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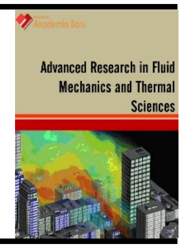

Assessment of atomization parameters for flat fan nozzles based on wind tunnel measurements

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ABSTRACT

The main objective of this study involved testing of nozzle type, driving speed and wind speed effects on atomization parameters for broadcast spraying application. Two broadcast nozzle types flat fan extended range XR11003 and flat fan drift guard nozzle DG11003 were tested under wind tunnel conditions. To validate spraying results, the reference nozzle of spraying systems flat fan TeeJet nozzle TP11003 was used for comparison. The results of this study indicate an obvious effect of the technical variables and wind variable on atomization parameters. The nozzle DG11003 produced droplet size spectra of D0.1, D0.5 and D0.9 bigger than the extended range nozzle and reference nozzle. The droplet size spectra became smaller under increasing of the driving speed. Droplet size parameters generally tended to be coarser at the higher wind speeds. This study supports the use of nozzle DG11003 as a means for controlling spray distribution.

1. Introduction

The agricultural spraying application has long been interested in atomization parameters of the spray nozzles used on agricultural sprayers. The most important interest in droplet size was related to their influence on spray density, coverage and penetration in the plant canopy. Recent concerns about spray drift to the non-targeted areas by the action of air flow have increased an interest in droplet spectra classifications (DSC) of sprayed chemical. Droplet size, driving speed of the sprayer, and wind speed are the dominant factors in determining spray drift [1-4].

Practical trails of spraying applications have shown that small-to-medium sized droplets are desirable to achieve better spray distribution within the canopy but large droplets are good for drift reduction and attaining a balance between the two is essential [5]. Spray nozzle is carefully designed to achieve specific performance under certain conditions [6, 7]. The use of new hydraulic nozzles in

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controlled droplet application (CDA) represents a significant advance in the precision of spraying over conventional spraying nozzles [8-10].

In agricultural sprays, the nozzles generally are carried behind equipment and move over the plants. The driving speed of an equipment induces a relative cross-wind, increases pressure of air on spraying nozzle. The air flow around the spray which together with any cross wind affect spray droplets in two ways: the first effect is by bending and distorting the vertical air jet induced by the spray and the second effect is deflecting the larger droplets. The smallest and finest droplets escape from the spray as a result to the first effect and therefore not falling directly on to the crops, resulting in a higher amount of spray falling far away from the target, and this is commonly termed as spray drift [11]. Driving speed is the main factor that affects the Drift potential index (DPI) [2, 12-14] and there is a positive correlation between driving speed of sprayer and drift [15-17].

Wind speed is the most critical variable that affects drift. The higher wind speed, the farther drift will be carried. In a weak cross-wind, small droplets resort to aggregate towards the spray centerline. Meanwhile, in a strong wind, the small droplets have low inertial energy and cannot resist strong air flow, making them highly susceptible to drift [11]; and therefor, important agrochemical amounts are transferred to an ecosystem by wind [4]. The main objective of this study is to estimate atomization parameters for different flat fan nozzles under the effect of driving sprayer speed and wind speed.

2. Materials and Methods

2.1 Selection Nozzles

Spray nozzles selected for this study were two flat-fan nozzles for broadcasting spraying**:** extended range XR11003 and drift guard DG11003 nozzles as shown in Figure 1. These nozzles are manufactured by spraying systems co, Inc. Wheaton, Illinois, USA and classified according to the International Organization for Standardization (ISO) of size 03 (0.3gpm) [18]. The reference nozzle of spraying systems 110° Flat fan TeeJet nozzle with a 03 orifice operated was selected to define the fine/medium spraying boundary in the ASABE Standard. Table 1 shows specifications of spray nozzles.

A b c

Fig. 1. Flat fan nozzles: (a) DG11003 (b) XR11003 (c) TP11003

Table 1
Specifications of spray nozzles

Nozzle type	Nozzle code	$D_{0.5}$ (μm)*	Pressure (bar)	Flow rate (L/m)
TeeJet**	TP11003	136 - 177	3	1.18
Extended range	XR11003	136 - 177	3	1.18
Drift guard	DG11003	177 - 218	3	1.18

* Droplet size classifications are based on BCPC specifications and in accordance with ASAE Standard S-572.
**TeeJet standard flat fan nozzle was used as a reference nozzle.

2.2 Wind Tunnel

The subsonic wind tunnel built by the department of aeronautic at university technology Malaysia was used to determine the effect of wind speed on spray distribution from the nozzle ([19-24]. The test section of the wind tunnel has a cross-sectional area of 1.36 m by 1.36 m and an overall length of 5 m with a honeycomb and porous fabric to produce the required air turbulence intensity and uniform velocity.

A multi speed spraying mechanism was designed and installed on the wind tunnel to investigate effect of driving sprayer speed and wind speed combinations on spray distribution. The spray mechanism consists of the following systems: Linear motion system consists of linear motion platform (SIMO series, PBC linear, A pacific Bearing Company, 6402 East Rokton Road, Roscoe, IL61073, USA), servo motor (GYS - 751 D5 - HC 2, Japan) and servo amplifier (RYT - 751 D5 - VV 2 Japan) and spraying system consists of an external pressurized water tank, filter, water pressure gauge, and single spray nozzle [25]. The spray liquid was tap water. The spraying nozzle was moving horizontally in the wind tunnel; perpendicular to the airflow [26] to generate two-dimensional spray pattern. The speed of the linear motion system was controlled from a laptop depending on the software programmed.

3.4 Measuring Protocol

Two groups of factorial experiments were carried out in the wind tunnel to evaluate the effect of the nozzle type, driving speed and wind speed on spray parameters. The first group comprised of two nozzle types XR11003 and DG11003 with reference nozzle TP11003 and three wind speeds of 1, 2, and 3m/s at driving speed of 2.2 m/s. The second group comprised of three driving speeds of the reference nozzle TP11003 of 2.2, 3.3 and 4.4 m/s at three wind speeds of 1, 2, and 3m/s. Spray height was 0.50m above the wind tunnel ground, with spray pressure of 3 bar. For spray distribution data, water sensitive papers (WSPs) were used as collections placed at the center of the wind tunnel at one row under the spray nozzle at five places [27, 28], and the distance between two samples was 25cm. All samples were at a height of 0.07 m above the wind tunnel floor to avoid boundary layer effects and the corresponding long axis parallel to the wind direction as shown in Figures 2. After each spray run, the WSPs were allowed to dry and then collect. Each test was repeated three times. Each piece of WSPs was put in a small plastic box and took to the laboratory for calculating DSC. To determine the real droplet diameter, the spot diameters were inserted into the following calibration equation [29, 30]

$$D_r = 1.033 D_s^{0.879} \tag{1}$$

where D_r is represented the actual droplet diameter (µm), Ds is represented the spot diameter (µm). Program was written to calculate the droplet spectra characteristics. Analyses of the droplet spectra characteristics (DSC) were made within 28 different diameter class ranges. In the software, the mean droplet diameters (D_{10}, D_{20}, D_{30}, D_{32}), the diameter values corresponding to 10, 25, 50, 75 and 90% in volumetric distributions ($DV_{0.10}$, $DV_{0.25}$, $DV_{0.50}$, $DV_{0.75}$ and $DV_{0.90}$), numerical and volumetric percentage ratio of droplets in diameter smaller than 200 µm were calculated [29, 31]. Performance evaluating of the tested nozzle was obtained from testing the results in comparison to the reference spray. The reference spray was defined as a standard horizontal spray boom without air support, a spray boom height of 0.50 m, ISO 110 03 standard flat fan nozzles at pressure of 3.0 bar, wind speed of 2m/s and a driving speed of 8 km h^{-1}, resulting in an application rate of approximately 180 L ha^{-1} [32, 33].

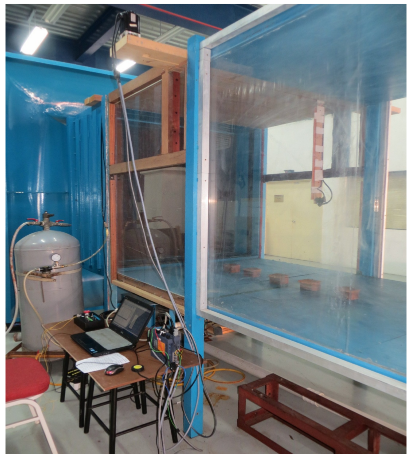

Fig. 2. Experimental set up for testing spray nozzles in the wind tunnel.

3. Results and Discussion

3.1 Effect Nozzle Type

In Figure 3, it is clear that the nozzle type has an important effect on droplet size. Pre orifice nozzle DG11003 produced droplet sizes coarser than the extended range nozzle XR11003 and the reference nozzle. The $Dv_{0.5}$ value of the pre orifice nozzle DG11003 increased 24.3% and 23.5% in comparison to the extended range nozzle XR11003and reference nozzle respectively.

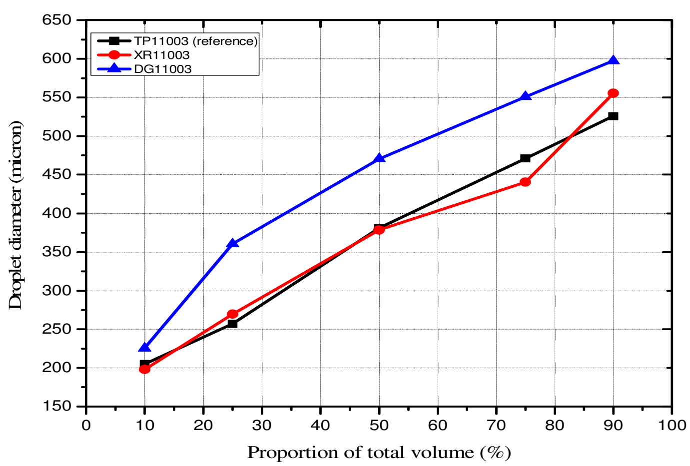

Fig. 3. Graph of droplet diameters vs proportion of total volume for three nozzles

3.2 Effect Nozzle Type and Wind Speed Combinations

The results of the droplet size measurements smaller than 200 µm for tested nozzles are described in Figure 4. Measured volume fractions of droplets smaller than 200µm of the nozzles at three wind speeds ranged from 6% to 20%. Based on the change in the percentage of droplet smaller than 200 µm under the effect of wind speed, the tested nozzles produced less drift potential than the reference nozzle [28]. It is clear that nozzle DG1103 achieved the best control the droplet spectra under the effect of a high wind speed in which the parentage of droplet smaller than 200 µm reduced only 40.82% when wind speed changed in the range of 1to 3m/s in comparison to the reference nozzle, which reached 58.68 %. Increasing wind speed reduced the percentage of the droplet smaller than 200 µm in the total spray volume.

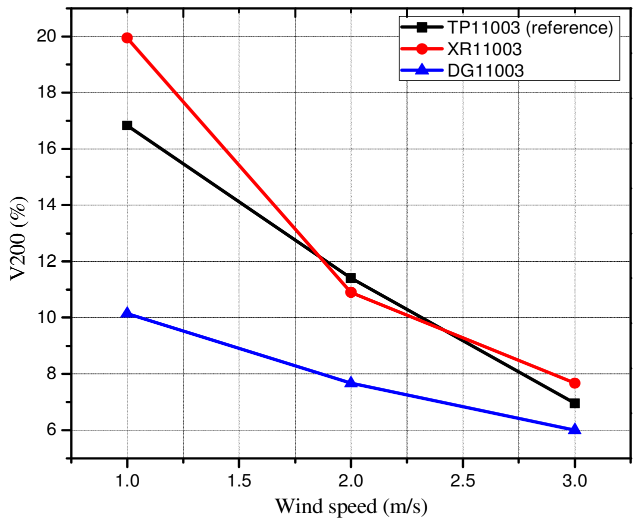

Fig. 4. Graph of V200 vs wind speed for three nozzles

Table 2
DSC: $Dv_{0.1}$, $Dv_{0.25}$, $Dv_{0.5}$, $Dv_{0.75}$, $Dv_{0.9}$, at driving speed of 2.2 m/s

Nozzle type	Wind Speed (m/s)	Dv0.1 (µm)	std	Dv0.25 (µm)	std	Dv0.5 (µm)	std	Dv0.75 (µm)	std	Dv0.9 (µm)	std
	1	168.6	12.70	253.2	38.49	373.9	55.37	482.4	76.82	549.0	31.19
TP11003	2	205.2	14.99	257.1	45.37	381.0	54.70	470.9	23.36	525.6	29.75
	3	228.9	25.13	298.9	26.70	381.0	37.11	490.1	23.22	538.6	7.073
	1	163.0	6.557	226.9	10.15	323.8	24.49	440.2	29.03	521.1	14.97
XR11003	2	198.1	16.18	269.7	30.32	378.6	33.31	440.4	31.95	555.5	73.50
	3	228.5	21.28	334.7	45.03	415.4	19.46	501.0	14.73	581.7	2.250
	1	198.1	6.868	339.6	8.736	456.0	4.35	522.2	15.67	567.3	9.073
DG11003	2	225.6	26.07	360.4	32.46	470.6	21.22	550.9	42.45	597.3	56.72
	3	244.0	34.37	343.7	26.78	471.6	23.15	550.3	5.710	594.3	34.26

std: average ± standard deviation

Table 3
DSC: D_{10}, D_{20}, D_{30} *and* D_{32} at driving speed of 2.2 m/s

Nozzle type	Wind speed (m/s)	D_{10} (µm)	std	D_{20} (µm)	std	D_{30} (µm)	std	D_{32} (µm)	std
	1	169.1	5.556	200.1	9.732	231.1	15.61	308.6	33.71
TP11003	2	206.0	3.896	237.2	9.791	264.9	14.45	330.6	26.92
	3	216.6	12.99	249.9	11.77	279.7	13.14	350.4	23.70
	1	191.9	8.450	234.3	6.614	273.6	6.156	372.9	4.499
XR11003	2	196.3	16.01	240.2	18.09	282.2	20.63	389.4	29.56
	3	248.7	10.07	285.2	14.35	318.2	17.01	396.1	23.67
	1	169.5	7.212	196.2	6.868	223.1	5.601	288.8	4.152
DG11003	2	205.0	7.449	232.5	10.49	259.7	12.66	324.0	18.37
	3	219.8	6.077	254.0	1.823	286.8	2.266	365.9	13.12

std: average ± standard deviation

Tables 2 and 3 show the effect of type of nozzle and the wind speed on droplet spectra. Increasing wind speed increased droplet size spectra of the nozzles. The nozzle DG1103 achieved the highest DSC values in comparison to the reference nozzle at the range of wind speed of 1-3 m/s. DSC values indicate that increasing of the wind speed changed the spray quality to be coarser.

3.3 Effect of Driving Sprayer-Wind Speed Combinations

Driving speed is an important factor that affects DSC [11, 34]. A greater portion of smaller spray droplet volumes is subject to entrainment in the air [28]. The data in Tables 4and 5 typically showed important variations in droplet sizes under the effect of the different driving speeds and wind speeds, the droplet size spectra measurements from nozzles became smaller for increasing of driving speed [35]. The droplet sizes parameters in generally tended to be larger under the nozzle at higher wind speeds [16, 28] because the smallest droplets would move the farthest distance before depositing on the ground [36].

Table 4
DSC: $Dv_{0.1}$, $Dv_{0.25}$, $Dv_{0.5}$, $Dv_{0.75}$, $Dv_{0.9}$ for nozzle TP1103

Driving Speed m/s	Wind Speed m/s	Dv0.1 (µm)	std	Dv0.25 (µm)	std	Dv0.5 (µm)	std	Dv0.75 (µm)	std	Dv0.9 (µm)	std
	1	168.6	12.70	253.2	38.49	373.9	55.37	482.4	76.82	549.0	31.19
2.2	2	205.2	14.99	257.1	45.37	381.0	54.70	470.9	23.36	525.6	29.75
	3	228.9	25.13	298.9	26.70	381.0	37.11	490.1	23.22	538.6	7.073
	1	164.3	10.88	252.0	7.850	353.9	13.46	436.2	9.254	520.0	23.63
3.3	2	190.3	19.21	268.6	15.82	354.0	47.82	425.9	55.55	498.0	55.02
	3	216.5	6.083	298.4	3.385	368.0	2.000	441.8	9.224	482.1	4.636
	1	168.9	9.430	211.3	11.98	323.2	15.39	431.8	46.87	506.9	27.46
4.4	2	169.5	10.25	263.2	7.868	329.6	3.055	435.2	50.64	488.4	50.93
	3	189.6	9.865	288.6	10.69	360.6	28.90	440.1	38.03	486.0	45.02

std: average ± standard deviation

Table 5
DSC: D_{10}, D_{20}, D_{30} and D_{32} for nozzle TP1103

Driving Speed m/s	Wind Speed m/s	D_{10} (µm)	std	D_{20} (µm)	std	D_{30} (µm)	std	D_{32} (µm)	std
	1	169.1	5.556	200.1	9.732	231.1	15.61	308.6	33.71
2.2	2	206.0	3.896	237.2	9.791	264.9	14.45	330.6	26.92
	3	216.6	12.99	249.9	11.77	279.7	13.14	350.4	23.70
	1	182.6	13.18	210.5	13.78	238.1	13.78	304.4	13.24
3.3	2	193.4	10.36	223.7	5.797	250.5	5.578	314.5	20.11
	3	206.8	4.700	239.1	5.031	267.3	4.505	333.9	3.320
	1	161.6	6.670	189.6	9.464	216.5	11.74	282.1	18.14
4.4	2	202.9	9.737	228.8	6.074	251.9	2.856	305.6	8.080
	3	211.8	4.670	242.0	7.000	267.9	9.760	328.3	16.92

std: average ± standard deviation

Practically, droplets fall downward under effect of the gravitational force whereas, drag forces act to slow the fall rate. Very small droplets fall so slowly because the upward drag forces are almost equally opposed by gravitational force. Pre-orifice flat fan nozzle DG has ability to produce more coarse and drift-resistant spray droplets in comparison to the standard flat nozzle [37] due to reduce internal liquid pressure by pre-orifice locates on the side of the nozzle to restrict the flow [38]. Driving speed plays an important role in controlling the drift potential. The performance of hydraulic nozzles is affected by air shear; as airspeed increases, so does air shear that shatters the large droplets resulting in increasing the percentage of the fine droplets and turbulence. The higher the driving speed, the greater the spray drift. The droplet sizes parameters under the nozzle generally tended to be larger at higher wind speeds due to drift the smallest droplets under the effect of the action of the air flow.

4. Conclusion

Agricultural spraying application raises a lot of problems; spray distribution and drift is the most important. Squandering of big quantities of chemical can cause a lot of problems such as pollution of the ecosystem and increasing the farming cost. Wind tunnel experiments provided efficient methods to assess atomization parameters and helped interpretation number of variables involved in the field because the weather conditions can be controlled easily. According to the result of the wind tunnel for investigating droplet spectra classifications (DSC), drift guard nozzles DG have improved spray distribution by controlling drop size at higher wind speeds. This study supports the use of drift guard nozzle DG instead of the standard flat fan nozzle on every sprayer.

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References

[1] Hofman, Vern, and Elton Solseng. "Reducing spray drift." (2009)..

[2] Kirk, Iva W. "Measurement and prediction of helicopter spray nozzle atomization." *Transactions of the ASAE* 45, no. 1 (2002): 27.

[3] Ellis, MC Butler, T. Swan, P. C. H. Miller, S. Waddelow, A. Bradley, and C. R. Tuck. "PM—power and machinery: design factors affecting spray characteristics and drift performance of air induction nozzles." *Biosystems Engineering* 82, no. 3 (2002): 289-296.

[4] Bahrouni, H., C. Sinfort, and E. Hamza. "An approach for pesticide loss estimation adapted to field crops in Mediterranean conditions." In *XVIIth World Congress of the International Commission of Agricultural Engineering (CIGR)*, pp. 1-p. 2010.

[5] Grisso, R.D., Ozkan, H. E., Hofman, V. L., Womac, A., Wolfe, R., Hoffmann, W.C., Williford, J., and Valco, T., Pesticide application Equipment. In: Conservation Tillage Systems and Management Handbook. MWPS-45, Ames, IA:MWPS., 2000

[6] Hoffmann, Wesley Clint, and Ivan W. Kirk. "Spray deposition and drift from two “medium” nozzles." *Transactions of the ASAE* 48, no. 1 (2005): 5-11.

[7] Hoffmann, Wesley, Bradley Fritz, William Bagley, Joe Gednalske, Curt Elsik, and Greg Kruger. "Determination of selection criteria for spray drift reduction from atomization data." In *Pesticide Formulation and Delivery Systems: 32 nd Volume, Innovating Legacy Products for New Uses*. ASTM International, 2013.

[8] Bals, T. E. "Economical Pesticide Application: The Reasons for Controlled Droplet Application." In *Pesticide Formulations and Application Systems: Seventh Volume*. ASTM International, 1987..

[9] Nuyttens, D., M. De Schampheleire, W. Steurbaut, Katrijn Baetens, Pieter Verboven, Bart Nicolai, Herman Ramon, and B. Sonck. "Characterization of agricultural sprays using laser techniques." *Aspects of applied biology* 77, no. 1 (2006): 179.

[10] Hoffmann, Wesley, Bradley Fritz, Jonathan Thornburg, William Bagley, Norman Birchfield, and Jay Ellenberger. "Spray drift reduction evaluations of spray nozzles using a standardized testing protocol." In *Pesticide Formulations and Delivery Systems, 30th Volume: Regulations and Innovation*. ASTM International, 2011.

[11] Ghosh, S., and J. C. R. Hunt. "Spray jets in a cross-flow." *Journal of Fluid Mechanics* 365 (1998): 109-136.

[12] Akesson, N. B., and W. E. Yates. "Pesticide deposit and activity as a function of spray atomizers and liquid formulation." In *Agricultural engineering: Proceedings of the eleventh International Congress on Agricultural Engineering, Dublin*, pp. 2081-2090. 1989.

[13] Barbosa, R. "Equipment Setup for Aerial Application of Liquid Pesticides." *LSU, ag center, Department of Biological and Agricultural Engineering* (2010).

[14] Vanella, Giuseppe, Masoud Salyani, Paolo Balsari, Stephen H. Futch, and Roy D. Sweeb. "A method for assessing drift potential of a citrus herbicide applicator." *HortTechnology* 21, no. 6 (2011): 745-751.

[15] Arvidsson, Tommy, Lars Bergström, and Jenny Kreuger. "Spray drift as influenced by meteorological and technical factors." *Pest management science* 67, no. 5 (2011): 586-598.

[16] Van de Zande, J., et al. Effect of sprayer speed on spray drift. in International Conference on Pesticide Application for Drift Management, Waikoloa, Hawaii. 2004.

[17] De Schampheleire, Mieke, K. Baetens, D. Nuyttens, and Pieter Spanoghe. "Spray drift measurements to evaluate the Belgian drift mitigation measures in field crops." *Crop Protection* 27, no. 3 (2008): 577-589.

[18] Southcombe, E. S. E., P. C. H. Miller, H. Ganzelmeier, J. C. Van de Zande, A. Miralles, and A. J. Hewitt. "The international (BCPC) spray classification system including a drift potential factor." In *Proceedings of the Brighton Crop Protection Conference-Weeds*, pp. 371-380. 1997.

[19] Parkin, C. S., and P. N. Wheeler. "Influence of spray induced vortices on the movement of drops in wind tunnels." *Journal of Agricultural Engineering Research* 63, no. 1 (1996): 35-44.

[20] Phillips, J. C., and P. C. H. Miller. "Field and wind tunnel measurements of the airborne spray volume downwind of single flat-fan nozzles." *Journal of Agricultural Engineering Research* 72, no. 2 (1999): 161-170.

[21] Miller, P. C. H., and MC Butler Ellis. "Effects of formulation on spray nozzle performance for applications from ground-based boom sprayers." *Crop protection* 19, no. 8 (2000): 609-615.

[22] Murphy, S. D., P. C. H. Miller, and C. S. Parkin. "The effect of boom section and nozzle configuration on the risk of spray drift." *Journal of agricultural engineering research* 75, no. 2 (2000): 127-137.

[23] Walklate, P. J., P. C. H. Miller, and A. J. Gilbert. "Drift classification of boom sprayers based on single nozzle measurements in a wind tunnel." *Aspects of applied Biology* 57 (2000): 49-56.

[24] Taylor, W. A., A. R. Womac, P. C. H. Miller, and B. P. Taylor. "An attempt to relate drop size to drift risk." In *Proceedings of the International Conference on Pesticide Application for Drift Management*, pp. 210-223. Pullman, WA: Washington State University, 2004.

[25] Nuyttens, D., S. Windey, and B. Sonck. "Optimisation of a vertical spray boom for greenhouse spray applications." *Biosystems Engineering* 89, no. 4 (2004): 417-423.

[26] Stainier, C., M-F. Destain, Bruno Schiffers, and Frédéric Lebeau. "Droplet size spectra and drift effect of two phenmedipham formulations and four adjuvants mixtures." *Crop Protection* 25, no. 12 (2006): 1238-1243.

[27] Fritz, B. K., Christopher Parker, J. D. López Jr, W. C. Hoffmann, and Paul Schleider. "Deposition and droplet sizing characterization of a laboratory spray table." *Applied engineering in agriculture* 25, no. 2 (2009): 175-180.

[28] Hoffmann, W.C., et al., Field swath and drift analyses techniques. Paper Number: AA03-007, 2003.

[29] Sayinci, B., S. Bastaban, and J. Sánchez-Hermosilla. "Determination of optimal spot roundness variation interval for droplet size analysis on water sensitive paper." *Journal of Agricultural Science and technology* 14, no. 2 (2011): 285-298.

[30] Fox, R. D., M. Salyani, J. A. Cooper, and R. D. Brazee. "Spot size comparisons on oil–and water–sensitive paper." *Applied Engineering in Agriculture* 17, no. 2 (2001): 131.

[31] Nuyttens, David, Katrijn Baetens, Mieke De Schampheleire, and B. Sonck. "Effect of nozzle type, size and pressure on spray droplet characteristics." *Biosystems Engineering* 97, no. 3 (2007): 333-345.

[32] Huijsmans, J. F. M., H. A. J. Porskamp, and J. C. Van de Zande. "Spray drift reduction in crop protection application technology. Evaluation of spray drift in orchards, field crops and nursery tree crops spraying (state-of-the-art December 1996)." *Dutch with English summary* (1997).

[33] Nuyttens, D., Drift from field crop sprayers: The influence of spray application technology determined using indirect and direct drift assessment means. 2007.

[34] Arvidsson, Tommy, Lars Bergström, and Jenny Kreuger. "Spray drift as influenced by meteorological and technical factors." *Pest management science* 67, no. 5 (2011): 586-598.

[35] Fritz, Bradley, Wesley Hoffmann, and Yubin Lan. "Evaluation of the EPA drift reduction technology (DRT) low-speed wind tunnel protocol." In *29th Symposium on Pesticide Formulations and Delivery Systems*. ASTM International, 2009.

[36] Felsot, Allan S. "Evaluation and mitigation of spray drift." In *Proc. International Workshop on Crop Protection Chemistry in Latin America*. 2005.

[37] Dursun, E., İ. Çilingir, and A. Erman. "Tarımsal Savaşım ve Mekanizasyonunda Yeni Yaklaşımlar." *TMMOB Ziraat Mühendisleri Odası* 6 (2005): 669-686.

[38] Wolf, Robert E. "Equipment to reduce spray drift." *Kansas State University Agricultural Experiment Station and Cooperative Extension Service Publication# MF-2445* (2000): 1-4.