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Performance evaluation of newly developed variable rate sprayer for spray deposition in guava orchard

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ABSTRACT

Application of pesticide inside orchards with conventional sprayers often results in an inefficient application as these are constant rate applicators and also the significant amount of pesticide gets lost in spaces between trees. To reduce the pesticide losses inside orchards, a variable rate sprayer was developed which sprayed only after the occurrence of the tree and according to the size of the tree. The performance of the developed variable rate sprayer was evaluated inside guava trees to quantify the spray deposition at six different plant positions. The sprayer was operated at three forward speeds (2, 3 and 4 km/h) with four air velocity levels (20, 25, 30 and 35 m/s) and two different types of nozzles (hollow cone and flat fan nozzle). The observed data was statistically analyzed to study the significance of selected parameters on spray deposition. The spray deposition was found to significantly increase with the increase in air velocity and hollow cone nozzle was able to deposit more amount of spray as compared to flat fan nozzle. There was no significant variation was observed with different forward speeds. The maximum spray was deposited on upper leaf surface at all selected plant position. The uniform spray deposition was observed with the air velocity of 35 m/s and hollow cone nozzle. Even though the developed variable rate sprayer varied the discharge of nozzles according to tree size, it was able to deposit the adequate amount of spray at all selected plant positions.

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INTRODUCTION

Horticulture has become one of the important components of Indian agriculture. In recent years, it has gained the commercial importance with a very significant share in the economy of the country (Anonymous, 2011). India is the leader in the production of several horticultural crops, namely mango, banana, papaya, cashew nut, areca nut, potato and okra (Anonymous, 2014). During the production of horticultural crops especially orchard crops, one of the most important task is to protect the crop from pest and disease infestation. Agro-chemicals such as pesticides are commonly used to protect the crop. In India, out of total pesticide consumption, about 14 per cent pesticides are consumed in fruit and vegetable crops (Singh *et al.*, 2014). Farmers typically use aero-blast sprayers (*i.e.* canon sprayers) or high-speed blowers to apply these pesticides inside orchards and all these sprayers are constant rate applicators. In contrast with field crops, orchard crops have great diversity in their size and density. Also, within the row, trees are spacedat some distance. So, spraying with conventional constant rate sprayers often results in either over-spraying or under-spraying of crops (Salyani *et al*., 2007). These sprayers also apply pesticides in spaces between trees resulting in loss of a significant portion of applied chemicals to air and ground (Derksen *et al.*, 2007 and Zhu *et al*., 2006) causing environmental pollution and also an economic loss to the farmers (Chen *et al.*, 2013).

For better pesticide application and to reduce pesticide losses inside orchards, several researchers have developed sensor-based variable-rate sprayers. Sensors are used to identify the target trees and apply the precise amount of pesticide required for adequate pest and disease control (Chen *et al.*, 2012). Different types of sensors were used by the researchers. Giles *et al*. (1989); Molto *et al*. (2000 and 2001); Escola *et al*. (2003); Solanelles *et al*. (2006) and Gil *et al*. (2007) developed ultrasonic sensorbased variable-rate sprayers for orchards and vineyards and reported pesticide savings from 28 to 70 per cent while spraying in different orchards. Llorens *et al*. (2010) compared ultrasonic sensor based variable-rate sprayer with constant rate sprayer and reported pesticide savings of about 58 per cent with variable rate spraying. Jeon *et al*. (2011 and 2012) developed variable rate sprayer for liner crops based on ultrasonic scanning and reported saving of upto 86 per cent as compared to conventional constant rate application. Some scientist developed variable-rate sprayers for orchards and vineyards based on LIDAR technology for canopy detection (Escola *et al.*, 2013 and Gil *et al.*, 2013). Chen *et al*. (2012 and 2013) developed laser sensor based sprayer for variable rate application in orchards and nurseries and reported pesticide consumption of only 27 to 53 per cent as compared to constant rate sprayers inside apple canopies. Chen *et al*. (2013) also compared its performance for spray drift and off-target losses in an apple orchard and reported reduction in average spray losses on the ground by 68 to 90 and around tree canopies by 70 to 92 per cent, reduced airborne spray drift by 70 to 100 per cent and most importantly, reduced the spray volume by 47 to 73 per cent.

Such variable-rate sprayers have widely been developed around developed countries but no efforts have been done in India. So, an experimental air assisted variable-rate sprayer based on ultrasonic scanning technology was developed for orchard crops. The laboratory tests of the developed sprayer demonstrated that the sprayer has the capability to modify the sprayer output as per the tree size and spray only after the occurrence of the target. Therefore, it was decided to evaluate the sprayer inside the guava orchard with the objective: to study the spray deposition at different positions of a guava tree.

MATERIAL AND METHODS

Variable rate sprayer :

The developed air assisted variable rate sprayer had three main systems: an electronic variable rate control system, spray supply system and air delivery system. The sprayer consisted of two nozzles mounted on a vertical boom. The electronic variable rate control system consisted of asensing unit, a micro-controller and spray modulation unit. Two ultrasonic sensors (model: UC2000-30GM-IU-V1, Pepperl+Fuchs) were used for canopy size detection. Pulse width modulated (PWM) proportional solenoid valves (model: SD8202G052V, ASCONumatics) were used for spray modulation. One solenoid valve was connected to one nozzle to control respective nozzle output independently. A micro controller based on Arduino software (version: 1.6.6) was fabricated to control the ultrasonic sensors and proportional solenoid valves. A programme was developed to compute canopy size from the sensor readings, determine the instantaneous nozzle flow rate and the control signals to modulate PWM valves to deliver determined discharge through nozzles. The spacing between the nozzles can be adjusted as per requirement and provision was provided to change the distance between sensor and nozzle outlet so that nozzle should start spraying exactly when it comes in front of the target.

The spray supply system consisted of a 200-lit pesticide tank, a 36 lit/min capacity HTP pump (model: PS-16, ASPEE, India) to pressurize spray fluid, a control panel to maintain the constant spray pressure, high-pressure spray delivery hoses (ASPEE, India) and nozzles. Air delivery system consisted of a centrifugal blower (ASPEE, India) having the maximum discharge of 1.2 m^3/s and air delivery hoses. Nozzles were fitted inside the outlet of air delivery hoses mounted on a vertical boom. The nozzles discharged variable flow rates independently to their assigned sections of the canopy based on the size of the section. The developed sprayer is shown in Fig. A.

Spray deposition test setup :

The developed air assisted variable rate sprayer was tested inside guava orchard to determine the spray deposits at different positions inside guava trees. The selected guava field was 95 m long and 45 m wide. It had 8 rows of guava trees with 17 trees in each row spaced at 5 m distance. The distance between adjacent rows was 5 m. The average tree width and height measured during the testing were 3.25 m and 3.20 m, respectively. The weather data such as temperature, wind velocity and relative humidity recorded during the testing are shown in Table A. The deposition was measured at six different plant positions *viz.*, top plant position, upper

Fig. A : Developed variable rate sprayer for orchard crops

Table A : Orchard and weather data recorded during field tests

Sr. No.	Orchard			Wind, km/h	Ambient temperature, °C	Relative humidity, %
1.	Guava	Row spacing, m	5	SE 7-9	30-32	42-44
		Plant spacing, m	5			

leaf surface (TU); top plant position, lower leaf surface (TL); middle plant position, upper leaf surface (MU); middle plant position, lower leaf surface (ML);bottom plant position, upper leaf surface (BU) and bottom plant position, lower leaf surface (BL). The spacing between the two nozzles was kept 500 mm so that sprayer can cover most of the canopy. During the testing, the sprayer was operated at three different forward speeds (2, 3 and 4 km/h) and two types of nozzle *i.e.* hollow cone and flat fan nozzle were used. The air discharge of the blower was also varied by varying the air velocity by four levels, 20, 25, 30 and 35 m/s.

Before commencement of the experiment, it was assured that the tractor was set at selected gear and throttle position to get specified travel speed and air velocity. After making all adjustments, the sprayer was run for 15 minutes before actually starting the experiment.For each test, three tree rows were randomly picked from selected orchard. From each selected row, three trees were randomly selected as main spray target on which artificial targets were attached (Fig. B). For better exposure of crop to spraying, the sprayer was started 5 m before the canopy. The sprayer was stopped immediately after spraying last of three selected trees in selected row. Each run was replicated three times in order to achieve greater precision in obtained results.

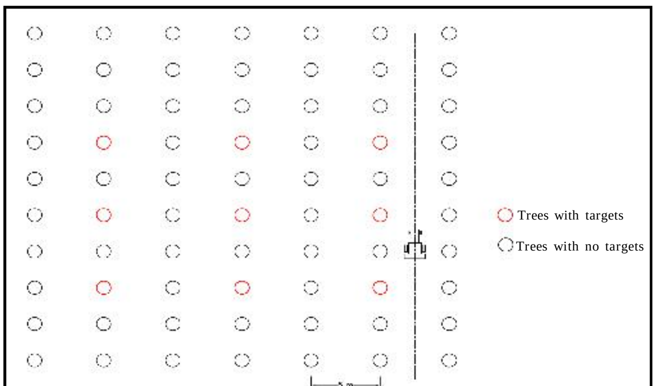

Fig. B : Arrangement of the orchard used in field tests

Highly absorbent nylon screens (50 x 50 mm) were stapled at selected plant positions to document the spray deposition. The spray solution was prepared by mixing royal blue indigo dye (5 g of dye per litre of water) in the clean water. Before the start of the experiment, initial weight of each screen was measured. During the experiment, as soon as spraying was done, all screens were collected and kept inside the seal pack polythene bags and their final weights were measured using electronic weighing balance (least count 0.001 g). By taking the difference between the initial and final weight of the screen and dividing it by the total area of the screen, gave the amount of spray deposited per unit area.The data obtained from each experiment was statistically analyzed at 5 per cent significance level using SPSS Statistics (version: 23, IBM, USA) to study the significance of forward speed, nozzle type and air velocity on spray deposition observed at six plant positions. The developed sprayer during field evaluation in guava orchard is shown in Fig. C.

Fig. C : Field testing of the developed sprayer in guava orchard

RESULTS AND DISCUSSION

The effect of air velocity, forward speed and type of nozzle on spray deposition observed at top, middle and bottom plant positions and on upper and lower leaf surfaces was studied. The analysis of variance was carried out at to study the significance of selected variables on spray deposition and it is presented in Table 1.

Effect of air velocity :

Analysis of variance (Table 1) showed that air velocity had the significant effect on spray deposition. The effect of air velocity on spray deposition is presented in Fig. 1. The mean spray deposition increased with increase in the air velocity from 20 to 35 m/s at all plant positions. Increased air velocity helped to deposit more spray on target tree, thus, increasing the spray deposition. Higher spray deposition was observed on upper leaf surface than on lower leaf surface at the top, middle and bottom plant position because upper leaf surface

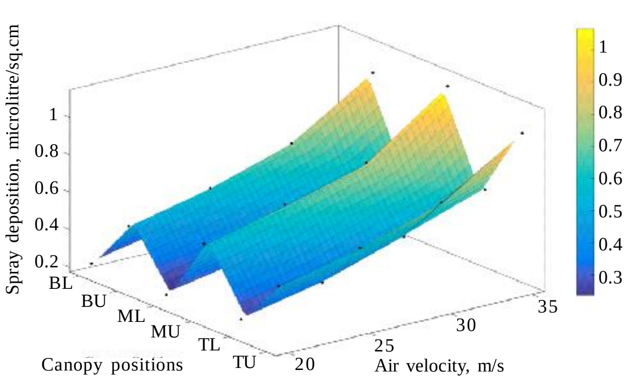

Fig. 1 : Effect of air velocity on spray deposition at different plant positons

comes in direct contact of spray trajectory. Spray deposition values observed at middle plant position both on the upper and lower leaf surface were marginally higher than values observed at other plant positions.The maximum spray deposition of 1.105 µl/cm^2 was observed with the air velocity of 35 m/s at middle plant position and on upper leaf surface whereas minimum spray deposition of was 0.219 µl/cm^2 was observed with the air velocity of 20 m/s at middle plant position and on lower leaf surface. The spray deposition values observed with the air velocity of 35 m/s were significantly higher than values observed at other levels.

Effect of forward speed :

Forward speed had the non-significant effect on spray deposition values observed at different plant positions (Table 1). Variable rate function of the sprayer varied the discharge of the nozzle with the change of the forward speed thus maintaining the same amount of sprayed fluid with respect to time which helped to deposit the same amount of spray for different forward speeds.

Effect of type of nozzle :

Two types of nozzles were used for spraying and statistical analysis (Table 1) shows that spraying with different types of nozzle had the significant effect on spray deposition when analyzed at 5 per cent significance level. The mean spray deposition values observed at selected plant position as an effect of type of nozzle are shown in Fig. 2. At all selected plant positions, higher spray deposition was observed with hollow cone nozzle as compared to flat fan nozzle. Because of internal swirl plate, hollow cone nozzle produces finer droplets as

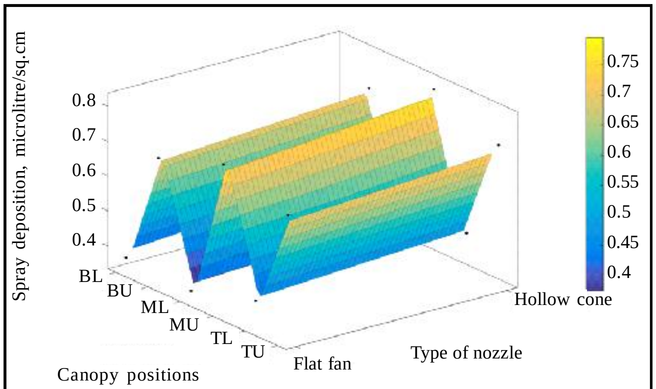

Fig. 2 : Effect of type of nozzle on spray deposition at different plant positons

Table 1 : ANOVA showing effect of selected variables on spray deposition

Source	Sum of squares	DF	Mean square	F	S.E.±	C.D. (P=0.05)
Treatments	25.384	143	0.178	74.017**	0.026	0.072
Air velocity (AV)	11.446	3	3.815	1590.944**	0.004	0.012
Forward speed (FS)	0.005	2	0.003	1.132	0.004	NS
Nozzle type (NZ)	0.173	1	0.173	72.27**	0.003	0.008
Canopy position (CP)	13.164	5	2.633	1097.775**	0.005	0.015
AV * CP	0.49	15	0.033	13.616**	0.011	0.029
FS * CP	0.007	10	0.001	0.309	0.009	NS
NZ * CP	0.007	5	0.001	0.56	0.007	NS
AV * FS * CP	0.028	30	0.001	0.392	0.018	NS
AV * NZ * CP	0.01	15	0.001	0.279	0.015	NS
FS * NZ * CP	0.006	10	0.001	0.259	0.013	NS
AV * FS * NZ * CP	0.036	30	0.001	0.502	0.026	NS
Error	0.691	288	0.002			

** indicate significance of value at P=0.05, NS = Non-significant GM = 0.569, CV = 7.8596 compared to flat fan nozzle and it also helps to produce the higher number of droplets than flat fan nozzle. The maximum spray deposition of 0.816 μl/cm^2 was obtained at middle plant position and on upper leaf surface with hollow cone nozzle and minimum spray deposition of 0.357 μl/cm^2 was obtained at middle plant position and lower leaf surface with the flat fan nozzle.

The combination of air velocity of 35 m/s and hollow cone nozzle produced more spray deposition at all selected plant positions for all selected plant positions than any other combination. The range of the spray deposition values observed with the selected combination of variables were closer to the values reported by Jeon *et al*. (2011) and Chen *et al*. (2013).

Conclusion :

The performance of the newly developed variable rate sprayer was evaluated inside guava orchard to determine the effect of air velocity, forward speed and nozzle type on spray deposition at six different plant position. From the experiment, it can be concluded that increase in air velocity increased spray deposition at all selected plant positions whereas forward speed had the non-significant effect on spray deposition. Hollow cone nozzle was able to deposit more spray as compared to flat fan nozzle. The higher spray deposition was observed on upper leaf surface at the top, middle and bottom plant position. The combination of air velocity of 35 m/s and hollow cone nozzle was found to deposit higher spray deposition as compared to others for all selected forward speeds.

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