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Research Article

AN AIR-ASSISTED HYDRAULIC NOZZLE AND ITS PERFORMANCE ON SPRAY DEPOSITION

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Abstract- An air-assisted system was used with a hydraulic nozzle to assess its effects on spray penetration and deposition on cotton plants. Three cone angles (0^0, 30^0, 45^0), air velocity (5, 10, 15 ms^{-1}) and forward speed (1, 1.25, 1.5 kmh^{-1}) were selected to investigate the effect of spray deposition on adaxial and abaxial surface of top and bottom portion of the cotton plant under laboratory condition. The photographic paper was attached to the surface of leaves to collect spray deposition and analysed by Deposit Scan software. The selected parameters were significantly affecting deposition on all surfaces of the plants. The combination of an air velocity of 15ms^{-1}, forward speed of 1 kmh^{-1} and cone angle of 30^0 deposited spray material throughout the plant and offered better deposition on the abaxial surface of the leave.

Keywords- Air assisted sprayer, Hydraulic nozzle, Pesticide, Spray deposition

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Introduction

Spraying of pesticide is generally used for effective crop protection. The amount of pesticide deposited by sprayers on a target depends on the interaction of crop, equipment used and pesticide formulation. To control the pest, pesticides need to be deposited effectively within the plant canopy and on the undersides of leaves. Hydraulic nozzles are widely used in the field applications to control the insects and fungus but the deposition is highly inefficient as high proportion of the spray fails to reach the target. Many times, high application rates with these sprayer nozzles are used to increase the amount of pesticide deposit inside crop canopies which it is not practically achieved. The excessive pesticide application results in increased cost, health hazards and contamination of the environment. The attachment of extra system (air assisted) with hydraulic nozzle sprayers enables the droplets to penetrate into the crop canopy and increases the deposition uniformity.

Air-assist to hydraulic nozzle sprayers has been developed in recent years showed an improvement in pesticide penetration and deposition within the plant canopy. This is due to the extra momentum developed by applied air velocity on spray droplet increases impaction and improves penetration into the crop as well as negating the influence of wind [1]. This process additionally improves the distribution of spray on normally inaccessible targets by virtue of the turbulence created within the crop. It was reported that air assistance increases the spray deposition of fluorescent tracer on the underside of sugar beet leaf [2]. The effects of air-assisted, drop-nozzle and over-the top spray applications, with different targets and chemicals in cotton crop were compared and air-assisted sprayer with 16ms^{-1} air velocity was found to provide greater canopy penetration [3].

Air-assisted sprayers have potential to deliver pest control agents inside crop canopies economically and effectively [4]. The effectiveness of air assisted over the conventional spraying technique was studied during past showed that air assisted spraying provided a better overall spray penetration and coverage than conventional application and the yield was achieved at lower volume (100 l/ha) using air assistance while it was higher (200 l/ha) without air assistance are same [5]. The deposition characteristics with conventional hydraulic nozzle, air-assisted and electrostatic sprayers in cotton plants revealed that an air-assisted sprayer offered better coverage than other conventional hydraulic nozzle on the undersides of the leaves and good coverage on the topsides [6]. It was reported that a minimum air velocity of 12.2 ms^{-1} was required to increase the spray penetrate beyond the outer canopy of tree crop [7].

The recent studies demonstrated that computational fluid dynamics model can also be used to evaluate spray application performance; to operate sprayers with a better spray efficiency [8]. Air sleeve (cone) angle even affects the deposition of the droplets. The use of an air velocity coupled with an air jet angle of 20^0 increased the coverage of hidden parts of the plants and the spray penetration towards the bottom of the canopy potato plants [9]. [10] studied the spray deposition on potato plants. He reported that the spray coverage increased with air assistance and was found even better with an air sleeve angle set 30° backward. The study was based on the principle that spray intercepted the jet and got entrained with air to carry to the target. Based on the earlier works, this experiment was conducted to design an effective air assisted system with three forward speed of 1, 1.25, 1.5 kmh^{-1}, three cone angles of 0^0, 30^0, 45^0 and an air velocity of 5, 10, 15 ms^{-1}. Various results were obtained in canopy penetration and coverage studies with a range of nozzle types conducted [11-16].

Materials and methods

An air-assisted system was developed to operate along with a hydraulic spray nozzle. The objectives of air-assist were to carry the droplets produced by the hydraulic nozzle at adaxial (top side) and abaxial (under side) leaf surface of the top and bottom portion of the plant. To study the spray deposition characteristics of the air assisted system as influenced by pertinent variable under laboratory condition, a spray carrier trolley system developed at AMRC (Agricultural Machinery Research Centre), Coimbatore was used to simulate the moving sprayer in the real field condition. The air assist system was carried by the trolley as hinged to its frame. The air assist system consists of hydraulic sprayer, blower unit and modified nozzle was mounted with the trolley. In these experiments, three forward speed of 1, 1.25, 1.5 kmh^{-1}, three cone angles of 0^0, 30^0, 45^0 and an air velocity of 5, 10, 15 ms^{-1} was selected.

A variable speed blower was used to change air velocity at the outlet of the air delivery system. Average air velocities of 5, 10 and 15ms^{-1} were measured using a hot wire anemometer near the centre of the air delivery outlet [Fig-1, 2] at six different points. Coefficients of variation of air velocity at the outlet were 13.1, 9.2 and 9.4 per cent for 5, 10 and 15ms^{-1} air velocities, respectively. A spray carrier trolley system was developed with variable forward speed of 1, 1.25 and 1.5 kmh^{-1} using motor and the cone pulley system. The same forward speed levels were selected since these levels lay within the practical travel speeds of knapsack sprayer. The newly developed nozzle consists of two inlets, one is for pressurized liquid to hydraulic nozzle to produce fine droplets and another is for flow of air from blower to carry the produced droplet towards crop canopy. The different cone angle is attached at air outlet of nozzle to divert the air. The different air diversion cone angle of 0^0, 30^0, 45^0 was developed using 3D printer.

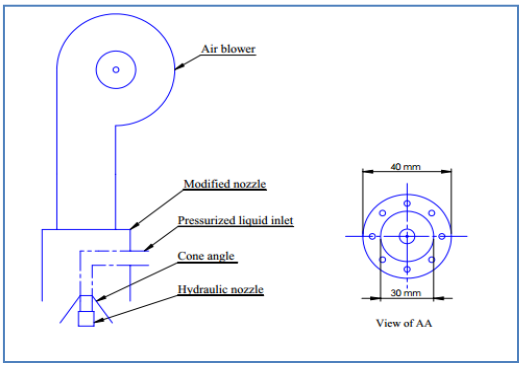


Fig-1 A schematic view of air-assist delivery system with hydraulic nozzle

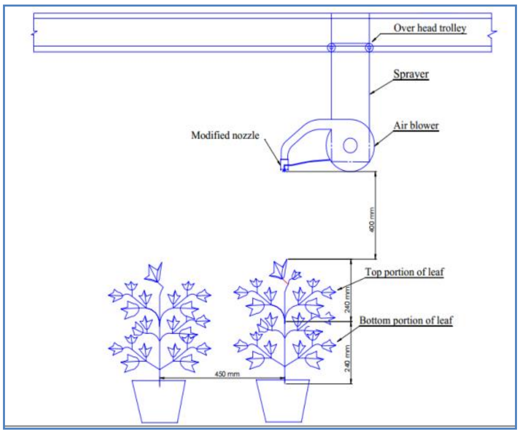


Fig-2 A schematic view of the natural plants under laboratory condition

Deposition: Natural cotton plants grown in pot were placed under the nozzle at 450 mm intervals in a single row. The height, width and leaf area index of RCH 708 cotton hybrid after 55 DAP were 480 mm, 391 mm and 2.1. Total height of plant was divided into two equal portions, 240 mm from ground level as bottom portion of the plant and another 240 mm as top portion of the plant. Spray deposition was evaluated by fixing 25 mm photographic paper on the two leaves of adaxial and abaxial leaf surfaces at top and bottom portion of the plant. The spraying height of nozzle was fixed at 400 mm above the plant height. A mixture of water plus 3.33 per cent methyl alcohol and 1g l^{-1} tracer dye was used as spray liquid.

After spraying, the photographic paper samples were collected and scanned with hand held optical scanner. The scanner connected to computer software, which enables directly visualize and capture the image on computer screen. Spray coverage and deposition on the capture image were analyzed using Deposit Scan software. The deposition was calculated for all combinations of cone angle, forward speed and air velocity. Three replicates were carried out for each experiment. All data were analyzed with three factor completely randomized design methods using AGRESS software.

Results and discussion

The Significant differences were observed in average deposition between air velocities (V), Forward speed (S) and cone angle (C) on photographic papers of the leaves at adaxial and abaxial surface of top and bottom portion of the plant [Table-1]. All the interactions between air velocity, forward speed and cone angle were also significant at 5 per cent level of significance.

Effect of cone angle on deposition at adaxial and abaxial surface of the top portion of the plant

Considering an adaxial surface at top and bottom portion of the plant, the maximum deposition on top portion and bottom portion of the plant was observed at cone angle of 0^0 (12.21µl cm^{-2}) and 30^0 (5.22µl cm^{-2}). The effect of cone angle of 30^0 showed maximum deposition at bottom portion of the plant this is because of the diversion of air by the cone angle 30^0 penetrate the spray deep into canopy upto lower adaxial surface [Fig.-3]. The effect of cone angle of 45^0 showed minimum deposition at both portion of the plant. This might be due to the fact that the air through cone angle diverts the spray outside the canopy.

The effect of cone angle with respect to the deposition on abaxial surface at top and bottom portion showed slight different trend as compared to deposition of droplets on adaxial surface. The maximum deposition at abaxial surface on top and bottom portion of the plant was observed as 1.71 µl cm^{-2} and 1 µl cm^{-2} at same cone angle 30^0 followed by cone angle 0^0 and minimum deposition at cone angle 45^0.

Therefore, at 30^0 cone angle, the deposition at top and bottom portion of the plant and adaxial and abaxial surface was found significantly high compared to other cone angle except at top portion of the plant and adaxial surface. However, the deposition at top portion of the plant and adaxial surface at 30^0 cone angle was found acceptable. Hence the cone angle 30^0 was found most effective for pest control.

Table-1 *Analysis of variance of average deposition on filter papers of leaves at abaixal, adaxial surface of top and bottom portion of cotton plants*

	df	Top Adaxial	Top abaxial	Bottom Adaxial	Bottom Abaxial
Main effects	MSS				
Cone angle, degree (C)	2	3.016*	5.936*	39.027*	3.145*
Air velocity, ms^{-1} (V)	2	6.720*	25.35*	99.52*	14.384*
Forward speed, kmh^{-1} (S)	2	122.55*	3.378*	50.81*	1.484*
Interactions					
C x V	4	2.968*	2.776*	4.772*	1.240*
V x S	4	1.323*	0.850*	0.915*	0.600*
C x S	4	4.939*	0.091*	0.413*	0.009*
C x V x S	8	0.956*	0.142*	0.488*	0.024*
Coff.variation		3.99%	2.87%	3.91%	2.19%
CD (0.05)		0.026	0.079	0.013	0.160

*P<0.05 significant

Effect of air velocity on deposition at adaxial and abaxial surface of the top portion of the plant

Considering an adaxial surface at top and bottom portion of the plant, the maximum deposition on top portion and bottom portion of the plant was observed at air velocity of 5 ms^{-1} (12.37 µl cm^{-2}) and 15 ms^{-1} (6.93 µl cm^{-2}).

The maximum deposition on top portion (2.07 µl cm^{-2}) and bottom portion (1.447 µl cm^{-2}) of the plant at abaxial surface was observed at air velocity 15 ms^{-1} [Fig-4]. It was also observed that the deposition showed significantly increase with increase in air velocity except in top portion of plant and adaxial surface. This is due to extra force created by air velocity of 15 ms^{-1} shakes the crop canopy and exposure its hidden target of top portion of abaxial surface and bottom portion of adaxial and abaxial surface to the spray material.

Therefore, the effect of air velocity at 15 ms^{-1}, the deposition at top and bottom portion of the plant and adaxial and abaxial surface was found significantly high compared to other air velocity of 5 ms^{-1} and 10 ms^{-1} except at top portion of the plant and adaxial surface. However, the deposition at top portion of the plant and adaxial surface at 15 ms^{-1} air velocity was high. Hence the air velocity of 15 ms^{-1} was found most effective to target normally inaccessible surface by virtue of the air turbulence created within the crop.

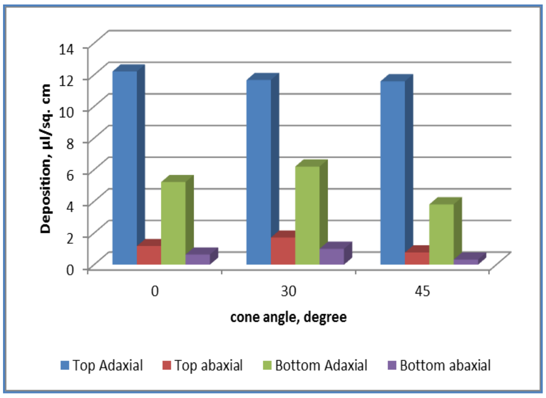


Fig-3 Deposition rate on different surface of the top and bottom portion of the plant at varying cone angle (degree).

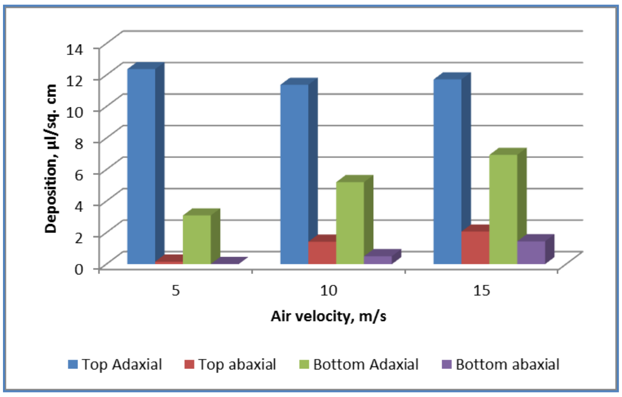


Fig-4 Deposition rate on different surface of the top and bottom portion of the plant at different air velocity (ms^{-1}).

Effect of forward speed on deposition at adaxial and abaxial surface of the top portion of the plant

The speed of operation affects a velocity of the spray and the deposition on the plant surface. From the [Fig-5], it was observed that maximum mean deposition was highest at forward speed of 1kmh^{-1} on all the plant surface. The maximum deposition on top portion of the plant of adaxial and abaxial was 13.92 µl cm^{-2} and 1.56 µl cm^{-2} and the bottom portion of the plant of adaxial and abaxial was (6.40 µl cm^{-2}) and (0.90 µl cm^{-2}) with forward speed of 1kmh^{-1}. As forward speed increases the deposition decreased at adaxial and abaxial surface of top portion and bottom portion of the plant. This is due to increases in application speed decreases the total exposure time of crop canopy to spray material hence the deposition at the plant was decreases.

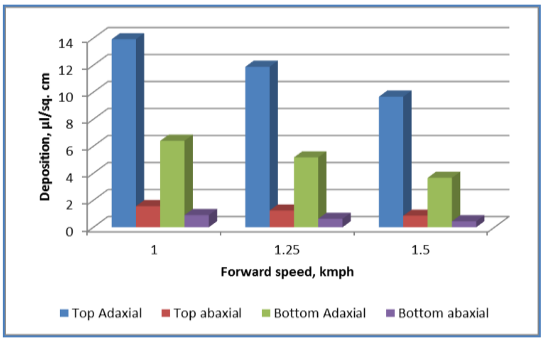
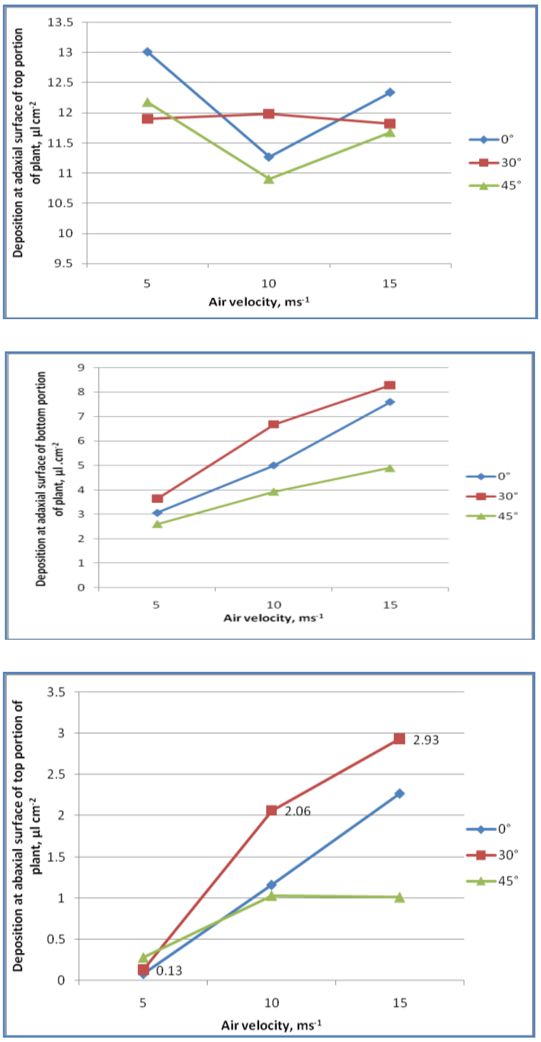


Fig-5 Deposition rate on different surface of the top and bottom portion of the plant at varying forward speed (kmh^{-1}).

Combined effect of cone angle and air velocity on deposition

The results of combined effect of cone angle and air velocity on mean deposition at adaxial surface of top and bottom portion of the plant is represented in [Fig-6]. The mean deposition obtained due to air velocity of 5 ms^{-1} in combination with cone angle of 0° was maximum (13.01 µl cm^{-2}) at top portion of the plant and at air velocity of 15 ms^{-1} in combination with cone angle of 30° was maximum (8.29 µl cm^{-2}) at bottom portion of the plant. Similarly, the result of mean deposition on abaxial surface at top and bottom portion of the plant showed that mean deposition obtained due to air velocity of 15 ms^{-1} in combination with cone angle of 30° was maximum at top (2.93 µl cm^{-2}) and bottom portion (2.18 µl cm^{-2}) of the plant.



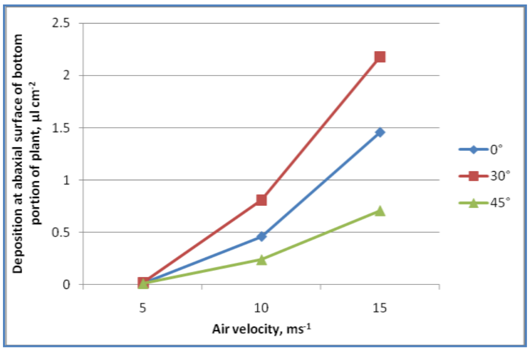
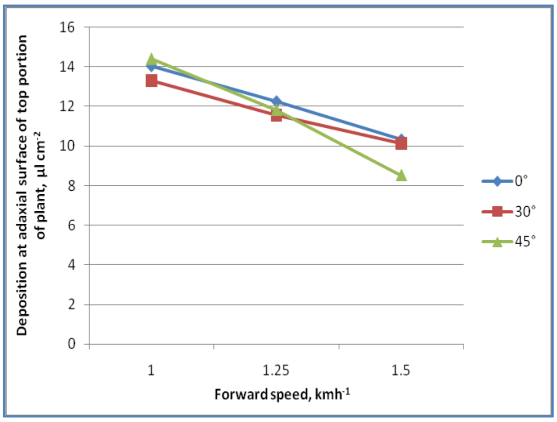


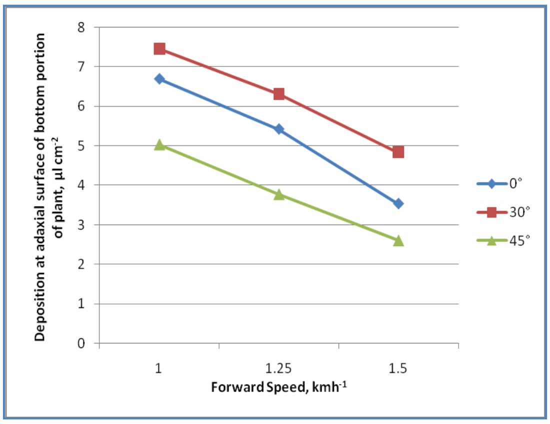
Fig-6 Combined effect of cone angle (degree) and air velocity (ms^{-1}) on mean deposition at different surface of top and bottom portions of the plant

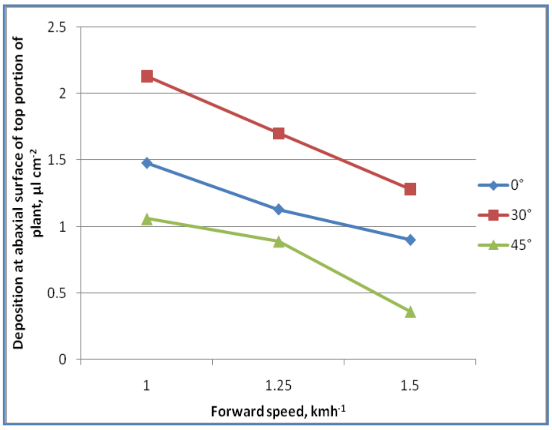
From the Fig, the combination of 0^0 cone angle and 15 ms^{-1} air velocities was recorded highest mean deposition at top portion of adaxial surface. However, its mean deposition at other surface is significantly lower than the combined effect of 30° cone angle and air velocity of 15 ms^{-1}. Overall the combined effect of 30° cone angle and 15 ms^{-1} air velocities was found best for throughout deposition of spray material on the plant canopy

Combined effect of cone angle and forward speed on deposition

The mean deposition on plant surface decreases with increase in forward speed for all the cone angles [Fig-7]. The results of mean deposition on adaxial surface at top and bottom portion of the plant showed that the mean deposition obtained due to forward speed of 1 kmh^{-1} in combination with cone angle of 45° was maximum (14.42 µl cm^{-2}) at top of the plant and at forward speed 1 kmh^{-1} in combination with cone angle of 30° was maximum (7.46 µl cm^{-2}) at bottom of the plant. Similarly, the mean deposition on abaxial surface at top and bottom portion of the plant showed that mean deposition obtained due to forward speed of 1 kmh^{-1} in combination with cone angle of 30° was maximum at top (2.13 µl cm^{-2}) and bottom portion (1.284 µl cm^{-2}) of the plant.







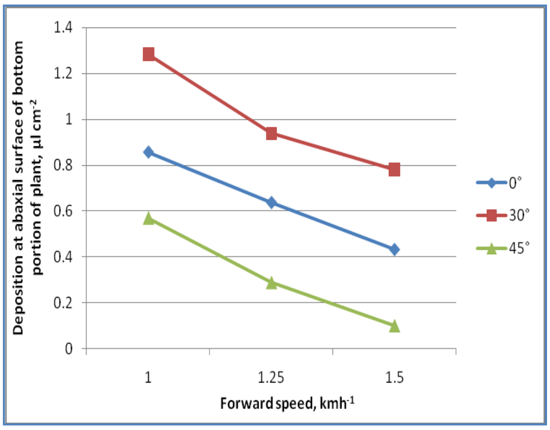


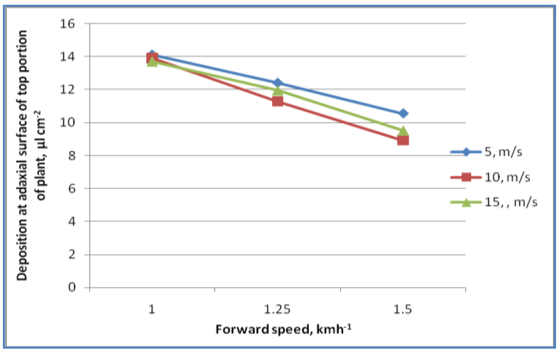
Fig-7 Combined effect of cone angle (degree) and forward speed (kmh^{-1}) on mean deposition at different surface of top and bottom portions of the plant

The combination of 45^0 cone angle and 1 kmh^{-1} forward speed was recorded highest mean deposition at top portion of adaxial surface and also lowest at other plant surface. The effective mean deposition on all the surface of plant canopy was found with the combined effect of 30° cone angle and forward speed of 1 kmh^{-1}.

Combined effect of air velocity and forward Speed on deposition

The deposition on adaxial surface at top and bottom portion of the plant is represented in [Fig-8]. The results showed that mean deposition obtained due to forward speed of 1 kmh^{-1} in combination with air velocity of 5 ms^{-1} was maximum (14.13 µl cm^{-2}) at top of the plant and the mean deposition at forward speed of 1 kmh^{-1} in combination with air velocity of 15 ms^{-1} was maximum (8.28 µl cm^{-2}) at bottom of the plant. Similarly, the deposition on abaxial surface at top and bottom portion of the plant showed that mean deposition obtained due to forward speed of 1 kmh^{-1} in combination with air velocity of 15 ms^{-1} was maximum at top (2.71 µl cm^{-2}) and bottom portion (1.99 µl cm^{-2}) of the plant.

The forward speed of 1 kmh^{-1} in combination with air velocity of 15 ms^{-1} was found best than the other combination at all the plant surface.



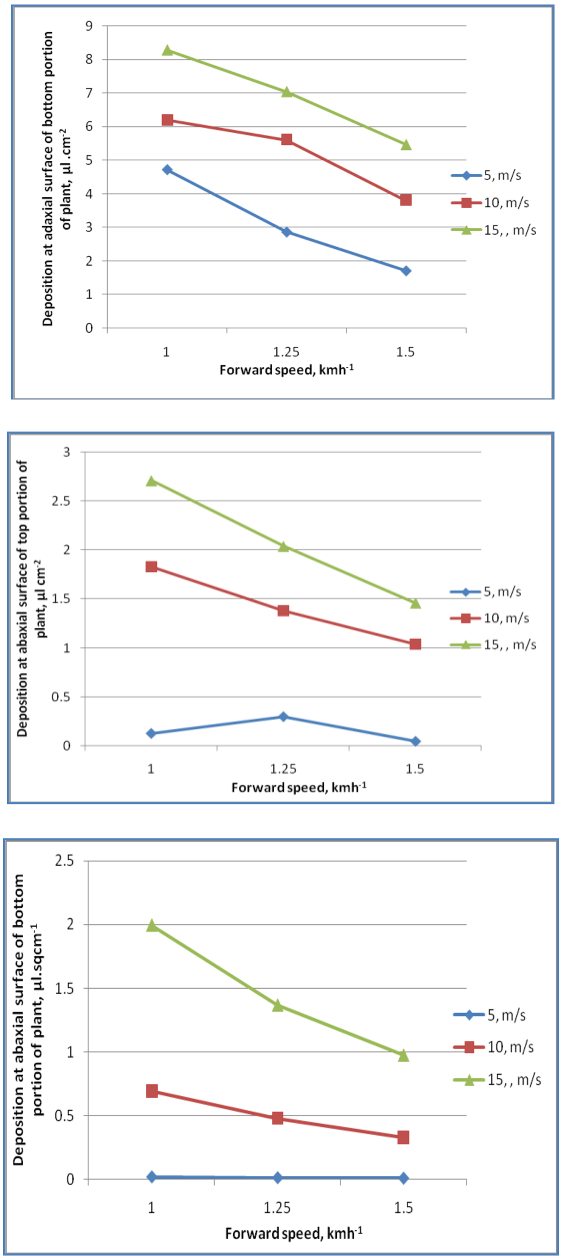


Fig-8 Combined effect of air velocity (ms^{-1}) and forward speed (kmh^{-1}) on mean deposition at different surface of top and bottom portions of the plant.

Conclusion

The air assisted system was developed to study the influences of cone angle, forward speed and air velocity. The results indicated that the selected variables and their interactions significantly affecting the deposition on adaxial (topside) and abaxial (underside) leaf surface of the top and bottom portion of the plant. The combination of the air velocity of 15 ms^{-1}, forward speed of 1kmh^{-1} and cone angle of 30^0 has significantly increases the deposition on abaxial leaf surface of top portion of the plant and at adaxial and abaxial portion of the bottom of the plant which is normally inaccessible target by the conventional sprayer.

Application of research: Pesticide Management/use efficiency

Research Category: Farm Machinery/ Agricultural Engineering

Author Contributions: All author equally contributed

Author statement: All authors read, agree and approved the final manuscript

Conflict of Interest: None declared

Abbreviations: µl- Microliter, kmh^{-1}- kilometre per hour, ms^{-1}-meter per sec, ha – hectare.

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Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors

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