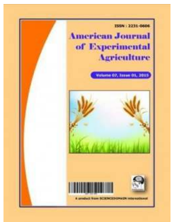

American Journal of Experimental Agriculture
11(3): 1-5, 2016, Article no.AJEA.23785
ISSN: 2231-0606

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Evaluation of the Spray Droplet Size Spectra of Drift-reducing Agricultural Spray Nozzle Designs

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JAM and PAB designed the study. Authors WCH and BKF constructed the wind tunnel and designed the droplet sizing protocol. Author JAM conducted the droplet size testing and statistical analyses. Author JAM wrote the first draft. Authors PAB, WCH and BKF assisted in final manuscript preparation. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2016/23785
Editor(s):
(1) Craig Ramsey, Department of Agriculture, Animal & Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, 2301 Research Blvd., Suite 108, Fort Collins, CO 80526, USA.
(2) Mariusz Cycon, Department and Institute of Microbiology and Virology, School of Pharmacy, Division of Laboratoty Medicine, Medical University of Silesia, Poland.
Reviewers:
(1) Bahadir Sayınci, Ataturk University, Turkey.
(2) Gandolfo, Northern Parana State University, Brazil.
Complete Peer review History: http://sciencedomain.org/review-history/13218

Received 22nd December 2015
Accepted 29th January 2016
Published 8th February 2016

Original Research Article

ABSTRACT

Aims: To evaluate the spray droplet size spectra of several different agricultural spray nozzles using laser diffraction technology.

Place and Duration of Study: This study was conducted at the United States Department of Agriculture – Agricultural Research Service Aerial Application Technology Research Unit facility in College Station, Texas during April 2014.

Methodology: The spray droplet size spectra of five agricultural spray nozzles utilizing different designs were evaluated in a low-speed wind tunnel. These designs included standard flat-fan, pre-orifice, and air-induction designs. This wind tunnel was equipped with a laser diffraction sensor to analyze spray droplet diameters. A solution of 0.25% v/v nonionic surfactant in water was used to

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simulate the solution characteristics of many pesticide sprays.

Results: Due to the precision of the droplet sizing equipment, many significant differences in droplet size spectra were detected among all nozzle designs. Increases in median droplet diameters as great as 265% were observed between drift reducing nozzles and standard flat-fan nozzles. Additionally, decreases in the production of drift-prone droplets (≤ 100 μm in diameter) as great as 97.3% were observed with the use of drift reducing designs.

Conclusion: Nozzle designs that utilized a pre-orifice resulting in larger median droplet diameters and fewer droplets of very small diameter. Additional reductions in spray drift potential were achieved with nozzles that utilized an air induction design in conjunction with a pre-orifice.

Keywords: Spray nozzles; droplet size; spray drift; pre-orifice; air induction; venture.

1. INTRODUCTION

The prevention of harmful drift of pesticide sprays remains a large concern for pesticide applicators. With the widespread popularity of existing herbicide-tolerant crop technologies and the likely release of new synthetic auxin-tolerant crop technologies in the near future, there is an increased need for understanding the influence of spray nozzle design on spray drift reduction. The size of droplets exiting the spray nozzle has a large effect on the potential for physical spray drift to occur. Smaller droplet diameters generally correspond to lower droplet velocity, especially for droplets smaller than 400 μm in diameter [1]. Lower droplet velocities translate into an increased duration of time between exiting the spray nozzle and deposition on the target [2]. The length of this interval is directly related to the potential for off-target movement of the droplet. Further complicating this effect is the decrease in droplet size after exiting the nozzle due to evaporation. Smaller droplets have higher surface area to volume ratios, resulting in an increased rate of evaporation of water in the spray solution [3]. This evaporation of water can result in a rapid decrease in droplet size before deposition takes place, further exacerbating the risk for drift of spray droplets [4].

There are three common designs seen in modern agricultural flat-fan spray nozzles: (1) conventional nozzles where the spray solution simply passes through an orifice and exits the nozzle, (2) low-drift nozzles that typically utilize a pre-orifice of smaller size than the exit orifice to slow the flow of the spray solution prior to reaching the exit orifice, and (3) air induction nozzles that draw air into the spray solution through venturi ports before exiting the nozzle. Spray nozzles advertised as drift-reducing nozzles often utilize either of the latter two designs or a combination of these [5]. Past experiments have found that air induction nozzles had the greatest drift reduction potential, followed by nozzles with pre-orifice and conventional flat-fan nozzles [6]. This trend has been observed by several others [1,7,8], though the role of the air induction design on increasing droplet diameters is somewhat unclear and may simply be a result of larger exit orifice size [5,9].

2. MATERIALS AND METHODS

A low-speed wind tunnel in College Station, TX was utilized for analyzing the effect of herbicide formulation and spray nozzle on droplet size spectra. The tunnel is 1.2 X 1.2 m in cross-section and 14.6 m in length. Airflow from a fan at the upstream end of the tunnel pushes air through flow straighteners to produce a laminar flow in the tunnel. Air speed was 6.7 m sec^{-1}. Spray droplet sizing was conducted with the Sympatec Helos/KR laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany). The sensor consists of two portions, an emitter and a receiver. The emitter houses a 623 nm helium-neon laser that is aligned with the receiver. The receiver is fitted with an R7 lens with a dynamic sizing range of 0.5 to 3500 μm across 32 sizing “bins”. The sensor is positioned such that the laser horizontally crosses the center of the downstream end of the tunnel. A single spray nozzle is affixed to a vertically-mounted traverse system that allows the nozzle to travel from the top to the bottom of the tunnel over a 1-m length. The traverse system is positioned such that the spray nozzle is 30.5 cm upstream of the Helos sensor. Three replications were conducted for each combination of spray nozzle and operating pressure. Each replication consisted of traversing the vertically-aligned spray nozzle from the top to the bottom of the tunnel so that the entire spray plume travelled across the Helos laser. A portable air scrubber was positioned at the downstream end of the tunnel to capture airborne spray solution.

Spray nozzles for this study included the XR 11002 Extended Range, DG 11002 Drift Guard, AIXR 11002 Air Induction XR, AI 11002 Air Induction, and TTI 11002 Turbo TeeJet Induction flat spray tips (TeeJet Technologies, Wheaton, Illinois). Nozzles, recommended operating pressures and manufacturer-estimated droplet sizes produced at a given pressure are shown in Table 1. The numerical designation of spray nozzles denotes the angle of the spray plume and the flow when operated at a pressure of 275 kPa (40 psi). In the case of the nozzles included in this study, all produce 110° spray plumes and flow 0.757 L min^{-1} (0.2 GPM) at 275 kPa. The XR nozzle is a conventional flat-fan nozzle with a single orifice. The DG nozzle utilizes a pre-orifice to regulate the flow of the spray solution before it is discharged through a larger exit orifice. The AI, AIXR, and TTI nozzles are all air-induction nozzles that also utilize a pre-orifice. Operating pressures for this study were 207 and 414 kPa. New, unused nozzles were utilized for this study. Before droplet size analyses were conducted, nozzles were tested to verify that their flow rate is within manufacturer specifications. TeeJet 8079 50-mesh strainers were used for all nozzles to prevent any contaminant from altering the spray pattern characteristics or droplet sizes produced by the nozzles. The spray solution included 0.25 % v/v Activator 90 non-ionic surfactant (Loveland Products, Greeley, CO) in water. This spray solution was chosen as a representative of water-based post-emergence herbicide solutions. Spray solutions were prepared in 11 L samples placed into 19 L stainless steel containers pressurized by compressed air. An inline air pressure regulator was placed between the compressed air source and spray containers to regulate operating pressure. Nozzles were operated at both 207 and 414 kPa.

Table 1. Spray nozzle specifications as supplied by the manufacturer

Nozzle	Operating pressure range	Manufacturer-estimated VMD	
		207 kPa	414 kPa
	kPa	μm	μm
XR	103-414	136-177	136-177
DG	207-414	177-218	177-218
AIXR	103-620	349-428	218-349
AI	207-689	428-622	349-428
TTI	103-689	>622	>622

For each simulated spray, the Helos sensor system calculates $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ values, which are the droplet sizes in μm for which 10, 50, and 90% of the spray volume is made up of droplets less than or equal to that size. Relative span (RS) is a relative measure of the spread of the droplet size distribution of the spray volume and is calculated by the following equation: $(D_{v0.9} - D_{v0.1}) / D_{v0.5}$. Also, the percentage of the total spray volume made up of droplets less than 50 and 100 μm was recorded and used as indicators of the portions of the spray that are highly susceptible to spray drift. Data were subjected to ANOVA and means were separated by using Tukey's honestly significant difference (HSD). All statistical analyses were conducted using JMP 10 [10].

3. RESULTS AND DISCUSSION

When the effect of spray nozzles on droplet size spectra was analyzed, many differences were detected. These data are summarized in Tables 2 and 3. At both 207 and 414 kPa, all nozzles differ significantly from each other for $D_{v0.1}$, $D_{v0.5}$ and $D_{v0.9}$ values. Nozzles ranked in order of increasing droplet size spectra based on these data are as follows; XR < DG < AIXR < AI < TTI.

At 207 kPa, $D_{v0.5}$ values range from 265 μm with the XR nozzle to 969 μm with the TTI nozzle. Further examination of droplet size spectra at 207 kPa revealed that sprays produced by the XR nozzle contained the greatest portion of total spray volume in drift prone droplets (0.33% ≤ 50 μm, 3.80% ≤ 100 μm). Nozzles ranked in order of increasing production of drift-prone droplets are as follows; TTI and AI < AIXR < DG < XR. As expected, droplet size spectra of all nozzles decreased when operating pressure was increased to 414 kPa. Overall, droplet size spectra produced at 414 kPa followed a similar trend to that observed at 207 kPa. $D_{v0.5}$ values ranged from 195 μm with the XR nozzle to 656 μm with the TTI nozzle. At 414 kPa, the percentage of the total spray volume made up of droplets less than 50 and 100 μm with the XR nozzle increased to 1.67 and 11.57%, respectively. An increase in the production of fine droplets due to increased operating pressure was also observed with the other nozzles, but to a lesser extent. RS values of the TTI nozzle increased by approximately 23% when operating pressure was increased from 207 to 414 kPa, indicating an increase in the width of the droplet size distribution of that nozzle. Slight changes in RS values were observed with the other nozzle designs when operating pressure was increased, but to a lesser degree than that of the TTI nozzle.

Table 2. Effect of spray nozzle on droplet size spectra at 207 kPa

Nozzle	$D_{v0.1}$[a]	$D_{v0.5}$	$D_{v0.9}$	RS	Percentage of spray volume comprising droplets with diameters less than:	
	µm	µm	µm	µm	50 µm	100 µm
XR 11002	134 a	265 a	427 a	1.107	0.332 a	3.800 a
DG 11002	205 b	393 b	624 b	1.077	0.168 b	1.010 b
AIXR 11002	301 c	538 c	841 c	1.067	0.100 c	0.396 c
AI 11002	459 d	838 d	1362 d	1.047	0.005 d	0.067 d
TTI 11002	526 e	969 e	1540 e	1.003	0.002 d	0.044 d

[a] *Within a column, means followed by different letters are significantly (P<0.05) different*

Table 3. Effect of spray nozzle on droplet size spectra at 414 kPa

Nozzle	$D_{v0.1}$[a]	$D_{v0.5}$	$D_{v0.9}$	RS	Percentage of spray volume comprising droplets with diameters less than:	
	µm	µm	µm	µm	50 µm	100 µm
XR 11002	94 a	195 a	320 a	1.157	1.672 a	11.565 a
DG 11002	141 b	284 b	452 b	1.093	0.386 b	3.584 b
AIXR 11002	192 c	370 c	581 c	1.050	0.182 bc	1.505 c
AI 11002	297 d	536 d	837 d	1.007	0.049 c	0.424 d
TTI 11002	334 e	656 e	1137 e	1.220	0.043 c	0.245 d

[a] *Within a column, means followed by different letters are significantly (P<0.05) different*

Nozzles that utilized a pre-orifice (DG, AIXR, AI, and TTI) resulted in greater median droplet diameters than the XR nozzle. In addition, nozzles with a pre-orifice produced fewer drift-prone droplets of very small diameter, indicating a lower potential for spray drift to occur. Similar to the findings of [6], nozzles that utilized an air induction design in addition to a pre-orifice (AIXR, AI, and TTI) resulted in additional reductions of spray drift potential compared to the XR or DG nozzles.

4. CONCLUSION

A major goal for all agricultural pesticide applicators should be the reduction of harmful spray drift. The results of this study provide valuable insight into the efficacy of drift-reducing spray nozzles designs and demonstrate that of the nozzle designs tested, those which utilize air induction designs in conjunction with a pre-orifice produce a greater proportion of large diameter spray droplets and fewer drift-prone fine spray droplets, both of which will certainly reduce the risk of spray drift. The selection of the proper spray nozzle by applicators will be vital to help reduce off-target damage and contamination by pesticides due to spray drift.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/13218