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Use of rotary atomiser to optimize retention on barley leaves while reducing driftable droplets

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Summary

Controlled Droplet Application using rotary atomiser is based on an improved control of droplet size and trajectory comparatively to hydraulic nozzles. On the basis of literature, it was stated that the use of 60° forward angled spray combined with the narrow drop size distribution of a rotary atomiser could lead to low drift and high retention on monocotyledonous and superhydrophobic weeds at early stage. A Micromax120 atomiser was tuned to emit 270 µm VMD, 60° angled forward, to increase interception by the canopy structure. A spray mixture containing a superspreader adjuvant was used to avoid drop bouncing. An increase of spray retention comparatively to a Teejet 11002 at 1.4 bars was observed, although not proved statistically significant by these preliminary trials. On the drift side, the tilted spinning disc seemed to be advantageous since droplet spectra contains a low percentage of droplets under 100 µm and presents an ejection velocity of 25 $m.s^{-1}$ at 5000 RPM. The spray drift was reduced about 50%. However, these setting were not found as efficient as expected. Indeed, angled spray proved to be more sensitive to advection and turbulence, as the spray was more exposed to the airflow than for the vertical position. It appears that angling the spray and choosing a drop size spectrum with a Volume Median Diameter as big as 270 µm is not sufficient to reduce significantly this issue. Some alternatives as decreasing the emission height are possible with angled sprays but require height control that seems difficult to reach in practical situations.

Key words: Controlled droplet application, rotary atomiser, hydraulic nozzle, spray retention, droplet spectrum, spray drift

Introduction

In the crop protection field, decades of technical developments have led to a wide spectrum of designs to apply Plant Protection Products (PPP). PPP application methods rely extensively on hydraulic nozzles that employ only energy from the spray liquid itself to produce droplets. Orifices shaped to develop thin liquid sheets are the preferred solution, either relying on swirl, flat fan or anvil design. Several parameters are known to influence the droplet size distribution, namely pressure, liquid physico-chemical properties, nozzle shape and size, air induction. On this basis, practitioners have at their disposal nozzles offering a wide range of flow rates and producing various drop size distributions to reach their target. Spray quality is classified using standard reference nozzles and pressures to define limits between very fine/fine/medium/coarse/very coarse/extra coarse/ ultra coarse classes (Southcombe *et al*., 1997). Pesticide application efficiency as a function of drop size has been subject of extensive investigation. Although some confounding results have been published because of the complex nature of PPP retention process on crops, some trends are well established. As a rule of thumb, finer droplets are known to usually result in better coverage but are prone to drift while bigger droplet follow a more predictable trajectory but may result in inadequate coverage.

Retention of sprays on a crop or weed is influenced by numerous parameters as canopy structure, surface hydrophobicity, spray mixture physico-chemical properties, drop speeds and diameters before impact. Processes involved in spray retention have been reviewed (Massinon & Lebeau, 2013; Zabkiewicz, 2000). On this basis, a thoughtful understanding is within specialists' reach with the development of a process-driven retention model (Forster *et al*., 2013). It has been shown that surface tension of PPP formulations and active ingredients can improve retention on superhydrophobic plants, avoiding bouncing of medium sized drops but may result in run-off on easy-to-wet species as the drop spreading results in a continuous water film and drain from the leaf. Drops with a high kinetic energy relative to their surface tension (i.e. a 300 µm drop with a Weber number >50) may shatter at impact, what results in losses if adhesion at first interception is needed. As a result, finer sprays are generally more efficient but may result in unacceptable drift to non-target area and coarser sprays are inefficient on small superhydrophobic targets as monocotyledonous weeds at early growth stages. Furthermore, annual grass species present vertically oriented leaves which for standard flat fan application technique is an ineffective method. It has be shown that using a 60° forward angled spray results in a large increase in herbicide efficacy (Jensen, 2012). However, such an approach may cause a drift issue because downward entrained air is a key component of drift reduction for hydraulic nozzles. Indeed, hydraulic nozzles used in agriculture produce a wide spectrum of droplet sizes because of the sheet break-up mode resulting from aerodynamic instabilities. Smallest drops are usually entrained downward by the spray generated airflow, the momentum of drops being transferred through the air because of drag. Therefore, small drops should be avoided using angled sprays. Rotary atomizers produce drops using either single droplet sizes, ligament or sheet mode depending on flow rate. Some mechanical designs have resulted in a narrow range of drop sizes for high flow output using grooves on the surface of a serrated cup. Indeed, the relative span factor (DV_{90}-DV_{10}/DV_{50}) that characterizes these designs can be as low as 0.5 when for most hydraulic designs this parameter exceeds 1 (Derksen & Bode, 1986). Using rotary atomizers that can be adjusted over a range of rotary speeds and flow rates, many drop sizes and drop speeds can be selected using proper settings.

This paper investigates the capabilities of combining high retention and low spray drift on an annual grass species at an early growth stage using a narrow spectrum of medium sized drops generated by a rotary atomizer.

Material and Methods

Spray generators

For comparison purpose, two types of spray generators were used :

- a rotary atomiser equipped with a shield to capture spray outside the 120° spray opening (Micromax 120, Micron Sprayers Ltd) and featuring an internal Venturi system to recirculate unsprayed liquid.
- a hydraulic flat fan nozzle Teejet XR11002 (spraying systems) which is of widespread use in early stage weed control.

The settings of these nozzles were chosen to apply the same volume application rate (Table 1).

Spray mixture

The spray mixture was mixed and pressurised in a 10 L stainless steel tank. It contained 0.1% vol/vol Break-Thru S240 superspreader (Evonik, Germany) and 0.2 g L^{-1} sodium fluorescein tracer in water. The superspreader was added to avoid droplet bouncing at impact.

Table 1. *Spray settings used in the experiments*

Nozzle model	Liquid pressure (bar)	Flow rate (L.min^{-1})
Micromax 120-5000 RPM	1.2	0.563
Teejet XR11002	1.4	0.563

Droplet sizing

A high-speed camera (XS-3, Integrated Design Tools) used in double exposure mode coupled to a LED backlighting records shadow images of water droplets produced by each spray generator. Droplet size measurements for the spinning disc were carried out at 120 mm of the edge while the disc remained static because it is expected that the spray characteristics remain constant throughout the disc opening angle (the oblique disc orientation makes drop size measurements so hard). To measure drop sizes of the single hydraulic sprayer, the nozzle was fixed on a 2-D movable carrier in order to sample the whole spray pattern. Droplet image acquisitions were performed 300 mm down the nozzle (The set up of the drop acquisition bench allows only droplet size measurements at this distance). Images were analyzed with a Particle Tracking Velocimetry Sizing (PTVS) algorithm developed in Matlab® that provided droplet size and velocity components perpendicular to optic axis.

Retention trials

A dynamic spray application bench with a single nozzle spraying was used to assess spray retention. Nozzle height was set 500 mm above the target and spray application was performed at 2 m.s^{-1} forward speed. The Micromax 120 designed to emit droplets on a 120° wide opening angle was tilted 30° to produce 60° forward angled spray (15° tilt is the usual recommended setting).

Barley plants were grown under artificial conditions until the 2–3 leaf stage (BBCH13). Each application was performed on five barley plants, placed in the length of the driving direction, spaced by 100 mm and sprayed two times with the same nozzle, directly under the nozzle axis and translated laterally 500 mm, to account for usual nozzle overlapping. This double spraying corresponds to 93 L ha^{-1} volume application rate. During nozzle passage, water sensitive papers were placed on the floor at the centre of the spray pattern where barley plants are sprayed the first time and 500 mm right in order to asses deposits from nozzle output across the spray pattern (Fig. 1).

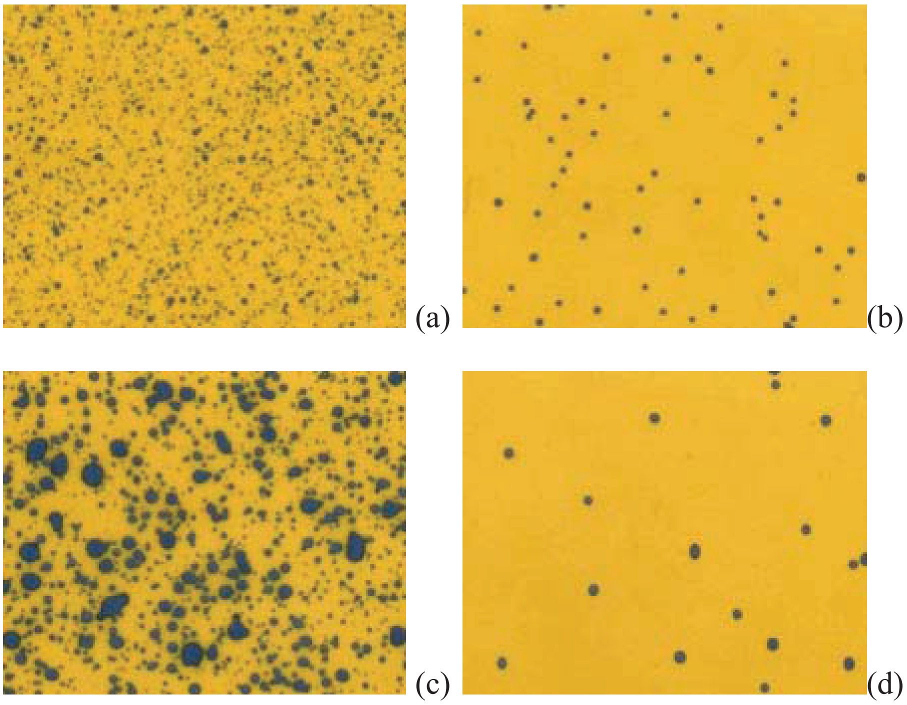


Fig. 1. Spray deposits for the two spray applicators: Micromax 120 centre (a), Micromax 500 mm right (b), Teejet XR11002 centre (c), Teejet XR11002 500 mm right (d).

Trials were made under ambient climatic conditions (temperature 22°C and relative humidity 55%). Five replicates were conducted for each modality. After the spray application, the plants were rapidly cut, washed off in plastic containers with 20 mL of buffer solution K_2HPO_4. The solution was stored dark and cool before analysis. Leaf surface area was measured using a A4 flat-bed scanner and image analysis to determine spot sizes were performed using Matlab©.

Drift trials

Experiments were conducted in the wind tunnel facility of Gembloux Agro-Bio Tech. This tunnel is a closed circuit wind tunnel which 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 speed in the tunnel was set at 2 $m.s^{-1}$ measured by a hot wire anemometer placed 500 mm above the floor and 800 mm from the nozzle. Sample collectors lines were 2 mm diameter cylindrical polyethylene (PTFE) wires (Carlisleit), stretched horizontally and set perpendicular to the wind direction at 2.0 m downwind of the nozzle displacement axis. Collector wires, resulting from a bobbin, are cut into pieces of a 100 mm length. Three pieces are attached together with electrical connectors at each level line (a collector corresponds to 3 sections of 100 mm). The lines were spaced at 100 mm vertical intervals. The highest line was 600 mm above the floor, 100 mm higher than the nozzle height. The nearest line relative to the wind tunnel floor corresponds to a virtual floor which is located at 150 mm above the real floor. Nozzles were always 500 mm above the wind tunnel floor in all tests. A linear movement of the single sprayer at a forward speed of 2 $m.s^{-1}$ is ensured by a servomotor. Ten nozzle passes were done across the tunnel per measurement. The Micromax was angled 30° relative to the horizontal nozzle axe. Nozzles were set to a flow rate of 0.563 $L.min^{-1}$ corresponding to a pressure of 1.2 bar for the Micromax and 1.4 bar for the Teejet XR11002 nozzles. Three replicates for each nozzle were conducted. Trials were carried out under recommended conditions by ISO 22856 standard: Temperature was 20 °C ± 1°C and relative humidity was 80% ± 5%.

After spray applications, collectors of each line were stored in plastic containers with 10 mL of buffer solution K_2HPO_4 to wash the spray liquid. The washed solutions were put in the dark until deposits were measured with a spectrofluorophotometer RF-1501 (Shimadzu).

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

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).

Results

Droplet size distribution

As expected, the Micromax sprayer (Fig. 3a) produces narrower droplet size distributions than the hydraulic nozzle (Fig. 3b). Some spray characteristics measured for the two nozzles are presented in Table 2. D_{V10}, D_{V50} and D_{V90} indicates that 10%, 50% and 90% of the spray volume is composed of drops whose diameters are smaller than this value (µm). The span is a uniformity index of droplets spectrum calculated as $(D_{V90}-D_{V10})/ D_{V50}$. Vol <100 and Vol >350 represent the volume percentage of drops whose diameters are under 100 µm and above 350 µm, respectively corresponding to easily driftable drops and the ones expected to splash.

Table 2. *Characteristics of the droplet spray of a Micromax(5000 rpm) rotary atomiser and a Teejet XR11002 flat fan nozzle (1,4 bar spray pressure)*

Nozzle model	Flow rate (L.min^{-1})	D_{V10} (µm)	D_{V50} (µm)	D_{V90} (µm)	Span	Vol <100 (%)	Vol >350 (%)	Droplet Numbers
Micromax (5000 rpm)	0.563	181	271	347	0.60	0.70	8	4388
Teejet XR11002	0.563	113	208	361	1.18	6	11	8222

The uniformity of the rotary atomiser droplet spectrum is highlighted by a lower span. These results are corroborated by recent studies (Qi *et al*., 2008). Despite the uniformity of the Micromax atomiser, droplet size distributions are often bimodal, corresponding to the main and satellite droplets. Fig. 2 illustrates satellite drops formation due to natural ligament break-up. The rotary atomiser emits theoretically a low percentage of droplets smaller than 100 µm and larger than 350 µm compared to a flat fan nozzle at the same flow rate. The large droplet size distribution of hydraulic nozzle shown in Fig. 3b can be highlighted by the deposits on water sensitive papers (Fig. 1) where satellite droplets are only located in the centre of the spray while coarser droplets characterise the spray edge. However, the droplet size distribution of rotary atomiser seems to be more homogeneous at both spray sampling locations.

Fig. 2. Drop formation for Micromax 120.

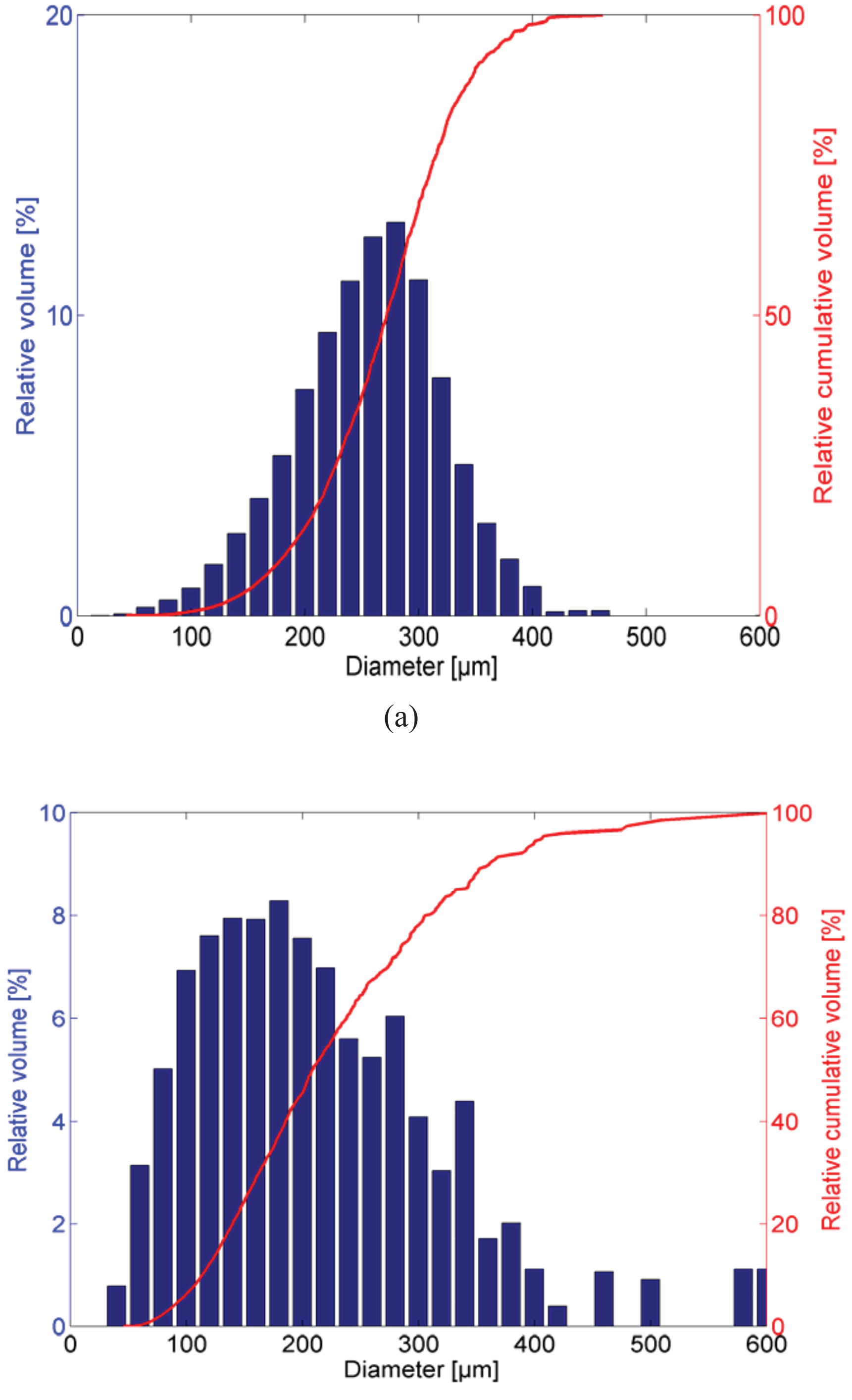
Spray retention

Measurements of spray retention for the two single spray generators are presented in Table 3. At this early growth stage of barley, results show that a higher retention can be achieved by the Micromax compared to the XR11002 flat fan nozzle. This difference is not statistically significant because of the high variation in deposits (Table 3). This can be linked to the natural variability of barley plants shapes and orientations which are slightly different from one trial to another. Furthermore, each plant is not exposed exactly to the same droplet flow during the spray generator passage.

It can be concluded that the coarser spray quality of the Micromax was not detrimental to retention when a surface active ingredient was used in the spray mixture to avoid bouncing. The forward angled spray may have also a positive influence as forward angling trends toward a higher retention.

Spray drift measurements

The spray drift percentage for each sampling line at 2.0 m distance from the nozzle for the two nozzles are plotted to illustrate the vertical drift profile (Fig. 4). It appears that the two ssingle spray generators present different drift profiles. The hydraulic nozzle does not contaminate the collectors located above (600 mm) and at nozzle height (500 mm). The drift contamination starts 10 cm below the nozzle height and then increases rapidly. The profile of the rotary atomiser is much more regular and starts 10 cm above the ejection height. The curves for both nozzle types cross at 30 cm



(a)

(b)

Fig. 3. Relative and cumulative droplet size distributions for both nozzles: (a) Micromax120 rotary atomiser (5000 rpm) (b) Teejet XR11002 flat fan nozzle (1,4 bar spray pressure).

height, the hydraulic nozzle deposits increase much faster with lower heights. These differences are linked to the combined action of top angle differences, drop size span and entrained air. For the hydraulic nozzle, the entrained air acts as the ejection height of drops was reduced. The high drop 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 drops are entrained according to their size. For the Micromax, the air entrainment is not marked, probably because of the atomiser geometry that results in a less dense spray and the forward angle used and the drop density in the spray. Drops, of much more homogeneous size ejected 60° forward, drift under the combined effect of advection and turbulence that brings some big drops above the ejection point. The hydraulic

Table 3. *Spray retention (fluorescein dose per cm^2) on barley 2–3 leaves (BBCH13)for a Micromax rotary atomiser and a Teejet XR11002 flat fan nozzle both delivering a flow rate of 0.563 L min^{-1} at a forward speed of 2 m s^{-1}*

	Micromax 120			Teejet 11002		
Trial #	Leaves area (cm^2)	Deposits (µL)	Volume rate (µL cm^{-2})	Leaves area (cm^2)	Deposits (µL)	Volume rate (µL cm^{-2})
1	41.55	8.53	0.21	41.59	5.32	0.13
2	43.36	6.57	0.15	39.4	3.17	0.08
3	41.19	4.87	0.12	55.61	5.86	0.11
4	71.64	7.21	0.10	47.87	5.28	0.11
5	63.64	6.27	0.10	54.06	2.67	0.05
Mean	52.28	6.69	0.13	47.71	4.46	0.09
STD	14.33	1.34	0.04	7.23	1.44	0.03

nozzle whose total drift is 9.10% drifts generally more than the rotary atomizer characterized by a total drift of 4.73%.

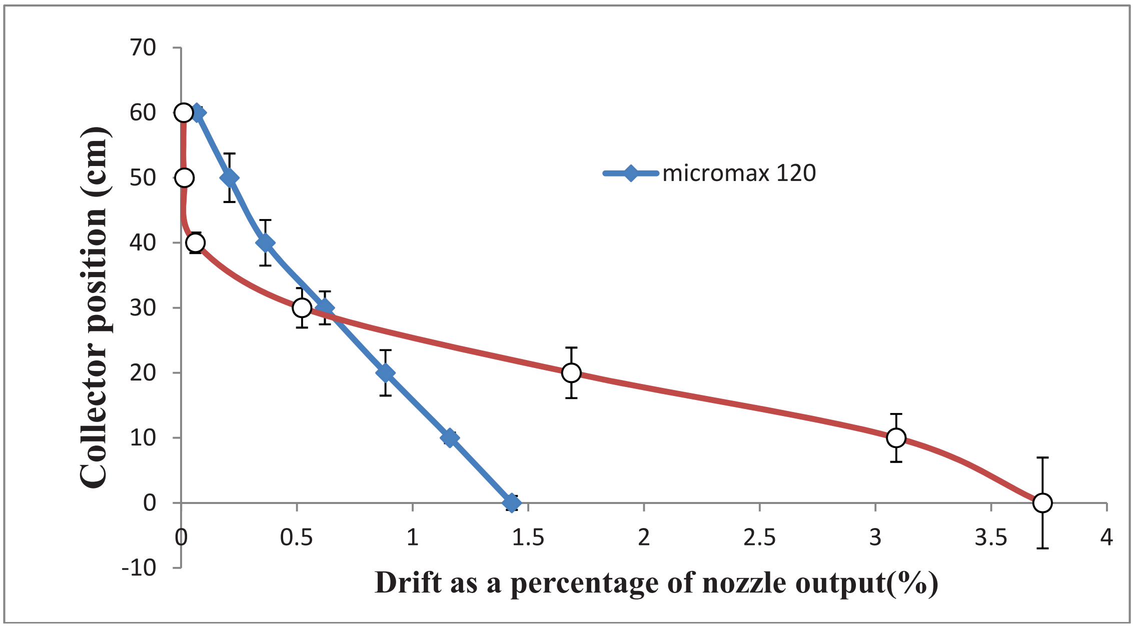


Fig. 4. Vertical drift profile as a percentage of nozzle output: (% of what?) the Micromax 120 rotary atomiser and the Teejet XR11002 flat fan nozzle at 2.0 m from the nozzle in a wind tunnel operating at a wind speed of 2 m s^{-1} and the nozzle moving perpendicular to the wind direction with a speed of 2 m s^{-1}.

Discussion

Based on literature, it was stated that the use of 60° forward angled spray combined with the narrow and coarser drop size distribution of a rotary atomiser could be a mean to combine low drift and higher retention on monocotyledonous weeds at early stage. The tilted atomiser with 270 µm VMD seems to be an efficient approach since higher retention was achieved using the Micromax 120 and a superspreader adjuvant even if the increase was not proved statistically significant by these trials. This can be explained by the fact that upstanding barley leaves target represents the ideal structure to intercept the spinning disc droplets with an angled trajectory (Jensen, 2012). On the drift side, the tilted rotary atomiser seemed to be advantageous since droplet spectra contains a low percentage of droplets under 100 µm and present a high ejection velocity, 25 m.s^{-1} at 5000 RPM. However, these settings were not as efficient as expected and angled spray proved to be more sensitive to advection and turbulence, as the spray was more exposed to the airflow than for the vertical position. Drift studies performed by Qi *et al*. (2008) showed that horizontal spinning disc produced general more drift than flat fan nozzles. An attempt to compare their results seems difficult since the setting are quite different but it appears that angling the spray and choosing drops as big as 270 µm are not sufficient to reduce significantly this issue. Some alternatives as decreasing the emission height are possible with an angled spray but require height control in the field that may be out of reach in practical situations. A complete modelling of the spray application process is needed to seek an optimal angle and diameter according to the canopy structure to guide future trials.

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