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Development and evaluation of tractor mounted inter-row weeder-cum-fertilizer applicator for dryland crops

Ramesh Beerge, U Momin, Revanth K, Vinayaka and Basavaraj

Abstract
Weeding and fertilizer application are two most tedious and laborious field operations in crop production. At present, the unavailability of timely labour and high labour wages is a serious issue in field crop cultivation. An inter-row weeder cum fertilizer applicator for small and medium sized tractors was developed and evaluated for wide row field crops. The equipment performs inter row weeding and application of fertilizer simultaneously for crops having a row spacing of 45 to 120 cm. The fertilizer metering mechanism was calibrated in the laboratory at different combinations of forward speed (S), hopper levels (H) and orifice settings (O) for optimum rate of delivery of fertilizer. It was found that fertilizer rate was optimum at a forward speed of 4.04 km h^{-1} with 3/4th hopper capacity and orifice opening being "maximum" which was on par with the recommended rate of delivery. Field evaluation was carried out at RARS seed production farm, Vijayapur having moisture content in the range of 14.70 to 19.90 % (d.b). The fertilizer rate was in the range of 26.33 to 31.49 kg ha^{-1}, average theoretical field capacity of the operation was 0.83 ha h^{-1}. Field efficiency and effective field capacity were 81.12 % and 0.67 ha h^{-1}, respectively. The mean value of weeding efficiency was determined to be 90.45 %. Plant damage was found to vary between 3.3 to 4.2 % with an average value of 3.6 %. The fertilizer use efficiency was found better as compared to the traditional methods of application thereby reducing the cost of cultivation considerably.

Keywords: Weeder, weeding efficiency, fertilizer, urea and plant damage

Introduction

Indian agriculture is of the subsistence type and therefore, there is a very little scope for increasing cultivable area. It is imperative to improve the yield by intensive agriculture, which necessitates better use of available resources through better management practices. Inter-culture is one of the critical management practices which has proportionate effect on soil moisture conservation, nutrients loss, subsequent crop yield and cost of production. Modern agriculture is defined by the use of improved machineries as a result of labour issues and higher cost of cultivation. Mechanization in agriculture is need of the hour and is regarded as a major player in next green revolution.

Weeding operation consumes more time and involves high human drudgery. Weeding operation requires around 900 to 1200 man-h ha^{-1} (Nag and Dutta., 1979) [8]. Conventionally, different types of tools or implements are being used to carry out interculture operation depending upon the crop spacing (Alizadeh., 2011) [1]. Weeding is usually performed manually with the use of traditional hand tools (*Khurpi*) in upright bending posture which induces back pain due to fatigue for majority of the working labours. It is costly mainly because human labour is not available at the critical stage of crop production. Hand weeding operation causes drudgery and leads higher cost of operation demanding more number of labours. Use of animal drawn weeders is limited to wide row crops and also it is relatively more time consuming (Biswas *et al*., 1999) [2].

Farmers, researchers and entrepreneurs are putting up combined effort to tackle the problem of weed management. Introduction of effective mechanical intercultivators is expected to encourage subsistent farmers leading to increased production and reducing cost of cultivation. In case of dry land, where the moisture availability in soil is limited, the weeds compete more for soil moisture unlike in irrigated crops. The loss of yields in dry land crops due to the weeds has been estimated to be very high in the range of 16 to 42 per cent (Rangasamy *et al*., 1993) [9].

In majority of the crops, the intercultural operation accompanies with top dressing of fertilizer. Availability and quality of matching equipment for small mechanical power sources is a major concern in general and weeding and fertilizer application equipment in particular.

Any new developments in this aspect will substantially reduce the drudgery of small land holders besides meeting timeliness of operations and precise application of fertilizer.

The application of granular fertilizer to the crops after 30, 60 and 90 days after sowing (DAS) is recommended practice in field crops for supplying required amount of nutrients (N, P and K). Application of an optimum dose of NPK maximizes the growth and yield of crop and increases efficiency of nutrients (Islam *et al*., 2014) [4]. The fertilizer application is traditionally accomplished by broadcasting, bullock drawn implements and hill dropping which requires more human effort and it lacks precision in application (Miller *et al*., 2004) [7]. To overcome these problems, there is a need to introduce a suitable equipment which can be used for the intercultivation and fertilizer application operations in one pass. Keeping all these problems in mind, a tractor mounted weeder cum fertilizer applicator has been developed and evaluated for its performance in laboratory and field conditions.

Materials and methods

The inter-row weeder cum fertilizer applicator suitable for wide row crops like cotton, chilli and redgram was developed in association with M/s Gayatri Vishwakarma Industries, Vijayapur to operate two rows at a time.

Crop, weed and soil parameters

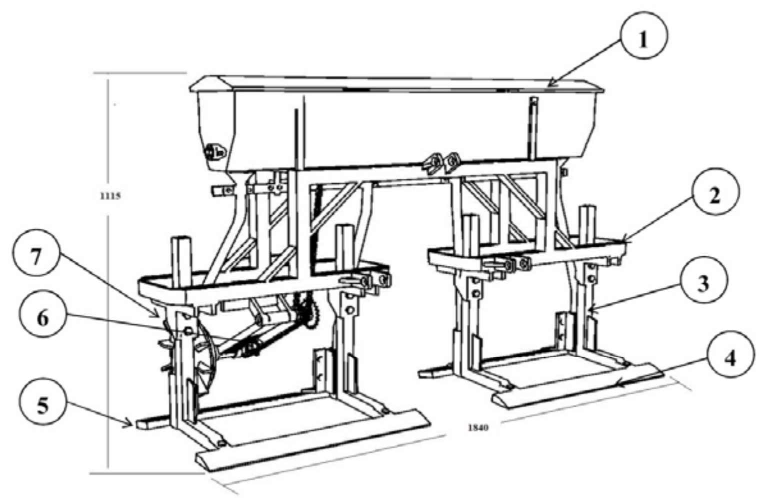
The agronomic parameters of crop, weed and soil parameters were studied prior to the evaluation of tractor operated intercultivator cum fertilizer applicator. The important crop parameters which influence the mechanical weeding of field crops were identified as variety, row spacing and height of crop. The operational response of implement is influenced by type of crop since the crop types are found to differ in their growth factor and foliage, which also varies for each variety. The row to row spacing and intra row spacing also affects weed biomass which has to be handled by the implement. Weed parameters namely, type of weeds, root length and weed density were measured before evaluation. Weed removal process alone or in combination with intercultural operation is being taken up at different time intervals. Two or three such operations are preferably carried out by the farmers in the crop cycle of wide row crops. In normal conditions, weeding after 30, 60 and 90 days after sowing (DAS) is recommended practice and it varies with type and variety of crop. The soil properties relevant for intercultivation were identified as soil type, soil moisture, bulk density and cone index. Type of soil was determined using international pipette method. Soil moisture content was determined by hot air oven method in which five soil samples of known weight were oven dried for 24 h at 105^{o} C temperature and final weights were recorded and then the moisture content of soil was computed. Cone index of soil is a measure of resistance offered by the soil to the penetrating tool. It was determined using a standard cone penetrometer.

Development of inter row weeder cum fertilizer applicator

The tractor mounted inter-row weeder cum fertilizer applicator was developed. It consisted of various working components as described below. Isometric view of the tractor operated weeder cum fertilizer applicator is as shown in Fig. 1.

Main frame

The main frame of the unit was fabricated as two separate units. *i.e.,* one for each row. The main frame was made of MS angular and MS flats. Overall dimensions of main frame were 740 × 353 mm on each side. The support frame was fabricated by MS angulars to form a square hollow shaft. Such six square (three on front side and three on rear side) hollow shafts were welded to form a support frame above which the fertilizer box was mounted. A pyramid shaped three point hitch made of MS flats was attached to the front side of the implement.



S. No.	Component	S. No.	Component
1	Fertilizer box	5	Covering device
2	Main frame	6	Power transmission system
3	Tine	7	Ground wheel
4	Weeding blade		

Fig 1: Conceptual view of inter-row weeder cum fertilizer applicator

Tine
Two tines were attached by means of two support flats to the frame at their extremities which are made from mild steel. The tine was made of MS hollow box of size 845 × 30 × 30 mm.

Weeding blade
A carbon steel bevel edged flat was bolted at the bottom of tines as a weeding tool. It had dimensions of 760 mm length, 50 mm width and 12 mm thickness with length of bevel edge and bevel angles being 35 mm and 15 deg, respectively.

Fertilizer box
The fertilizer box was mounted over the support frame and bolted to four MS flats for additional support which are welded to support frame. It was made of MS sheet of thickness 2 mm by shaping it to the trapezoidal form. The fertilizer box had overall dimensions of 1430 × 180 mm.

Power transmission system
The power transmission to the fertilizer box was accomplished through the chain drive from the ground wheel of diameter 418 mm with 12 lugs made up of MS flats. The ground wheel was mounted on the axle of size 225 mm length and 25 mm dia. The power was transmitted from the sprocket mounted on ground wheel axle to the fertilizer feed shaft through an intermediate sprocket with the transmission ratio of 1.5:1.

Fertilizer metering mechanism
Variable orifice with rubber agitator type fertilizer metering mechanism (Fig. 2) was provided to meter the granular fertilizer at uniform rate. Four numbers of (two for each row) rubber agitators were provided. A bottom plate having eight different sized holes to match different sized fertilizer and fertilizer rate were provided for each outlet.

Fig 2: Variable orifice with rubber agitator metering mechanism

Fertilizer feed cups
Four funnel type fertilizer cups were provided to collect the metered fertilizer to pass through the transparent fertilizer tube which connects fertilizer boot fitted at rear side of the tine and the funnel. A covering device is provided at the rear end of the plate to cover the soil over the dropped fertilizer which was made of hollow MS rectangular box.

Performance evaluation of inter-row weeder cum fertilizer applicator
The inter-row weeder cum fertilizer applicator was calibrated in the laboratory to optimize the fertilizer application rate at three different speeds varying from 3 to 5 km h^{-1} at three different hopper levels (Full, $3/4^{th}$ and 1/2) and at minimum, medium and maximum opening holes of bottom orifice plate. The experiments were designed in Response Surface Methodology (RSM) in Design Expert software. The experiments with different coded levels are shown in Table.1. Optimization of operational parameters was done using numerical optimization procedure in Design Expert statistical package.
The equipment was evaluated in the field to determine its performance parameters (Fig 3). The machine was operated in the field with the parameters optimized during laboratory calibration of fertilizer metering mechanism. The field capacity, field efficiency and weeding efficiency were determined by standard procedures. Weeding efficiency was calculated by weed count method in which the numbers of weeds before and after the field operation were recorded and weeding efficiency was expressed as the ratio of difference between the number of weeds before and after the operation to the number of weeds before operation. The fuel consumption of the tractor for the operation of inter-row weeder cum fertilizer applicator was measured using gravimetric method. The draft of the equipment during the operation of inter-row weeder cum fertilizer applicator was measured using the load cell dynamometer and by following standard two-tractor method. Power required to operate the inter-row weeder cum fertilizer applicator was also estimated.

Table 1: Design of experiments in optimal (custom) design of RSM with coded levels

Run	Forward speed, km h^{-1}	Hopper level	Orifice setting
1	3 (-1)	Full (+1)	Minimum (-1)
2	5 (+1)	Half (-1)	Maximum (+1)
3	3 (-1)	$3/4^{th}$ (0)	Minimum (-1)
4	5 (+1)	$3/4^{th}$ (0)	Minimum (-1)
5	4 (0)	Half (-1)	Maximum (+1)
6	4 (0)	Half (-1)	Medium (0)
7	3 (-1)	Half (-1)	Minimum (-1)
8	3 (-1)	$3/4^{th}$ (0)	Maximum (+1)
9	3 (-1)	$3/4^{th}$ (0)	Medium (0)

10	5 (+1)	Full (+1)	Minimum (-1)
11	4 (0)	$3/4^{th}$ (0)	Maximum (+1)
12	3 (-1)	Full (+1)	Medium (0)
13	4 (0)	Full (+1)	Minimum (-1)
14	4 (0)	Full (+1)	Medium (0)
15	4 (0)	$3/4^{th}$ (0)	Minimum (-1)
16	4 (0)	$3/4^{th}$ (0)	Maximum (+1)
17	4 (0)	Half (-1)	Maximum (+1)
18	5 (+1)	Full (+1)	Medium (0)
19	4 (0)	Half (-1)	Minimum (-1)
20	5 (+1)	Full (+1)	Maximum (+1)
21	4 (0)	Half (-1)	Minimum (-1)
22	5 (+1)	$3/4^{th}$ (0)	Medium (0)
23	4 (0)	Half (-1)	Medium (0)
24	4 (0)	Full (+1)	Maximum (+1)
25	4 (0)	Full (+1)	Maximum (+1)

Fig 3: Field evaluation of inter-row weeder cum fertilizer applicator in redgram field

Weeding efficiency

The weeding efficiency (E_w) was calculated by weed count method. To determine weeding efficiency, a quadrant of 300 x 300 mm was placed in the field at random and the number of weeds inside the quadrant was counted before (N_1) and after weeding (N_2) by the equipment. The weeding efficiency was calculated using the following equation (Manjunatha *et al*., 2015).

$$E_w = \frac{(N_1 - N_2)}{N_1} \times 100$$

Draft

Draft requirement of the inter-row weeder cum fertilizer applicator was computed using following equation (Mehta *et al*., 2005) [6].

$$D = D_1 - D_2$$

where,

D = Draft (N); D_1 = Draft at on load (N); D_2 = Draft at on load (N)

Power requirement

Power requirement of the inter-row weeder cum fertilizer applicator was determined by the ensuing relationship (Kepner *et al*., 1978) [5].

$$P = \frac{D \times S}{1000}$$

where,

P = Power (kW); D = Draft requirement (N); S = Speed (ms^{-1})

Plant damage

Number of main crop plants before (p) and after the operation (q) were counted and calculated using following expression (Manjunatha *et al*., 2015).

$$D_p = \frac{p-q}{p} \times 100$$

Results and discussion

Crop, weed and soil parameters

Different crop, weed and soil parameters were measured in field prior to evaluation and average values are tabulated in Table 2.

Crop parameters

The average row to row spacing of red gram was observed to be 92 cm and it varied from 85 to 98 cm. Average plant height of the red gram after 60 DAS was measured to be 52 cm. The equipment was operated in the TS3R variety of red gram crop which is dominant variety in the study area.

Weed parameters

Common weeds identified in the red gram field were *Eleusine indica, Echinocloa crusgalli, Ageratum conzoides,* and *Launaea cornuta.* Length of roots of identified weeds varied from 60 to 95 mm with an average value of 88 mm. Average weed density was measured to be 36 weeds m^{-2}.

Table 2: Crop, weed and soil parameters

S. No.	Parameter	Details
Crop parameters		
1	Type of crop	Redgram
2	Variety	TS3R
3	Row to row spacing, cm	92
4	Height of crop, cm	52
Weed parameters		
5	Types of weeds	*Eleusine indica, Echinocloa crusgalli, Ageratum conzoides,* and *Launaea cornuta.*
6	Length of roots, mm	88
7	Weed density before operation, weeds m^{-2}	36
Soil parameters		
8	Type of soil	Black cotton
9	Moisture content, % (d.b)	14.60
10	Bulk density, g cm^{-3}	1.55
11	Cone index, MPa	1.82

Soil parameters

Soil parameters in the test plot were recorded before the field operation. Soil type was found to be black cotton soil with 57 % clay, 22 % silt and 21 % sand particles. Average soil moisture content during the field evaluation was observed to be 16.80 % (d.b). It ranged between 14.70 to 19.90 % (d.b). Bulk density of soil was measured by core cutter method and it was found to vary between 1.35 to 1.82 g cm^{-3} with an average value of 1.55 g cm^{-3}. Cone index was determined using a standard cone penetrometer. Average cone index of soil was observed as 1.82 MPa.

Laboratory calibration of fertilizer metering mechanism for fertilizer application rate

Laboratory calibration was conducted with different parameters considered for the study (IS: 6316-1993). Fertilizer rate was measured for the different combinations of independent parameters *viz*., forward speed (S), hopper levels (H) and orifice settings (O). The results of the experiments are presented in Table 3. The minimum fertilizer rate of 23.3 kg ha^{-1} was observed at a forward speed of 4 km h^{-1}, at half hopper level and when the orifice setting was minimum whereas the maximum value of 27.7 kg ha^{-1} was found at a forward speed of 5 km h^{-1}, at full hopper level and when the orifice setting was maximum.

Effect of forward speed (S), hopper levels (H) and orifice settings (O) on the fertilizer rate of inter-row weeder cum fertilizer applicator

Influence of forward speed (S), hopper levels (H) and orifice settings (O) on the fertilizer rate are depicted in Fig. 4, 5 and 6. The fertilizer rate increased with increase in forward speed of operation. This is because, with increase in forward speed, the ground wheel rotates faster and it drives metering shaft at faster rate. Because of high speed of rotation of metering auger, higher amount of fertilizer would be discharged through the orifice. Hopper level also had direct relationship with the fertilizer rate. With increase in hopper level from half to full, the fertilizer rate also increased constantly. This may be due to the fact that as the hopper level increased, the force of gravitation will push the granules of fertilizer down at rapid rate and hence the rate of feed of fertilizer will increase. Similarly, the fertilizer rate increased with increase in orifice setting. This could be because, as the orifice setting increased, it would open up larger area for the fertilizer granules to pass through, thereby the fertilizer rate also increases significantly.

Table 3: Results of laboratory calibration of tractor mounted inter-row weeder cum fertilizer applicator

Exp. No.	Forward speed, km h^{-1}	Hopper level	Orifice setting	Fertilizer rate, kg ha^{-1}
1	3	Full	Minimum	23.9
2	5	Half	Maximum	26.5
3	3	3/4th	Minimum	24.9
4	5	3/4th	Minimum	25.6
5	4	Half	Maximum	26.2
6	4	Half	Medium	24.8
7	3	Half	Minimum	23.6
8	3	3/4th	Maximum	25.3
9	3	3/4th	Medium	24.8
10	5	Full	Minimum	24.5
11	4	3/4th	Maximum	27.6
12	3	Full	Medium	26.4
13	4	Full	Minimum	24.4
14	4	Full	Medium	25.8
15	4	3/4th	Minimum	23.9
16	4	3/4th	Maximum	26.6
17	4	Half	Maximum	26.4
18	5	Full	Medium	27.3
19	4	Half	Minimum	23.4

20	5	Full	Maximum	27.7
21	4	Half	Minimum	23.3
22	5	3/4th	Medium	25.3
23	4	Half	Medium	24.8
24	4	Full	Maximum	26.6
25	4	Full	Maximum	26.2

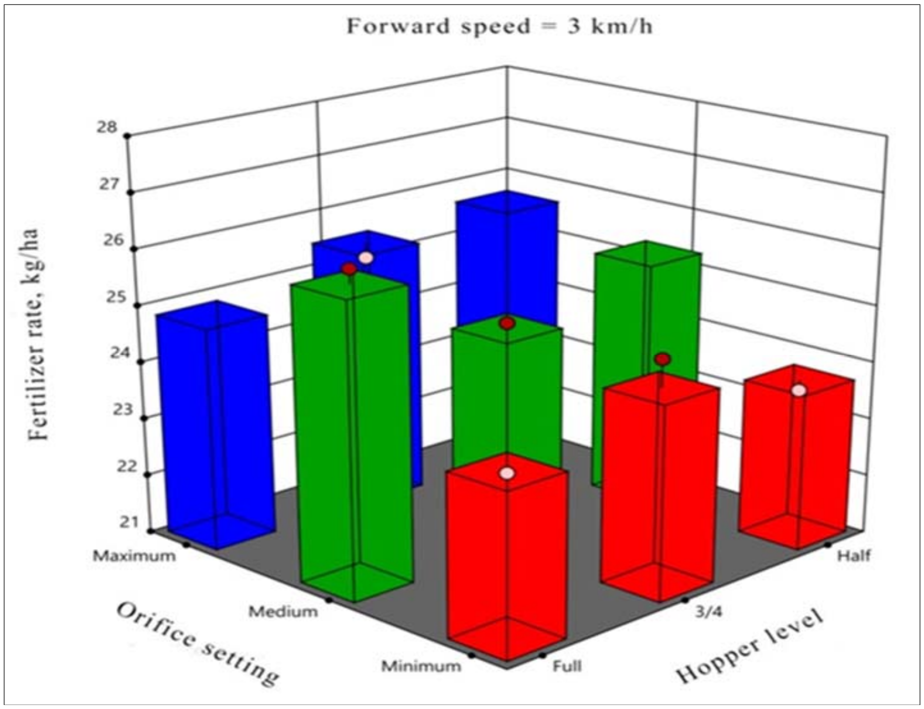


Fig 4: Fertilizer rate as a function of orifice setting (O) and hopper level (H) at a forward speed of 3 km h^{-1} (S_1)

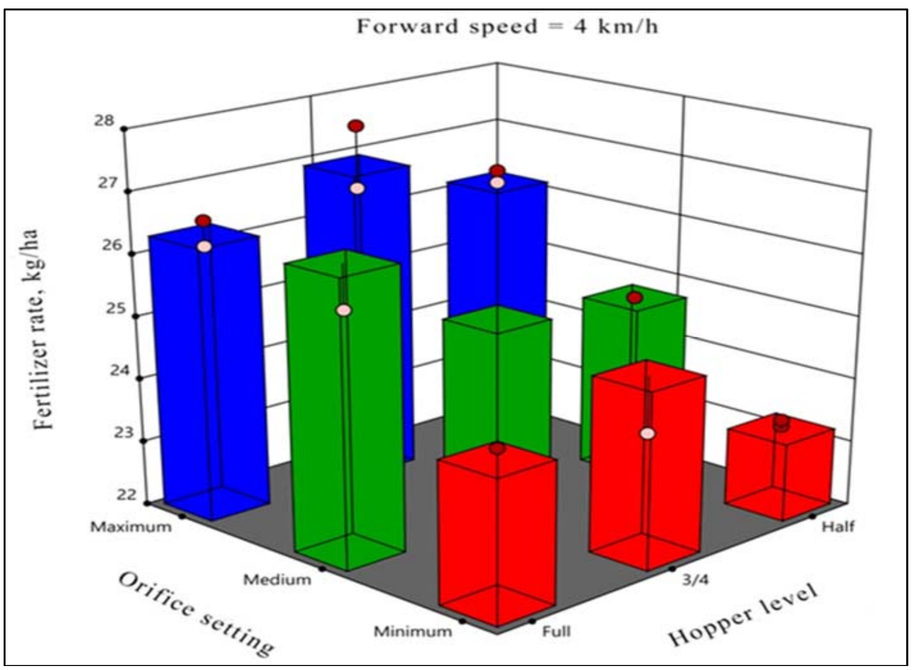


Fig 5: Fertilizer rate as a function of orifice setting (O) and hopper level (H) at a forward speed of 4 km h^{-1} (S_2)

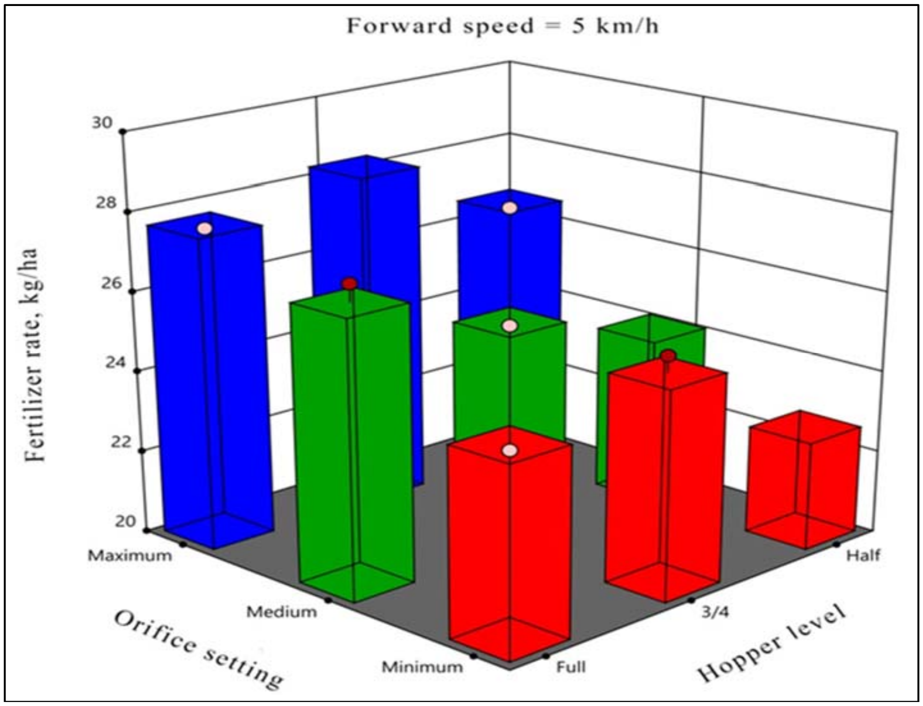


Fig 6: Fertilizer rate as a function of orifice setting (O) and hopper level (H) at a forward speed of 5 km h^{-1} (S_3)

Results obtained from the laboratory calibration of inter-row weeder cum fertilizer applicator were statistically analysed using Design Expert software and the analysis is given in Table 4. The quadratic polynomial model was applied for the analysis. From the Table, it was inferred that the model was significant at 1 % level of significance. The main effects of forward speed (S), hopper level (H) and orifice setting (O) had significant effect on the fertilizer rate at 1 % level of significance. The interactions of H × O also had significant effect on fertilizer rate at 1 % level of significance while S × O was significant at 5 % level of significance. The mean value of fertilizer rate was observed to be 25.43 kg ha^{-1} with a standard deviation of 0.51 and coefficient of variation was about 2.01 %.

The model coefficient of determination (R^2) was obtained to be 0.9301. The predicted R^2 value of 0.6491 was in reasonable agreement with adjusted R^2 value of 0.8475. The signal to noise ratio which was measured by adequate precision was about 11.849 and it was greater than 4, which indicates an adequate signal and the model can be used to navigate the design space. The actual and predicted values of fertilizer rate during laboratory calibration are presented in Fig 7.

Table 4: Analysis of variance (ANOVA) for fertilizer rate using response surface quadratic model

Source	Sum of squares	DF	Mean square	F-value	p-value
Model	38.0503	13	2.9269	11.2569	0.0002**
Forward speed (S)	2.1901	1	2.1901	8.4230	0.0144**
Hopper level (H)	4.1938	2	2.0969	8.0646	0.0070**
Orifice setting (O)	21.8403	2	10.9201	41.9983	<0.0001**
S×H	0.8756	2	0.4378	1.6837	0.2302NS
S×O	1.5726	2	0.7863	3.0241	0.0898*
H×O	3.9496	4	0.9874	3.7975	0.0355**
Residual	2.8601	11	0.2600		
Lack of Fit	2.2551	6	0.3759	3.1063	0.1171NS
Pure Error	0.605	5	0.121		
Corr Total	40.9104	24			

** Significant at 1% *Significant at 5% NS – Not significant

Numerical optimization technique was used for optimization of operational parameters *viz*, forward speed (S), hopper level (H) and orifice setting (O). The optimized parameters obtained were forward speed of 4.02 km h^{-1}, $3/4^{th}$ hopper level and 'maximum' orifice setting.

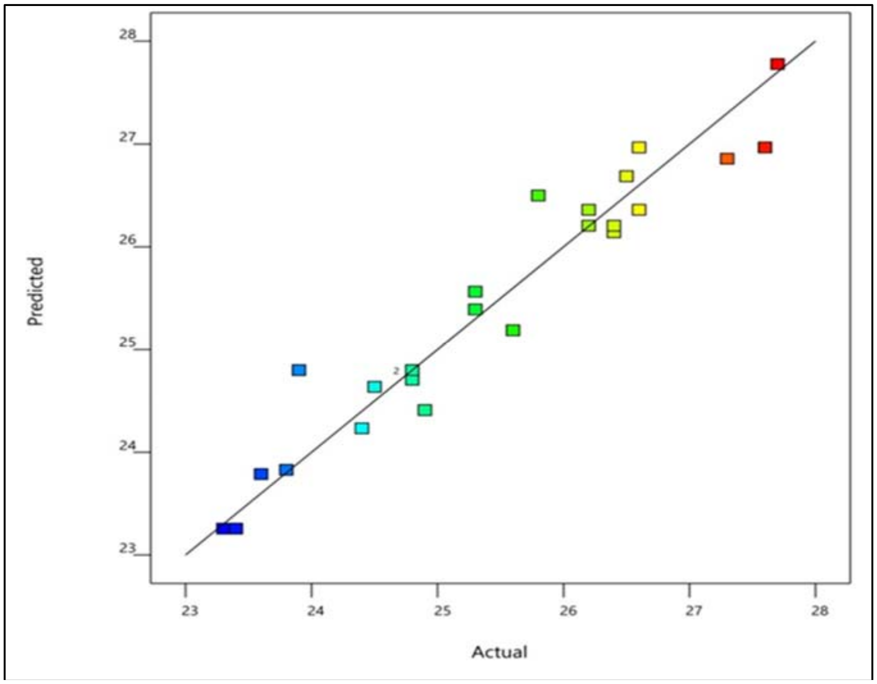


Fig 7: Plot of actual and predicted values of fertilizer rate in laboratory calibration

Field evaluation of inter-row weeder cum fertilizer applicator

The inter-row weeder cum fertilizer applicator was evaluated in field conditions at optimized operational parameters of fertilizer rate to evaluate its performance in black cotton soil with average moisture content varying from 14.67 to 19.94 % and average bulk density of 1.35 to 1.82 g/cc. During the operation, the width and depth of cut of weeding tool were noticed to be in the range 1.81 to 1.84 m and 5.4 to 5.8 cm respectively. The rate of fertilizer application was found to be 26.33 to 31.49 kg ha^{-1} which is on par with recommended values of fertilizer rate.

Theoretical field capacity of the operation was found to be in the range of 0.79 to 0.85 ha h^{-1} with an average value of 0.83 ha h^{-1}. Field efficiency was found as 79.36 to 83.36 % with a mean of 81.12 %. Actual field capacity of the inter-row weeder cum fertilizer applicator was in the range of 0.63 to 0.71 ha h^{-1} with an average of 0.67 ha h^{-1}.

The weeding efficiency was determined to be 89.38 to 92.75 % with an average of 90.45 %. Draft of the implement was obtained as 3689 to 4169 N. The average fuel consumption of the tractor during the operation was found be in the range of 2.86 to 3.18 l/h and average power requirement was determined as 4.38 kW. Plant damage was found to vary between 3.3 to 4.2 % with an average value of 3.6 %.

Conclusion

Inter-row weeder cum fertilizer applicator can perform two operations simultaneously. A tractor mounted inter-row weeder cum fertilizer applicator was evaluated in laboratory as well as in field conditions. The calibration for fertilizer dropping was conducted to determine optimum forward speed, hopper capacity and orifice setting at which fertilizer rate can be close to the recommended rate. The optimum operational parameters were found to be forward speed of 4.02 km h^{-1}, 3/4th level of hopper capacity and when the orifice setting was in "maximum" condition. Field evaluation of inter-row weeder cum fertilizer applicator under optimized parameters showed that the fertilizer rate was in the range of 26.33 to 31.49 kg ha^{-1}, Mean theoretical field capacity of the operation was 0.83 ha h^{-1}. Field efficiency and effective field capacity were 81.12 % and 0.67 ha h^{-1}, respectively. The mean value of weeding efficiency was determined to be 90.45 %. Average plant damage was determined as 3.6 %. Hence, the performance of inter-row weeder cum fertilizer applicator was found satisfactory and it was popularized among the farmers in the study locality.

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