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Design and Development of Tractor Drawn Inter-cultivator cum Sprayer for Soybean and Cotton

A. M. Kolhe[1*], S. N. Solanki[2], A. A. Waghmare[3] and R. T. Ramteke[4]

[1]Department of Agricultural Engineering and Technology, VNMKV, Parbhani, Maharashtra, India
[2]Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology VNMKV, Parbhani, Maharashtra, India
[3]Senior Research Assistant, AICRP on UAE, VNMKV Parbhani, Maharashtra, India
[4]Department of Electrical and Other Energy Sources, College of Agricultural Engineering & Technology VNMKV, Parbhani, Maharashtra, India

**Corresponding author*

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Inter-cultivation and spraying are two important operations in crop protection techniques in order to ensure full healthy growth of crop from the time of germination to the harvest for a quality produce and thereby good returns. Cotton is a major fiber crops and soybean is one of the important oilseed crops of the world. The food grain losses due to weeds alone and only in India ranges as high as 40 million tons per year in addition to the losses incurred by pests/insects infestation. Furthermore, there is under-utilization of tractor due to comparatively larger tread width of tractor tyres rendering it inaccessible in soybean and cotton due to their short crop row spacing. A tractor drawn inter-cultivator cum sprayer for soybean and cotton was thus developed to carry out inter-cultivation and spraying operation simultaneously. The test results revealed the effective field capacity, field efficiency, weeding efficiency, plant damage and spray application rate of 0.631 ha h^{-1}, 85.32 %, 86.12 %, 5 % and 297.76 l ha^{-1} respectively for soybean at a forward speed of 3.30 km h^{-1}; and of 0.733 ha h^{-1}, 81.56 %, 84.87 %, 3.06 % and 334.50 l ha^{-1} respectively for cotton at a forward speed of 2.50 km h^{-1}.

Introduction

Agriculture plays a major role in Indian economy as India is a developing and an agrarian country with about 65 % of its population still dependant on agriculture for livelihood. Such a large sector of economy requires sustainable development which is possible only by farm mechanization. Every year about four thousand two hundred million rupees are spent to eradicate weeds to support production of crops, in our country. The loss of food grains due to weeds alone is very high in India ranging about 40 million tons per year in addition to the losses incurred due to pests/insect infestation. This traces out the importance of weeding and spraying operation in agriculture in order to control the weeds, pests and insects infestation. Moreover, these operations are required to be carried out in timely manner to get better result and also in a safe manner as the exposure of chemical spray to the operator may cause health hazards as in the case of manual knapsack spraying.

India ranks first in area under cotton cultivation and fourth in area under soybean cultivation with 12.235 million hectare and 7.9 million hectare area respectively. However, the productivity of cotton and soybean in India of 519 kg ha^{-1} and 839.62 kg ha^{-1} is far less than the world average productivity of 806 kg ha^{-1} and 2771.92 kg ha^{-1} respectively. Similar trend is observed within the country with Maharashtra state having the largest area under cotton cultivation of 43.51 lakh hectare but least productivity of 325.66 kg ha^{-1} as against the Punjab state with 2.91 lakh hectare area under cultivation and productivity of 687.01 kg ha^{-1}. In case of soybean, Maharashtra is the second largest producer state with 4.351 million hectare area under cultivation and productivity of 944 kg ha^{-1} as against Madhya Pradesh having a productivity of 1075 kg ha^{-1}. There was also observed under-utilization of tractors as manual weeding and spraying was preferred by farmers in spite of owning tractors due to the comparatively larger tread width of tractor tyres. In the light of the above mentioned scenario, a tractor drawn inter-cultivator cum sprayer for soybean and cotton was developed that could carry out simultaneously weeding and spraying operation and it was tested for its performance evaluation in fields of soybean and cotton.

Design considerations

A due attention was given on the following design aspects while designing and fabrication of tractor operated inter-cultivator cum sprayer for soybean and cotton.

Physical and economical consideration

Functional requirement

Agronomical requirements

Physical and economical considerations

Machine should be simple in design and it should be easy to operate.

Cost of the machine should be as low as possible.

It should be easily repairable and maintained by farmer or village artisan.

It should reduce the labour engaged in weeding as well as time required for weeding operation.

Functional requirements

Machine should have economical actual field capacity.

Tractor rear wheel should travel between the crop rows.

It should be suitable for using with tractors of 40 hp and above range.

Agronomical requirements

The agronomical requirements consisted of crop parameters and weed parameters. The crop parameters included crop row spacing and crop height depending upon the crop variety of Soybean and Cotton. The general crop parameters for soybean and cotton are tabulated in Table 1. The weed parameters included common weed types and weeding intervals. Weeding for both crops viz. soybean and cotton is generally carried out at three stages at a weeding interval of 18-20 DAS, 30-45 DAS and 45-60 DAS for obtaining maximum yield.

Design consideration for inter-cultivator unit

Width of implement

The total working width of implement for cotton and soybean weeder was calculated using the following formula

$$W = \frac{\text{Total Draft on the implement}}{\text{Unit draft}\left(\frac{kg}{cm^2}\right) \times \text{Depth of interculture (cm)}}$$

Where,

W= Width of implement, cm

Design of blades

Blade width for inter-cultivators is dependent on crop spacing whereas the number of blades is dependent on the total width of implement and other factors.

Blade width

The blade widths of inter-culture units for soybean and cotton were calculated using the following formula

$$S_c = Z_f + Z_p$$

Where,

S_c = Crop spacing, cm

Z_f = Effective soil failure zone, cm

Z_p = Crop protection zone, cm

And,

$$Z_f = w + 2d \times \tan\emptyset$$

Where,

w = Width of cutting blade

d = Depth of weeding

Ø = Angle of internal friction

Number of blades

The number of cutting blades for soybean and cotton inter-cultivators was determined using the following formula

$$\text{Number of cutting blades} = \frac{\text{Total width of implement}}{\text{width of cutting blade}}$$

The computed values using the above mentioned formulae of different parameters of inter-cultivator unit are tabulated in Table 2.

Design consideration for sprayer unit

Design of spray boom

The Boom size in terms of length was established based on field capacity, speed of operation and time available using the expression given by Mathews (1992) and Anibude *et al.*, (2016).

$$L = \frac{A}{T \times S}$$

Where,

L = Length of boom (m)

A = Area to be covered (ha)

T = Time available (h)

S = Forward speed (km h^{-1})

Selection of storage tank

The storage tank capacity was determined using the following equation

$$Q_t = D_b \times t$$

Where,

Q_t = Storage tank capacity, (litre)

D_b = Total discharge rate of all the nozzles on boom. (lpm)

t = Duration of use, (minute)

Selection of pump

Pump was selected considering the water horse power and shaft horse power requirement.

Water horse power

Water horse power (WHP) is the power required for pumping the liquid. The water horse power requirement of pump was calculated by using the following formula

$$Whp = \frac{Q \times H}{75}$$

Where,

Whp = Water horse power

Q = Discharge, lps

H = Total head, m

Shaft horse power

Shaft horse power is the power available at the pump shaft from the power source through a power transmission mechanism and is given by the formula

$$\text{Shaft horse power} = \frac{\text{Water horse power}}{\text{Pump efficiency}}$$

$$\text{Shaft horse power} = \frac{\text{Water horse power}}{\text{Pump efficiency}}$$

Design of hydraulic agitation unit

The flow required for hydraulic agitation was thus calculated using the following formula

$$Q_a = 5 \text{ to } 10\% \text{ of } Q_t$$

Where,

Q_a = Agitation requirements, lph

Q_t = tank capacity, litre

Design of power transmission system

Power is transferred from tractor PTO to the HDP pump for conducting the chemical spray under pressure using belt and pulley and transmission system.

Design of pulley

For designing the pulley of the power transmission system velocity ratio of the power transmission system was determined using the following formula:

$$\text{Velocity ratio} = \frac{\text{Speed of the pump (rpm)}}{\text{Speed of P.T.O. (rpm)}}$$

Also,

$$\text{Velocity ratio} = \frac{\text{Diameter of driver pulley}}{\text{Diameter of driven pulley}}$$

By using the standard driven pulley obtained with the HDP pump as the driven pulley, the diameter of driver pulley was determined using the above formula.

Design of belt

Various parameters of a belt of V-cross section were required for designing of the belt viz., allowable tensile strength, density and grove angle (2β). These were taken as 2.5 MPa and 1000 kg m^{-3} (Khurmi and Gupta, 2006) and 35°

The velocity of belt was determined using the formula:

$$V = \frac{\pi \times D \times N}{60}$$

Where,

V = Velocity of the belt, m s^{-1}

D = Diameter of driver/driven pulley, mm

N = Speed of same driver/driven pulley, rpm

The maximum tension in belt was determined using the formula:

$$T = \sigma \times a$$

Where,

T = Maximum tension in belt

σ = Allowable tensile stress, N mm^{-2}

a = Section area of belt, mm^2

The tension at the slack side of the belt was determined using the following formula:

$$2.303\log\left(\frac{T_1}{T_2}\right) = \mu \times \theta \times \text{cosec}\left(\frac{\beta}{2}\right)$$

Where,

T_1 = Tension on tight side of belt

T_2 = Tension on slack side of belt

μ = Angle of friction

θ = Angle of lap on smaller pulley

β = Groove angle

The power transmitted by the belt was calculated using the formula:

$$P = (T_1 - T_2) \times V$$

Where,

T_1 = Tension on tight side of belt

T_2 = Tension on slack side of belt

V = Velocity of belt, m s^{-1}

The length of the belt required was determined using the formula:

$$L = \frac{\pi}{2} \times (d_2 + d_1) + 2C + \frac{(d_2 - d_1)}{4C}$$

Where,

L = Length of belt, m

d_1 = Diameter of driver pulley

d_2 = Diameter of driven pulley

C = Distance between the centers of driver and driven pulley

Materials and Methods

Machine components

This machine consists of the following functional components.

Main frame

Hoe assembly for soybean

Ridger

Hoe assembly for cotton

Storage tank

HDP piston pump

Supporting frame for HDP pump and storage tank

Pulley And Belt

Spray nozzle

Flexible hose

Main Frame

A frame of size 3000 x 550 mm, was fabricated using M.S. angles of 55 x 55 x 5 mm in the workshop (Fig. 1).

Blade

Straight blades were chosen and as per the design considerations, four blades of 220 mm each were used for soybean; two blades of 900 mm and two blades of 450 mm were used for cotton. The sharpness angle for the blade was kept 30^0.

Hoe assembly for soybean

The hoe assembly for soybean is a unit to hold the weeding blade firmly and attach it to the main frame. It consists of 350 mm tyne welded to a C shape MS plate of dimension 235×100 mm. At both the edges of this plate, blade holding bars are attached using nuts and bolt and on the end of these bars is mounted the weeding blade.

The hoe assembly was attached to the main frame with the help of clamps on tyne and can be moved on the main frame to adjust according to the row spacing of crop. The height of hoe assembly could be adjusted by sliding the tynes up or down in the clamps as per the crop height.

Ridger

The ridger consisted of two wings made up of MS plates, tyne, shovel and width adjusting braces. The width adjusting braces were welded to the inner side of the wings and had holes drilled for adjusting the wing span and consequently the width of furrow.

The load angle of shovel was 30° and the setting angle of wings was 45°. The ridgers could be mounted for re-opening of furrows in broad bed furrow planted soybean or dismounted as per the need.

Hoe assembly for cotton

The hoe assembly for cotton consisted weeding blade attached to the bottom end of 600 mm tynes using nut and bolt and clamps attached to its top end for mounting on main frame.

Two hoe assemblies consisted of three tynes for holding the 900 mm weeding blade and the other two hoe assembly consisted of two tynes for holding 450 mm weeding blade. The whole hoe assembly could be moved on main frame according to the crop row spacing. The height of hoe assembly could be adjusted by sliding the tynes up or down in the clamps as per the crop height.

Storage tank

A high density plastic tank of 220 litre capacity was selected as storage tank for storing the spray solution.

HDP Pump

For pumping the spray solution from storage tank to the nozzles with pressure, a horizontal duplex piston pump from a range of standard pumps available in the market was selected. The specifications of pump are shown in Table 3. The pump was supplied with a pulley, pressure gauge, pressure valve, by-pass cum pressure regulator valve, 3 meter long by-pass hose, a suction hose with strainer and couplings for delivery hose.

Supporting Frame for HDP and Storage tank

A supporting frame for holding and carrying the storage tank and HDP pump on tractor was designed and fabricated considering various dimensions of the pump and tank. The frame was fabricated using MS angles and attached to the rear of tractor with help of nuts, bolts and washers (Fig. 2).

Pulley and Belt

The HDP pump was provided with 170 mm diameter driven pulley. A driver pulley having diameter of 205 mm was attached to the PTO shaft of tractor and two A-82 V belts were used for connecting the two pulleys for transmitting the power from PTO shaft to the HDP pump.

Spray nozzles

Six standard hollow cone nozzles of discharge rate 700 ml min^{-1} and pressure rating of 2 to 2.5 kg cm^{-2} made by ASPEE were used. The maximum spacing between two adjacent nozzles was 45 cm and was adjustable for any length below 45 cm as per requirement. For spraying in soybean field 6 nozzles were used with nozzle spacing of 40 cm and for spraying in cotton, 6 nozzles were used with nozzle spacing of 45 cm.

Flexible hose pipe

For carrying spray solution from storage tank to the nozzle, 8 mm diameter hose was used. 15 mm diameter hose was used for overflow discharge and 20 mm diameter hose for conveying water or spray solution to the storage tank.

Performance evaluation

The developed tractor drawn inter-cultivator cum sprayer for soybean and cotton was tested for its performance evaluation in the fields of soybean and cotton of VNMKV, Parbhani (MS) as per the RNAM test code. Inter-cultivation cum spraying was carried out at 40 DAS in three test fields of 1800 m^2 each of soybean and cotton and their average values were considered for evaluation.

Effective field capacity

Effective field capacity of developed tractor operated inter-cultivator cum sprayer was calculated using the following formula.

$$E.F.C. = \frac{A}{T_2 - T_1}$$

Where,

E.F.C. = Effective field capacity, (ha h^{-1})

A = Actual area covered, (ha)

T_2 = Total time required for operation, (h)

T_1 = Non-productive time, (h)

Field efficiency

Field efficiency was computed from T.F.C and E.F.C. using the following formula.

$$\text{Field efficiency}(\%) = \frac{\text{Effective field capacity (ha h}^{-1})}{\text{Theoretical field capacity (ha h}^{-1})} \times 100$$

Weeding efficiency

The number of weeds present in randomly selected same one m^2 area before and after weeding operation was counted. Weeding efficiency was computed by using the following formula.

$$\text{Weeding efficiency (\%)} = \frac{w_1 - w_2}{w_1} \times 100$$

Where,

w_1 = Number of weeds present before weeding operation

w_2 = Number of weeds present after weeding operation

Plant damage

The plant damage percentage was then calculated using the formula.

$$Q = \frac{p\text{-}q}{p} \times 100$$

Where,

Q = Plant damage percentage

p = Number of plants in a row before weeding

q = Number of plants in the same row after weeding

Spray application rate

The application rate of sprayer was determined using the following formula.

$$\text{Application rate (l ha}^{-1}) = \frac{600 \times \text{total boom discharge (l min}^{-1})}{\text{swath width (m)} \times \text{travel speed (m s}^{-1})}$$

Results and Discussion

Development of tractor drawn inter-cultivator cum Sprayer

The tractor drawn inter-cultivator cum sprayer for soybean and cotton was fabricated as per the designed values obtained using the formulae mentioned in design consideration.

The various functional components of the machine viz. main frame, hoe assembly for soybean, hoe assembly for cotton, ridgers, storage tank, pump, nozzles, etc. were fabricated/selected and assembled as discussed in Material and methodology. The isometric view of the designed machine is shown in Fig. 3. The fabricated prototype of machine with soybean hoe assembly and cotton hoe assembly used for performance evaluation is shown in Fig. 4 and Fig. 5 respectively.

Performance evaluation

Field trials were conducted in three test fields each of soybean and cotton and their average results were considered for performance evaluation. The results of the field tests are shown in Table 4.

Table.1 Row spacing and crop height of soybean and cotton

Crop	Row spacing	Crop height		
		20 DAS	40 DAS	60 DAS
Soybean	300-500	147-177	246-320	328-609
Cotton	450-1200	228-270	311-392	520-559

Table.2 Designed parameters of inter-cultivator unit

Sr. No.	Parameter	Cotton		Soybean
1	Crop spacing, mm	1000-1200		30-45
2	Total allowable designed width of implement, mm	2700		2160
3	Width of blade, mm	900	450	220
4	Number of cutting blade	2	2	4
5	Spacing between consequent weeder unit, mm	950-1200		235-250
6	Theoretical width of operation, mm	2700		880

Table.3 Specification HDP piston pump

Sr. No.	Specification	Value
1	Model	AS-26
2	Dry Weight (without pulley & oil), (kgs)	9.6
3	Suction Capacity (lpm)	24
4	Pump (rpm)	950
5	Pressure, (kg cm^{-2})(max)	28
6	Pressure (kg cm^{-2})(working)	14
7	Power Required (hp)	3
8	Engine (Ps.)	3.5
9	L x W x H (mm)	320 x 240 x 395
10	Pump Material	Brass

Table.4 Performance evaluation of developed tractor drawn inter-cultivator cum sprayer for soybean and cotton

Particulars	Soybean	Cotton
Weeding Interval, (Days after sowing)	40	40
Area of the plot, (m^2)	1800	1800
Speed of operation (km h^{-1})	3.30	2.50
Effective Field Capacity, (ha h^{-1})	0.631	0.733
Field Efficiency, (%)	85.32	81.56
Weeding Efficiency, (%)	86.12	84.87
Plant damage, (%)	5	3.06
Spray application rate, (l ha^{-1})	297.76	334.50

Fig.1 Schematic view of main frame

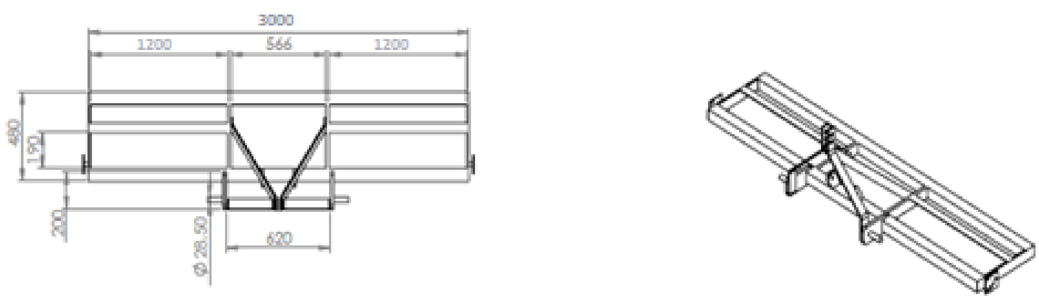

Fig.2 Schematic view of supporting frame for storage tank and HDP pump

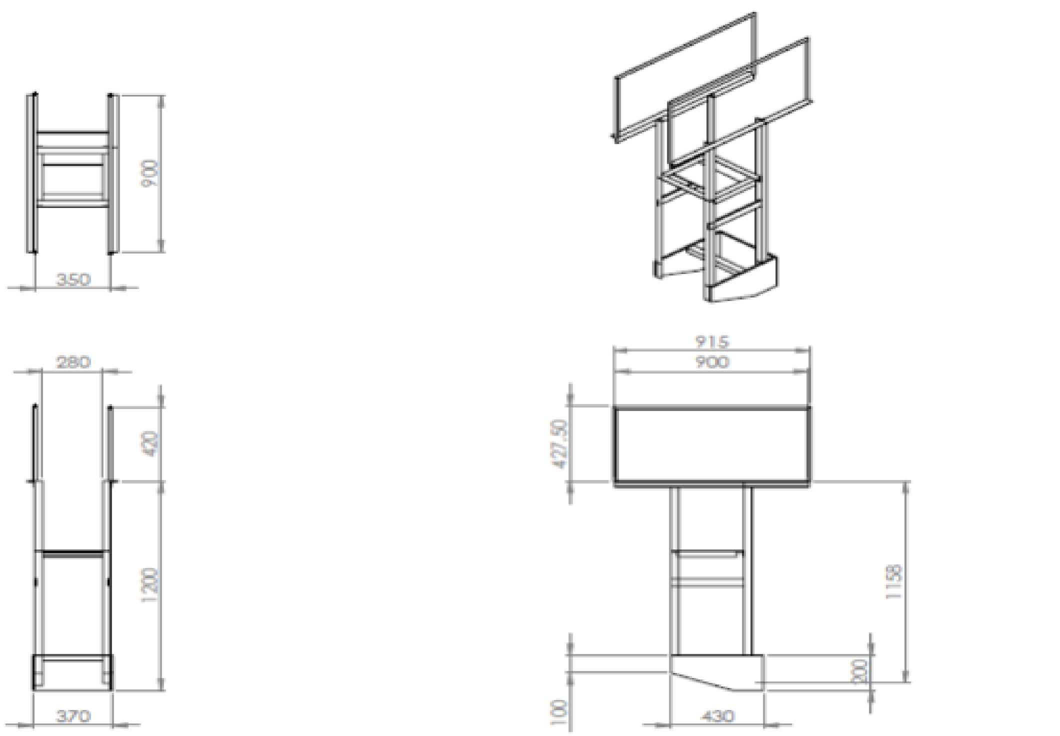

Fig.3 Isometric view of designed Inter-cultivator cum sprayer for soybean and cotton

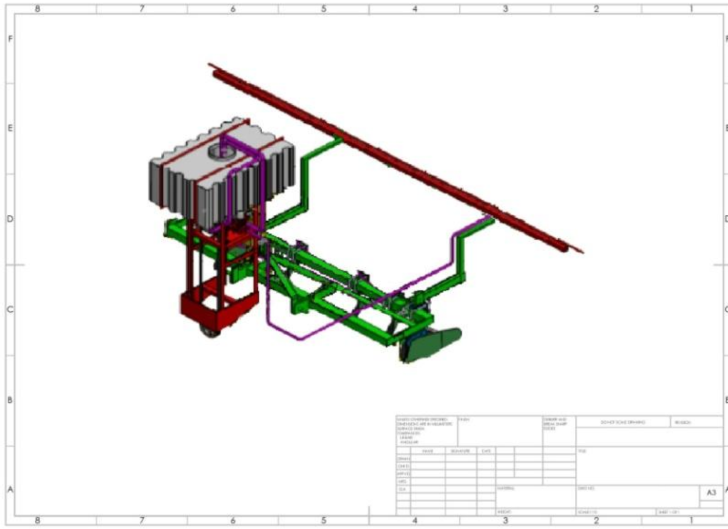

Fig.4 Developed tractor drawn Inter-cultivator cum sprayer with soybean hoe assembly

Fig.5 Developed tractor drawn Inter-cultivator cum sprayer with cotton hoe assembly

The effective field capacity, field efficiency, weeding efficiency, plant damage and application rate for soybean was observed to be 0.631 ha h^{-1}, 85.32 %, 86.12 %, 5 % and 297.76 l ha^{-1} respectively at a forward speed of 3.30 km $h^{-1}$and for cotton it was observed to be 0.733 ha h^{-1}, 81.56 %, 84.87 %, 3.06 % and 334.50 l ha^{-1} respectively at a forward speed of 2.50 km h^{-1}.

A tractor operated inter-cultivator cum sprayer operated using slim tyre for the tractor was developed which consisted of soybean and cotton hoe assemblies and PTO operated sprayer with ridgers for reopening the furrows if required. Straight type of cutting blades was used for development of hoe assemblies for the weeder. The same machine could be used for weeding in cotton field and soybean field only by mounting the respective soybean or cotton hoe assembly. The effective field capacity, field efficiency, weeding efficiency, plant damage and application rate for soybean was observed to be 0.631 ha h^{-1}, 85.32 %, 86.12 %, 5 % and 297.76 l ha^{-1} respectively at a forward speed of 3.30 km $h^{-1}$and for cotton it was observed to be 0.733 ha h^{-1}, 81.56 %, 84.87 %, 3.06 % and 334.50 l ha^{-1} respectively at a forward speed of 2.50 km h^{-1}.

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