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DRIFT POTENTIAL OF TILTED SHIELDED ROTARY ATOMISERS BASED ON WIND TUNNEL MEASUREMENTS

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SUMMARY

Crop protection is mainly achieved by applying Plant Protection Products (PPP) using hydraulic nozzles, which rely on pressure, to produce a wide droplet size distribution. Because of always increased concerns about drift reduction, a wider range of low drift nozzles, such as air induction nozzles, was adopted in order to reduce the finest part of the spray. While successful for some treatments, the efficiency of coarser sprays is dramatically reduced on small and superhydrophobic target, i.e. at early stage weed control. This may be related to the increased proportion of big bouncing and splashing droplets. On the other hand, Controlled Droplet Application (CDA), using shielded rotary atomizers, stands for an improved control of droplets diameters and trajectories compared to hydraulic nozzles. Unfortunately, these atomizers, because of their horizontal droplet release, are widely recognized to produce more drift than hydraulic nozzles. The present contribution investigates whether the setting of a rotary atomizer 60° forward tilted can reduce drift to acceptable levels in comparison with vertical and 60° forward tilted standard and low drift flat fan nozzles for the same flow rate. In a wind tunnel, the drift potential of a medium spray produced by a tilted shielded rotary atomizer Micromax 120 was benchmarked with that of a flat fan nozzle XR11002 fine spray and that of an anti-drift nozzle Hardi Injet 015 medium spray. Operating parameters were set to apply 0.56 l/min for every spray generator. Vertical drift profiles were measured 2.0 m downward from nozzle axis for a 2 $m.s^{-1}$ wind speed. The tilted hydraulic nozzles resulted in a significant drift increase while droplets trajectories are affected by the decrease of the droplet initial vertical speed. Droplets emitted by the shielded rotary atomizer drift due to low entrained air and turbulence. A significant reduction of the cumulative drift was achieved by the rotary atomizer in comparison with flat fan nozzle while still being higher than the anti-drift nozzle. Unfortunately, the drift potential index (DIX) revealed that the cumulative drift reduction may not results in actual drift decrease because of higher drift at higher sampling locations. As a result, the DIX of the shielded rotary atomizer was similar to the standard flat-fan nozzle while the anti-drift nozzle reduced drastically drift as intended. Therefore, the 60° tilted rotary atomizer failed to reach low drift levels as expected despite the reduced span.

Key words: Tilted shielded rotary atomiser, hydraulic nozzles, drift potential, wind tunnel.

HIGHLIGHTS

60° forward tilted nozzles increased drift relative to vertically oriented nozzles.
Rotary atomisers with a narrow droplet size distribution centred around a VMD of 300µm do not significantly reduce drift comparatively to hydraulic nozzles.
Turbulence and lower entrained air flows may explain drift at higher sampling locations of rotary atomisers comparatively to hydraulic nozzles.

INTRODUCTION

In the crop protection field, increased concern of environmental issues related to Plant Protection Products application (PPP) was marked since it can still drastically contaminate the surrounding environment and expose bystanders to chemical contaminations. Therefore, the need of targeting PPP more accurately is increasingly pressing. This can be essentially linked to spray quality, which is classified using standard reference nozzles to define very fine, fine, medium, coarse and extra coarse classes (Southcombe *et al.*, 1997). Droplet size may affect both spray drift (Holterman, van de Zande, Porskamp and Huijsmans, 1997; Mokeba, Salt, Lee, and Ford, 1997; Nuyttens, De Schampheleire, Verboven and Sonck, 2010; Walklate, 1987) and spray retention (Knoche, 1994). PPP treatment efficiency as a function of drop size has been the subject of extensive investigation. Although the complexity of the PPP application process on targets, some trends are thoroughly established. As a rule of thumb, smaller droplets whose diameters under 150 µm are usually prone to drift due to the quick loss of their initial ejection velocity because of drag and reduced entrained air since droplet density near the orifice decreases (Ghosh and Hunt, 1998). Hence, their trajectories are sensitive to wind. Bigger droplets follow a more predictable trajectory but may result in a lower efficiency, especially on a superhydrophobic and upstanding surface weeds, such as black grass. Furthermore, a recent study stated that droplets above 350 µm still splash despite adding a powerful surface active adjuvant to spray mixture (Boukhalfa, Massinon, Belhamra, and Lebeau, 2014). An efficient spray application therefore results from a sound compromise in terms of the optimal droplet size and trajectory according to target characteristics.

Spray application methods are nowadays performed using the standard technique where hydraulic nozzles are mounted vertically downward. These hydraulic nozzles produce wide droplet size distribution under the combined effect of surface tension and aerodynamic forces (Gebhardt, 1988). The emitted spray is characterized by a high spray uniformity index, namely span, calculated as (DV90-DV10)/ DV_{50} [1], which typically lies usually around unity. Anti-drift nozzles, which rely on air induction or pressure drop to increase the proportion of big droplets, also lead to a wide span around one. As a result, the proportion of splashing and bouncing droplets dramatically increases while the proportion of smallest droplets that tend to adhere easily decreases. To increase retention of big droplets, it was proposed to tilt hydraulic nozzles forward have improved herbicide efficiency on black grass (Jensen, 2007, 2012). Indeed, it was proved that droplet impact angles affect significantly spray retention (Massinon, Boukhalfa, and Lebeau, 2014). However, such application technique may increase drift because of decreased downward velocity component resulting in an increased exposure to wind effects that may be detrimental for medium sized droplets.

Avoiding drawbacks of current drift reducing techniques rely on the reduction of droplet size distribution width. Controlled Droplet Application (CDA), using rotary atomizers, which employ centrifugal forces and grooves placed on a serrated disc to produce droplets, has proved to be a successful way to control droplet diameters and trajectories (Bode, Butler, and Pearson, 1983; Frost, 1981; Holland, Jepson, Jones, and Turner, 1997; Matthews, 1992). The span of rotary atomisers is much lower than hydraulic nozzles and typically lies in the 0.5 to 0.6 range (Derksen and Bode, 1986; Qi, Miller, and Fu, 2008). However, these mechanical designs are reputed to produce higher drift as they are usually operated at low volume median diameter for low application volumes. Furthermore, this may also result from the horizontal

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[1] DV_{10}, DV_{50} and DV_{90} indicate respectively that 10%, 50% and 90% of the spray volume is composed of drops whose diameters are smaller than this value (µm)

ejection plane increasing the droplet travel time to reach the canopy despite the higher initial droplet ejection velocities (Qi *et al.*, 2008). As soon as in 1980, manufacturers have developed shielded rotary atomisers that can produce bigger droplets and a 120° spray opening similar to the usual flat fan shaped spray pattern, what may reduce drift. However, it was not investigated because of low concern and absence of established measurement methods at that time.

Drift is a complex process driven by spray droplet size, droplet speed and direction as well as entrained air effects that may be difficult to predict accurately. Therefore, the objective of this study is to investigate whether a 60° forward tilted rotary atomizer, with reduced drift able droplet proportion and a VMD centered around 300 µm to ensure sufficient spray retention, can reduce drift potential to acceptable levels on the basis of wind tunnel measurements. These settings are benchmarked with vertical and 60° forward tilted standard and low drift flat fan nozzles.

MATERIALS AND METHODS

Droplet generators

Three types of spray generators were used: a shielded rotary atomiser (Micromax 120, Micron Sprayers Ltd) featured with a 120° spray opening to produce a flat fan shaped spray pattern and equipped with a venturi system to recirculate unsprayed liquid collected by the shield, a flat fan nozzle Teejet XR110 02 (Spraying Systems) and an anti-drift nozzle Hardi Injet 015 (Hardi). The rotary atomiser was tested at two rotation speeds by setting the tuneable pulley system respectively to 3500 rpm and 5000 rpm set point. The settings of these nozzles were chosen to deliver the same flow rate (Table 1).

Spray mixture

The spray mixture contained 0.2 g.l^{-1} sodium fluorescein tracer dye and 0.1% vol/vol organosilicone trisiloxane surfactant Break Thru S240 (Evonik Industries AG, Essen Germany) in water. The mixture was mixed and pressured in a 10 L stainless steel tank.

Spray generators characterization and droplet size distribution

A laboratory test bench based on high speed shadow imagery technique was used to measure spray generators characteristics. A 10-bit PIV camera (X-Stream^{TM} XS-3, Integrated Designs Tools) set in double mode exposure was coupled to a LED-controller (PP600F, Gardsoft Vision) which provides repeatable intensity control of the LED backlighting. The camera records shadow images of droplets emitted par each spray generator.

Droplet size measurements for the hydraulic nozzles were performed 300 mm beneath the nozzle output. The single nozzle was fitted on a 2-D movable carrier to sample the whole spray pattern produced by nozzle. To measure sprays from the rotary atomiser, the single shielded rotary atomiser was set horizontally and static as the emitted spray characteristics were expected to be constant within the 120° spray opening. Droplet images acquisitions were carried out at 120 mm from the disc edge. Sampling approaches were therefore different for the two systems. Obtained images were analysed with a Particle Tracking Velocimetry Sizing (PTVS) algorithm developed in Matlab (De Cock, Massinon, and Lebeau, 2014). The obtained data are presented in Table 2.

As expected, the Micromax 120 atomiser produces narrower droplet size distributions than the hydraulic nozzles. The volume percentage of drops whose diameters are under 100 µm corresponding to easily driftable drops was determined. It is noteworthy that the shielded rotary atomiser was operated in the ligament spray formation mode (figure 1) which leads probably to a droplet size distribution less uniform than the direct droplet formation mode (Frost, 1981; Walton and Prewett, 1949).

Spray drift measurements

Experiments were conducted in the wind tunnel facility of Gembloux Agro-Bio Tech (University of Liege). The closed circuit wind tunnel has overall dimensions of 25.0 m total length, 7.0 m working length, 2.0 m width and 2.0 m height for the working section. Wind in the tunnel was blown using a 1.2 m diameter bladed axial flow fan driven by a 22 kW motor. It allows to reach wind speeds from 0 to 6 $m.s^{-1}$ adjustable via a speed controller Danfoss VLT6032. Tunnel air flow conditions were uniform with a maximum local variability of air velocity of 5% and a maximum degree of turbulence of 8% along the tunnel area where the measurements were performed. Tunnel wind speed was set at 2 $m.s^{-1}$ measured by a hot wire anemometer placed 800 mm from the nozzle and 500 mm above the tunnel floor. Trials were performed under recommended conditions by ISO 22856 standard where temperature was 20 °C ± 1°C and relative humidity was 80% ± 5%.

The sampling collector's lines are two millimetres diameter cylindrical polyethylene wires (Carlisleit). They were set horizontally across the tunnel at 2.0 m from the nozzle axis, perpendicular to the wind direction. Each collector corresponds to a three wire section of 100 mm bound by connectors. The sampling lines, were vertically spaced at 100 mm intervals. The highest sampling line was set 100 mm above nozzle height. The lowest sample line was set on the virtual wind tunnel floor located 150 mm above the real floor (ISO 22856:2008).

Single nozzle orifices were set 500 mm above the virtual wind tunnel floor. Nozzles were set vertically or tilted 60° relative to the vertical to produce 60° forward spray angle. The rotary atomiser was only set 60° forward tilted because the device was not designed of vertical orientation operation. A servomotor acting on the linear movable nozzle carrier ensures a forward nozzle speed of 2.0 $m.s^{-1}$ and ten nozzle passes across the tunnel. The number of single nozzle passes per measurement were chosen to avoid sampling line saturation. Three replicate measurements were conducted of each nozzle and each disc speed.

After spray application, each sampling line was stored in a polyethylene container with a 10 ml of buffer solutions (K_2HPO_4) to wash spray liquid. Then, the washed solutions were put in dark and cold environment until measured using a fluorescence spectrophotometer (RF-1501, Shimadzu Corporation) at 460 nm excitation wave length and 540 nm emission wave length.

The drift percentage for each line is calculated by:

$$d_{line} = V_b * 100 / V_p * f_c$$

and the total drift at 2.0 m downwind is calculated by:

$$d_{total} = \sum d_{line}$$

Where V_b corresponds to the sprayed volume deposited on each collector (µl). It is calculated by multiplying the measured fluorescein concentration ($\mu g.mL^{-1}$) by the volume of buffer solution added to each tube and dividing the result by the fluorescein concentration of the sprayed solution ($\mu g.mL^{-1}$); V_p corresponds to the nominal spray volume. It is determined by multiplying the nozzle flow rate by the application time. The application time is therefore calculated as the product of the collector length and number of nozzle passages divided by the nozzle speed; f_c is the fraction of drift sampled by the collector. It is calculated as the ratio between the width of the sample collector (2 mm) and the interval between collectors (100 mm).

The potential drift reduction was calculated based on the Potential Drift Index (DIX) (Herbst, 2001).

The potential drift volume V at 2.0 m is calculated by:

$$V= \sum h_i * d_i$$

Where: i is the number of the sample collector from 1 to 7 (1 corresponds to the virtual floor set at 0 mm and 7 corresponds to 600 mm above the virtual floor); h_i is the height where the i^{th} collector is located (mm); d_i is the measured drift for the i^{th} collector (%, mean of three replicates).

The characteristic height of potential drift H is calculated by:

$$H=V/\sum d_i$$

Therefore, the DIX is calculated by:

$$DIX= [(H_{ESS})^a * (V_{ESS})^b / (H_{REF})^a * (V_{REF})^b] * 100$$

Where:
H_{ESS} is the characteristic height of potential drift corresponding to the test spray mixture
H_{REF} is the characteristic height of potential drift corresponding to the reference spray mixture
V_{ESS} is the drift potential volume at 2.0 m corresponding to the test spray mixture
V_{REF} is the drift potential volume at 2.0 m corresponding to the test spray mixture
a= 0.88 and b= 0.78 (experimental values from Helck and Herbst, 1998).

Water sensitive papers were placed 100 mm from each sampling line on the same height in order to asses drifted drops at 2.0 m. One square centimetre samples were scanned at 2400 dpi and binarized on an operator based threshold procedure to enhance droplet spots.

RESULTS AND DISCUSSION

Table 3 presents binarized images of water-sensitive papers at six different collector heights. It appears that droplet spots are present at each measurement height, even at 600mm height, 100 mm higher than the nozzle output height. Droplet spot densities clearly increase with decreasing height as expected. Mean spot sizes decrease with increasing height but the diversity of spot diameters is wide at each height, reflecting the effect of turbulence in the wind tunnel that results in a wide range of droplet trajectory, whatever the spray generator. The mean spot diameter for a specific height seems independent of the spray generator.
Table 4a and 4b presents quantitative measurements of drift deposits on wire collectors 2 m away from the spray generator axis. The fluorescein concentration in the rinse solution appears in line with the qualitative measurements on water sensitive papers. The observed variability between the three repetitions for each measurement lies in an acceptable range with regards to the drift process and sample size, the higher lines presenting a higher coefficient of variation because of higher variability of deposits.

On this basis calculated drift percentages are presented in Figure 2. The three spray generators present different drift profiles and their global shapes are more related to the spray generator than to the particular setting of the generator. The drift contamination starts 100 mm above the ejection height for all atomizers as highlighted by droplet spots on water sensitive papers. On one hand, the Teejet XR11002 fine spray delivering a big amount of small driftable droplets (6% volume of the spray being smaller than 100 µm) (Table 2) resulted in a high drift. The effect of nozzle orientation clearly affects drift as a 60° forward tilt results in a significant drift increase. Therefore, the entrained air acts as the ejection height of droplets was reduced. Indeed, the high droplet density near the orifice prevents the airflow to penetrate the spray, creating an obstruction. When the spray density decreases, the airflow penetrates the spray and droplets are entrained according to their size. As intended, the Hardi injet 015 coarse spray reduced drift drastically. The effect of orientation is similar to that of the fine spray as a significant increase of drift is observed when the nozzle is tilted 60° forward. On the other hand, when the Micromax 120 was operated at 5000 rpm and hence delivering the same percentage of droplets smaller than 100 µm as the anti-drift nozzle (Table 2), drift was significantly higher. This surprising result must be related to a lower effect of entrained air for the Micromax 120. When rotational speed is decreased to 3500 rpm, drift was reduced significantly but remains higher than for the anti-drift nozzle.

It is noteworthy that the rotary atomizer contaminates much higher collectors located 100 mm beneath the ejection height except the tilted flat fan nozzle (Figure 2). Water sensitive papers corroborate these observations. This can be linked to the combined effect of the atomizer geometry which results in less spray density and the vortex motion of the bulky atomizer created during atomizer passage across the tunnel. Hence, emitted droplets are rapidly carried out from spray pattern.

Drift cumulative measurements at 2.0 m downwind are presented in Table 3. They confirm that shielded tilted rotary atomizer, set to produce a small amount of driftable droplets, reduce significantly the cumulative amount of drift in comparison with a standard flat fan at the same flow rate. However, the drift is even more reduced with an anti-drift nozzle. This may be related to the higher VMD but this seems to account only for a part of the explanation as it is clear for the comparison between vertical an 60° forward tilted Hardi Injet 015 results that the orientation of the generator has an important contribution to drift reduction.

On the sole basis of cumulative drift measurements, drift can be reduced two to three times for the same nozzle flow rate using the rotary atomizer, and even more for similar orientation. Unfortunately, closer observation of drift measurements reveals that higher collectors are highly contaminated for the rotary atomizer. The drift potential index (DIX) that takes into account drift height (Table 6) reveals that cumulative drift reduction may not results in actual drift decrease, especially at long distance, because of higher drift at higher sampling locations. Indeed, on the basis of this indicator, drift is very similar for the settings used for the rotary shielded atomizer than for the standard flat-fan nozzle.

The Hardi injet 015 medium spray reduced drastically drift as intended in comparison with the fine spray produced by the standard flat fan nozzle. The effect of the nozzle orientation was similar for both nozzles with a significant increase of drift and drift potential. However, this effect was lower for the low-drift nozzle, as expected from higher VMD.

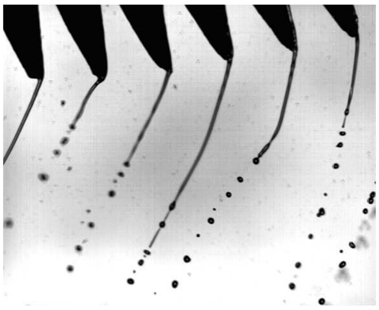


Figure 1. Spray formation in the ligament mode from the Micromax 120 operated at 5000 rpm and 0.56 l.min^{-1}

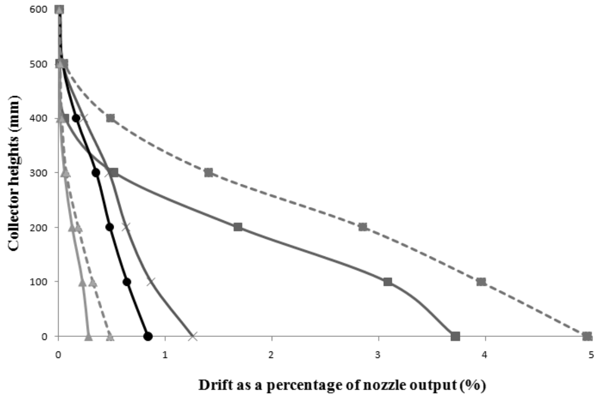


Figure 2. Vertical drift profiles as a percentage of nozzle output for different nozzles at 2.0 m downwind for 2 m.s^{-1} wind speed; ▲ and ■ refer respectively to Hardi Injet 015 and to Teejet XR11002 where continuous and dashed lines represent respectively vertically and represent 60° forward orientations; ● and × represent respectively the 3500 rpm and 5000 rpm disc rotation speed of the Micromax 120 set 60° forward tilt.

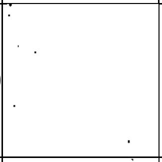
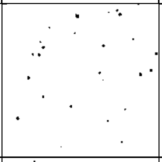
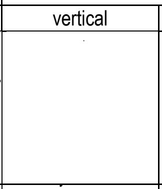
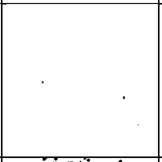
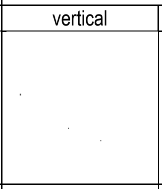
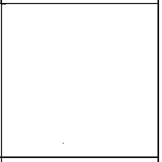
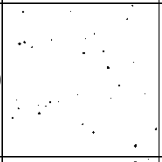
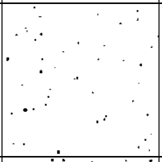
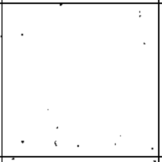
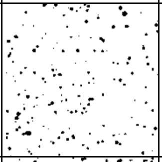
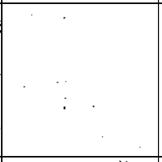
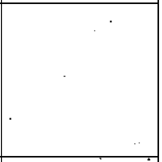
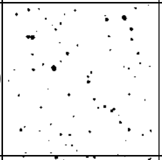
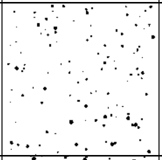
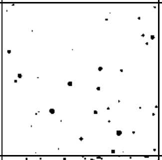
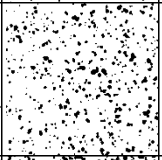
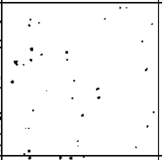
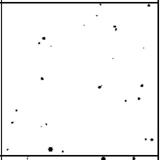
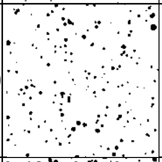
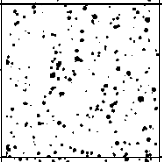
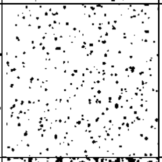
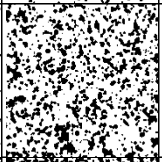
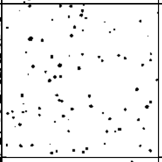
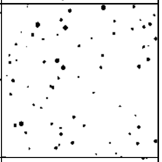
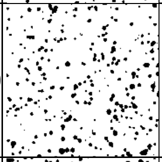
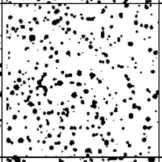
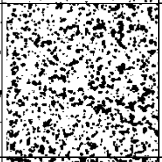
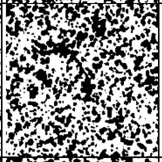
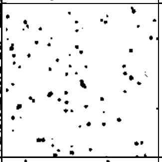
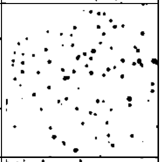
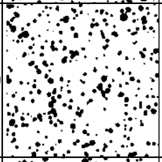
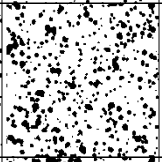
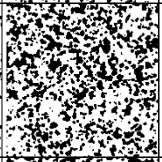
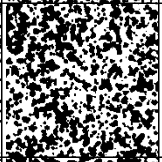
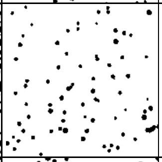
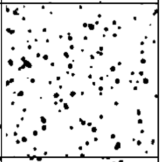
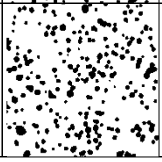
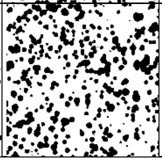
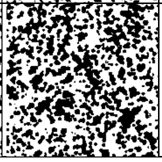
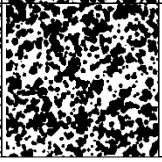
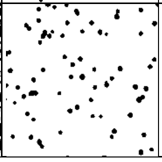
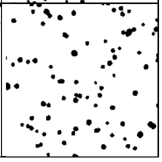
Table 1. Spray settings used in the experiments

Spray generator model	Liquid pressure (Bar)	Flow rate (l.mn^{-1})
Micromax 120 (3500 rpm)	1.2 (yellow restrictor)	0.56
Micromax 120 (5000 rpm)	1.2 (yellow restrictor)	0.56
Teejet XR11002	1.4	0.56
Hardi Injet 015	2.5	0.56

Table 2. Spray characteristics of the tested atomizers

Nozzle model	Flow rate (l.min^{-1})	D_{V10} (µm)	D_{V50} (µm)	D_{V90} (µm)	Span	Volume percentage of droplets <100 µm (%)	Droplet Numbers
Micromax (3500 rpm)	0.56	221	310	398	0.57	0.49	7367
Micromax (5000 rpm)	0.56	181	271	347	0.60	0.70	4388
Teejet XR11002	0.56	113	208	361	1.18	6	8222
Hardi Injet 015	0.56	177	325	514	1.03	0.99	3319

Table 3. Droplet spots observed on water sensitive papers placed 45° to the airflow 2.0 m from spray generator axis and at 2.0 m.s^{-1} wind speed.

Spray generator model / Spray orientation		**Micromax 120 3500 rpm**	**Micromax 120 5000 rpm**	**Teejet XR11002**		**Hardi Injet 015**	
		60° forward	60° forward	vertical	60° forward	vertical	60° forward
Water sensitive heights (mm)	600						
	500						
	400						
	300						
	200						
	100						
	00						

CONCLUSIONS

This paper investigated whether a tilted shielded rotary atomizer, set to produce only a small amount of driftable droplets, could reduce drift in wind tunnel experiments. It can be concluded from these experiments that the reduced span of these generators combined with a VMD in the 270 to 310 range was not sufficient to reach low drift level standards. Indeed, if total cumulative drift was greatly reduced, drift potential index (DIX) was not reduced significantly because of the detrimental effect of contamination of the higher collectors. It can also be concluded from the measurements that the effect of the spray generator orientation was not sufficient to account for the observed phenomena. As a conclusion, even if the span was reduced and the rotary atomizer shielded and tilted 60° forward, the device failed at offering significant advantage at the drift level. However, this particular setting may bring some significant advantage on retention, especially on small superhydrophobic targets while keeping drift to acceptable levels.

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