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RESEARCH ARTICLE

Tractor-drawn weeder to manage weeds in garlic grown on raised beds

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ABSTRACT

Currently, manual weeding is done in garlic, with hand tools like *Khurpi* or hand pulling which is a cumbersome operation. The cost of weeding by manual method alone accounts for more than one-fourth of the total cultivation cost in garlic. Tractor drawn mechanical weeding helps reduce time consumption and drudgery of manual weeding in non-herbicidal growing systems. A soil bin study with laboratory model weeder was carried out to investigate the effect of number of tines (soil working tool), depth of operation and forward speed of simulated weeds on weed control factor (WCF). The experimental study showed that the number of tines, depth of operation and forward speed significantly affected the WCF and it increased with an increase of all the three parameters. Three tines operated at 75 mm depth at 3 km/h speed gave the maximum value of WCF. Depth of operation of tine was the predominant factor influencing the WCF. Based on the soil bin investigation, tractor-drawn weeder was developed with multiple flexible round tines that vibrate perpendicular to the tractor direction to remove weeds from the soil. Developed weeder was evaluated for managing weeds in garlic crop grown on raised beds. The effective field capacity and field efficiency were observed as 0.18 ha/h and 76.62%, respectively, at forward speed of 2 km/h. The plant damage and weeding efficiency was observed as 1.61 and 68.64%, respectively. The cost saving due to usage of the developed weeder, in comparison with the existing manual weeding, was 51.3%. The machine has potential for adoption by farmers growing garlic on raised beds.

Keywords: Cost saving, Garlic, Narrow crop weeder, Raised beds, Weed control factor, Weed management

INTRODUCTION

In India, garlic (*Allium sativum*) is cultivated in an area of about 0.39 million hectares, with a production capacity of 31.9 lakh metric tons and a productivity of 8.1 t/ha (Indiastat 2022**)**. India is the second largest producer of garlic with 12% of global area. However, the garlic productivity in India is lowest in world. One of the major reasons of low productivity of garlic is weeds competition with garlic crop for different resources like sunlight, water soil nutrients etc. The garlic bulb yield loss due to weeds was estimated as 30-60% (Lawande *et al.* 2009). The common non-herbicide method of weed management used in garlic cultivation is manual weeding by hand pulling or using hand tools like *Khurpi*. Manual weeding generally requires about 50 to 60 man-days/ha. Moreover, manual weed control is the most laborious and tedious operations in garlic production. The non-availability of labour is high during peak time and labour scarcity due to industrialization delays the weeding operation in garlic crop resulting in reduced garlic bulb yield. Thus, farmers mostly prefer herbicides usage for weed management. Currently, government is encouraging organic cultivation in view of its benefit to human health, other organisms and non-target plants (Damalas and Koutroubas 2016). Mechanical inter-row weeding is the best option for weed management in organic food production systems (Pullen 1997).

Numerous active and passive mechanical weeders were developed, with manual, animal-drawn, tractor-drawn and self-propelled as power source, to control weed in wider row crops. These weeders could not be adopted in narrow row adopting crops like garlic, onion as it causes huge crop damage. In low-density crops, mechanical devices such as cultivators, finger-weeders, brush weeders, and torsion weeders are utilised, while spring-tine weeders are used mostly in narrow-row high-density crops (Peruzzi *et al.* 2017). Several researchers have developed ergonomically designed inter-row as well as intra-row weeders (Chethan and Krishnan 2017, Chethan *et al.* 2018, Kumar *et al.* 2019, Kumar *et al.* 2020, Tewari and Chethan 2018). There is a need for controlled and precision weeding tools which effectively control weeds while avoiding crop damage in garlic. Currently, raised bed cultivation is getting popular among the garlic

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growing farmers. Mechanization of weeding in garlic with modern appropriate technology is one of the essential tools to overcome the labour shortage for weed management and increase garlic productivity and farmer's income. This problem was addressed by development of tractor-drawn weeder for garlic grown on raised beds.

MATERIALS AND METHODS

The present study was undertaken to develop technically feasible and economical viable tractor-drawn garlic weeder with the help of optimized value in soil bin using laboratory model weeder. The fabrication and evaluation of the developed weeder was done at ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh (MP).

Soil bin study for development of weeder

In the experimental study, the spring tine was used for mechanically uprooting the simulated weeds. A spring tine unit, made of 5 mm diameter stainless steel was attached on the rectangular main frame. The main frame was mounted on tool carriage of soil bin through free linked chain. The spring tines has vertical and angled segment of 200 and 100 mm respectively and the rake angle was 30°. The spring factor of the selected spring tine was 320 N/m. The experimental setup for soil bin study of garlic weeder is shown in **Figure 1**.

The soil bin consists of a stationary bin, tool carriage, soil processing trolley, load cell fixture and power transmission system. The soil bin was 16 m long, 2.5 m wide and 1.0 m deep. The bin was filled with vertisols soil up to a depth of 0.8 m. The clay, silt and sand content were 44, 34 and 24%. Before each experiment, water was sprayed for soil preparation and the soil was carefully prepared using soil processing unit (roto-tiller) and it is levelled by soil leveler. To achieve the resemblance of soil condition in actual field, uniform pressure is applied using the hydraulic roller attached in soil bin. The moisture content of soil during the tests was maintained in the range of 15-18% (db) (Yadav *et al.* 2005). The cone index and bulk density were maintained as 473.5±36.5 kPa and 1.47±0.01 kg/cm^3, respectively, for the study. It was tilled, levelled and compacted to achieve desired soil properties for each test run. The forward speed of the weeder was varied through the control panel, variable speed drive and linear distance sensor of the soil bin instrumentation system. The desired speed was set with the help of a speed control switch, which was calibrated with the frequency and displayed on the control panel.

Experimental procedure

Experiment was conducted in the soil bin of soil tillage laboratory to investigate the effect of number of tines (working tool), depth of operation and forward speed on weed control factor (WCF). WCF indicated the disturbance of simulated weeds due to the passes of tines. Wooden sticks were used to simulate the weed plants for the laboratory experiments because they are consistent, uniform and resemble the weed stems. They can be easily penetrated into the soil and their depth was easily adjusted. Wooden sticks were inserted into the soil to a depth of 50 mm in a row perpendicular to the direction of travel of the tine at a spacing of 12.5 mm between sticks for all selected level of treatment. Description of WCF with respect to position of wooden sticks as suggested by Jiken and Bin (2016) is given in **Table 1**. It was calculated by using following formula (Equation 1).

Table 1. Description of WCF with respect to position of wooden sticks

WCF	Description
90	The simulated weeds were removed fully out of the soil
60	The simulated weeds were dragged from its original position and angled
30	The simulated weeds were dragged from its original position but was still horizontally straight
10	The simulated weeds were on their original position but angled
0	No change in original position of sticks

Figure 1. Experimental setup for soil bin study of garlic weeder (a) laboratory model weeder (b) soil bin

Table 2. Experimental parameters for the perfomance of spring tine in soil bin

Parameters		Level 1	Level 2	Level 3
Actual	Coded	(-1)	(0)	(+1)
Independent parameter				
Tine row numbers, no.	X_1	1	2	3
Forward speed, km/h	X_2	1	2	3
Depth of operation, mm	X_3	25	50	75
Dependent parameter				
Weed control factor (WCF)				

$$WCF = \frac{Sum\ of\ WCF\ of\ all\ the\ wood\ sticks}{Number\ of\ sticks} \quad (1)$$

Experimental parameters selected for the performance of spring tine in soil bin are given in **Table 2**. The experiment was designed as per face-centered central composite design (FCCCD) and was subjected to response surface methodology (RSM) (Myers 2002). RSM was also used by other researchers to optimize the operational parameters of the machine in the soil bin as well as in the field (Jat *et al.* 2020, Jat *et al.* 2022). Design expert software (Version 7.1.6. Stat-Ease, Inc., MN, USA) was used for the design of experiments. A total 20 runs were carried out with three replicates.

Second order polynomial regression model was developed for WCF in terms of the coded value of number of tines, depth of operation and forward speed. The adequacy of the models was tested using F-value, p-value and coefficient of determination (R^2). The second order polynomial model is given in Equation 2:

$$Y_i = \beta + \Sigma\beta_i X_i + \Sigma\beta_{ii} X_i^2 + \beta_{i\hat{j}} X_i X\hat{j} \quad (2)$$

Where,

Y_i is the predicted response (*i.e.* Weed Control Factor), X_i, X_j are input variables (*i.e.* number of tine, depth of operation and forward speed); β_0 is the offset term; β_i is the linear coefficient; β_{ii} the i^{th} quadratic coefficient and $\beta_{i\hat{j}}$ is the $\hat{j}^{th}$ interaction coefficient (Myers *et al.* 2002).

Development of tractor-drawn garlic weeder

A tractor-drawn seven row weeder was developed for weeding in garlic crop grown on raised beds. The schematic diagram of the developed garlic weeder was shown in **Figure 2**. The technical specification of developed tractor-drawn garlic weeder was given in **Table 3**. The overall dimensions of machine were 1650×1430×1130 mm. It consists of main frame, tine frame, depth control wheel, link chain, spring tine and three-point hitching system. Main frame was made of mild steel square box of 50×50×5 mm size. Main frame was in T shape made by welding square box of 1500 mm length with square box of 1200 mm length. The developed weeder had passive type spring tines. The movement of spring tines strikes the weeds to uproot them from the soil. Spring tine was made of stainless-steel round bar of 5 mm diameter, 300 mm length and it had rake angle of 45° from the vertical plane in the direction of travel. The upper vertical segment and angled segment of spring tines was 200 mm and 100 mm. Each tine was mounted on perpendicular mounting bar member, adjustment was provided to move tine laterally in the members. The mounting bar members are increased or decreased to alter the intensity of weeding of the tines frame with the help of nuts and bolts. Tine frame was in rectangular shape made by welding two square boxes of 1200 mm length with two square boxes of 990 mm length.

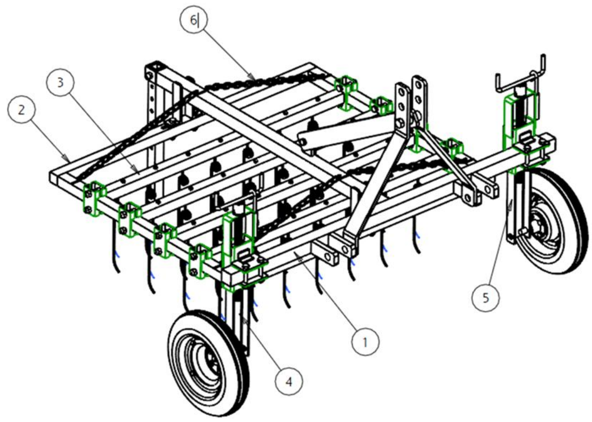

Figure 2. Drawing of garlic weeder for raised beds. (1) Main frame (2) tine frame (3) members (4) spring tine (5) depth control wheel and (6) link chain

Table 3. Technical specification of developed garlic weeder

Particulars	Specifications
Dimensions of weeder (L×W×T) (mm)	1650 × 1430 × 1130
Type of tine	Spring type, Ø 5 mm
Number of tines	28 (4 for each row for 150 mm R×R spacing) 30 (3 for each row for 100 mm R×R spacing)
Number of rows	7 and 10
Row spacing (mm)	100 and 150
Effective width of operation	1.1±0.1 m (excluding 0.3 m furrow width)
Provision for depth control	Two depth control wheels (Ø 400 mm)
Soil type	Black cotton soil
Soil moisture content	21±2.3% (dry basis)
Depth of operation	75 mm
Forward speed	1.0-3.0 km/h
Power source	Tractor (30 hp or above)

Field experiments

The developed weeder was evaluated in Vertisol soil in raised bed planted garlic at the ICAR-Central

Institute of Agricultural Engineering, Bhopal (23°182 36.693 N, 77°242 17.683 E). The weeder was evaluated with three different forward speeds, *viz.* 1, 2, 3 km/h with three tines at constant depth of operation of 75 mm. The experiment consisted of a randomized block design with nine replications. The performance of developed weeder was evaluated in the garlic sown on broad beds of 150 mm height and 1200 mm top width with 300 mm furrow width to the length of 20 m. The moisture content of the soil was 21±2.3% (dry basis) during operation. Machine performance parameters such as effective field capacity, field efficiency and weeding efficiency were measured. The speed of operation was measured by recording the time required to cover 10 m length of the experimental plot. Effective field capacity was calculated by dividing the actual area coverage during weeding by the total time taken to cover the area. Field efficiency was calculated by dividing the effective field capacity by the theoretical field capacity, and expressed in percentage. The weeding efficiency and plant damage were calculated based on the equations below (Chethan and Krishnan 2017).

Weeding efficiency was calculated by following formula (Equation 3)

$$\rho, \% = \frac{W1 - W2}{W1} \times 100 \quad (3)$$

Where,

W_1 – number of weeds before operation

W_2 – number of weeds after operation

The plant damage was calculated as follows (Equation 4):

$$Plant\ damage\ (PD), \% = \frac{P - Q}{P} \times 100 \quad (4)$$

Where,

P – number of plants in a 10 m crop row length before weeding

Q – number of plants in a 10 m crop row length after weeding

Cost of operation

The total cost of operation of garlic weeder was determined based on fixed cost and variable cost following the test code IS: 1964–1979 (Indian Standard 1979). The cost of operation of garlic weeder was compared with manual operation of weeding. The cost involved in the manual operation was calculated by considering man-hour required per hectare for weeding in garlic.

RESULTS AND DISCUSSION

Soil bin study

The analysis of variance (ANOVA) showed the significant effect of number of tines, forward speed and depth of operation on WCF (**Table 4**). The interaction effect of forward speed and depth of operation was also found to be significant. The model for WCF in coded terms was developed using the values of significant coefficients as follows (Equation 5):

$$WCF = 22.29+1.63A+3.34B+10.56C+1.83BC \quad (5)$$

The statistical significance of equation was evaluated via ANOVA. The F-value of 29.9 indicated that the model was highly significant (p<0.01). For the fitted model, the coefficient of determination was recorded as 0.96, which indicated the goodness of the model. The lack of fit was also not significant, which indicated the fitness of the model. The results of performance of laboratory model weeder in soil bin

Table 4. ANOVA for the response surface quadratic model of weed control factor

Source	Sum of squares	df	Mean square	F value	p-value	Test result
Model	1320.8	9	146.8	29.9	< 0.0001	S
A-Number of tines	26.6	1	26.6	5.4	0.0423	S
B-Forward speed	111.6	1	111.6	22.7	0.0008	S
C-Depth of operation	1115.1	1	1115.1	227.3	< 0.0001	S
AB	3.9	1	3.9	0.8	0.3924	NS
AC	18.6	1	18.6	3.8	0.0801	NS
BC	26.7	1	26.7	5.4	0.042	S
A^2	2.7	1	2.7	0.6	0.4753	NS
B^2	8.3	1	8.3	1.7	0.2217	NS
C^2	12.8	1	12.8	2.6	0.1371	NS
Residual	49.1	10	4.9			
Lack of fit	28.7	5	5.7	1.4	0.3579	NS
Pure error	20.37	5	4.1			
Corrected total	1369.8	19				
R^2						0.96

S: significant, NS: not significant, R^2: Coefficient of determination, df: degrees of freedom, is given in **Table 5**. Three numbers of tines operated at 75 mm depth at 3 km/h speed gave the maximum value of WCF.

Effect of forward speed and depth of operation on WCF

The effect of forward speed and depth of operation on WCF was presented in **Figure 3** as response surface graph. It was observed that, the WCF increased with increase in depth of operation and forward speed. Larger depth of operation yielded higher WCF values due to increase in soil depth increases penetration that removes the soil in excess amount. Hence, the width of soil failure increases in the direction perpendicular to the tine travel. Increase in forward speed increased the WCF of simulated weed. This is due to the tine move faster through the soil increased the acceleration of soil in front of the tine as observed by Zeng *et al.* (2020) and Gilandeh *et al.* (2020). It increases soil throw and soil disturbance on the soil surface and removes the simulated weeds. The effects of forward speed were found to be smaller than the effect of depth of operation on WCF as observed by Rahman *et al.* (2005) and Sahu and Raheman (2006). The maximum value of WCF observed with the combination of depth of operation 75 mm and forward speed of 3 km/h and minimum was with the combination of depth of operation 25 mm and forward speed 1 km/h.

Effect of no. of tines and forward speed on WCF

The mean WCF values were plotted against number of tines and forward speed in **Figure 4**. The increase in forward speed and number of tines increased the WCF values. Increasing forward speed has significant effect on soil disturbance. This was confirmed by many researchers (Hasimu and Chen 2014, Shinde *et al.* 2011). The number of tines had less effort at WCF compared to forward speed. This may be due to the tine arranged one behind another had less influence on soil disturbance and soil failure.

Table 5. Results of performance of laboratory model weeder in soil bin

Trials	Number of tines (Nos)	Forward speed (Km/h)	Depth of operation (mm)	Weed control factor (WCF)
1	3	1	25	12.2
2	2	2	50	20.0
3	2	2	50	20.0
4	2	2	50	24.4
5	2	2	50	23.3
6	1	1	75	24.4
7	3	1	75	33.3
8	1	3	75	35.6
9	1	2	50	24.4
10	2	2	25	11.1
11	2	2	50	24.4
12	2	2	75	28.9
13	1	3	25	13.3
14	2	3	50	27.8
15	3	2	50	21.9
16	3	3	75	42.2
17	1	1	25	8.9
18	3	3	25	13.3
19	2	2	50	22.2
20	2	1	50	20.0

The first tine sets creating more soil disturbance and WCF on simulated weeds than the other tine sets. The maximum values of WCF observed at combination of forward speed of 3 km/h and three numbers of tines set and minimum was at combination of single number of tines set and forward speed of 1 km/h.

Effect of depth of operation and no. of tines on WCF

The effect of depth of operation and number of tines on WCF is presented in **Figure 5** as response surface graph. The WCF of the simulated weeds increased with the higher values of depth of operations and number of tines. This pattern was expected as deeper depth of operations affects wider widths of soil. The increasing pattern of the WCF was also significant for depth of operation. The highest value of WCF was achieved at combination level of three numbers of tine set and depth of operation of 75 mm and the lowest value was obtained at single numbers of tine set and depth of operation of 25 mm.

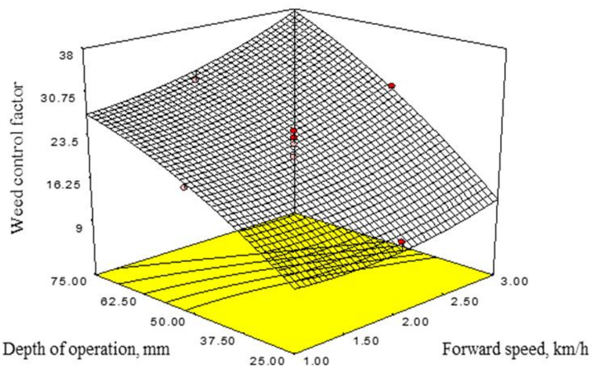

Figure 3. Response surface graph of effect of forward speed and depth of operation on WCF

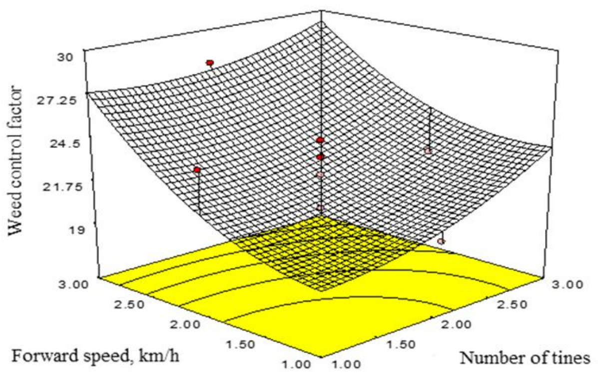

Figure 4. Response surface graph of effect of number of tines and forward speed on WCF

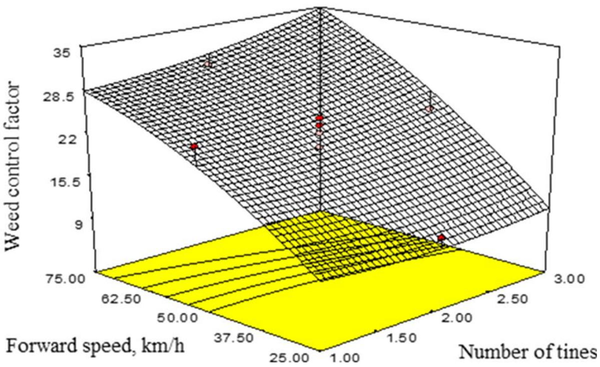

Figure 5. Response surface graph of effect of number of tines and depth of operation on WCF

Performance evaluation of garlic weeder in field

The performance evaluation of developed garlic weeder was done by operating it at a constant depth of operation of 75 mm (**Figure 6**). The weeding efficiency and plant damage increases with increase in forward speed. The weeding efficiency at 1, 2 and 3 km/h of forward speed was 63.42, 68.64 and 73.44% while the plant damages were observed at 0.74, 1.61 and 4.63% respectively (**Table 6**). The effective field capacity had significant difference

Figure 6. Garlic weeder during the operation in the garlic field

Table 6. Result of performance evaluation of garlic weeder in field

Forward speed (km/h)	Effective field capacity (ha/h)	Field efficiency (%)	Plant damage (%)	Weeding efficiency (%)
1	0.09[c]	75.65[a]	0.74[c]	63.42[c]
2	0.18[b]	76.62[a]	1.61[b]	68.64[b]
3	0.26[a]	73.44[b]	4.63[a]	73.44[a]

[a,b,c] means within the column followed by same letter has no significant difference (p<0.05)

Table 7. Cost analysis of operation of garlic weeder

Parameters		Tractor	Garlic weeder
(A) Fixed cost			
i.	Initial cost of tractor, `	450000	16000
ii.	Salvage value 10% of initial cost, `	45000	1600
iii.	Service life, years	15	10
iv.	Depreciation {(i-ii)/iii}, `/year	27000	1440
v.	Annual uses, h/year	1000	250
vi.	Interest on investment 8.8% per annum, `/year	39600	1408
vii.	Effective field capacity of machine, ha/h	-	0.18
viii.	Insurance, taxes and housing 2% of initial cost per annum, `/year	9000	320
ix.	Total fixed cost (iv+vi+viii), `/year	75600	3168
x.	Fixed cost of operation, `/h	75.6	12.7
xi.	Total fixed cost of operation, `/h	88.3	
(B) Variable cost			
i.	Repair and maintenance cost, `/h	22.5	3.2
ii.	Fuel required, l/h	3	-
iii.	Fuel cost ` 70/l, `/h	210	-
iv.	Cost of lubricant 20% of fuel cost, `/h	28	-
v.	Labour required with machine 8 h/day, no.	1	1
vi.	Labour cost (`/h) Rs. 50/h for skilled and ` 40/h for unskilled labour	50	40
vii.	Variable cost (i+iii+iv+vi), `/h	324.5	43.2
viii.	Total variable cost, `/h	367.7	
(C) Cost of operation			
i.	Total cost of operation (fixed cost + variable cost), `/h	456	
ii.	Effective field capacity of machine, `/h	0.18	
iii.	Cost of operation, `/ha		
	a) Cost of machine operation at 76.6% weeding efficiency	2533.3	
	b) Cost of manual operation for remaining 23.4% weeding (Considering cost of ` 10000/ha as given in D, ii)	2340	
	Total cost of operation for 100 % weeding	4873.3	
(D) Labour cost in manual weeding			
i.	Labour required, man-h/ha	250	
ii.	Cost of operation ` 40 per h for unskilled labour, `/ha	10000	
(E)	Saving in cost, %	51.3	

between forward speed of weeder and it increased with increase in the forward speed of the machine. It was observed that the average effective field capacity was 0.09, 0.18 and 0.26 ha/h at forward speed of 1, 2 and 3 km/h respectively. There was no significant effect observed at 1 and 2 km/h forward speed but 3 km/h had significant difference in field efficiency. The forward speed of 2 km/h had the highest field efficiency of 76.62% followed by 1 km/h of 75.65% and 3 km/h of 73.44% respectively.

Cost analysis

The cost analysis of tractor-drawn garlic weeder and manual operation is given in **Table 7**. The results showed that the fixed and variable costs of garlic weeder were ₹ 88.3 and ₹ 367.7/hour respectively which gave the total cost of operation as ₹ 456/hour. The operating cost of garlic weeder (₹ 3507.7/ha) was less as compared to manual weeding (₹ 8000/ha). A 51% saving in cost was observed with garlic weeder compared to manual operation.

Manual weed management in garlic is tedious and laborious work due to the frequent requirement of weeding. This problem could be addressed with the help of developed weeder. The lesser plant damage of 1.61% and its weeding efficiency of 68.64% were found best for weeding in raised bed condition. The field efficiency and effective field capacity at 2 km/h were 76.62% and 0.18 ha/h respectively. Also, 51.3% cost of weeding can be saved as compared to the traditional method of weeding. Thus, this study proved the potential of developed tractor-drawn weeder to complete the mechanization of weeding operation in raised bed narrow row spaced cultivation of garlic and onion.

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