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Development of small tractor operated boom sprayer for effective control of weeds in maize

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ABSTRACT

The application of pesticides is one of the important aspects of a crop production system. The development of a single spraying system for all types of pesticide application is a solution for a cost-effective and efficient crop production system. Standardizing the droplet sizes at different operating pressure of hollow cone nozzle will be a solution for controlling the weeds as well as the other pests. A small tractor-operated hollow cone-based boom sprayer was developed to overcome said problems. The developed sprayer can be mounted on three-point linkage and can be operated by tractor PTO. The developed system was evaluated for 0.1, 0.2 and 0.3 MPa of operating pressure through water-sensitive papers and ImageJ software. Under this pressure, the selected hollow cone nozzle produced medium to coarser droplet size. The highest VMD of 346.4 µm was obtained under operating pressure of 0.1 MPa and the least VMD of 277.1 µm was obtained under operating pressure of 0.3 MPa. The increase in operating pressure causes a reduction in droplet size. However, the relative span (RS) was increasing with a decrease in operating pressure. It was 0.72 at an operating pressure of 0.3 MPa and increased to 1.27 at an operating pressure of 0.1 MPa. The highest weed control efficiency (WCE) of 88.1% was obtained under 0.1 MPa of operating pressure. However, the operating pressure does not had significant effect on WCE.

INTRODUCTION

Pesticide application remains an important component of agricultural production system (Jyoti *et al.* 2017 and 2019). Furthermore, chemical application inhibits the growth of weeds, pests and diseases, ultimately reducing crop and fruit yield losses. Though, pests, weeds and diseases pose a severe impact on the production and quality of agricultural produce (Tewari *et al.* 2014a, Chandel *et al.* 2018) nevertheless, the increased use of pesticides as well as efficient utilization of plant protection equipment plays a significant role to control diseases, pests and weeds by dispensing, distributing and depositing recommended doses of chemicals on the intended target (Tewari *et al.* 2014b, Jyoti *et al.* 2020). Chemical application via plant protection equipment is the most practiced method because of its ease in operation and economical aspects. Despite being the commonly used method, chemical application by means of plant protection equipment leads to extensive dispersion of harmful chemicals in the environment (Kumar *et al.* 2020). These traditional pest management techniques involve human drudgery and higher operational cost compared to tractor-drawn chemical spraying systems (Chethan and Krishnan 2017, Chethan *et al.* 2018, Kumar *et al.* 2019).

The main challenge in plant protection through spraying equipment involves ground surface deposition and off-target drift. This drift often results in a source of environmental pollution and a threat to human and animal health (Maski and Durairaj 2010). To mitigate the said problem and achieve uniform deposition, distribution and uniform vertical fluid distribution, a tractor-based spray application system can be encouraged (Sedlar *et al.* 2013). Government, agricultural research organizations and agricultural machinery manufacturers have a serious challenge developing agricultural technologies suitable for small and marginal farmers. The developed implements and machinery should reduce drudgery and enhance crop productivity. Hence, the use of tractor-operated time-saving equipment needs to be promoted (Raut *et al.* 2013).

Developing a spray application system as an attachment for a small tractor can offer a solution to the above-cited problem. Therefore, an efficient single spraying system needs to be developed which can be suitable for spray of insecticides, fungicides and herbicides with easy attachment of flat fan, flood jet nozzles, hollow cone and solid cone nozzles (Chethan *et al.* 2019). However, the hollow cone nozzles are used in some cases of herbicide applications with droplet sizes ranging from medium to coarser (ASABE 2009, Hartzler 2016). Hence, the present study was undertaken to develop a mechanical power-based universal spray application system and evaluated for herbicide application in maize crops.

MATERIALS AND METHODS

Development of "Small tractor operated boom sprayer"

A small tractor (22 hp) operated boom sprayer system was developed for field crops at ICAR-Central Institute for Agricultural Engineering, Bhopal (23°182 36.693 N, 77°242 17.683 E) (**Figure 1**). The spraying system consists of storage loft tank having 300 liters of capacity and made of polyethylene plastic material, HTTP horizontal triplex axial piston pump, hollow cone nozzles, pressure regulating valve, strainer, boom, pressure gauge, and hose pipe. The pump discharges 36 lpm at 28 bar pressure and 950 rpm. Spray control valves were provided with a spring-loaded ball that opens as pressure increases, so the excess flow will be bypassed back to the tank to prevent damage to the sprayer components when the boom is closed. The pump discharge was connected with the tank and nozzles boom through hose pipes. A strainer was used between suction line of the tank and pump. The filter of mesh size 16 to 80 meshes were used to filter out unwanted materials from spraying solution. The mesh size of the filter (>50) refers to the opening per linear inch in the screen (Grisso *et al.* 2014).

The hollow cone nozzle was selected to standardize the developed spraying system to apply herbicide, insecticide and fungicide (Grisso *et al.* 2019). The main use of hollow cone nozzle is in application of insecticide and fungicide, however, in some cases; it is also used for herbicide application under lower operating pressure and medium to coarser spray droplet size (ASABE 2009, Chethan *et al.* 2019). The developed sprayer will be mounted on three-point linkage and will drive by tractor PTO. The pump was fixed over the drawbar and driven by the PTO of the tractor by belt pulley arrangement. The loft tank was fitted as the tractor roof canopy or ROPS (rollover protective structure). The total length of the boom was 7 m. A flexible type hinge was fabricated to achieve a five folded boom system. The fold system is arranged in such a way that the spray boom can be fixed in horizontal as well as vertical positions based on crop canopy geometry. A three-point linkage system was fabricated to mount the nozzles boom at a variable height according to crops height.

Evaluation of developed boom sprayer under laboratory

The developed spraying system was calibrated in the laboratory. The calibration of nozzles was carried out at different pump pressure and engine rpm. The pressure of the pump was maintained with the help of pressure regulating valve at different engine rpm with the help of the throttle lever of tractor. The experiment of the calibration was carried out at three pressure levels, 0.1, 0.2 and 0.3 MPa. The spraying system was operated at different pump pressure and their corresponding discharge was recorded.

Spray droplet characteristics were taken using water-sensitive paper (WSP). Under the laboratory, the WSPs were fixed on metal sheets with the help of paper clips. These WSPs fixed system and was placed at the center of swath and at 500 mm below the nozzle tip. After applying the herbicide, the WSPs

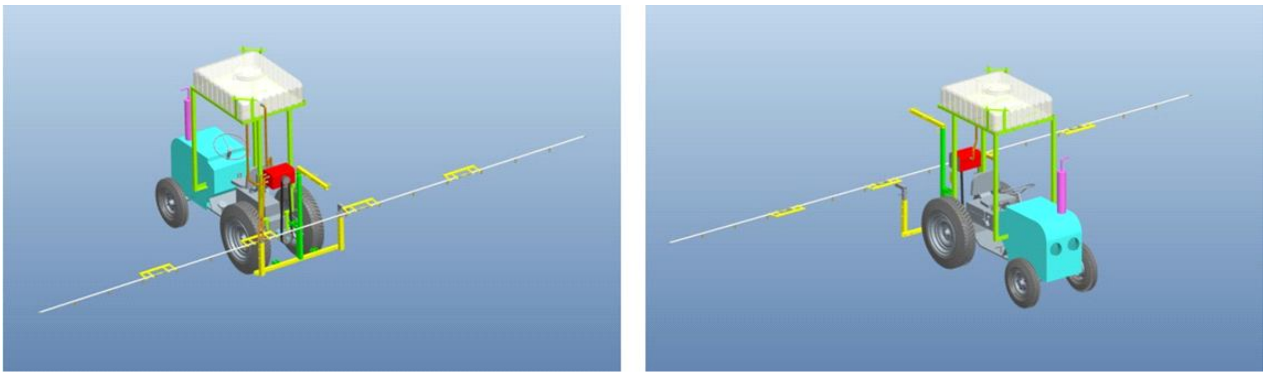

Figure 1. CAD diagram of developed small tractor operated boom sprayer

were collected immediately and placed in a darker box to avoid volatilization losses. Later, the WSPs were scanned with the help of a scanner and saved in a JPGE file of 600dpi. The spray droplet analysis was carried out in the laboratory by using scanned images with the help of ImageJ software (Lv *et al.* 2019, Ozluoymak *et al.* 2019). The ImageJ is Java-based image-processing software used for acquisition and analysis of images. The different spray performance parameters, *viz.* spray rate, DV_{10}, DV_{50}, DV_{90}, number median diameter (NMD), droplets density (droplets/cm^2), coverage (%), mean diameter and standard deviation (SD) were determined by analyzing spray traces collected on water-sensitive papers (Lv *et al.* 2019, Longo *et al.* 2020). Also the relative span (RS) a dimensionless number was also calculated to obtain the spray uniformity (Simão *et al.* 2020). The RS is used to estimate the distribution spread and homogeneity of spray application. It is calculated by using the following formula.

$$RS = \frac{(D_{90} - D_{10})}{D_{50}} \quad \text{--- (Eq.1)}$$

Evaluation of developed boom sprayer under field condition

The developed small tractor operated boom sprayer was evaluated in maize crop during *Rabi* 2020-21 at research farm of ICAR-Central Institute for Agricultural Engineering, Bhopal. A field was prepared by 2 times passing of rotavator and one time passing of leveler. The maize crop was sown at a row spacing of 450 mm and plant to plant spacing of 250 mm. The developed boom sprayer was attached to a small tractor and was operated at 2.5 km/h speed of operation to achieve the target application rate of 375 l/ha (**Figure 2**).

The weed floral data was recorded from testing field at 60 DAS. To check the weed control efficiency and effectiveness (WCE) of the developed boom sprayer, the weed floral data was compared with the weedy plot. The weed control efficiency was calculated by using the following formula (Chethan *et al.* 2020).

$$WCE = \frac{(W_c - W_t)}{W_c} \times 100 \quad \text{--- (Eq.2)}$$

Where W_c and W_t are weed dry weight in weedy and herbicide applied plots, respectively.

Figure 2. Field evaluation of developed "Small tractor operated boom sprayer"

Statistical analysis

The obtained parameters under laboratory were analyzed using a CRD design and field evaluation parameters were analyzed using RBD. Evaluation of the system was replicated thrice and was analyzed in SAS software (Version 9.4M7 / August 18, 2020, SAS Institute, US). The inferences were drawn at a 5% level of significance.

RESULTS AND DISCUSSION

Effect of operating pressure on droplet size

The operating pressure of the spraying system had a significant effect on droplet size, produced from the developed spraying system (**Table 1** and **Figure 3**). During testing of developed boom sprayer, the nozzle holding height was maintained constant to obtain spray uniformity. The spray droplet accumulated on WSPs, analyzed by ImageJ is Java-based image-processing software (Fig.4) that clearly differentiates the effect of operating pressure on the droplet size. When effect of droplet size on herbicide efficacy is considered, the Volume Mean Diameter (VMD) *i.e.*VD_{50} plays a very important role (ASABE 2009, Chethan *et al.* 2019).

The highest VMD of 346.4 µm was recorded under operating pressure of 0.1 MPa, followed by 313.5 µm at operating pressure of 0.2 MPa and 277.1 µm at operating pressure of 0.3 MPa. The higher operating pressure caused the reduction of droplets size and increases the droplet number (**Figure 5**). The droplets obtained under the operating pressure of 0.1 and 0.2 MPa are classified as coarse and droplets obtained in 0.3 MPa classified as medium. It is recommended that the medium to ultra-coarse droplet size is best suited for herbicide application (ASABE 2009, Chethan *et al.* 2019). The RS was increasing with a decrease in operating pressure (**Table 1**). It shows that a higher degree of homogeneity at lower operating pressure.

The lowest VMD was found at operating pressure of 0.3 MPa, which was 19.98% and 11.46% lower than VMD at operating pressures of 0.1 and 0.2

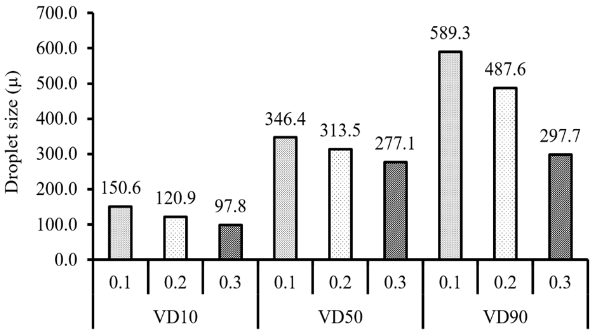

Figure 3. Spray droplet size obtained under different operating pressure

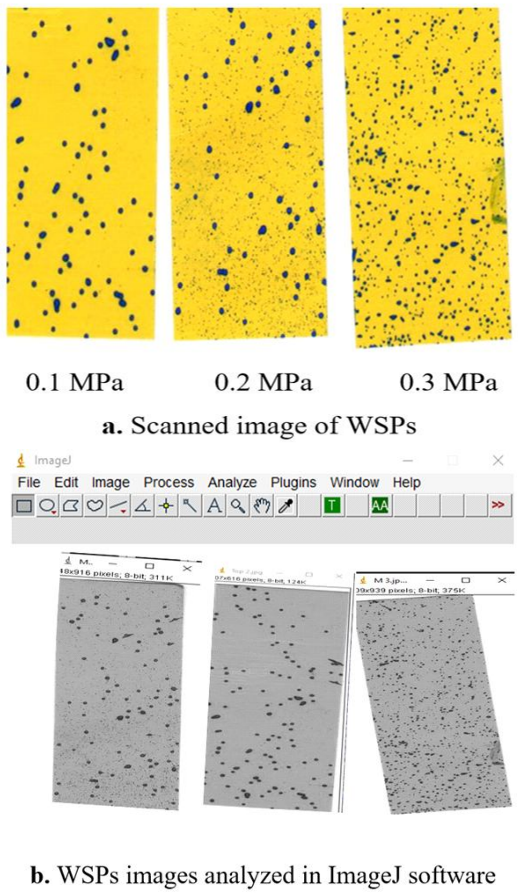

Figure 4. Droplet size obtained under different operating pressure

Table 1. Effect of operating pressure on droplet size diameter and weed dry weight

Operating pressure (MPa)	Droplet size (µm)			Relative span	Weed dry weight (g/m^2)	WCE (%)
	VD_{10}	VD_{50}	VD_{90}	RS		
0.1	150.6	346.4	589.3	1.27	1.64 (2.27)	88.1
0.2	120.9	313.5	487.6	1.17	1.94 (3.29)	85.9
0.3	97.8	277.1	297.7	0.72	2.13 (4.21)	84.5
LSD (p=0.05)	1.687	1.458	0.840	0.003	1.11	NS

*Weed data subjected to square root transformation $\sqrt{x+0.5}$; original data is in parentheses

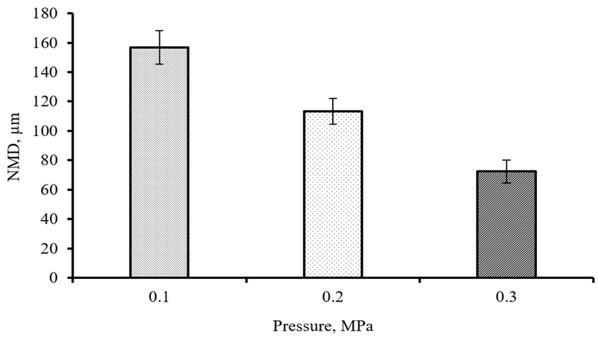

Figure 5. NMD of the droplets obtained under different operating pressure

MPa respectively. It has been noted that through a wide range of atmospheric conditions, droplets with diameters greater than 140 µm show little tendency to drift (Thread gill *et al.* 1975). The VMD at 0.2 MPa was 9.5% lesser compared to VMD at 0.1 MPa. The average droplet size was found to be decreased with an increase in operating pressure during the spraying process (Alheidary *et al.* 2019).

The number median diameter (NMD) was found to be decreased from 156.48 µm (SD: ±11.4), 113.6 µm (SD: ±8.7) and 72.4 µm (SD: ±7.9) for the increased pressure level of 0.1, 0.2 and 0.3 MPa, respectively. The lowest NMD was found to be 72.4.8 ìm, at the operating pressure of 0.3 MPa, which was 53.82% lower than NMD at operating pressures of 0.1 MPa for fixed nozzle height of 500 mm (**Figure 4**). The NMD at 0.2 MPa was found to be 27.67% lower compared to the operating pressure of 0.1 MPa.

Effect of operating pressure on droplets density and coverage

The droplets density and coverage were also analyzed from WSPs. **Figure 3, 4** and **5** show a significant effect of the operating pressure on the mean of the droplet density and coverage. It was observed that a constant nozzle height of 500 mm resulted in a considerable increase in droplets density (**Figure 6a and b**).

The droplet density was found to be increased by 42.76% and 100.28% at operating pressure of 0.2 and 0.3 MPa compare to 0.1 MPa. The reason for the increase in droplet number may be due to a decrease in the mean of the droplet sizes. The droplet density was found to be 105.7 (SD: ±9.4), 150.9 (SD: ±12.3) and 211.7 (SD: ±14.7) deposit/cm^2 at operating pressure of 0.1, 0.2 and 0.3 MPa of operating pressure. The effect of operating pressure at droplet density is shown in **Figure 5**. The coverage of droplets was found to be increased with an increase in operating pressure. Coverage was 30% (SD: ±3.5),

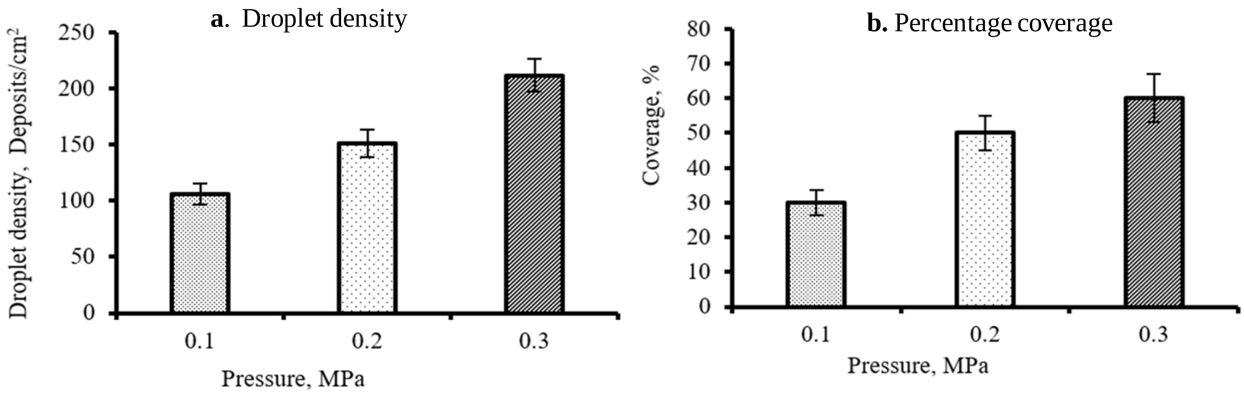

Figure 6. Effect of operating pressure on droplet density and percentage coverage

50% (SD: ±5.1) and 60% (SD: ±6.9) at operating pressure of 0.1, 0.2 and 0.3 MPa, respectively. The coverage percentage was found to be increased by 66.67% at 0.2 MPa and 100% at 0.3 MPa compare to 0.1 MPa of operating pressure. This result agreed with the studies of Taylor *et al.* (2004) and Yashiro *et al.* (2012). The spraying system was operated in the field at 0.3 MPa operating pressure due to effective VMD, droplets deposition and coverage.

Effect of herbicide application at different operating pressure on weed control

The selected treatments for field evaluation include application of herbicide at operating pressure of 0.1, 0.2 and 0.3 MPa and the results were compared with the weedy plot where herbicide was not applied. The major weed flora observed in the testing plots were *Lathyrus aphaca, Vicia sativa, Chenopodium album, Medicago polymorpha* and others. A significantly highest weed dry weight of 13.78g/m^{2}was recorded in weedy plots, while the least dry biomass was observed in herbicide applied plots (**Table 1**). The weed control efficiency (ECE) was not affected by the operating pressure (**Table 1**). However, the highest weed control efficiency of 88.1% was obtained in 0.1 MPa operating pressure followed by 85.9% at0.2 MPa. The least WCE was obtained in 0.3 MPa of operating pressure.

Weeds are effectively controlled when larger droplet sizes (coarser) are generated at lower operating pressure. It is because, at coarser droplet size, spray drift was minimum and applied herbicide reached the target (Simão *et al.* 2020). Thus, higher WCE was obtained at 0.1 MPa is that over 0.2 and 0.3 MPa. The same is the case when a comparison was made between the 0.2 and 0.3 MPa. Thus, the hollow cone nozzle also can be used to control weeds effectively at operating pressure from 0.1 to 0.3 MPa.

Field evaluation and cost economic

The average height of maize crops during testing was 340±32 mm. The total length of the boom was 7 m with 15 hollow cone nozzles. The fold system was designed in such a way that the spray boom can be fixed in horizontal as well as vertical displacement according to the need of crop canopy geometry. The theoretical and effective field capacity of the sprayer was measured as 1.8 ha/h and 1.45 ha/h, respectively, at a forward speed of 2.8 km/h. The field efficiency of the sprayer was 73% due to the loss of time in tank filling. The area covered by one time of filling of the tank (300 L) was 0.57 ha. The average fuel consumption was 3.5 L/h. The cost of the spraying system was calculated as ₹ 30000. The cost of operation of a sprayer with a tractor was calculated by considering the fixed and variable cost of the tractor and sprayer. Assuming the appropriate rate of depreciation, interest on investment, housing, insurance and taxes and calculating the cost of fuel, lubricants, operator wages, repair and maintenance charges, the cost of operation of developed tractor operated sprayer costs 500 ₹/ha (exclusing the cost of chemicals).

Conclusions

A small tractor-operated boom sprayer was developed for small and marginal land holding farmers. The spraying can be done at different heights above the crop canopy surface. The system was compact in design and easily attached with a small tractor three-point linkage. The droplet characteristics were decided at different pressures and found that 0.1 to 0.3 MPa was suitable for applying the herbicide through a hollow cone nozzle. The effective field capacity and field efficiency of the sprayer was measured as 1.45 ha/h and 73%, respectively. The cost of operation of tractor operated sprayer has amounted to 500 ₹/ha.

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