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# Performance evaluation of tractor operated boom: Type sprayer

**Aman, Rajender Kumar, Vinay Bansal and Anil Kumar**

**Aman**
Department of Farm Machinery and Power Engineering, CCS Haryana Agricultural University, Hisar, Haryana, India

**Rajender Kumar**
Department of Basic Engineering, CCS Haryana Agricultural University, Hisar, Haryana, India

**Vinay Bansal**
Department of Farm Machinery and Power Engineering, CCS Haryana Agricultural University, Hisar, Haryana, India

**Anil Kumar**
Department of Farm Machinery and Power Engineering, CCS Haryana Agricultural University, Hisar, Haryana, India

**Corresponding Author:**
**Aman**
Department of Farm Machinery and Power Engineering, CCS Haryana Agricultural University, Hisar, Haryana, India

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## Abstract

A small tractor operated boom type sprayer was selected to evaluate its performance under local agro-climatic conditions. The nozzles were spaced at 50 cm apart on the boom and operated in the field at nozzle height of 55 cm above the target surface. The sprayer was operated in the Guar field at three forward speeds (3.0, 3.5 and 4 km/h) and at three fluid flow pressures (2.0, 3.0 and 4.0 kg/cm$^2$). The droplet density on leaves varied from 8.86 to 155.46 drops/cm$^2$. An Area covered with droplets on the upper side of the top leaves and bottom leaves varied from 8.4 to 70.55 mm$^2$/cm$^2$ and 2.85 to 66.4 mm$^2$/cm$^2$ respectively. An Area covered with droplets on the underside of the top leaves and bottom leaves varied from 1.83 to 40.48 mm$^2$/cm$^2$ and 2.21 to 30.91 mm$^2$/cm$^2$ respectively. The volume of spray deposition on the upper side of the top leaves and bottom leaves varied from 82.5 to 1201.53 × 10$^{-6}$ cc/cm$^2$ and 41.74 to 958.73 × 10$^{-6}$ cc/cm$^2$ respectively. The volume of spray deposition on the underside of the top leaves and bottom leaves varied from 22.63 to 601.62 × 10$^{-6}$ cc/cm$^2$ and 21.89 to 9418.4 × 10$^{-6}$ cc/cm$^2$ respectively. RSF varied from 0.46 to 1.22 and 1.37 to 3.77 for volume basis and number basis, respectively.

**Keywords:** Nozzle, droplet size, droplet density, spray deposition, boom sprayer, RSF

## Introduction

Guar [*Cyamopsis tetragonoloba* (Taub)] is commonly known as cluster bean. Being a legume; it has good capability to fix atmospheric nitrogen. Its seeds contain protein-18 % and Fibre-32 % and about 30-33 % gum in the endosperm. This endosperm gum is used in textile, paper, pharmaceutical, nutraceutical, cosmeceutical, and petroleum industries. It is grown primarily for gum purpose. India ranks first among the guar producing countries and contributes around 80% share of the worlds' total production. It is grown in Rajasthan, Gujarat, Haryana, and Uttar Pradesh. In India, Rajasthan stands first in terms of area and production of Cluster bean. In India, the total area under guar crop was 53.5 lakh ha and the production was 32.9 lakh tons with a yield of 615 kg/ha in (2014-15), (Anonymous, 2015) [2]. In Haryana, the total area under guar crop was 2.15 lakh ha and the production was 2.9 lakh tons with a yield of 1.35 q/ha (2011-12), (Anonymous, 2012) [1].

Spray technology plays an important role to minimize spray and to maintain biological efficacy (Zande *et al.*, 2008; Balsari *et al.*, 2017) [17, 3]. There are several types of sprayers available in the market to protect the crops from insects and pests. The performance of sprayer depends on many technological, technical and environmental factors. These include type of nozzles, appropriate spray parameters, temperature, and humidity as well as the instructions of plant protection products (Koszel, 2015) [5]. Boom sprayers are designed to apply sprays to a relatively large area and the coefficient of variation (CV) in spray distribution for all the three nozzles (solid cone, hollow cone and flat fan) have influenced by the pressure (Kumar *et al.*, 2020) [6]. These sprayers are generally mounted on trailers or fitted to tractors or trucks. They deliver a low to moderate volume of spray and work at pressures ranging from 6.9 to 551.6KPa. The problem of over dosage of pesticide is common in many countries and its application leads to wastage of costly chemical and environmental pollution from spray drift (Jensen *et al.*, 2001; Patel B. *et al.*, 2016; Patel M. K. *et al.*, 2017) [4, 13, 14], which severely affects human and animal health.

Majorly in India, small and marginal farmers grow guar crop. Therefore, small tractor operated boom sprayer can prove very helpful to farmers.

There is very less crop damage by tractor tires as it can operate easily between the inter-row spacing (Nalavade *et al.*, 2008) [9]. An efficient sprayer will be helpful in enhancing the effectiveness of pesticides (Singh *et al.*, 2019) [16]. Spraying in developed countries allows consumers to consume high-quality product that is free of insect blemishes and insect contamination (Prokop & Kejklicek, 2002) [15]. Therefore, there is a need to optimize and evaluate the performance of different spray parameters such as pressure, nozzle height, swath width and discharge for improving the effectiveness of spray in guar crop under local conditions for the sprayer. (Nuyttens *et al.*, 2007; Narang *et al*., 2015) [11, 10].

## Material and methods

The field experiments were carried out at the Director's farm of the Department of Agronomy, CCSHAU, Hisar on Guar crop in the month of September. Hisar lies between the North latitudes $28^0$56'00" to $29^0$38'30" and East latitudes $75^0$21'12" to $76^0$18'12". It has a tropical monsoonal climate and is characterized as an arid type of climate. The summers are generally quite hot and winters are fairly cool. The normal annual rainfall of the district is 330 mm which mostly receives between mid-June to end of September with an occasional winter shower during December and January months.

## Description of sprayer used in the study

Sprayer consists of a polyethylene tank having capacity of 200 litres, a plunger type pump, controlling unit, filling unit and twelve flat fan type spraying nozzles. The controlling unit consists of top of the sprayer at which all the controlling panel and pressure gauges attached to control the pressure and working of sprayer. On the folding type boom, 12 flat fan type (Teejet 110-VP) nozzles attached at the spacing of 50 cm and its height adjusted about 60 cm. The detailed specifications of sprayer are given in the table no. 1.

**Table 1:** Detailed specifications of boom sprayer

| S. No. | Particulars | Specifications |
|---|---|---|
| **1** | **Power source:** | |
| 1.1 | Name & Model | VST Shakti MT 270 VIRAAT 4W PLUS Tractor |
| 1.2 | PTO (HP) | 24 |
| 1.3 | Standard PTO (rpm) | 540 & 1000 |
| 1.4 | Weight (kg) | 900 |
| **2** | **Spray Tank :** | |
| 2.1 | Capacity, liters | 200 |
| 2.2 | Material | Polyethylene |
| 2.3 | Agitation | Hydraulic |
| 2.4 | Level indicator | Graduated transparent tube |
| **3** | **Hydraulic Pump :** | |
| 3.1 | Type | Triplex plunger pumping unit |
| 3.2 | Discharge Rate (liter per minute) | 36 |
| 3.3 | Recommended liquid pressure, $kg/cm^2$ | 1-10 |
| 3.4 | RPM | 900 |
| **4** | **Boom :** | |
| 4.1 | Width, cm | 600 |
| 4.2 | Type | Wet Boom |
| 4.3 | Height Adjustment, cm | 60 |
| 4.4 | Nozzle spacing, cm | 50 |
| 4.5 | Number of nozzles | 12 |
| 4.6 | Type of Nozzle | Flat Fan type (TeeJet 110-VP) |
| **5** | **Dimensions :** | |
| 5.1 | Length x Width x height, cm | 76 x 180 x 147 |
| 5.2 | Weight, kg | 110 |

**Fig 1:** Small tractor operated boom type sprayer

**Table 2:** Parameters used for evaluation of sprayer in the field conditions

| Independent Parameters | Levels | Dependent Parameters |
|---|---|---|
| Forward Speed of the Sprayer, km/h | 3.0, 3.5 & 4.0 | 1. Field Capacity (ha/h)<br>2. Field Efficiency (%)<br>3. Fuel consumption (l/h)<br>4. NMD<br>5. VMD<br>6. UC<br>7. Droplet density (drops/cm$^2$)<br>8. Area Coverage (mm$^2$/cm$^2$)<br>9. Volume of spray deposition<br>10. Relative Span Factor |
| Liquid Pressure, kg/cm$^2$ | 2.0, 3.0 & 4.0 | |

### Instruments used

A spray patternator was used to find the spray angle, spray pattern and a swath width of the nozzle (i.e. nozzle characteristics). It consists of piston type pump, water regulating valve, cutoff valve, pressure gauge and 36 V-shape channels (spacing 48 mm) for conveying the water to the glass tubes. The height and width of the nozzle assembly were adjustable.

### Performance parameters

### Discharge rate

The nozzle was mounted on the patternator and the pump was started. The liquid flow was set at a particular pressure. When the pressure of liquid flowing through nozzle gets stabilized, the discharge of liquid through a single nozzle was collected for one minute in the measuring glass and volume of collected liquid was noted. The process was repeated three times at each working pressures of 2.0, 3.0 and 4.0 kg/cm$^2$. The average volume of collected liquid at each pressure per unit time was the discharge rate at that pressure.

### Swath width

The average width covered by the liquid sprayed from the nozzle from a height of 53, 54.5 and 56 cm above the surface at each pressure was termed as the swath width at that pressure and height of the nozzle. When the spray pattern of nozzle gets stabilized, we put the straight, plumb on the channel surface. After one second we withdraw the plumb and measure the width of the spray. The swath width was measured by measuring the distance between the outermost channels in which

### Spray angle

The angle made from the liquid coming out of the nozzle at each operating pressure was measured and termed as the spray angle at that pressure. The spray angle was also calculated by the tangent to the height of the nozzle and half of the swath width. (Padmanathan *et al.*, 2007) [12].

### Spray pattern

The nozzle was mounted at three different heights 53, 54.5 and 56 cm on the patternator. At pressure settings of 2.0, 3.0 and 4.0 kg/cm$^2$, liquid was sprayed from the nozzle. The sprayed liquid in one minute was collected from each channel of the patternator in the glass tubes and volume of liquid collected in the each tube was recorded. Each experiment was repeated three times. The average volumes of collected liquid from each channel were used to determine spray distribution pattern and the coefficient of variation (C.V.) of the sprayer.

### Field parameters

The sprayer was evaluated in the field for three levels of revolutions of 1500, 1800, and 2000 rpm. The plants were randomly selected and water sensitive papers were placed on upper and underside of leaves at the top and the bottom portion of plants and on the ground surface. Zineb mixed @2kg/500 l of water per hectare was sprayed on Guar crop. When the sprayed material dried, the water-sensitive paper strips were collected for analysis.

**Fig 2:** Operational view of small tractor operated boom sprayer in Guar crop

### Analysis of water sensitive paper strips

Analysis of water sensitive paper (WSP) strips were done by using Fiji app based on image processing. The techniques permit a calculation of the fraction of spray coverage, an evaluation of the uniformity of the spray spread at various scales and directions, and droplet size range and distribution. The technique suggested for calculation overlapping droplets based on mathematical morphology became quite effective for spray evaluation of WSP (Marçal *et al.*, 2008) [7]. Image of WSP is changed into binary images. Water sensitive papers were placed on the plant leaves at different positions to determine spray distribution pattern and various other parameters.

(i) (ii) (iii)

**Fig 3:** Positions of WSP on plant leaf (i) Scanned (ii) Binary image of water sensitive paper (iii)

## Relative Span Factor (RSF)

Comparing drop size distributions from alternative nozzles can be confusing. The Relative Span Factor (RSF) reduces the distribution to a single number. The parameter indicates the uniformity of the drop size distribution. The closer this number to zero, the more uniform the spray will be (i.e. tightest distribution, the smallest variance from the maximum drop size, $D_{max}$, to the minimum drop size, $D_{min}$). RSF provides a practical means for comparing various drop size distributions. (Meierhofer *et al.*, 2014) [8].

$$RSF\ (V) = \frac{|D_{V0.9} - D_{V0.1}|}{D_{V0.5}} \quad RSF\ (N) = \frac{|D_{N0.9} - D_{N0.1}|}{D_{N0.5}}$$

Where $D_{V0.9}$ signifies the point in the size distribution, up to and including which, 90% of the total volume of droplets in the sample is contained. The definition of $D_{V0.5}$ then is the size point below which 50% of the droplets is contained, and the $D_{V0.1}$ is that size below which 10% of the droplets are contained. And $D_{N0.9}$ signifies the point in the size distribution, up to and including which, 90% of the total numbers of droplets in the sample is contained. The definition of $D_{N0.5}$ then is the size point below which 50% of the total numbers of droplets is contained, and the $D_{N0.1}$ is that size below which 10% of the total numbers of droplets are contained.

## Results and discussion

### Spray distribution by single nozzle

The spray distribution pattern of the nozzle was found out by using the spray patternator. The spray distribution pattern of spray nozzle was studied and observed that the minimum volume of spray was collected at the outer edges, which increased gradually towards the centre of the nozzle. (Fig 4 to 6). The average value of liquid collected from each channel of patternator into glass tubes was used to calculate the coefficient of variation in the spray distribution (Table 3).

**Table 3:** Effect of working pressure and height on nozzle characteristics

| Air induction flat fan nozzle | | | |
|---|---|---|---|
| **Nozzle Height (mm)** | **Pressure (kg/cm$^2$)** | **Standard deviation** | **Coefficient of variation (%)** |
| 530 | 2 | 9.61 | 32.72 |
| | 3 | 13.91 | 44.36 |
| | 4 | 12.98 | 37.58 |
| 545 | 2 | 11.64 | 39.47 |
| | 3 | 12.82 | 40.14 |
| | 4 | 14.54 | 42.39 |
| 560 | 2 | 8.25 | 28.5 |
| | 3 | 12.03 | 36.33 |
| | 4 | 12.79 | 37.29 |

The coefficient of variation for air induction flat fan nozzle varied from 28.5% to 44.36% and was found to be more at higher pressure, but better coefficient of variation was obtained at medium and low pressures.

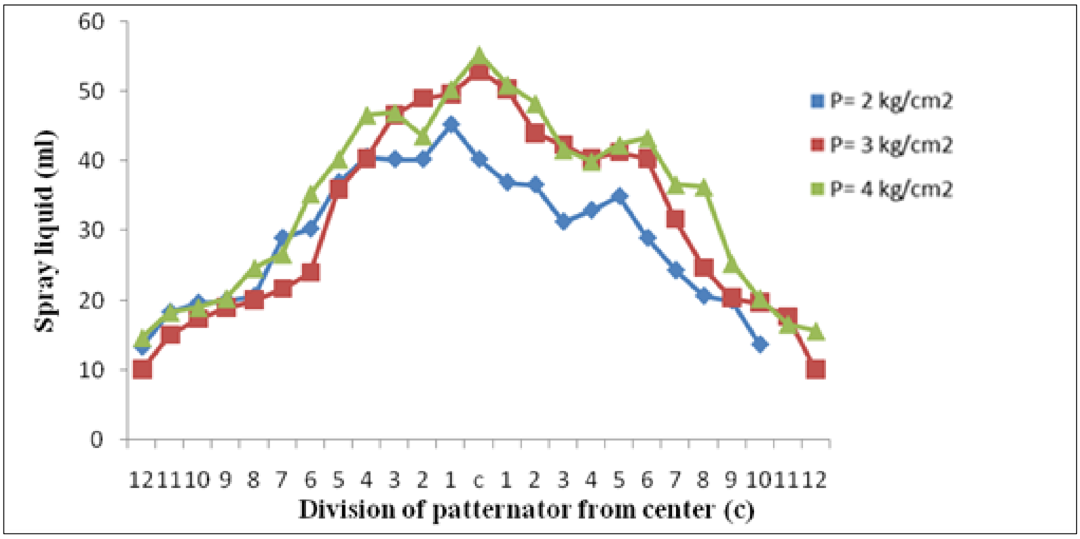

**Fig 4:** Spray distribution when air induction flat fan nozzle at 530 mm height

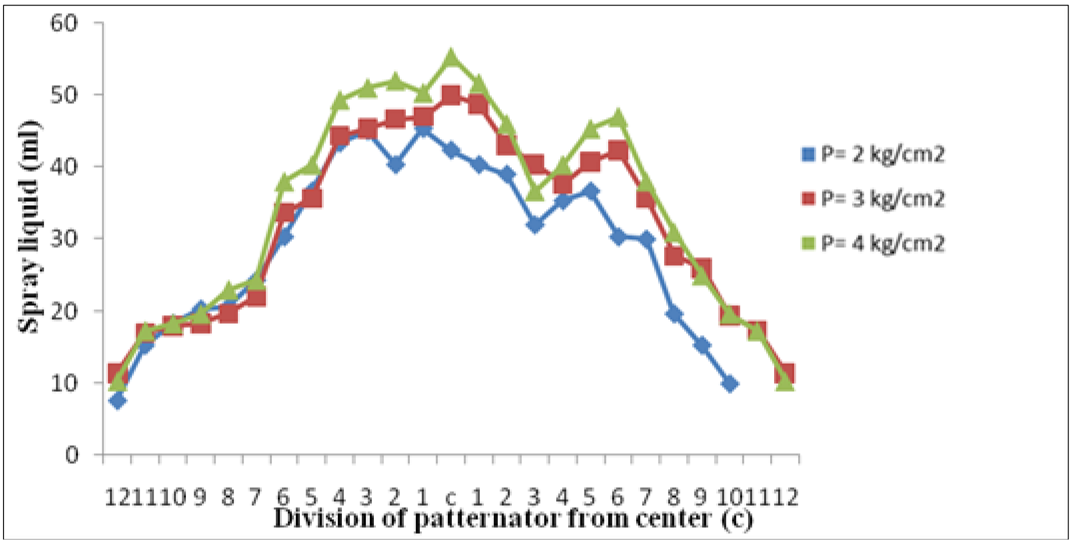

**Fig 5:** Spray distribution when air induction flat fan nozzle at 545 mm height

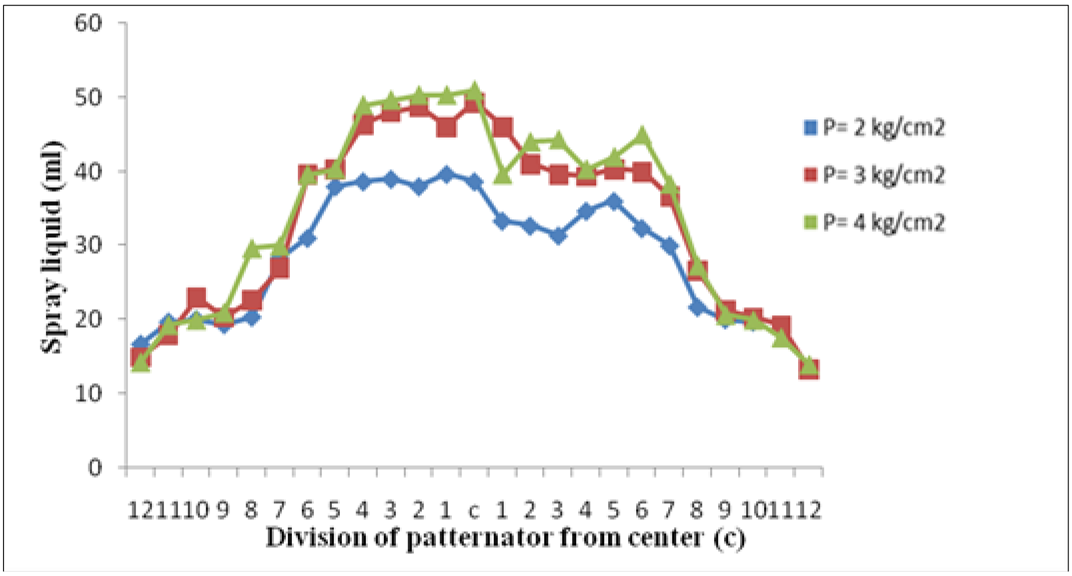

**Fig 6:** Spray distribution when air induction flat fan nozzle at 560 mm height

**Discharge rate, spray angle and swath width at different height of single nozzle**

The air induction flat fan nozzle discharge increased from 680 ml/min to 860 ml/min with increase in pressure from 2 kg/cm$^2$ to 4 kg/cm$^2$. Similarly the spray angle for flat fan nozzle spray angle increased from 92$^0$ to 97$^0$ degrees with increase in pressure from 2 kg/cm$^2$ to 4 kg/cm$^2$.

Swath width for single nozzle was measured by measuring the distance between the outermost channels in which liquid was sprayed on either side of the nozzle over patternator. It was observed that swath width for air induction flat fan increases from 104 cm to 127 cm with an increase in nozzle height from 53 to 56 cm and pressure from 2 kg/cm$^2$ to 4 kg/cm$^2$.Minimum swath width was found to be 104 cm at pressure 2 kg/cm$^2$ with nozzle height 53 cm and maximum swath width for was found to be 127 cm at pressure 4 kg/cm$^2$ with nozzle height 56 cm. Smaller swath width was obtained at very low pressure. Large swath width at higher pressure with high heights could be achieved, but that would cause wastage of pesticides due to drift.

### Field evaluation for the sprayer

### Number median diameter (NMD), volume median diameter (VMD) and uniformity coefficient (UC)

The cumulative percentage of the number of droplets contributed by each range of droplet diameter was calculated. Using plots of the cumulative percentage of the number of droplets and actual droplet diameter, Number Median Diameter (NMD) was determined.

It was observed that with an increase in pressure from 2 to 3 kg/cm$^2$, NMD increases, but if we further increase the pressure from 3 to 4 kg/cm$^2$, the NMD again decreases. The analysis showed that both forward speed and pressure had a significant effect on the change in NMD.NMD on the upper side of the bottom leaves varied from 72.9 to 140.6.

**Table 4:** Effect of pressure and forward speed on NMDon T (top) position of leaves under field conditions

| Liquid pressure(kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 112.3 | 110.1 | 148.6 |
| 3 | 163.5 | 131.0 | 169.1 |
| 4 | 105.3 | 102.9 | 115.6 |

The cumulative percentage of the volume of droplets contributed by each range of droplet diameter was calculated. Volume Median Diameter (VMD) was determined using a plot of the cumulative percentage of the volume of droplets and actual droplet diameter. VMD decreases with an increase in pressure from 2 to 3 kg/cm$^2$ but again increases with further increase in pressure from 3 to 4 kg/cm$^2$.

VMD in field conditions for different forward speed and pressure were determined. VMD on the upper side of the top leaves vary from 276.7 to 434.2 (Table 4).VMD on underside of the top leaves vary from 164.4 to 446.

**Table 5:** Effect of pressure and forward speed on VM Don T (top) position of leaves under field conditions

| Liquid pressure(kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 434.2 | 433.8 | 425.4 |
| 3 | 424.7 | 397.6 | 412.0 |
| 4 | 429.7 | 276.7 | 433.9 |

Volume median diameter and number median diameter were used to calculate the uniformity coefficient. As the droplet size becomes more uniform, the uniformity coefficient becomes nearer to unity. As UC is the division of VMD by NMD, UC also decreases with increase in pressure from 2 to 3 kg/cm$^2$ but again increases with further increase in pressure from 3 to 4 kg/cm$^2$. For all combinations of forward speed and pressure, uniformity coefficient varied from 1.54 to 6.59.

### Droplet Density (drops/cm$^2$)

Droplet density in field conditions for different forward speed and pressure were determined. The droplet density on the upper side of the top leaves vary from 33.15 to 116.05 droplets per square centimeter (Table 6). The analysis showed that both forward speed and pressure had a significant effect on the change in droplet density.

**Table 6:** Effect of pressure and forward speed on droplet density on T (top) position of leaves under field conditions

| Liquid pressure(kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 60.15 | 51.67 | 104.20 |
| 3 | 116.05 | 33.15 | 44.64 |
| 4 | 36.85 | 34.62 | 100.20 |

### Area covered by droplet spots (mm$^2$/cm$^2$)

Area covered by droplet spots on leaves of guar crop at different forward speed and pressure was obtained. Area covered on the upper side of the top leaves varied from 8.4 mm$^2$/cm$^2$to 70.55 mm$^2$/cm$^2$ (Table 7). The maximum area covered was at 4.0 kg/cm$^2$ and the minimum area covered was at 3.0 kg/cm$^2$ pressure. The analysis showed that change in area covered by droplet spots due to both pressure and forward speed was significant.

**Table 7:** Effect of pressure and forward speed on the area covered by droplet spots on T (top) position of leaves under field conditions

| Liquid pressure (kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 54.22 | 51.36 | 36.52 |
| 3 | 29.08 | 56.83 | 8.40 |
| 4 | 62.41 | 70.55 | 20.21 |

### Volume of spray deposition ($10^{-6}$ cc/cm$^2$)

The volume of spray deposition per unit area of the droplets in field conditions at different forward speed and pressure were determined from droplet density and the actual sizes of the droplets. The volume of spray deposition on the upper side of the top leaves varied from 82.5 to 1201.53 x$10^{-6}$ cc/cm$^2$ (Table 8). The analysis showed that both pressure and forward speed had a significant effect on the change in the volume of spray deposition.

**Table 8:** Effect of pressure and forward speed on the volume of spray deposition on T (top) position of leaves under field conditions

| Liquid pressure (kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 369.67 | 334.59 | 985.01 |
| 3 | 1201.53 | 222.6 | 483.80 |
| 4 | 233.67 | 82.50 | 853.76 |

### RSF (Volume basis)

Relative Span Factor on a volume basis was calculated by seeing the drop size distribution. It was calculated by using Volume Median Diameter (VMD). RSF (V) on the upper side of the top leaves varied from 1.0 to 1.19 (Table 9). The analysis showed that both pressure and forward speed had a significant effect on the change in RSF (V).RSF (V) on underside of the top leaves varied from 0.85 to 1.22.

**Table 9:** Effect of pressure and forward speed on RSF (V) on T (top) position of leaves under field conditions

| Liquid pressure (kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 1.19 | 1.16 | 1.04 |
| 3 | 1.02 | 1.12 | 1.01 |
| 4 | 1.15 | 1.16 | 1.00 |

## RSF (Number basis)

Relative Span Factor on number basis was calculated by seeing the drop size distribution. It was calculated by using Number Median Diameter (NMD). RSF (N) on the upper side of the top leaves varied from 1.69 to 2.81 (Table 10). The analysis showed that both pressure and forward speed had a significant effect on the change in the RSF (N).RSF (N) on underside of the top leaves varied from 1.37 to 2.84.

**Table 10:** Effect of pressure and forward speed on RSF (N) on T (top) position of leaves under field conditions

| Liquid pressure (kg/cm$^2$) | Forward speed (km/h) | | |
|---|---|---|---|
| | 3 | 3.5 | 4 |
| 2 | 2.28 | 2.38 | 2.14 |
| 3 | 2.01 | 1.98 | 1.93 |
| 4 | 2.54 | 1.69 | 2.81 |

## Conclusion

The study was undertaken to evaluate operational parameters of a small tractor operated boom type sprayer under local agro-climatic conditions. The sprayer was operated in the Guar (HG-365) crop at three forward speeds (3.0, 3.5 and 4.0 km/h) for its performance evaluation. The average theoretical field capacity was found to be 2.1 ha/h and the average effective field capacity was observed to be 1.85 ha/h. Hence the field efficiency of the operation was 88.1 %.The average fuel consumption was determined to be 1.26 l/h. The total fixed cost and variable cost of operation was determined to be 398.83 Rs/h. Total energy used for operation including direct and indirect energy was found to be 44.09 MJ/ha. The operating speed was 3-4km/h, the quality results showed that the VMD, NMD, spray droplets and volume of spray deposition were within the range. As well as consistent pressure influence on the spray deposit and coverage by controlling the flow rate and nozzle height at the time of application when applied at an acceptable meteorological conditions and also achieved a constant volume application rate at the time of application. The main results showed technological parameters have significant impact on spray characteristics. The impact varies with both of nozzle height and operating pressure. Spray deposit and coverage influenced by changing of droplet size diameters.

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