Development and Ergonomic Evaluation of Manually Operated Weeder for Dry Land Crops

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ABSTRACT

A manually operated weeder for dry land crops was developed and evaluated to find its performance. It was compared with other available weeders namely wheel finger weeder, wheel hoe and conventional weeding by using trench hoe for groundnut crop at four levels of soil moisture content of 13.52, 11.63, 9.52 and 8.04 per cent (db). It was found that the heart rate, oxygen consumption rate and energy consumption rate increases with decrease in soil moisture content for all the treatments. The highest performance index of 3689.74 was obtained with developed weeder at 11.63 per cent moisture content. Lowest plant damage (2.46 to 7.96%) and lower energy consumption rate (8.34 to 40.05 kJ/min) with highest performance index (678.66 to 3689.74) of developed weeder at different soil moisture content proved its superiority over other weeders. Soil moisture of 11.63 per cent was found to be optimum for weeding in groundnut crop and the cost of operation of developed weeder at this soil moisture content was found to be Rupees 244.00 as against Rupees 2450.00 per hectare in conventional method of weeding by using trench hoe.

Key words: Weeder, field performance, ergonomics, soil moisture, groundnut, India

1. INTRODUCTION

Weeding is one of the most important farm operations in crop production system. Weed growth is a major problem for dry land crops particularly in oilseed crops like groundnut and mustard causing a considerable lower yield. As oilseeds constitute the second major agricultural crops in India next to food grains in terms of quantity and cost, it is necessary to mechanize different farm operations of this crop. India is the third largest producers of groundnut in the world and accounts for about one-fifth of world's production (Anon, 2005-06). Manual weeding requires huge labour force and accounts for about 25 per cent of the total labour requirement (900-1200 man-hours/hectare) (Nag and Dutt, 1979). In India this operation is mostly performed manually with khurpi or trench hoe that requires higher labour input and also very tedious and time-consuming process. Moreover, 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 are necessary to keep the crop weed free. Reduction in yield due to weed alone is estimated to be 16-42 % depending on crop and location and involves 1/3 rd of the cost of cultivation (Rangasamy et al, 1993). 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 per cent loss in grain yield is quite usual which might increase up to 80 per cent if adequate crop management practice is not observed. Rice and groundnut are very 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 (Gunasena and Arceo, 1981).

Weeds compete with crop plants for nutrients and other growth factors and in the absence of an effective control measure, remove 30 to 40 per cent of applied nutrients resulting in significant yield reduction (Dryden and Krishnamurthy, 1977). Delay and negligence in weeding operation affect the crop yield and the loss in crop yields due to weeds in upland crops vary from 40-60 per cent and in many cases cause complete crop failure (Singh, 1988). In India about 4.2 billion rupees are spent every year for controlling weeds in the production of major crops. At least 40 million tones of major food grains are lost every year due to weeds alone (Singh and Sahay, 2001). Therefore, timely weeding is very much essential for a good yield and this can only be achieved by using mechanical weeders which perform simultaneous job of weeding and hoeing and can reduce the time spent on weeding (man hours), cost of weeding and drudgery involved in manual weeding.

The most common methods of weed control are mechanical, chemical, biological and cultural methods. Out of these four methods, mechanical weeding either by hand tools or weeders are most effective in both dry land and wet land (Nag and Dutt, 1979, Gite and Yadav, 1990, Gite and Yadav, 1985). Various types of cutting blades are used for manually operated weeders. V-shaped sweep is preferred where weeders are continuously pushed and tool geometry of these cutting blades are based on soil-tool-plant interaction (Bernacki et al, 1972). Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and water intake capacity. Manual weeding can give a clean weeding but it is a slow process (Biswas, 1990).

For maximum work efficiency, it is suggested that the elbow flexon angle should be 85-110^0 (Grandjean, 1988). For push-pull operation of a machine, the elbow flexon angle would be 90^0 (Tiwari, 1985) and the optimum holding height for male is 630-677 mm and that of female is 534-630 mm (Tiwari et al, 2007).

As the time period available for weeding is limited, improved mechanical weeders are to be used to complete the weeding operation in due time at less cost. At present, more than 15 different designs of hoes and weeders are available in India. All these designs are region specific to meet the requirements of soil type, crop grown, cropping pattern and availability of local resources. Therefore, effort has been made to develop a weeder for dry land crops, to evaluate its field performance along with the ergonomical aspects. Its performance was compared with other available weeders in the state namely wheel finger weeder, wheel hoe and traditional method of weeding by trench hoe for groundnut crop at different soil moisture content.

2. MATERIAL AND METHODS

Five numbers of weeding elements (hoof type tynes) were made up of 10 mm mild steel rod and 3 mm mild steel plate. The ground wheel is made up of two numbers of circular ring with 10 mm mild steel rod spaced at 5 cm apart (Figure 1). The diameter of the wheel was kept 320 mm and have mild steel rod spokes. Slots were made on the base plate to change the operating width of the weeder to suit the row spacing of different crops. L-shaped support was made from the mild steel flat (25 x 25 x 5 mm) and welded at the top of the weeding tynes. These tynes were fixed on the slots of base plate with the help of nut and bolts. Handle was fabricated from two numbers of 25 mm diameter mild steel pipes spaced at 320 mm apart at the grip and were fixed with the base plate by nut and bolts. Provision was made to change the operating height of the handle as per requirement of the operator. The minimum holding height was kept at 630 mm from the ground with 90^0 elbow flexon angle (Tiwari et al, 2007 and Tiwari, 1985). The performance of the developed weeder along with other available weeders in the state for dry land crops was studied. The specifications of the weeders are presented in Table1.

Table 1. Specification of weeders

Parameters		Developed weeder	Wheel finger weeder	Wheel hoe	Trench hoe
Overall dimensions, cm					
	Length	130	130	168	63
	Width	60	103	45.3	42
	Height	45	46	90.2	70
Weight , kg		6.3	6.0	9.5	1.8
Diameter of wheel, cm		32	30.6	34.5	-
Height of handle from ground, cm		94	90.2	98.5	63
No of weeding elements/tynes		5	5	1	1
Working width, cm		14.3	14.5	17.1	15.6
Depth of operation, cm		5.3	4.8	5.0	6.5

Field lay out was done as per randomized block design (RBD) of experiments with five replications. Test was carried out as per RNAM test code (1985). Experiment was conducted by employing four female workers as weeding is generally done by female workers in Orissa. Each worker was allowed to operate the weeder/trench hoe and the average of the observed values were calculated. The average of basic body dimensions of the weeder operators were measured and presented in Table 2.

Table 2. Average of basic body dimensions of weeder operators (N= 4)

Age group: 20-50 years

Sl No	Parameters	Mean	SD	5^{th} percentile	95^{th} percentile
1	Age, years	33.91	7.67	21.30	46.53
2	Weight, kg	44.01	6.18	33.84	54.19
3	Stature, cm	151.51	5.91	141.80	161.23
4	Eye height, cm	140.25	5.91	130.52	149.98
5	Acromial height, cm	125.05	5.59	115.86	134.25
6	Elbow height, cm	96.01	4.62	88.41	103.61
7	Olecranon height, cm	93.84	4.63	86.23	101.46
8	Iliocrystale height, cm	88.23	4.88	80.2	96.27
9	Trochanteric height, cm	75.97	5.40	67.08	84.86
10	Arm reach from wall, cm	76.55	4.96	68.39	84.72
11	Elbow rest height, cm	22.16	2.85	17.48	26.84
12	Elbow grip length, cm	33.62	3.05	28.60	38.64
13	Functional leg length, cm	90.93	5.39	82.06	99.80
14	Hand length, cm	16.41	1.05	14.68	18.13

15	Hand breadth at metacarpal - III, cm	7.03	0.92	5.51	8.54
16	Hand thickness at metacarpal - III, cm	3.26	0.68	2.14	4.38
17	Palm length, cm	9.32	0.90	7.84	10.80
18	Thump tip reach	67.57		56.57	78.56
19	Grip diameter (inside), cm	4.71	0.46	3.95	5.47
20	Instep length, cm	17.58	1.26	15.52	19.65
21	Push strength both hand Standing, N	136.47	43.63	64.71	208.24
22	Pull strength both hand Standing, N	163.39	37.79	101.23	225.56

Groundnut variety of ICGS-11 was planted by using a groundnut planter at 20 cm spacing in Central Farm of Orissa University of Agriculture and Technology (latitude: $21^0 15,'$ longitude: $85^0 15'$) in the year 2004. The size of each experimental plot was 100 m^2. The type of soil was found to be sandy loam (sand: 75.8 %, silt: 12.6 % , clay: 11.6 %) with bulk density of 1.62 g/cm^3. Weeding was done when height of weeds were about 3-5 cm. Working speed of weeders were kept within the range of 0.9 to 1.10 kmph. For all the treatments the average actual field capacity, weeding index and plant damage were recorded and performance indices were calculated to compare the performance of weeders.

Weeding index was calculated by using the following formula (Anon 1985).

$$e = [(W_1 - W_2)/W_1] \times 100 \qquad \text{…………..} \qquad (1)$$

Where,

e = weeding Index, per cent

W_1 = number of weeds/m^2 before weeding

W_2 = number of weeds/m^2 after weeding

Higher the value (e) means the weeder is more efficient to remove the weeds.

Plant damage per cent is measured by using following relation (Anon 1985, Yadav and Pund, 2007).

$$q = \{1- (Q/P)\} \times 100 \qquad \text{…………………} \quad (2)$$

Where,

q = plant damage per cent

Q = Number of plants in a 10 m row length after weeding

P= Number of plants in a 10 m row length before weeding

The performance of the weeders was assessed through performance index (PI) by using the following relation as suggested by Gupta (1981).

$$P1 = aqe / p \qquad \text{…………………….} \ (3)$$

Where,

a = field capacity of weeder, ha/hr

q = plant damage per cent

e = weeding index, per cent

p = power required to operate the weeder, hp

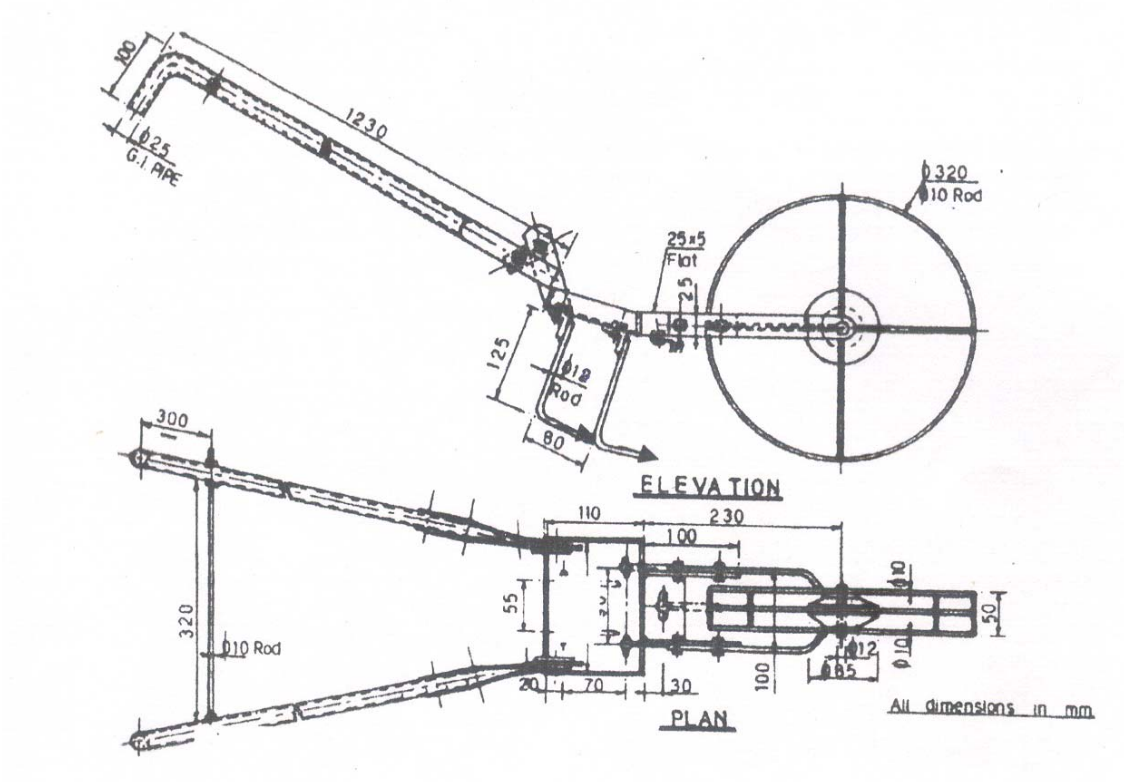

Figure 1. Developed weeder.

The ergonomic parameters like heart rate and oxygen consumption rate were recorded for each treatment and replication and the average values were calculated. Heart rate was measured by using Polar heart rate monitor and oxygen consumption rate was measured by using Metamax-II. Energy expenditure rate (kJ/min) was determined by multiplying 20.86 with litre of oxygen consumed (Nag et al, 1980).

Weeders were evaluated at different soil moisture of 13.52, 11.63, 9.52 and 8.04 per cent for groundnut crop to find out the most suitable weeder for the crop as well as to find the optimum moisture of soil for weeding. Above 13.52 per cent soil moisture content it was not possible for weeding due to stickiness of soil.

Treatments, replications and design of experiments adopted in this study were as follows.

Treatments

T_1: Developed weeder
T_2: Wheel finger weeder
T_3: Wheel hoe
T_4: Trench hoe

Replications: 5
Design: RBD

The experimental data obtained were analyzed statistically using analysis of variance (ANOVA) technique.

Figure 2. Weeding by developed weeder.

Figure 3. Weeding by trench hoe.

3. RESULTS AND DISCUSSION

The field performance of different weeders and trench hoe for groundnut crop at four levels of soil moisture content of 13.52, 11.63, 9.52 and 8.04 per cent (db) has been presented in Table 3.

3.1 Actual Field Capacity

The highest actual field capacity of 0.04, 0.04, 0.02 and 0.017 ha/h were obtained at 11.63 per cent moisture content under treatments T_1, T_2, T_3 and T_4 respectively followed by 0.03, 0.03, 0.01 and 0.016 ha/h for the same treatments in that order at 13.52 per cent moisture content (Table 3). A lower field capacity at 13.52 per cent moisture content may be due to stickiness of soil that causes clogging of soil weed mass in weeding elements that needed frequent cleaning. But at 11.63 per cent moisture content clogging of soil weed mass were not observed and hence resulted in higher field capacity. Thereafter, as soil moisture decreased further, the field capacity decreased for all the treatments. This may be due to the fact that with decrease in moisture content the soil hardness increased and the worker had to apply greater force for weeding operation and his speed of operation decreased. Lowest field capacity were observed under treatment T_4 (trench hoe) at all four levels of soil moisture content and this may be due to the reason that its operation was performed in bending posture that required higher energy consumption and worker developed greater fatigue during operation.

It was observed that the field capacity of treatments T_1 and T_2 are at par at all four levels of soil moisture content. This may be due to the reason that these two weeders had almost equal working width, weight and number of weeding elements.

3.2 Weeding Index

The weeding index of different treatments was found to be in the range of 68.22 to 99.18 per cent at different soil moisture content (Table 3). It was observed that the highest weeding index of 98.92 per cent was obtained with trench hoe (T_4) followed by 93.75 per cent with developed weeder (T_1) at 13.52 per cent moisture content. The weeding index with wheel finger weeder (T_2) and wheel hoe (T_3) were found to be 82.11 and 82.13 per cent respectively at the same moisture content.

The weeding index at 11.63 per cent moisture content were found to be 94.57, 83.34, 83.30 and 99.18 per cent for treatments T_1, T_2, T_3 and T_4 respectively. These values were observed to be highest among all the levels of moisture content. This may be due to the reason that minimum soil-weed interface force occurred at this moisture content. The lowest weeding index were found at 8.04 per cent moisture content for all the treatments and this may be due to higher hardness of soil with this moisture content.

The weeding index of the treatments varied significantly at 0.01 level ($P< 0.01$) whereas the replications were found to be non significant (Table 4).

3.3 Plant Damage

The plant damage at various moisture content has been presented in Table 3. It was found that lowest percentage of plant damage of 2.46, 3.26 and 2.71 per cent were observed at 11.63 per cent moisture content under treatment T_1, T_2 and T_3 respectively while for treatment T_4 the lowest plant damage of 4.19 per cent was obtained at 13.52 per cent moisture content. The highest percentage of plant damage of 7.96, 8.97 and 8.65 were observed at 13.52 per cent moisture content for treatment T_1, T_2 and T_3 respectively but the same was obtained under T_4 at 8.04 per cent moisture content. The plant damage increased with decrease in moisture content below 11.63 per cent moisture content. This may be due to the reason that with decrease in moisture content soil hardness increased and as a result weeding elements could not penetrate to desired depth and sometimes skid over hard surface and strikes the plant. Highest percentage of plant damage under treatments T_1, T_2 and T_3 at 13.52 per cent moisture content was due to more softness of soil which allowed higher penetration of weeding elements inside soil surface that caused root damage and uprooting of some plants but for treatment T_4 as it was not operated with a push-pull mode, minimum plant damage occurred at higher moisture content.

The effect of treatments on plant damage was highly significant while replications had no significant effect on plant damage (Table 4).

3.4 Performance Index

The highest performance index of 3689.74, 3158.25, 1554.21 and 1591.98 were obtained under treatments T_1, T_2, T_3 and T_4 respectively at 11.63 per cent moisture content while that of lowest value of 678.66, 631.65, 67.19 and 68.12 were obtained under the same treatments in that order at 8.04 per cent moisture content (Table 3). At 13.52 per cent moisture content a comparatively lower performance index of 2588.62, 2242.34, 750.25 and 1508.74 were obtained under treatments T_1, T_2, T_3 and T_4 respectively and this may be due to lower field capacity and higher plant damage of all the treatments at this moisture content.

Table 3. Performance of different weeders at various soil moisture content

Treatments	Moisture content, %	Actual field capacity, ha/h	Weeding index, %	Plant damage, %	Performance index
T_1	13.52	0.03	93.75	7.96	2588.62
	11.63	0.04	94.57	2.46	3689.74
	9.52	0.02	90.82	4.57	1733.39
	8.04	0.01	72.53	6.43	678.66
T_2	13.52	0.03	82.11	8.97	2242.34
	11.63	0.04	83.34	3.26	3158.25
	9.52	0.02	79.50	5.23	1506.84
	8.04	0.01	68.22	7.41	631.65
T_3	13.52	0.01	82.13	8.65	750.25
	11.63	0.02	83.30	2.71	1554.21
	9.52	0.005	78.49	4.82	373.53
	8.04	0.001	72.29	7.05	67.19
T_4	13.52	0.016	98.92	4.19	1508.74
	11.63	0.017	99.18	5.58	1591.98
	9.52	0.002	95.38	7.58	186.3
	8.04	0.001	75.27	9.49	68.12

Table 4. ANOVA of weeding index and plant damage at various soil moisture content

Sources of variation	df	F_{cal}							
		13.52 %		11.63 %		9.52 %		8.04 %	
		Weeding index	Plant damage	Weeding index	Plant damage	Weeding index	Plant damage	Weeding index	Plant damage
Replication	4	2.35	1.37	2.62	0.95	0.77	1.24	0.28	1.98
Treatments	3	80.41**	12.30**	91.67**	11.39**	97.76**	17.19**	17.29**	13.55**
Error	12								
Total	19								
SEM ±		0.924	0.390	0.840	0.392	0.845	0.34	0.83	0.37
CD = 0.05		2.847	1.22	2.591	1.21	2.606	1.03	2.72	1.156

** highly significant SEM: standard error of mean CD: critical difference

3.5 Increased Heart Rate

It was observed that with decrease in soil moisture content, the ΔHR of all the treatments increased (Table 5). At 8.04 per cent moisture content, ΔHR was found to be maximum followed by 9.52, 11.63 and 13.52 per cent moisture content for all the treatments. The lowest ΔHR at 13.52 per cent moisture content may be due to the soft condition of soil that required less effort during weeding operation. It was found that treatments had significant effect on ΔHR while replications have no effect on ΔHR (Table 6).

Table 5. Ergonomical performance of different weeders at various soil moisture content

Treatments	Moisture content, %	Increased heart rate (ΔHR), bpm	Oxygen consumption rate (VO_2), l/min	Energy consumption rate, kJ/min
T_1	13.52	15.42	0.40	8.34
	11.63	17.71	0.75	15.64
	9.52	22.38	1.29	26.91
	8.04	35.14	1.92	40.05
T_2	13.52	14.16	0.37	7.72
	11.63	16.58	0.76	15.85
	9.52	21.79	1.35	31.29
	8.04	34.85	2.03	42.35
T_3	13.52	16.74	0.41	8.55
	11.63	19.20	0.78	16.27
	9.52	23.89	1.35	28.16
	8.04	36.33	2.01	41.93
T_4	13.52	30.28	1.14	23.78
	11.63	32.70	1.54	32.12
	9.52	37.34	2.21	46.10
	8.04	49.93	2.91	60.70

Table 6. ANOVA of ΔHR and VO_2 at various soil moisture content

Sources of variation	df	F_{cal}							
		13.52 %		11.63 %		9.52 %		8.04 %	
		ΔHR	VO_2	ΔHR	VO_2	ΔHR	VO_2	ΔHR	VO_2
Replications	4	1.52	0.73	1.79	0.35	1.27	0.89	0.79	0.67
Treatments	3	342.67**	113.7**	228.7**	44.35**	197.53**	14.39**	56.95**	16.65**
Error	12								
Total	19								
SEM ±		0.404	0.035	0.496	0.058	0.525	0.115	0.963	0.113
CD = 0.05		1.247	0.108	1.53	0.18	1.617	0.356	2.97	0.348

** highly significant   SEM: standard error of mean   CD: critical difference

3.6 Oxygen Consumption Rate

It was observed that the oxygen consumption rate (VO_2) of all the treatments increased with decrease in moisture content and were highest at 8.04 per cent moisture content (Table 5). This may be due to the reason that with decrease in moisture content hardness of soil increased and the worker had to push the weeder at comparatively greater force. The VO_2 of treatments T_1, T_2 and T_3 are at par at all the levels of soil moisture content while T_4 varied significantly from all other treatments. This may be due to the reason that under this treatment worker had to work in bending posture and for every stroke he had to lift his arms up with the trench hoe.

The effect of treatments on oxygen consumption was found to be highly significant while that of replications were insignificant (Table 6).

3.7 Energy Consumption Rate

The energy consumption rate was determined for all the treatments and it was found that at each level of moisture content, the energy consumption rate was highest in case of treatment T_4 among all the treatments (Table 5). This may be due to higher oxygen consumption rate because the subject had to work under bending posture. Also the highest energy consumption rate of 40.05, 42.35, 41.93 and 60.70 kJ/min were obtained under treatments T_1, T_2, T_3 and T_4 respectively at 8.04 per cent moisture content and this may be due to more force required to operate the weeders at lower moisture content. The lowest value of 8.34, 7.72, 8.35and 23.78 kJ/min were obtained under the same treatments in that order at 13.52 per cent moisture content and this may be due to lower oxygen consumption rate because of softness of soil.

3.8 Cost of Operation

The cost of operation of different weeders was calculated by considering fixed cost and variable cost. These costs were found to be Rupees 244.00, 246.00, 479.00 and 2450.00 per hectare incase of treatments T_1, T_2, T_3 and T_4 respectively at 11.63 per cent moisture content. The lowest cost of operation was observed for treatment T_1. This may be due to higher field capacity and lower cost of the developed weeder.

4. CONCLUSIONS

The following conclusions were drawn from the studies.

- The weeding index and performance index of all the weeders were found to be maximum at 11.63 per cent and minimum at 8.04 per cent moisture content. Hence, a soil moisture of 11.63 per cent (db) was considered to be most suitable for weeding in groundnut crop in sandy loam soil.
- Ergonomic parameters like increased heart rate, oxygen consumption rate and energy consumption rate increases with decrease in soil moisture content for all the treatments.
- Treatment T_1 (developed weeder) with higher weeding index (72.53 to 94.57%), lowest plant damage (2.46 to 7.96%), lower energy consumption rate (8.34 to 40.05 kJ/min) and higher performance index (678.66 to 3689.74) at various soil moisture content proved its superiority over other treatments.
- The cost of operation of developed weeder was found to be Rupees 244.00 as against Rupees 2450.00 per hectare in conventional method of weeding by using trench hoe.

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