2 = \frac{N_1}{VR} \qquad \text{……………………… (3.7)}$$

$$N_2 = \frac{2000}{5}$$

$$N_2 = 400 \text{ rpm}$$

Belt length (Motor pulley to intermediate shaft)

The length of belt from motor pulley to intermediate shaft pulley

$$L = 2c + \frac{\pi}{2}\,(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4c} \quad \text{……...…………… (3.8)}$$

Where,

L = Length of belt, m

D_1 = Diameter of drive pulley, m

D_2 = Diameter of driven pulley, m

c = Centre to centre distance between two pulleys, cm (Taken 0.275 m)

$$L = 2 \times 0.275 + \frac{3.14}{2}\,(0.055 + 0.275) + \frac{(0.055 - 0.275)^2}{4 \times 27.5}$$

$$L = 0.55 + 0.52 + 0.044$$

$$L \cong 1.1 \text{ m.}$$

3.5.3.2 Design of Chain and Sprocket System

Chain was used to give power from intermediate shaft to rotor shaft.

Required velocity ratio

Required RPM on the intermediate shaft = 120 rpm

$$VR = \frac{RPM_1}{RPM_2} \quad \text{……………………...… (3.9)}$$

$$VR = \frac{400}{120}$$

$$VR = 3.33$$

Chain pitch:

The standard chain pitch was considered as 12.7 mm. (Sharma and Mukesh, 2013)

The intermediate shaft was fixed with sprocket of 12 teeth (T_1) which was act as derive sprocket and the number of teeth on driving sprocket was calculated by following equation.

$$T_2 = VR \times T_1 \quad \text{……………………… (3.10)}$$

$$T_2 = 3.33 \times 12$$

$$T_2 = 40$$

Chain length

Chain length is given by

$$L_C = m \text{ x } p \quad \text{………………………. (3.11)}$$

Where,

m = Number of chain link

p = Chain pitch, mm

$$m = \frac{2c}{p} + \frac{(T_1+T_2)}{2} + \frac{p(T_2-T_1)^2}{4\pi^2 c} \qquad \text{......................... (3.12)}$$

Where,

m = Chain links in pitches

C = Centre to centre distance between sprockets mm, (taken 360 mm)

T_1 = Number of teeth on smaller sprocket

T_2 = Number of teeth on larger sprocket

$$m = \frac{2\times360}{12.7} + \frac{(12+40)}{2} + \frac{12.7(40-12)^2}{4\times3.14^2\times360}$$

$$m = 56.69 + 26 + 0.70$$

$$m = 83.39 \text{ mm}$$

Chain length

$$L_C = 83.39 \text{ x } 12.7$$

$$L_C \cong 1060 \text{ mm}$$

Table 3.1: Specification of power transmission system

Sr. No.	Parameter	Dimension
1	Motor, rpm	2000
2	Intermediate shaft, rpm	400
3	Rotor shaft, rpm	120,100,80
4	Diameter of pulley on motor, cm	5.5
5	Diameter of pulley on intermediate shaft, cm	27.5
6	Belt length, mm	1100
7	Velocity ratio from motor pulley to intermediate shaft pulley	5:1
8	Number of sprocket teeth on intermediate shaft (T_1)	12
9	Number of sprocket teeth on rotor shaft (T_2)	40
10	Velocity ratio from intermediate shaft pulley to rotor shaft pulley	3.3:1
11	Chain links in pitches	83.39
12	Chain length, mm	1060

3.5.4 Rotary Blade Unit

In rotary weeder, blades were attached to a flange mounted on rotating shaft usually by nuts and bolts. Commonly three types of blades L-shaped blades, C-shaped blades and J-shaped blades were used in weeder. The C-shaped blades have greater curvature. They are recommended for penetration in hard soil and better performance in heavy and wet soils. The J-shaped blades are used for loosening, destroying the soil surface compaction and giving better ventilation to the soil. Generally, it was used for tilling hard and wet soils. Whereas L-shaped blades are the most common widely used for the fields with crop residue, removing weeds (Bernacki *et al.*, 1972 and Khodabakhshi *et al.*, 2013). So we selected L-Shaped blade for weeder.

A. Tangential force acting on the blades

The maximum tangential force which can be endured by the rotary shaft should be considered. The maximum tangential force occurs at the minimum tangential speed of blades was calculated by the following.(Khurmi & Khurmi, 2019)

$$K_s = \frac{\text{Cs} \times 75 \times \text{Nc} \times \eta\text{c} \times \eta\text{z}}{u} \quad \text{.............................(3.13)}$$

Where,

Ks = Maximum tangential force, kg

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

N_c = Power of motor, hp

η_c = Traction efficiency for the forward rotation of rotor shaft as 0.9

η_z = Coefficient of reservation of engine power (0.7- 0.8)

u = Minimum tangential speed of blades

Tangential peripheral speed, u is calculated using the following equation:

$$u = \frac{2 \times \pi \times N \times R}{6000} \quad \text{…………………………..(3.14)}$$

Where,

N = revolution of rotor, rpm

R = radius of rotor, cm

$$u = \frac{2 \times 3.14 \times 120 \times 15}{6000} = 1.884 \text{ ms}^{-1}$$

After substituting the value of revolution of rotor shaft (120 rpm) and its radius as 15 mm in the equation we get the tangential peripheral speed (u) to be 1.884 ms^{-1}.

By putting the tangential speed value in eqn. (3.13) the maximum tangential force acting on blades obtained as follow

$$K_s = \frac{1.5 \times 75 \times 1 \times 0.9 \ \times 0.8}{1.884} = 43 \text{ kg}$$

the soil force acting on the each of the blade (k_e) was calculated by the following equations:

$$K_e = \frac{K_s \times C_p}{i \times Z_e \times n_e} \qquad \text{..............................(3.15)}$$

Where,

K_s = Maximum tangential force, kg

C_p = Coefficient of tangential force

i = Number of flanges, 4

Z_e = Number of blades on each side of the flanges is 4

n_e = Number of blades which act jointly on the soil by the total number of blades

$$K_e = \frac{43.08 \times 2}{4 \times 4 \times \frac{1}{4}}$$

$$K_e = 21.54 \text{ kg}$$

The dimensions of the blades were defined as, the values of be, h_e, S_s, S and S_1 were equal to 0.4,2, 4, 3.75 and 3 cm respectively.

Considering the shape of the blades, the bending stress (σ_{zg}), shear stress (τ_{skt}), and equivalent stress (σ_{zt}) can be calculated by the following equations (Bernacki *et. al.*, 1972)

$$\sigma_{zg} = \frac{6K_s \times S}{b_e \times h_e^2} = 605.81 \text{ MPa} \qquad \text{..........................(3.16)}$$

$$\tau_{skt} = \frac{3K_s \times S}{(\frac{h_e}{b_e} - 0.63) \times b_e^3} = 1732.87 \text{ MPa} \qquad \text{..........................(3.17)}$$

$$\sigma_{zt} = \sqrt{\sigma_{zg}^2 + 4\tau_{skt}^2} = 3477.21 \text{ MPa} \qquad \text{..........................(3.18)}$$

Where,

σ_{zg} = bending stress, MPa

τ_{skt}= shear stress, MPa

σ_{zt} = equivalent stress, Mpa

The bending stress, shear stress and equivalent stress were determined as 605.81 MPa, 1732.87 MPa and 3477.21 MPa respectively.

B. Rotary blades design

The design of rotary weeder depends on the type of blade and also on the working condition. The total power coming from motor was distributed between the blades. The number of flanges was calculated by the following equation,

$$i = \frac{b}{bi} \quad \text{...............................(3.19)}$$

Where;

i = Number of flanges

b = Working width of rotary blade assembly (55 cm)

b_i = Distance between the two flanges on the rotary shaft (Assumed 15 cm)

Therefore, the total number of flanges obtained:

$$i = \frac{55}{15}$$

$$= 3.66 \cong 4$$

Four blades considered on each of the flanges (Z_e). Therefore, the total number of the blades obtained was:

$$Nb = i \times ze \quad \text{...............................(3.20)}$$

$$Nb = 4 \times 4$$

$$Nb = 16$$

Number of blades = 16 (Total 4-flange, 2-flange left side and 2- flange right side)

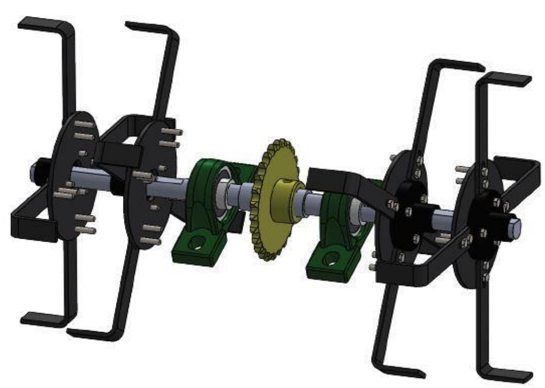

Fig. 3.1 Diagram and isometric view of rotary shaft assembly

3.6 Belt Tensioner

Near the handle two levers is provided which act as clutch lever. It actuates the jockey pulley to engage and disengage the V-belt drive.

3.7 Design of Handle

The handle of the implement is designed on the basis of the working position of the operator, easy working, shoe/floor friction and subject to anthropometry. The coefficient of friction (μ) between operators' shoe and the soil surface was 0.3. For the person with large reach and high working force if also provided with high traction surfaces and enough space to lean.

3.7.1 Handle height

Handle height (position) in working task have been standardize by many researches worked. Some relevant finding is given below in table 3.2. Therefore, machine handle height was kept at 1040 mm.

Table 3.2: Handle height for easy handling or capability

S. No.	Study conducted by	Handle height (mm) for maximum push
1	Rangasamy *et al.* (1993)	995
2	Singh. G (1989)	1000
3	Tiwari and Datta (1974)	998
4	Tajuddin *et al.* (1978)	950
5	Chaftin (1983)	680-1090

(Source: Gite and Yadav, 1985)

3.7.2 Handle length

Length of handle of implement and the angle of operation are interdependent. Angle of operation is based on functional design and geometry of the tool and geometry lies between 30º to 45º. The length of handle can be calculated as a thumb rule. In case of long handle tools, the total length of tool corresponds to 0.7 to 0.8 of shoulder height. Therefore, handle length of the present machine was kept as 810 mm. However, the handle length was decided keeping in view the lower angle between points of working plane in order to reduce strain on hands of the operator.

3.7.3 Handle grip

The optimum grip diameter recommended is 25-37.5 mm. The length of grip depends on hand and its value can be taken as 100 or 125 mm (Sharma and Mukesh, 2013). However, in the weeder designed for the present study, one horizontal bar is provided as the grip, which faciliates the worker to adjust the position of hands while operating.

3.7.4 Handle shape

Small deviations from a cylindrical shape will not have significant effect on handle performance. No difference was observed in terms of muscular fatigue between cylindrical and elliptical shaped (Gite and Yadav, 1990) Therefore, the cylindrical shape of the handle is chosen.

3.7.5 Handle material

Mild steel (pipe) and wood are common materials used for handle grips. Wood is felt more comfortable to hand because it has more coefficients of friction than mild steel. The relative movement between hand and the grip will also be less as compared to mild steel handle. However, there are some plus points of steel handles like few of them have more strength, durability, easiness in fabrication *etc*. Therefore, the material of the handle has been selected as mild steel keeping in mild functional design requirement, human comfort, economics and others advantages stated above.

Table 3.3: Specification of handle

Sr. No.	Parameter	Dimension (mm)
1	Height of handle	1040
2	Length of handle	810
3	Diameter of handle	25
4	Diameter of handle grip	35
5	Shape of handle	Cylindrical
6	Material	MS pipe

3.8 Selection of Material

The choice of the material is firstly governed by the requirements concerning the functions, stresses and the life of the component. In addition, the cost of the material in relation to the manufacturing price of the component was considered.

3.8.1 Frame material

The mild steel has 0.25-1 per cent of carbon. Frame of weeder could be fabricated from the mild steel. The mild steel has a quality to withstand with the loads that will occur against machine elements and also have low cost.

3.8.2 Blade material

The selection of a proper material for rotary blades is important in view of cost, durability, availability and machine performance. The rotary blades should generally be designed to satisfactorily and give adequate life. The high carbon steel has a good structure hardening property and resistance to abrasive wear which could withstand against soil resistance and thrust.

3.8.3 Rotor shaft material

The rotor shaft of weeder takes the entire loads *viz.* bending load, torsion loads and weight of weeder. Therefore, selection of proper material was important in view of durability, strength, availably and cost. High steel carbon has a good structure hardening property and resistance to abrasive wear which could withstand against soil resistance and thrust.

3.8.4 Transport wheels material

The wheels which are to be used on weeder, takes all the weight of the weeder and helps in transportation of the machine. Therefore, the wheels materials should be of light weight and strong enough to takes the weight of weeder while during transportation and also on working condition. The solid rubber tyre wheels are used because it easily bears the loads and does not damage the plant in field during working.

3.9 Requirement of Solar Panels

The solar photovoltaic panel is a device which converts solar energy directly into electrical power. A solar panel is actually a collection of solar (or photovoltaic) cells, which is used to generate electricity through photovoltaic effect. These solar cells are arranged in a grid-like pattern on the surface of solar panels.

$$\text{Total PV panels energy needed} = \frac{\text{Total power consumption}}{\text{(efficiency of all the auxiliary unit)}} \quad \ldots\ldots (3.21)$$

Assumption,

Efficiency of solar charge controller (ESC) = 95%

Efficiency of battery (Eb) = 95%

Efficiency of BLDC motor controller (Emc) = 95%

$$\text{Power of the panel} = \frac{\text{Total power required for motor}}{\text{(Esc x Eb x Emc)}}$$

$$\text{Power of the panel} = \frac{750}{(0.95 \text{ x } 0.95 \text{ x } 0.95)}$$

Power of the panel = 874 W

The size of solar panel was increased to provide more power, thereby, decreasing the time of charging of battery. So, we decided to use two panels, each having 240 W. Therefore, the size of PV panels is 480 W.

3.10 Consumption of Battery

A battery can be defined as an electrochemical device (consisting of one or more electrochemical cells) which can be charged with an electric current or solar panel and discharged whenever required. Batteries are usually devices that are made up of multiple lithium ion cells that are connected to external inputs and outputs. The battery capacity is directly proportional to days of autonomy and inversely to discharge rate.

$$\text{Battery capacity} = \frac{\text{Total Watthours per day used by appliance} \times \text{Days of autonomy}}{\text{Discharge rate of battery} \times \text{nominal battery voltage}} \quad \ldots\ldots\ldots (3.22)$$

Where,

Total watt hours per day = Total power used by appliance in one day

Days of autonomy is defined as the number of days that the battery can supply the site's loads without any support from generation sources.

Discharge rate is defined as the steady current in amperes (A) that can be taken from a battery of defined capacity (Ah) over a defined period (h).

Nominal battery voltage = the total battery voltage on full charged condition

Assumption,

For 1 hour application and for single day storage

Nominal voltage = 48 V

$$\text{Battery capacity} = \frac{750 \times 1}{0.95 \times 48}$$

Battery capacity =16.44 Ah (No-load)

Size of battery:

1 battery of 51.8 V and 35 amps is connected.

Equivalent voltage = 48 V

Equivalent charge = 35 Ah

Charging time of battery by solar photovoltaic module:

$= \text{amp required by battery} / \text{amp delivered by solar photovoltaic module}$ .... (3.23)

$= 35/8.62$ = 4 h

3.10.1 Discharging time of battery when connected to motor

Fully charged deep cycle battery, could up to 95% discharge

$$\text{Discharge time} = \frac{\text{amp delivered by battery}}{\text{amp required by BLDC motor}} \quad \text{................ (3.24)}$$

= (0.95 x 35) / 2.4

= 33.25 / 2.4

= 13.85 h (No-load condition)

3.11 Electrical Components of Weeder

The detailed design of the functional components and different mechanisms were carried out. The machine consisted of BLDC motor, solar panel, battery, Motor controller and speed controller system. The design of following components was taken up:

1. BLDC motor
2. Solar panel
3. Battery
4. Motor controller

3.11.1. BLDC Motor

The BLDC motor was selected based on the speed and power requirement from (Using Eq.3.2). It was the prime mover of the developed machine. It generates mechanical power through electrical energy. The DC motor of 750 W was selected for the development of prototype as per calculation and market availability. The technical specification of the DC motor is given in Table 3.4

Table 3.4: Specification of BLDC motor

Sr. No.	List of parameters	Specification
1	Model	BM1418ZXF
2	Power	750 W
3	Actual Speed	2000 rpm
4	Voltage	51.8 V
5	Current	2.4 A

3.11.2. Solar Panel

Panel was selected based on power required by motor and the efficiency of other auxiliary units such as solar charge controller, battery and motor controller (Using Eq. 3.19). The technical specification of the solar panel is given in Table 3.5

Table 3.5: Specification of solar panel

Sr. No.	List of parameters	Specification
1	Model	JP1518A009
2	Type	Polycrystalline
3	Rated maximum power (P_{max})	480 W
4	Rated operating voltage (V_{max})	37 V
5	Rated operating current (I_{max})	8.6 A
6	Maximum system voltage	1000 V
7	Module dimensions (L×W×T)	1340 mm × 1000 mm × 35 mm

3.11.3. Motor Controller:

The controller acts as by-pass system for the motor as wells as for the battery-solar panel combination. The speed of motor was control by adjusting current supply, higher the current supply higher the speed and vice-versa. The current from the battery first flows though the controller and then to the motor. If the drawn current was too low or too high it will cut-off the system. It protects the motor and battery from damage due to overload.

3.11.4. Battery

Lithium ION battery is widely used for commercial electrical vehicle because of high efficiency, long life and light weight (Wang *et al.*, 2012). The specification of such battery used in developed weeder is given in Table 3.6.

Table 3.6: Specification of battery

Sr. No.	List of parameters	Specification
1	Type	Litihum ion
2	No. of battery	1
3	Voltage	51.8 V
4	Current	35 A
5	Size (l*b*h)	120 x 300 x 300 mm
6	Discharge rate	Up to 80 %
7	Weight	10 kg

Table 3.7: Specification of walk behind type solar powered rotary weeder

Sr. No.	Specification	Value
1	Rated maximum power(P_{max})	750 W
2	Size of battery	51.8V 35A
3	Number of battery	1
4	Type of motor	BLDC motor
5	Number of BLDC motor	1
6	Maximum BLDC motor rpm	2000 rpm
7	Maximum BLDC motor power at 2000 rpm	750 W
8	Cutting width	55 cm
9	Operational width	60 cm
10	No. of Blades	4
11	No. of flange	4
12	Weeding depth	5 cm
13	Power transmission	Belt and pully Chain and Sprocket
14	Material of blade	High Carbon Steel

3.12 Experimental Design Layout

The experiment was laid out in large plot technics design with three different rotor speed (80, 100 and 120 rpm) for maize during *Rabi* 2022 in five replications. The details of treatment are shown in Table 3.8 and the layout plan is shown in Fig. 3.2. The experimental plot was having head land for turning and pre-setting of test implement.

Treatments - 03

Replication - 07

Test field - for weeding operation

Plot size – 80 x 4.2 m

Tables 3.8: Plan of experiment

Independent variables		
Sr. No.	**Variables**	**Levels**
1	Rotor speed (rpm)	80, 100, 120
Dependent variables		
1	Weeding efficiency (%)	-
2	Speed of operation	_
3	Plant damage (%)	-
4	Theoretical field capacity (ha/h)	-
5	Effective field capacity (ha/h)	-
6	Field efficiency (%)	-
7	Performance index	-
8	Cost of operation (Rs. /ha)	-

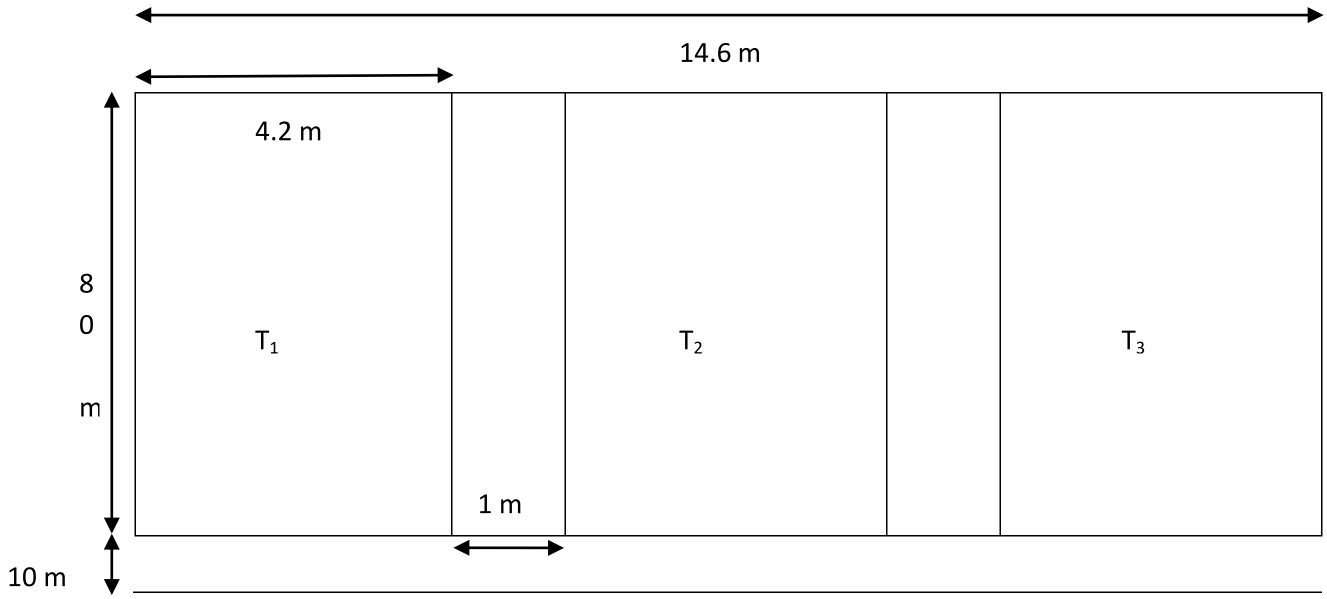

Fig.3.2 Detailed layout of experimental plot

3.12.1 Statistical Analysis of Data

During field evaluation of the weeder large plot technique was followed in the study. The observed data was analyzed statistically by Completely Randomized Design (CRD) with Microsoft Excel (2016) using ANOVA procedure.

3.13 Soil Properties at Weeding Stage

Blades of weeder directly interact with soil to uproot the weeds. Hence, soil properties directly affect the weeding performance of weeder. Following properties of soil were measured before actual testing of the weeder.

i. Soil moisture content

ii. Soil bulk density

iii. Soil resistance

3.13.1 Soil moisture content

The moisture content of the soil was measured randomly at five locations at time of weeding. Moisture content of soil was measured by digital multi parameter soil sensor. It is indicated in percentage (d.b)

$$MC = \frac{w_1 - w_2}{w_1} \times 100 \qquad \text{.............................. (3.25)}$$

Where,

MC = Soil moisture content, %,

W_1 = Initial weight of soil sample, g,

W_2 = Final weight of dry soil sample, g.

3.13.2 Soil bulk density

The bulk density of soil was determined by core cutter method. The core sampler of the soil of known volume was collected and weighed. The soil bulk density was be determined as:

$$\rho = \frac{M}{V} \qquad \text{.......................... (3.26)}$$

Where,

ρ = Bulk density of soil, g/cm^3,

M = Weight of dry soil, g,

V = Volume of the core cutter, cm^3.

3.13.3 Soil resistance

Soil resistance is an indication of soil hardness and is expressed as force per square centimeter required for a cone to penetrate into soil. Soil resistance in the soil varies with cone apex angle and area of cone bottom. A standard cone penetrometer is used to determine the soil resistance. At different moisture contents, soil resistances are different. Measurement of soil resistance is required to assess soil unit draft, which affected the power requirement and other performance parameters of the weeder. This is measured using manually operated cone penetrometer at different moisture levels *in-situ* condition. Soil resistance was calculated in terms of kg cm^{-2}.

3.14 Instrumentation requirement

3.14.1 Tachometer

Tachometer was used to measure the rotor rpm on which the flange and blades were fixed. Contact type tachometer was used to determine the rpm of the rotor shaft.

3.14.2 Digital multi meter

It was used to measure the flow of current from battery to motor. The rate of discharge of battery was estimated by digital multi meter. It has clamp like facility under which wire was clamped and reading was recorded.

3.14.3 Measuring tapes

It was to measure the width of cut and to measure the size of experimental plot. A 30-meter measuring tape was used marking the plots and measuring the width of cut after weeding operation by weeder.

3.15 Performance Evaluation of Walk behind Type Solar Powered Rotary Weeder

The developed solar powered walk behind type rotary weeder was tested under field conditions to evaluate its performance of weeder. Field testing was done by following the testing criteria and standards as per IS: 7925-1975 test code and following observations were recorded.

The machine is evaluated for its performance in the field in an area of 750 m^2 for maize crop. The following performance parameters of the solar powered walk behind type rotary weeder were recorded.

i. Weeding efficiency (%)
ii. Plant damage (%)
iii. Depth of cut, mm
iv. Theoretical field capacity (ha/h)
v. Effective field capacity (ha/h)
vi. Field efficiency (%)
vii. Performance index
viii. Cost of operation (Rs. /ha)

3.15.1 Weeding efficiency

Weeding efficiency is the ratio between the Number of weeds removed by solar powered rotary weeder to the Number of weeds present before weeding operation in a unit area and is expressed as a percentage. The samples were collected in quadrant method by random selection of spots by a square quadrant of 1 square meter area (Tajuddin, 2006).

$$\text{Weeding efficiency, (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad \text{……..…….. (3.27)}$$

Where,

W_1 = Number of weed removed by weeder,

W_2 = Numberof weed present after wedding operation.

3.15.2 Plant damage

It is the ratio of the number of plants damaged after operation in a unit area to the number of plants present before operation in the same unit area. It is expressed in percentage.

$$PD = \frac{q}{p} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.28)$$

Where,

PD = Plant damage (%)

p = Total number of plants per unit area before the weeding operation

q = Total number of plants damaged in the same unit area after the weeding operation

3.15.3 Depth of cut

The depth of weeding operation was measured by measuring scale in different rows at different places.

3.15.3 Theoretical field capacity

Theoretical field capacity of the machine is the rate of field coverage that would be obtained if the machine is performing its function 100% of the time at the rated forward speed and always covered 100% of its rated width. It is expressed as hectare per hour and determined as follows (Kepner *et al.*, 1978).

$$TFC = \frac{W \times S}{10} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.29)$$

Where,

TFC = Theoretical field capacity (ha/h)

W = Width of cut (m)

S = Speed of operation (Km/h)

3.15.4 Effective field capacity

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

$$EFC = \frac{A}{T_p + T_i} \quad \text{.............................. (3.30)}$$

Where,

EFC = Effective field capacity (ha/h)

A = Actual area covered (ha)

T_p = Productive time (h)

T_i = Non-productive time (h)

3.15.5 Field efficiency

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

$$\eta_e = \frac{EFC}{TFC} \times 100 \quad \text{............................. (3.31)}$$

Where,

η_e = Field efficiency (%)

EFC = Effective field capacity (ha/h)

TFC = Theoretical field capacity (ha/h)

3.15.6 Performance index

Performance of the weeder is assessed through performance index (PI) by using the following relation as suggested by (Srinivas *et al.*, 2010).

$$PI = \frac{FC \times (100 - \text{plant damage}) \times WE}{P} \quad \text{.................. (3.32)}$$

Where,

FC = Field capacity (ha/h)

PD = Plant damage (%)

WE = Weeding efficiency (%)

P = Power (HP)

3.15.7 Operational cost

Cost of weeding operation performed for all treatments was worked out on the basis of the prevailing input and fabrication cost of the implements, machinery and rental wages of operator and labours if required. The cost of operation of solar powered walk behind type rotary weeder is divided into two heads known as fixed cost and operation cost, where fixed cost is independent of operational use while variable cost varies proportionally with the amount of use (Kamboj *et al*., 2012).

The fixed cost includes depreciation, interest on the capital cost, shelter, insurance and taxes. Operation cost includes fuel, lubricants, repair and maintenances cost and wages. Cost of weeding operation for solar powered walk behind type rotary weeder was calculated in Rs./ha.

3.15.7.1 Fixed cost of solar powered walk behind type rotary weeder

(A) Depreciation

This cost reflects the reduction in value of machine with use (wear) and time. While actual depreciation would depend on the sale price of the machines after its use. On the basis of different computational method, depreciation can be estimated. The following formula based on straight line method was used.

$$D = \frac{P-S}{L \times H} \qquad \text{……………………… (3.33)}$$

Where,

P = Purchase price of the machine (Rs.)

S = Salvage value of the machine taken as 10% of purchase price

L = Useful life of the machine in year

H = Annual use (h/yr.)

B) Interest

Annual charges of interest were calculated on the basis of the actual rate of interest payable. It was taken at the rate of 10 % of average purchase price of the machine per year.

$$A = \left\{\frac{(P+S)}{2 \times H}\right\} \times \left\{\frac{i}{100}\right\} \qquad \text{……………..…………… (3.34)}$$

Where,

A = Annual charges of interest (Rs/h)

P = Purchase price of the machine (Rs)

S = Salvage value of the machine (Rs)

i = Interest rate (%)

H = Annual use (h/yr.)

C) Taxes, Insurances and shelter cost

It was calculated as 2 % of the purchase price of the machine.

3.15.7.2 Variable cost of solar powered walk behind type rotary weeder

A) Repair and maintenance

Repair and maintenance cost were considered as 5 % of purchase price of weeder.

B) Labour charges

Charges which taken by the labourer on the basis of the working 8 hours per day in the field. At present, a labour generally charges ₹.352/- for one day (8 h) during weeding season.

IV. RESULTS AND DISCUSSION

This chapter deals with the results obtained for different objectives of a study entitled design and development of solar powered walk behind type rotary weeder for maize crop. The possible justifications to the problems faced in the performance evaluation are discussed appropriately meeting the working viability of the machine. For the purpose of performance evaluation of the developed weeder, it was run with three different rotor speed. The performance of solar powered walk behind type rotary weeder was expressed in terms of working speed, weeding efficiency, plant damage, field capacity, field efficiency, performance index and operational cost.

4.1 Soil Parameter

4.1.1 Moisture content

The moisture content of the upper 30 cm soil on wet basis at time of weeding varied from 19.25 per cent to 23.22 per cent and the average moisture content was found to be 21.05 per cent (Appendix-A).

4.1.2 Bulk density

The bulk density of the soil varied from 1.70 to 1.84 g/cm^3 and the average bulk density of soil was found to be 1.78 g/cm^3 (Appendix-A).

4.1.3 Soil resistance

The soil resistance of loamy sand soil varied from 0.59 to 0.61 kg/cm^2 and the average soil resistance of loamy sand soil was found to be 0.60 kg/cm^2 (Appendix-A).

4.2 Performance Evaluation of Developed Walk behind Type Solar Powered Rotary Weeder

The solar powered walk behind type rotary weeder was evaluated to determine the operational parameter in maize crop at Agronomy Research Farm, S.D. Agricultural University, Sardarkrushinagar. Three different rotor speed (80, 100 and 120 rpm) were selected to test the developed solar powered walk behind type rotary weeder. The effect of operational parameters was studied to evaluate the performance of the solar powered walk behind type rotary weeder in terms of weeding efficiency, plant damage, effective field capacity, field efficiency and performance index.

4.2.1 Effect of rotor rpm on weeding efficiency

Table 4.1 and Fig. 4.1 shows that the weeding efficiency was affected by rotor speed, it was observed that highly significant weeding efficiency of 77.14 per cent was found with 120 rpm which was found at par with 100 rpm rotor speed (76.13 per cent). Similar results were reported by (Paul, 2003 and Raosaheb *et al.*, 2020).

The difference in weeding efficiency in all the rotor speed may be due to different operating speed, because all the rotor speed were tested at same moisture content of the test plot.

Table 4.1 Effect of rotor rpm on weeding efficiency

Treatment	Mean
T1 (per cent)	68.54
T2 (per cent)	76.13
T3 (per cent)	77.14
C.D. (0.05)	3.92
SE(m) ±	1.31
C.V. (per cent)	4.69

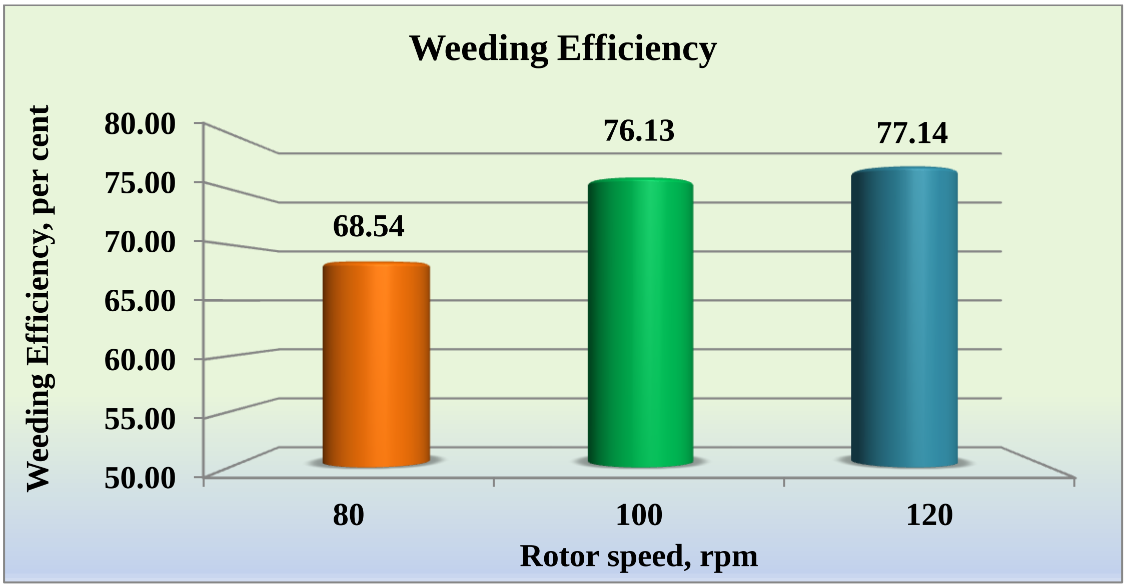

Fig.4.1 Effect of rotor rpm on weeding efficiency

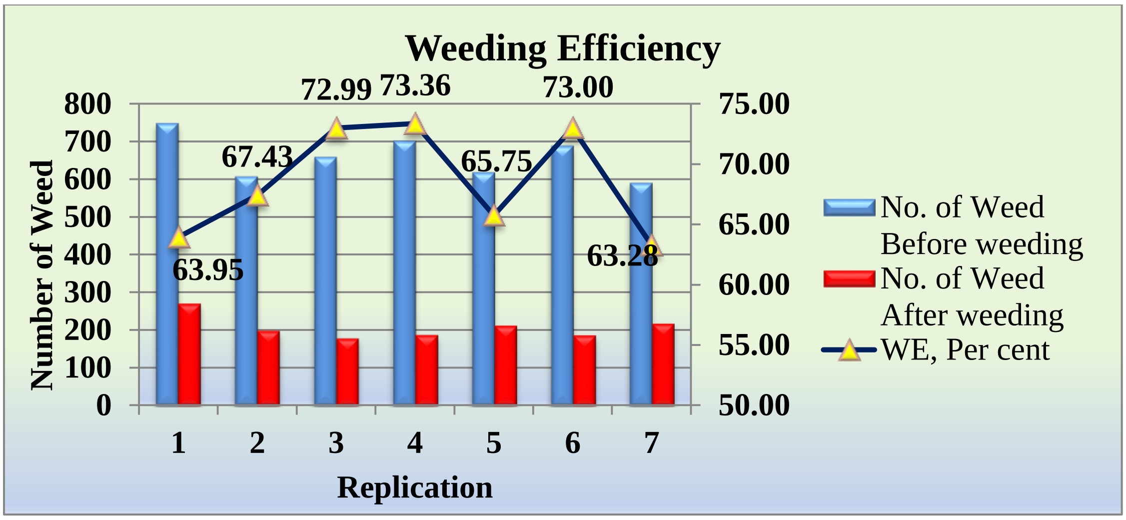

Fig. 4.2 Variation of weeding efficiency at 80 rpm rotor speed

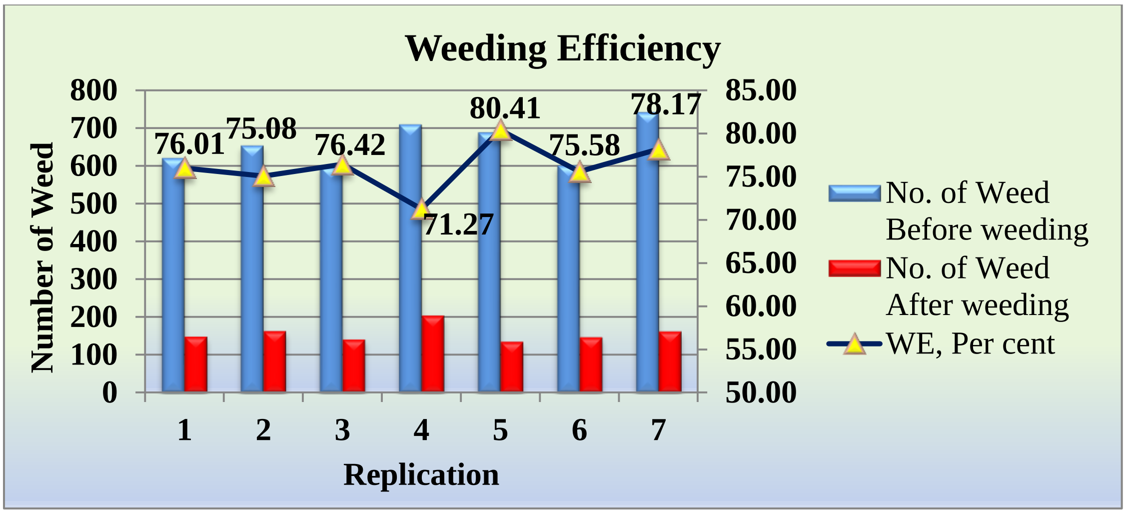

Fig. 4.3 Variation of weeding efficiency at 100 rpm rotor speed

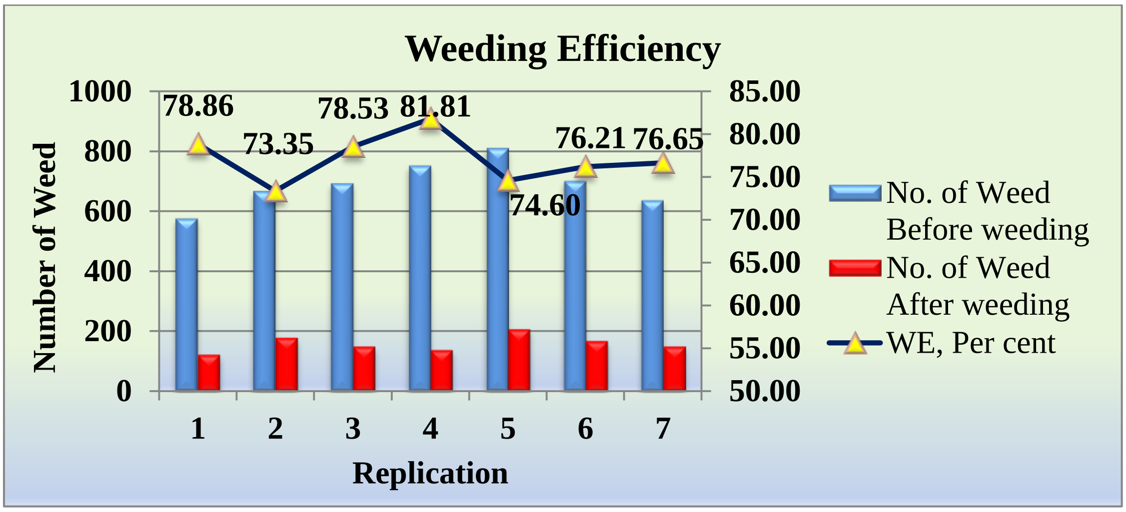

Fig. 4.4 Variation of weeding efficiency at 120 rpm rotor speed

4.2.2 Effect of rotor rpm on speed of operation

The operational speed of the weeder with three different rotor speed was determined. The highest working speed of weeder was found as 1.55 km/h at 120 rpm which was found at par with 100 rotor speed (1.45 km/h). It has been observed that the speed of rotor has a subsequent effect on the operational speed. The analysis showed that variation in speed of rotor data significantly affects the operational speed. The result shows that increasing the rotor speed increases the speed of operation and vice versa. Similar results were also reported by (Kachhot *et al.*, 2020).

Table 4.2 Effect of rotor rpm on speed of operation

Treatment	Mean
T1 (km/h)	1.24
T2 (km/h)	1.45
T3 (km/h)	1.55
C.D. (0.05)	0.16
SE(m) ±	0.05
C.V. (per cent)	10.08

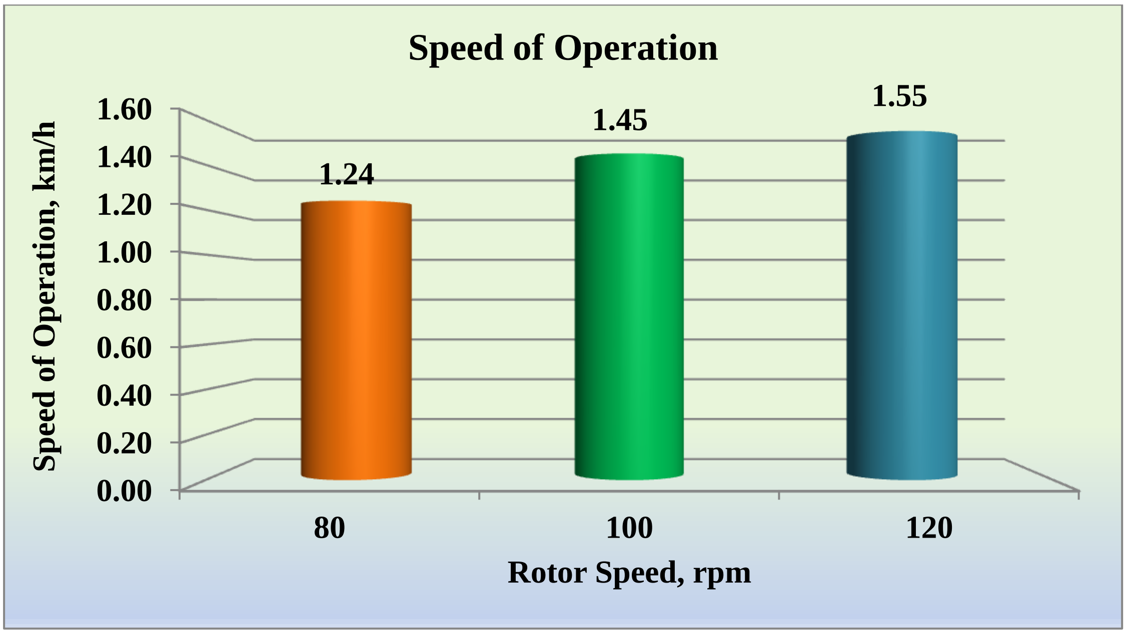

Fig.4.5 Effect of rotor rpm on operational speed

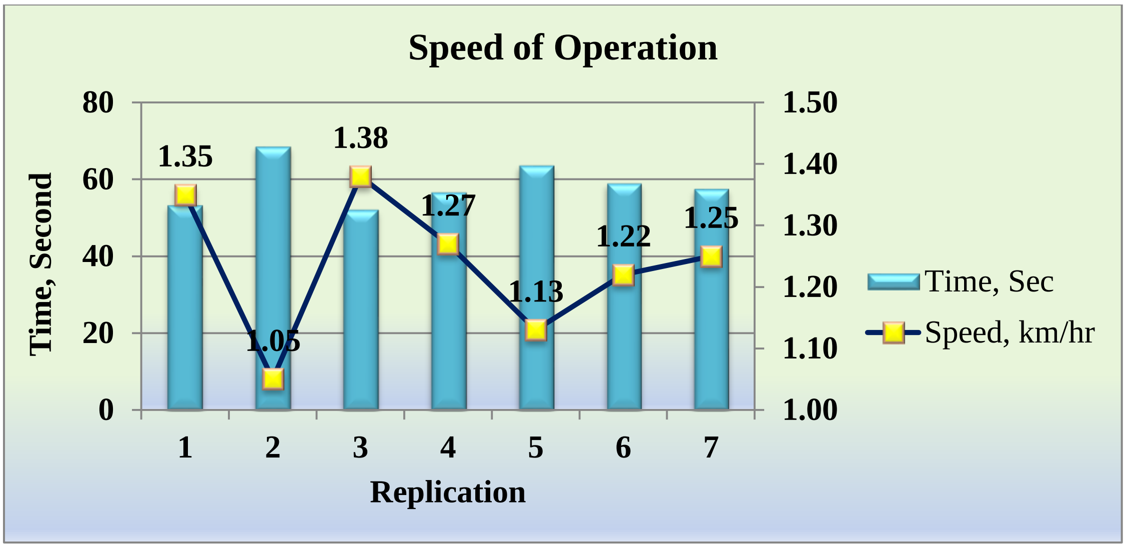

Fig. 4.6 Variation of speed at 80 rpm rotor speed

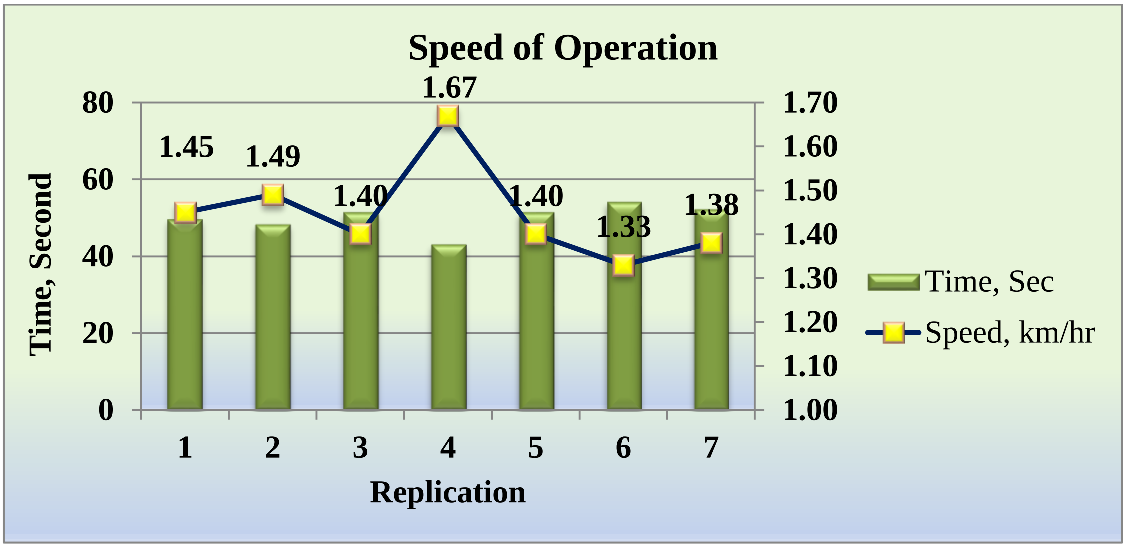

Fig. 4.7 Variation of speed at 100 rpm rotor speed

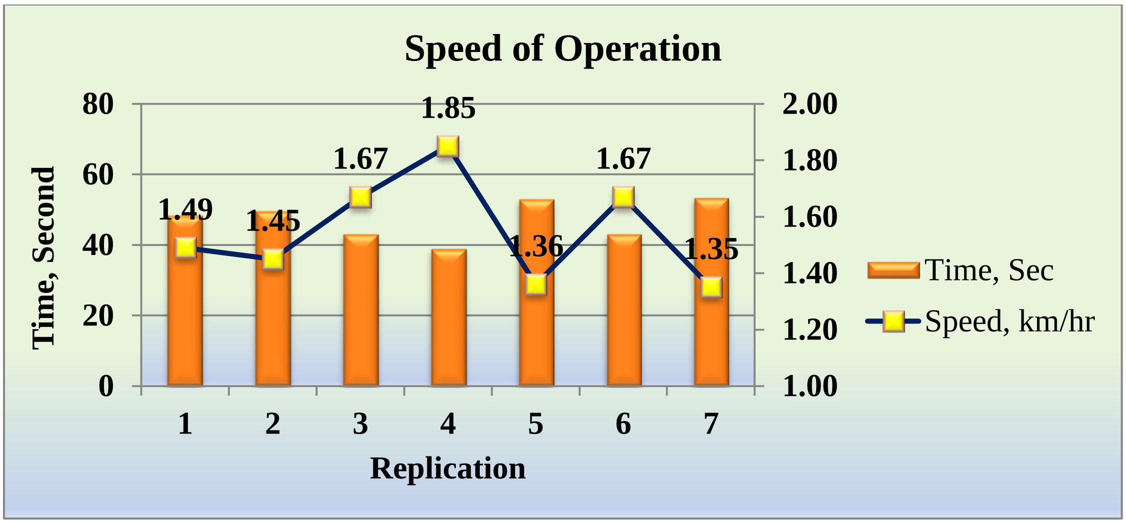

Fig. 4.8 Variation of speed at 120 rpm rotor speed

4.2.3 Effect of rotor rpm on plant damage

The plant damage for different treatment was depicted in Table 4.3 and figure 4.9. Significantly lower plant damage was observed in 80 rpm rotor speed (3.94 per cent) which was found at par with 100 rpm rotor speed (4.92 per cent). The plant damage was found to be on higher, when speed of rotor increases. The plant damage was found higher in 120 rpm speed (9.79 per cent) due to unbalancing of weeder because of higher operating speed of weeder. Similar results were also reported by (Raosaheb *et al.*, 2020 and Paul, 2003).

Table 4.3 Effect of rotor rpm on plant damage

Treatment	Mean
T1 (per cent)	3.94
T2 (per cent)	4.92
T3 (per cent)	9.79
C.D. (0.05)	3.47
SE(m) ±	1.16
C.V. (per cent)	20.39

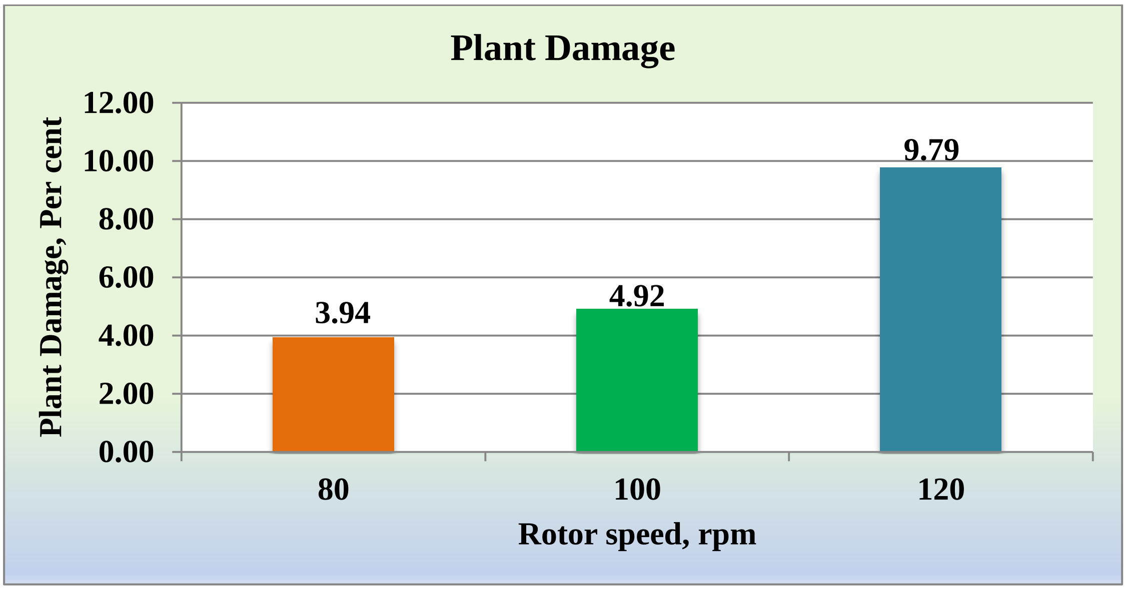

Fig.4.9 Effect of rotor rpm on plant damage

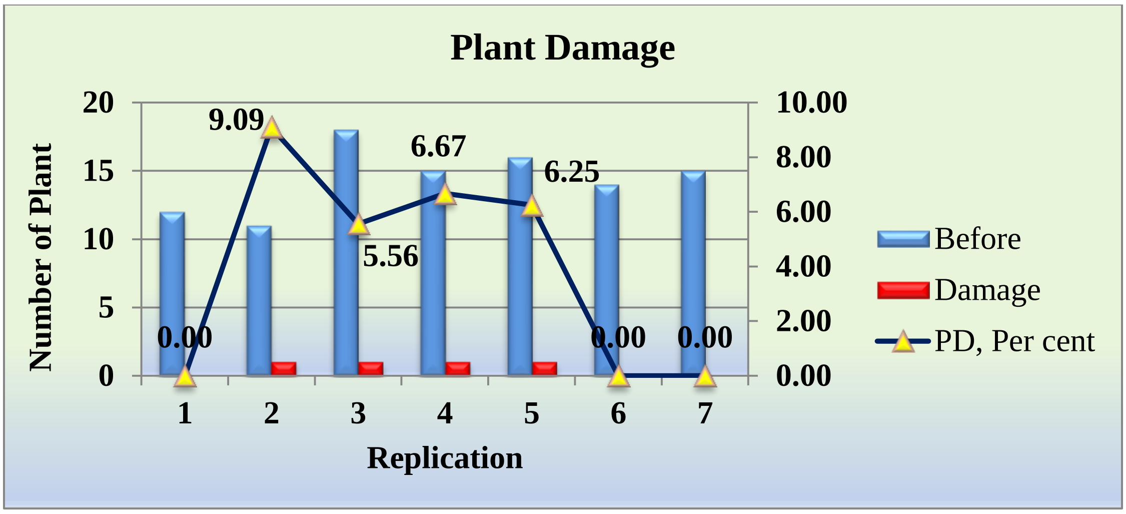

Fig. 4.10 Variation of plant damage at 80 rpm rotor speed

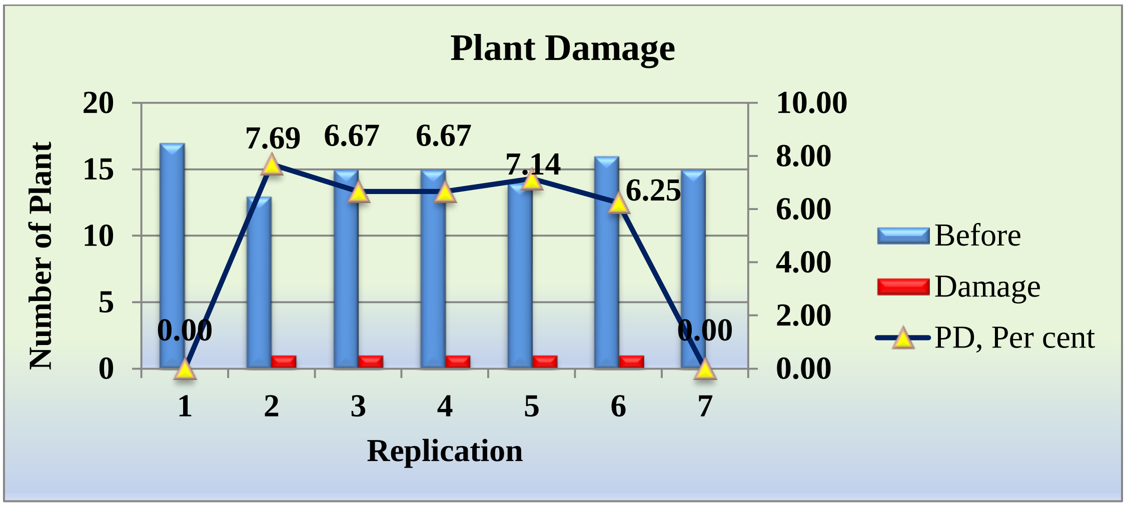

Fig. 4.11 Variation of plant damage at 100 rpm rotor speed

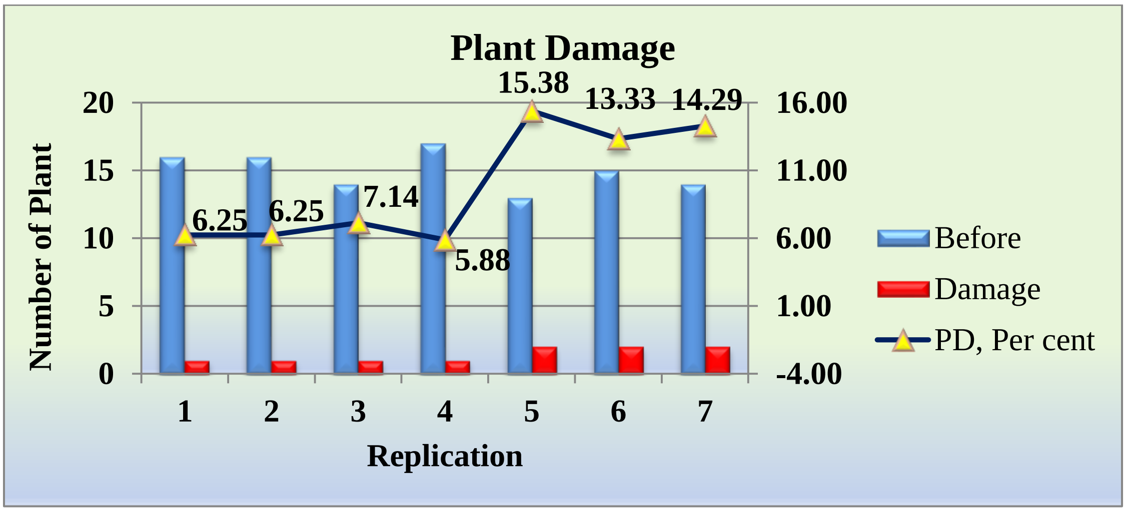

Fig. 4.12 Variation of plant damage at 120 rpm rotor speed

4.2.4 Effect of rotor rpm on depth of cut

The actual depth of cut was determined and summarized in Table 4.4. The maximum average depth of cut was found at 80 rpm (43.57 mm) which was found at par with 100 rpm (42.43 mm). The depth of cut varies between 36.14 to 43.57 mm. The analysis of data showed that maximum depth of cut found at 80 rpm and minimum depth of cut found at 120 rpm. These results are in accordance with the findings of earlier studies by (Mishra, 2021)

Table 4.4 Effect of rotor rpm on depth of cut

Treatment	Mean
T_1 (mm)	43.57
T2 (mm)	42.43
T3 (mm)	36.14
C.D. (0.05)	2.82
SE(m) ±	0.94
C.V. (per cent)	6.16

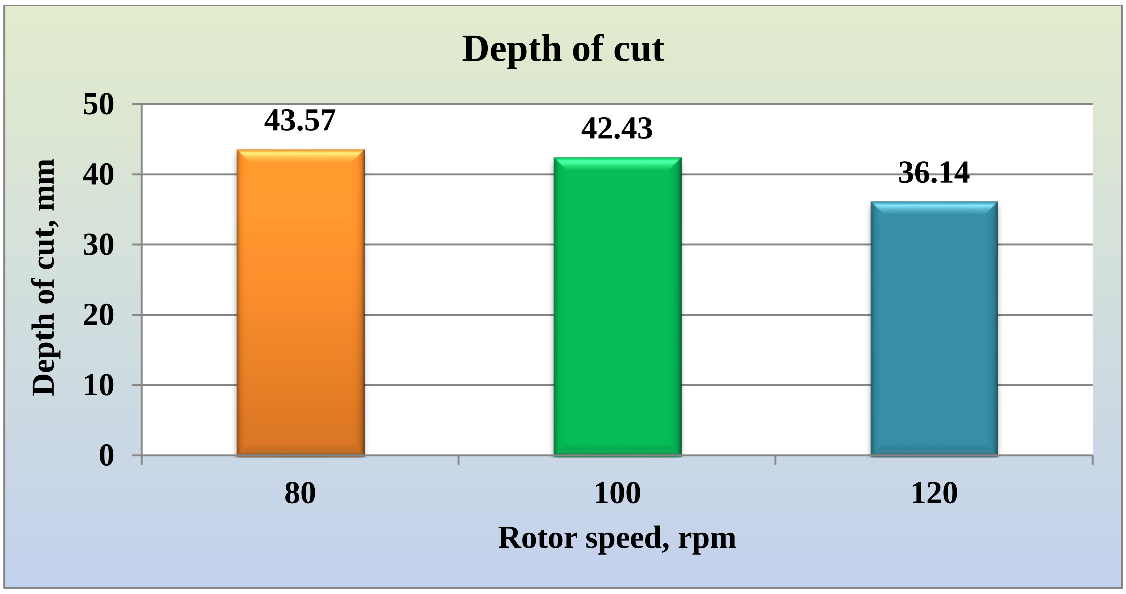

Fig. 4.13 Effect of rotor rpm on depth of cut

4.2.5 Effect of rotor rpm on theoretical field capacity

It was considered for only design purpose because on the field we encountered no. of problems. So it is impossible to achieve actual field capacity equal to theoretical field capacity.

4.2.6. Effect of rotor rpm on effective field capacity

Effective field capacity of the machine with the different speed of rotor was determined. The statistically analyzed results with mean effective field capacity are shown in Table 4.5 and figure 4.14. The data reveal that the maximum effective field capacity was found with 120 rpm (0.072 ha/h) which was found at par with 100 rpm (0.066 ha/h). These results are in accordance with the findings of earlier studies by (Olaoye and Adekanye, 2006, Singh 2017, and Paul, 2003).

The highest effective field capacity in case of 120 rpm speed was due to the comparatively higher rotor rpm for the operation. The lowest field capacity (0.054 ha/h) was found in 80 rpm rotor speed. This may be attributed to the more time required for operation due to more depth of cutting.

Table 4.5 Effect of rotor rpm on effective field capacity

Treatment	Mean
T1 (ha/h)	0.054
T2 (ha/h)	0.066
T3 (ha/h)	0.072
C.D. (0.05)	0.007
SE(m) ±	0.002
C.V. (per cent)	9.124

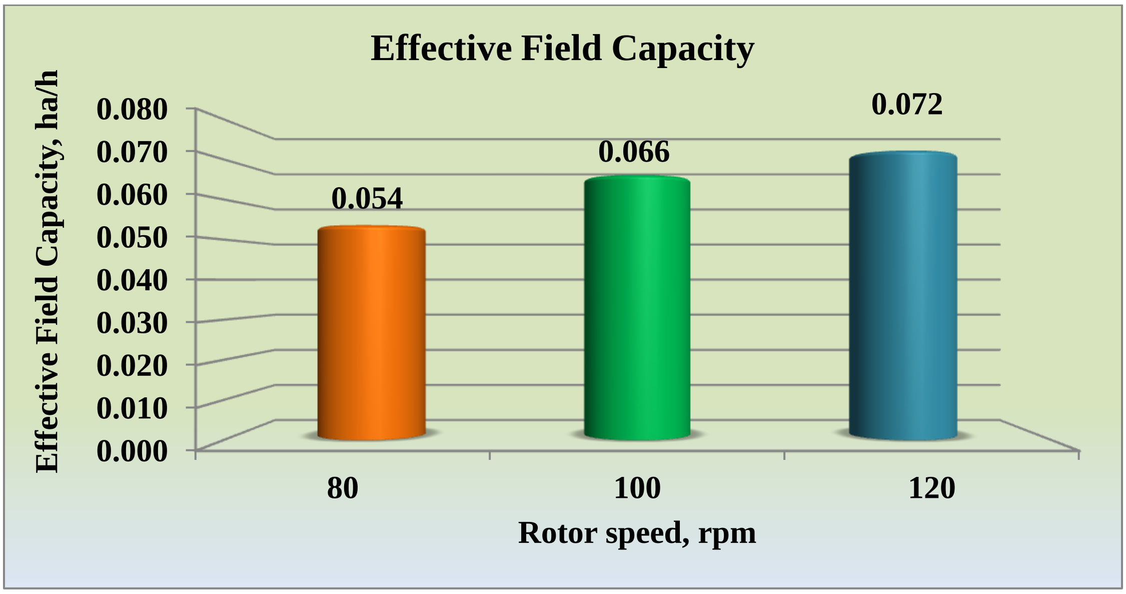

Fig. 4.14 Effect of rotor rpm on effective field capacity

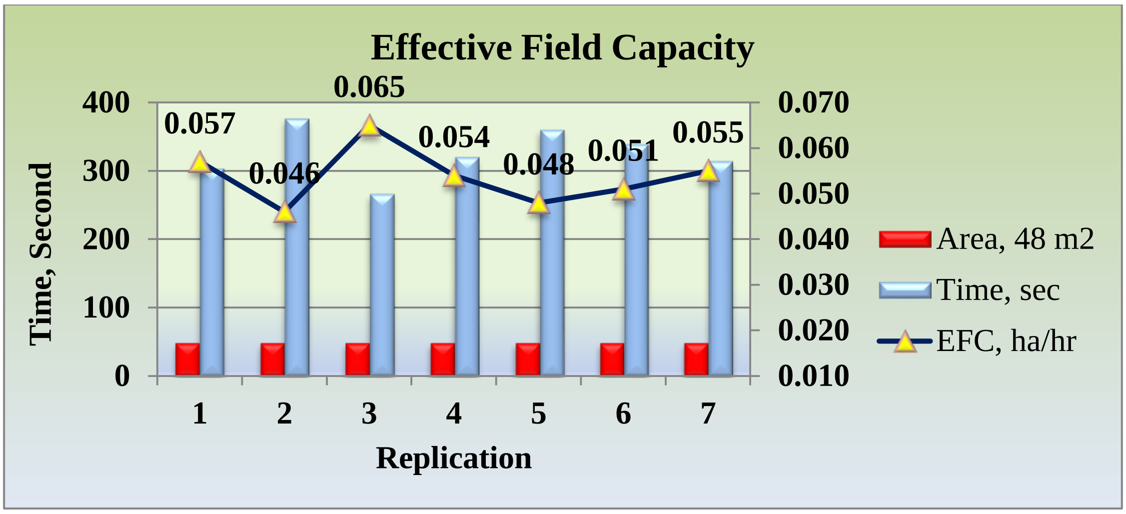

Fig. 4.15 Variation of effective field capacity at 80 rpm rotor speed

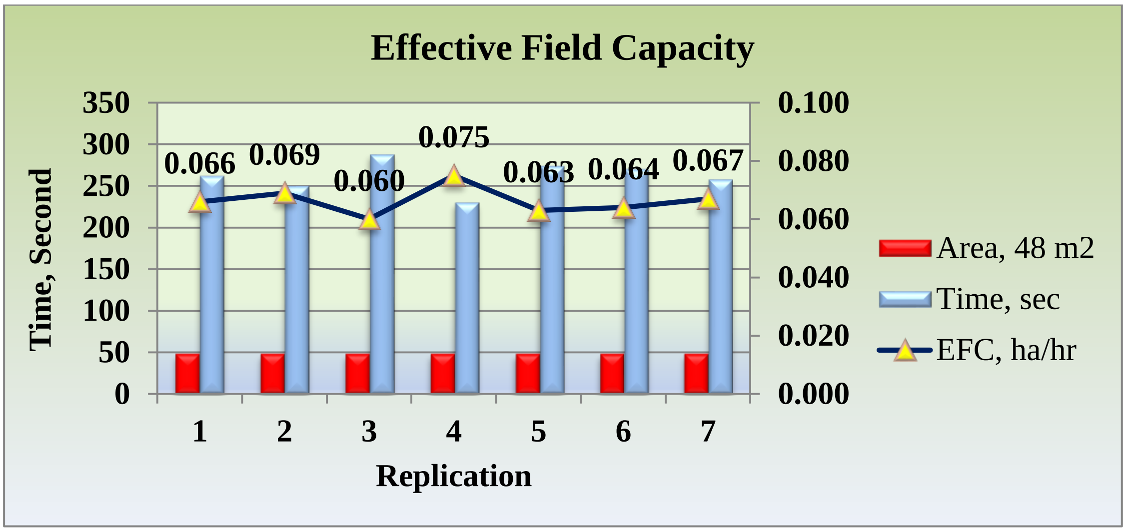

Fig. 4.16 Variation of effective field capacity at 100 rpm rotor speed

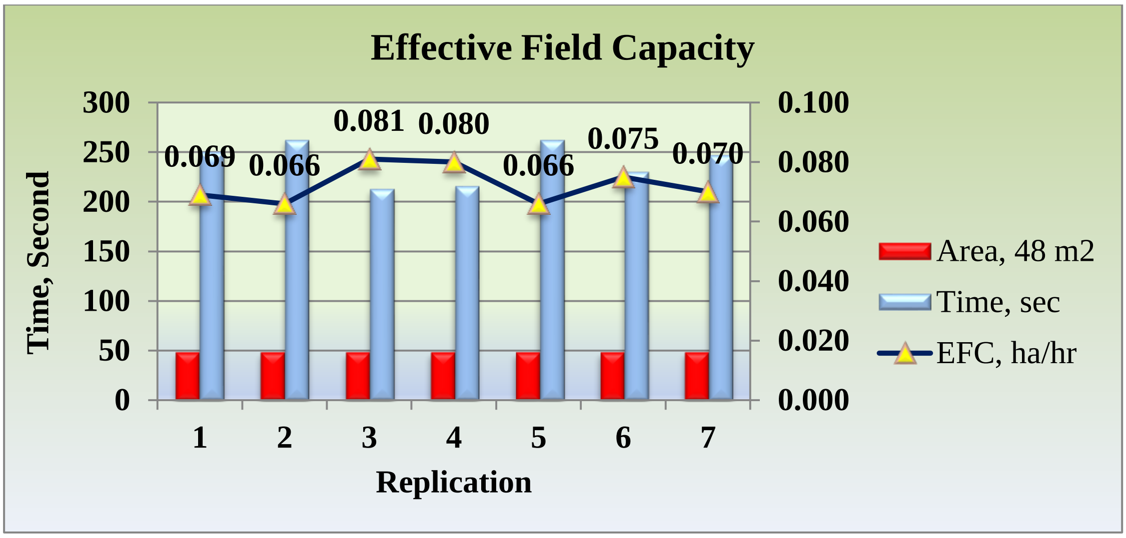

Fig. 4.17 Variation of effective field capacity at 120 rpm rotor speed

4.2.7. Effect of rotor rpm on effective field efficiency

The field efficiency of developed weeder was found highest at 120 rpm (85.32 per cent) which was found at par with 100 rpm (83.39 per cent) and there was significant difference between 80 rpm (78.89 per cent) and 120 rpm (85.32 per cent). These results are accordance with the findings of (Mishra, 2021and Raosaheb *et al.*, 2020).

Table 4.6 Effect of rotor rpm on effective filed efficiency

Treatment	Mean
T1 (per cent)	78.89
T2 (per cent)	83.39
T3 (per cent)	85.32
C.D. (0.05)	4.70
SE(m) ±	1.57
C.V. (per cent)	5.04

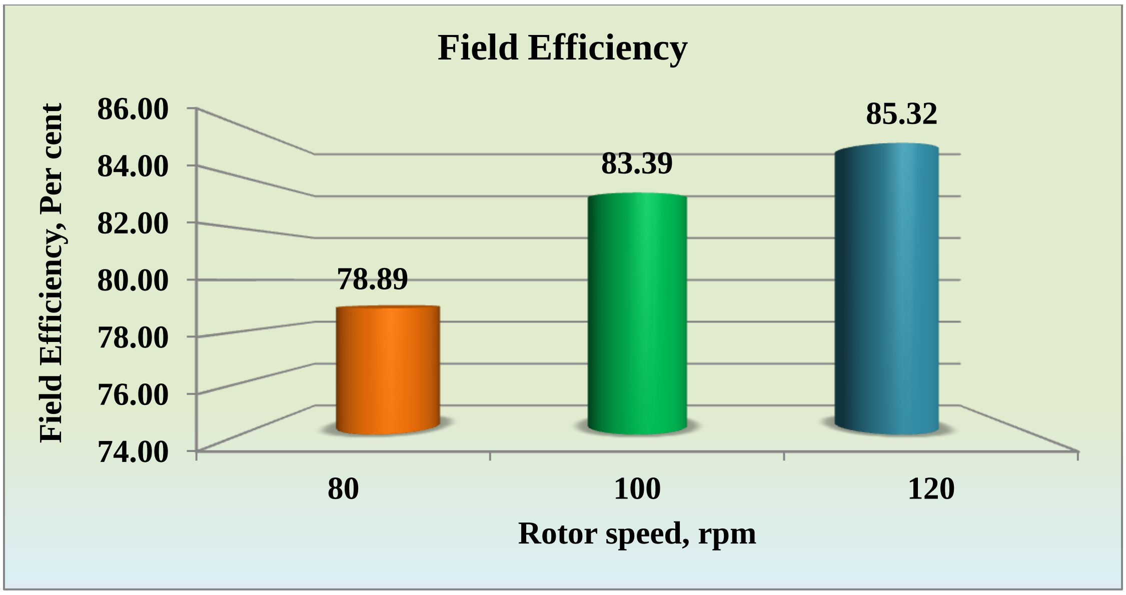

Fig. 4.18 Effect of rotor rpm on field efficiency

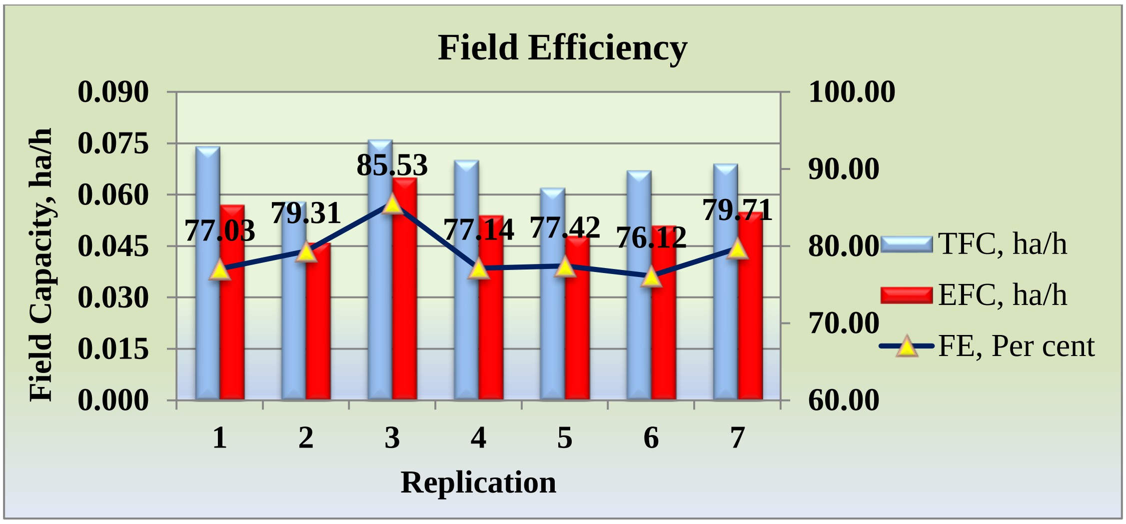

Fig. 4.19 Variation of field efficiency at 80 rpm rotor speed

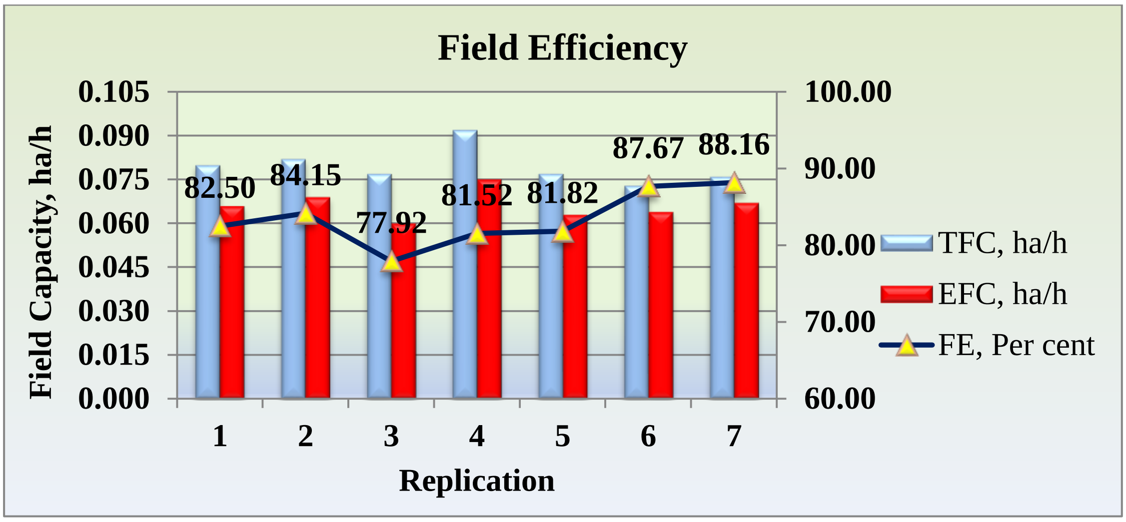

Fig. 4.20 Variation of field efficiency at 100 rpm rotor speed

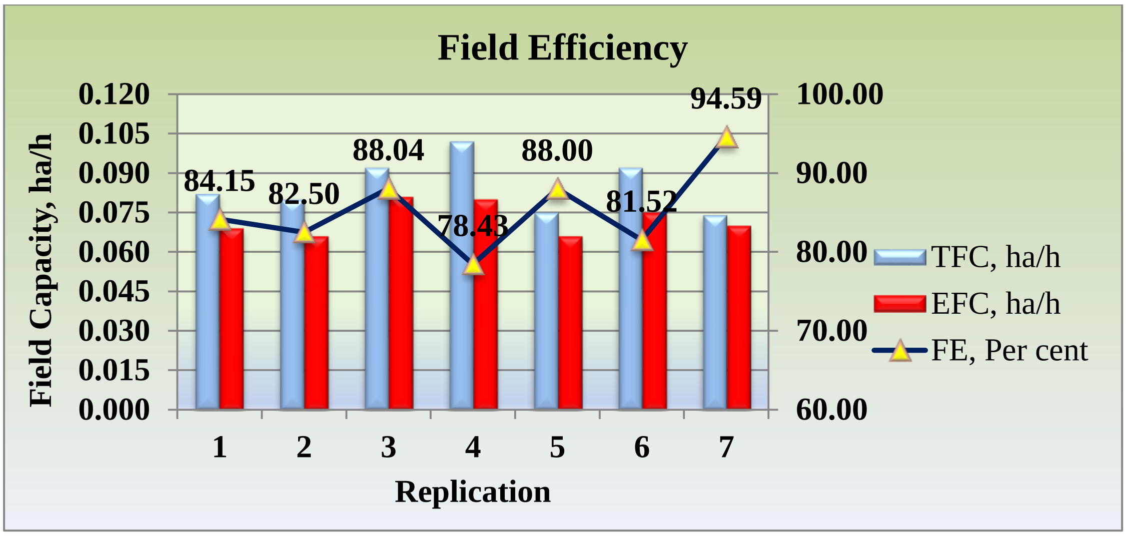

Fig. 4.21 Variation of field efficiency at 120 rpm rotor speed

4.2.8. Effect of rotor rpm on performance index

Performance index is directly related to field capacity, weeding efficiency and inversely with power exerted. Performance index were found according to equation 3.30. This parameter gives idea about overall performance of a particular rotor speed after making qualitative and quantitative analysis. Performance index for different rotor speed are shown in Table 4.7 and Fig. 4.22. Maximum performance index was observed in T_3 (120 rpm) as 506.06 which were found at par with T_2 (100 rpm) as 479.18.

Table 4.7 Effect of rotor rpm on performance index

Treatment	Mean
T1	354.37
T2	479.18
T3	506.06
C.D. (0.05)	63.46
SE(m)±	21.20
C.V. (per cent)	12.56

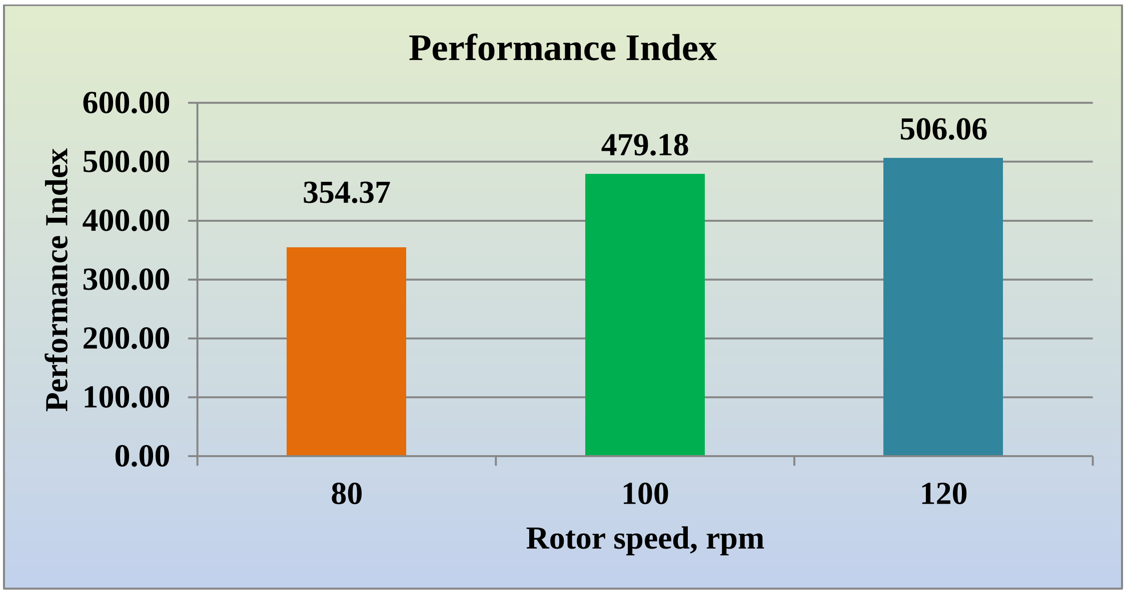

Fig. 4.22 Effect of rotor rpm on performance index

4.3 Performance Evaluation of Power Source

The weeder developed was powered with solar energy; hence performance of the system developed for powering the weeder was evaluated.

4.3.1 Estimation of total time taken to charge the battery by solar panel

The total time taken by solar panel to charge the battery depends upon the total output current is generating. The total time taken to fully charge a battery from fully discharged point is summarized in table 4.8. These results are in accordance with the findings of earlier studies by (Mishra, 2021).

Table 4.8 Charging time to fully charge battery from solar panel

Sr. No.	List of parameters	Specification
1	Current generates by solar panel	8.6 A
2	Total battery capacity	35 A
3	Charging time (hour)	4 h

4.3.2 Performance evaluation of battery

The discharge rate is used to determine performance of battery. When solar panel was disconnected from the battery the time taken to fully discharge the battery is summarized in Table 4.9. These results are in accordance with the findings of earlier studies by (Mishra, 2021).

Table 4.9 Discharge of fully charged battery

Sr. No.	List of parameters	Specification
1	Voltage stored in fully charged battery	51.8 V
2	Current stored in fully charged battery	35 Ah
3	Discharge rate of battery	85 %
4	Maximum voltage delivered by battery	48 V
5	Maximum current delivered by battery	29.8 A
6	Average Ah requirement of BLDC motor	13.1 Ah
7	Discharging time	2.27 h

4.4 Cost Economics of Developed Walk behind Type Solar Powered Rotary Weeder

Any agricultural machine should be designed, taking into consideration of its cost economics. A machine designed should have minimum cost with good field performance. Therefore, cost evaluation of solar powered rotary weeder was determined by straight line method. Total cost of solar powered rotary weeder was determined by adding both the net cost of material used for fabrication and labour cost for fabrication.

Annual usage of weeder, h = 350

Total life of weeder, years = 10

Initial cost of weeder, ₹ = 55700/-

Salvage value (10 % of initial cost), ₹ = 5570/-

A. **Fixed cost**

1. Depreciation (D)/h $= \frac{55700-5570}{10 \times 350}$ (Equation 3.31)

   = ₹ 14.32/-

2. Interest (I)/h $= \frac{(55700+5570)}{2} \times \frac{0.10}{350}$ (Equation 3.32)

   = ₹ 8.75/-

3. Taxes, Insurance and shelter charges (2 % of the purchase price) per hour

   $= \frac{55700 \times 0.02}{350}$

   = ₹ 3.18/-

Total fixed cost = 14.32 + 8.75 + 3.18

= ₹ 26.25/-

B. Variable cost

1. Repair and maintenance (5 % of purchase price)

   $= \frac{55700 \times 0.05}{350}$

   = ₹ 7.95/h

2. Labour charge @ 352/day

Per hour = ₹ 44

Total variable cost = 7.95 + 44

= ₹ 51.95/h

Total cost = fixed cost + variable cost

= 26.25 + 51.95

= ₹ 78.2 per hour

Actual field capacity at 100 rpm rotor speed = 0.066 ha/h

Cost of weeding per hectare **= ₹ 1185**

Cost of Weeding by Conventional Method

Man required for weeding one hectare of maize crop = 169 man-h/ha

Wage rate of Rs. 352 per man per day of 8 hours

The cost of manual weeding per hectare of maize crop = Rs. $\frac{169}{8} \times 352$

= ₹ 7436

Cost of Weeding by petrol run power weeder

Annual usage of weeder, h	= 350
Total life of weeder, years	= 10
Initial cost of weeder, ₹	= 45000/-
Salvage value (10 % of initial cost), ₹	= 4500/-

A. **Fixed cost**

1. Depreciation (D)/h $= \frac{45000-4500}{10 \times 350}$ (Equation 3.31)

   = ₹ 11.57/-

2. Interest (I)/h $= \frac{(45000+4500)}{2} \times \frac{0.10}{350}$ (Equation 3.32)

   = ₹ 7.07/-

3. Taxes, Insurance and shelter charges (2 % of the purchase price) per hour

   $= \frac{45000 \times 0.02}{350}$

   = ₹ 2.57/-

Total fixed cost = 14.32 + 8.75 + 3.18

= ₹ 21.21/-

B. Variable cost

1. Repair and maintenance (5 % of purchase price)

   $= \frac{45000 \times 0.05}{350}$

   = ₹ 6.42/h

2. Fuel cost

   Petrol @ Rs. 95 per litre (95 l/h)

   = ₹ 95/h

3. Labour charge @ 352/day

   Per hour = ₹ 44

Total variable cost = 6.42 + 95 + 44

= ₹ 145.42/h

Total cost = fixed cost + variable cost

= 21.21 + 145.42

= ₹ 166.63 per hour

Actual field capacity at of petrol run power weeder = 0.066 ha/h

Cost of weeding per hectare **= ₹ 2525**

Saving in cost

a) Compared with conventional method

Saving cost at 100 rpm rotor speed, per cent = $\frac{7436-1185}{7436} \times 100$

= 84.06 %

b) Compared with petrol run power weeder

Saving cost at 100 rpm rotor speed, per cent = $\frac{2525-1185}{2525} \times 100$

= 53.06 %

Saving in time

a) Compared with conventional method

The labour requirement in manual weeding per hectare = 169 man-h/ha

The labour requirement in solar power weeder per hectare at 100 rpm rotor speed = 15.15 man-h/ha

Saving time at 100 rpm rotor speed, per cent = $\frac{169-15.15}{169} \times 100$

= 91.03 %

b) Compared with petrol run power weeder

There is no time difference notice between solar power weeder and petrol run power weeder because of field capacity are same for both weeder.

The growing global demand of energy, the decrease of petroleum reserves and the current of environmental contamination problems, make it imperative to study renewable energy sources for use in farming, in order to decrease the dependence on fossil fuels and reduce emissions of pollutant gases. The uses of petrol run power weeder emissions of NO_x (1255 ppm)(de farias et all, 2019). Petrol produces 2.3035 kg of CO_2 per liter burnt. So its reduced up to 805 kg of carbon production annually. Petrol run power weeder generates noise up to 91dB. The developed weeder is fully operated by renewable energy sources and environment friendly because of its not emits any harmful gases and noise.

V. SUMMARY AND CONCLUSIONS

Mechanical weed control is very effective as it helps to reduce the drudgery involved in manual weeding, it also kills the weeds and keeps the soil surface loose ensuring soil aeration and moisture absorption capacity. Non-availability and high cost of labours limits manual weed control, and therefore development of suitable mechanized weed control method is imperative. Use of mechanical and power weeder is very limited amongst the farmers due to involvement of high cost.

In India, now mostly research activities have been focused on the development of solar operated machinery. Keeping this view in mind, a research study was undertaken with the aim of conceptual designing, development and performance evaluation of walk behind type solar powered rotary weeder that could be a low-cost technology, pollution free and easily adoptable in farmer's field.

At very first phase, the conceptual designing of the walk behind type solar powered rotary weeder was done in the form of solid models or drawings using 3-D software Pro-E wildfire 2.0 to visualize the weeder.

The experimental study on "Design and development of walk behind type solar powered rotary weeder" was planned and conducted during year 2022. Performance evaluation of walk behind type solar powered rotary weeder was conducted in maize crop. Present study was taken up with following objectives,

1. To design and development of walk behind type solar powered rotary weeder
2. To evaluate the performance of developed walk behind type solar powered rotary weeder
3. To study techno feasibility of the walk behind type solar powered rotary weeder.

The walk behind type solar powered rotary weeder testing was done in agronomy research farm of Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar and the data was statistically analyzed. The development of work for fabrication was carried out in the workshop of Centre for Resources Conservation Technology Cum-Farm Machinery and Power Engineering, College of Renewable Energy and Environmental Engineering, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The weeder was tested with three different rotor speed namely 80, 100 and 120. The comparative performance has been assessed on the basis of weeding efficiency, plant damage, theoretical field capacity, effective field capacity, field efficiency, battery discharging time and performance index. The study revealed many meaningful findings, which may provide a magnitude of substitution or replacing the existing methods of manual and animal operated weeders.

Out of this study following results were obtained.

1. Weeding efficiency of developed weeder was found maximum (77.14 per cent) at T_3 (120 rpm), followed by (76.13 per cent) at T_2 (100 rpm) and (68.54 per cent) at T_1 (80 rpm). It was observed that as the 120 rpm pull towards maximum, the weeding efficiency also increases.
2. The operational speed of the machine with 4 flange and at 3 different rotor speed were tested and the highest working speed of weeder was found as 1.55 km/h at 120 rpm of rotor speed and lowest as 1.24 km/h at 80 rpm of rotor speed. The analysis showed that variation in rotor speed of data significantly affects the operational speed.
3. The maximum average depth of cut was found at 43.57 mm (80 rpm) and average minimum depth of cut was at 36.14 mm (120 rpm). The depth of cut varies between 36.14 to 43.57 mm.
4. The maximum actual field capacity 0.072 ha/h was found at T_3 (120 rpm) and minimum 0.054 ha/ h at T_1 (80 rpm). The field efficiency was found highest in treatment T_3 (120 rpm) followed by T_2 (100 rpm) and T_1 (80 rpm). There was significant difference between treatment T_1 (80 rpm) and T_3 (120 rpm). However, there was no significant difference in treatment T_2 (100 rpm) and T_3 (120 rpm).
5. The plant damage was found to be maximum 9.79 per cent at T_3 (120 rpm) and minimum 3.94 per cent at T_1 (80 rpm). The plant damage was found to be on higher side when rotor speed increases and start unbalance of the weeder causes damage of plant increases.
6. The field capacity of the weeder was found as 0.054, 0.066 and 0.072 ha/h with field efficiency of 78.89, 83.39 and 85.32 per cent in 80, 100 and 120 rpm rotor speed, respectively.

7. The performance index was recorded as 354.37, 479.18 and 506.06 for 80, 100 and 120 rpm rotor speed, respectively.
8. The total charging time to fully charge battery was found to be 4 hours. The total discharging the battery during weeding operation was found to be 2.27 hours.
9. The cost of operation for weeding by manual was ₹ 7436 per ha and for developed weeder and petrol run power weeder it was ₹ 1185 and 2525 per ha, respectively. The developed weeder save cost 53.06 and 84.06 per cent as compared to petrol run power weeder and manual weeding, respectively.
10. The labour requirement by manual weeding was 169 man-h/ha and for developed weeder it was 15.15 man-h/ha. The developed weeder saves time 91.03 per cent over manual weeding.
11. Over all working of the developed weeder was found to be satisfactory with 100 rpm rotor speed, trouble free and smooth.

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APPENDICES

Appendix A: Observation of soil parameters

Soil moisture content

Replication	Wet weight of soil, G	Dry wet of soil, g	Moisture content, %
1	230.45	186.08	19.25
2	204.38	162.48	20.50
3	210.16	170.97	18.64
4	245.62	201.58	17.93
5	214.38	169.81	20.79
Mean			**19.42**

Bulk density

Replication	Weight of dry soil, G	Volume of core cutter, cm^3	Bulk density, kg/m^3
1	172.26	93.62	1.84
2	166.16	94.95	1.75
3	136.39	76.20	1.79
4	159.61	93.89	1.70
5	173.19	95.16	1.82
Mean			**1.78**

Soil resistance

Replication	Soil resistance, kg/cm^2
1	0.60
2	0.61
3	0.59
4	0.61
5	0.60
Mean	**0.60**

Appendix B: ANOVA table of analysis

ANOVA table of weeding efficiency

Anova	Df	Ss	Mss	cal f	test	5%	1%
Treatment	2	309.634	154.817	12.853	**	3.555	6.013
Error	18.00	216.812	12.045				
Total	20.00	526.446					

**=Highly significant *=Significant

ANOVA table of plant damage

Anova	Df	Ss	Mss	cal f	test	5%	1%
Treatment	2	85.269	42.634	4.520	*	3.555	6.013
Error	18.00	169.797	9.433				
Total	20.00	255.066					

**=Highly significant *=Significant

ANOVA table of speed of operation

Anova	Df	Ss	Mss	cal f	test	5%	1%
Treatment	2	0.356	0.178	8.806	**	3.555	6.013
Error	18.00	0.364	0.020				
Total	20.00	0.720					

**=Highly significant *=Significant

ANOVA table of depth of cut

Anova	df	Ss	Mss	cal f	test	5%	1%
Treatment	2	209.238	104.619	16.814	**	3.555	6.013
Error	18.00	112.000	6.222				
Total	20.00	321.238					

**=Highly significant *=Significant

ANOVA table of effective field capacity

Anova	df	Ss	Mss	cal f	test	5%	1%
Treatment	2	0.001	0.001	18.596	**	3.555	6.013
Error	18.00	0.001	0.000				
Total	20.00	0.002					

**=Highly significant *=Significant

ANOVA table of field efficiency

Anova	df	Ss	Mss	cal f	test	5%	1%
Treatment	2	152.115	76.058	4.397	**	3.555	6.013
Error	18.00	311.366	17.298				
Total	20.00	463.482					

**=Highly significant *=Significant

ANOVA table of performance index

Anova	df	Ss	mss	cal f	Test	5%	1%
Treatment	2	91723	45861.7	14.585	**	3.555	6.013
Error	18.00	56599	3144.4				
Total	20.00	148323					

**=Highly significant *=Significant

Appendix C: Selection of materials for construction of the solar powered rotary weeder

Sr. No.	Name of parts	Material used	Major specification	Qty	Rate (₹)	Amount (₹)
1.	Battery		51.8 V 35 A	1		25000/-
2.	Solar panel		240 W	2		12000/-
	Fabrication materials					
3.	BLDC Motor			1		3700/-
4.	Frame	M. S. Angle	40 × 40 × 3 mm 32 × 32 × 3 mm	3 kg 3 kg	55/- 55/-	165/- 165/-
5.	Tool bar frame	GI flat	40 × 3 mm 40 × 5 mm 40 × 10 mm	2 kg 6 kg 55 kg	50/- 55/- 57/-	200/- 330/- 3135/-
6.	Axle	Mild steel	Length 600 mm Dia 30 mm	4 kg	60/-	240/-
7.	V-pulley	Cast iron Plastic	Engine shaft pulley Outer dia 55 mm Intermediate shaft pulley Outer dia 275 mm	1 1		350/- 130/-
8.	V-belt	Rubber fabric cord	(A-Section) Length 1100mm	1		150/-
9.	Chain sprocket system	Chain Sprocket		1		750/-
10.	Traction wheel	GI flat	40 × 3 mm	6 kg	50/-	300/-
11.	Acceleration lever with wire		Length 2 m	1		370/-
12.	Handle pipe	Mild steel	2160 × 3 mm Dia 25 mm	15 ft	70/-	1050/-
13.	Cutting tools (Sweep)	High carbon steel	Width 240 mm Width 160 mm	3 kg 4 kg	200/- 200/-	600/- 800/-
14.	Auxiliary wheel	Rubber coated iron	Width 40 mm Dia 200 mm	2	350/-	800/-
15.	Belt tensioner Clutch lever with wire Jockey pulley	 Plastic	 Length 2m Dia 50 mm	 1 1		 250/- 70/-
16.	Nut bolts			3 kg	55/-	165/-
17.	Welding rod					230/-
18.	Miscellaneous					1000/-
19.	**Total**					**51950/-**
20.	Fabrication material cost					14950/-
21.	Fabrication charges (25 per cent of material cost, Victor, 2003)					3737.5/-
22.	Total material cost					18687.5/-

Cost of unit = Battery cost + Panel cost + Total material cost

$= 25000 + 12000 + 18687.5 = 55687.5$/- ≅ **55700/-**