An attempt to reduce spray drift in wind tunnel by substituting nozzles on the boom

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Abstract: Spray drift can be defined as the movement of a small droplet at application time by the air action. Several factors are known to affect spray drift with significant differences such as physical parameters, technological parameters, and meteorological parameters. The mitigation of spray drift from the agricultural application is an important issue that concerns many researchers and authors working with field tests. Wind tunnel technique is considered as an alternative method to assess spray drift that moves away from the target site intended under different settings as boom heights and wind speeds. In 2015, IRSTEA Montpellier wind tunnel was fitted with a new setup using different nozzle types mounted on the nozzle boom in a lateral position towards wind direction to study how nozzle combination has influenced on spray drift. The main goal of this present work aims for studying the effect of substitution nozzles on spray drift mitigation performance. The main results of this study showed significant differences in spray drift when one or two of air induction nozzles were placed before or after standard flat fan nozzles for different parameters setting as nozzle type and wind speed. Results showed that the best combination of nozzles leading to reduce spray drift ratio is when air induction nozzles are placed at the end of the boom especially the combination of 2Flat fan nozzles+2Flat fan air induction nozzles compared to other combinations and fill reference nozzle on the boom.

Keywords: drift ratio, nozzle type, wind speed

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1 Introduction

Several types of agriculture nozzles exist with many types of orifice shape which produce various spray patterns. Most of the nozzles used for plant protection are based on pressure-induced atomization where spray liquids under operating pressure are forced through small orifices of the nozzle, and the liquid mainly emerges under the form of particles droplet of different sizes (Ghosh and Hunt, 1998). Fine droplets less than 150 µm diameter are prone to drift thereby related to the risk of applied pesticide risks. According to the Environmental Protection Agency (EPA, 2019) and the American Society of Agriculture Engineers (ASAE) (ASAE Standards, 2009) spray drift is the pesticide by the air action during the application process or immediately after spray application. All pesticides can be subjected to drift far away from the target zone depending on several factors that can be classified as physical droplet parameters (size, velocity, and liquid properties (Nuyttens et al., 2007; Stainier et al., 2006); nozzle technological parameters (type, size, pressure, and forward speed for equipment (Nuyttens et al., 2009); and the weather conditions as wind speed, air temperature, relative humidity, and air stability (Nuyttens et al., 2005).

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As a result, spray drift is an unintended consequence of agricultural spray applications but has a great side effect and could cause serious contamination when considering the impact in terms of humans and environmental exposures, as well as, the damages to sensitive adjoining crops (Reddy et al., 2010; Londo et al., 2010; Butler et al., 2014; and Van De Zande et al., 2014). In many cases, spray drift has become an important issue generally leading to restrictions in the registration process of pesticides.

Many studies are carried out on spray drift at field level using the ISO 22866 (ISO, 2005) methodology. Over years ago, spray drift has been studied using different sampling techniques. These studies have evaluated spray drift using passive and active collectors considering different application parameters, meteorological conditions, and tank mix variables (Stainier et al., 2006; Nuyttens et al., 2005; Hewitt, 2000). Generally, the results of these studies revealed a significant amount of drift in the field test. However, drift measurements in the field are time-consuming, costly, and difficult to repeat because of natural weather conditions.

An alternative method to measure spray drift is by using a wind tunnel experiment which considers a suitable process for measuring and can be performed under controlled and stable meteorological conditions. Such devices also supply repeated measurement of the spray drift. Various experiments of the wind tunnel have been conducted (Miller, 1993; Parkinc and Wheelerp, 1996; Walkatep et al., 2000; and Murphys et al., 2000). Many wind tunnels exist in the world in the UK, Germany, USA, Australia, Belgium, and France.

Several researchers were conducted studies to determine spray drift in the wind tunnels by investigating the influence of each parameter after fixing the atmospheric conditions (Miller, 1993; Nuyttens et al., 2009; Miller et al., 2011).

All previous studies were mainly focused on measurement of the quantity deposited on collectors as nylon string at varied positions or heights according to ISO 22856 (ISO, 2008) depending on protocol tested. In general, only a frontally flat fan nozzle is tested. Also, the previous wind tunnel experiments are limited and haven't studied spray drift with different nozzle types mounted on boom and boom position towards wind direction.

A few studies were conducted on spray drift mitigation in a wind tunnel using coarse droplet size, lower boom height, suitable operating pressure, and shorter boom length. Also, the Pest Management Regulatory Agency (PMRA) investigated incorporating favourable reduction statements on the label and supported best application and land management practices into risk- reduced programs for both of spray drift and vapor drift (PMRA, 2019). However, these studies did not involve more details at the time of the test and evaluate spray drift control techniques. Some of these studies are intensified on the effect of types of adjuvants, nozzle technological parameters as type, size, boom height, and others on spray drift mitigation (Alheidary et al., 2014b). Also, there is a possibility to determine a spray drift reduction efficacy using different techniques as wingtip sails used to investigate spray drift reduction potential depending on theoretical calculations (Parkin and Spillman, 1980).

Different experiments were conducted in the wind tunnel to minimize spray drift from pesticides application. For example, Alheidary et al. (2014a) studied the effect of different parameters as nozzle type and configuration, and wind velocity on the drift in wind tunnel measurement. Thus, the main results of this study showed that there is a reduction in the drift using different types of a nozzle in comparison with using the same nozzles on the boom. Thereby, the study of Alheidary et al. (2014a) paved the way to the present study for proving more expected outcomes of the drift.

Thus, this present work came to investigate a new protocol in a wind tunnel taking into account a small boom of 4 nozzles where i) The nozzle type can be similar (reference situation) in a purpose of comparing the performance of different nozzles types. ii) The nozzle arrangement on the boom considered a mix of nozzle types (flat fan and air induction) specially to use anti drift nozzles at the beginning, or the end of the boom. iii) Results may lead to new recommendations for limiting spray drift.

2 Methodology

2.1 Wind tunnel setting-up

All measurements of the present study were performed in IRSTEA-Montpellier, France wind tunnel. The wind tunnel as shown in Figure 1 is a closed circuit type.

Figure 1 View of wind tunnel-IRSTEA- Montpellier

The internal section of the wind tunnel is 3× 2× 9 m height, width, and length respectively. The floor of the wind tunnel is composed of a distribution test bench with 180 grooves of 5 cm. Measurements are done by using a mobile device fitted with 60 tubes (3 m) mounted on weight cells traveling along the distribution test bench with steps of 1m. The scan of the 9 m distribution test bench is done through seven positions of the mobile device.

2.2 Boom settings

As shown in Figure 2 the lateral boom (parallel to the wind direction) with four nozzles is located at the central axis in the wind tunnel (50 cm spacing).

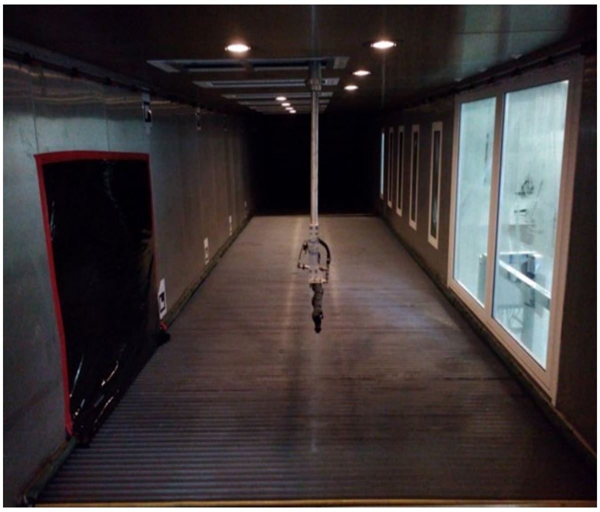

Figure 2 Boom position in a wind tunnel

Working height for the nozzle is adjustable at 60 cm as a practical reference height. Nozzles were fed with the water tap at an operating pressure of 2.5 bar through a high flowrate pump (80 L min^{-1}) and a pressure valve control. The pressure was controlled using a manometer (Keller, Germany) in the range of 0-10 bar.

2.3 Nozzle characteristics

Three types of flat fan nozzles were used in this study at the same working pressure of 2.5 bar and same angle and size (110 02) respectively as shown in Table 1. Albuz AXI nozzle was considered as a reference nozzle FF because it is recommended in France by previous experimental studies; CVI is a FF air Injection nozzle single jet and CVI Twin is a FF air induction Twin jets. All nozzle bodies are made of ceramics. These nozzles are considering in agricultural spraying where flat fan nozzles are widely being used for spraying pesticides. The volume median diameter for spray droplets of these nozzles is measured using the Spraytec (Malvern Instruments Co., Worcestershire, UK).

Table 1 Nozzle characteristics

Nozzle type	Nozzle flowrate (L min^{-1})	VMD* (μm)
Flat fan (AXI)	0.73	164.9
Flat fan air induction single jet (CVI)	0.73	434.6
Flat fan air induction Twin jet (CVI Twin)	0.73	380

Note: *VMD: Volume Median Diameter

Although the different nozzles have the same flowrate, the values of VMD were different that led to differences in spray drift values

2.4 Meteorological conditions

Air temperature and relative humidity were measured inside the wind tunnel using a Vaisala sensor, HMT337. Air temperature is maintained at 20ºC and relative humidity was above 90% due to the circulation in the wind tunnel. The sensor location used for measuring both air temperature and relative humidity was at the same height as the boom.

2.5 Experimental setup

Thirty-three different experiments were conducted in IRSTEA-Montpellier wind tunnel (Figure 3).

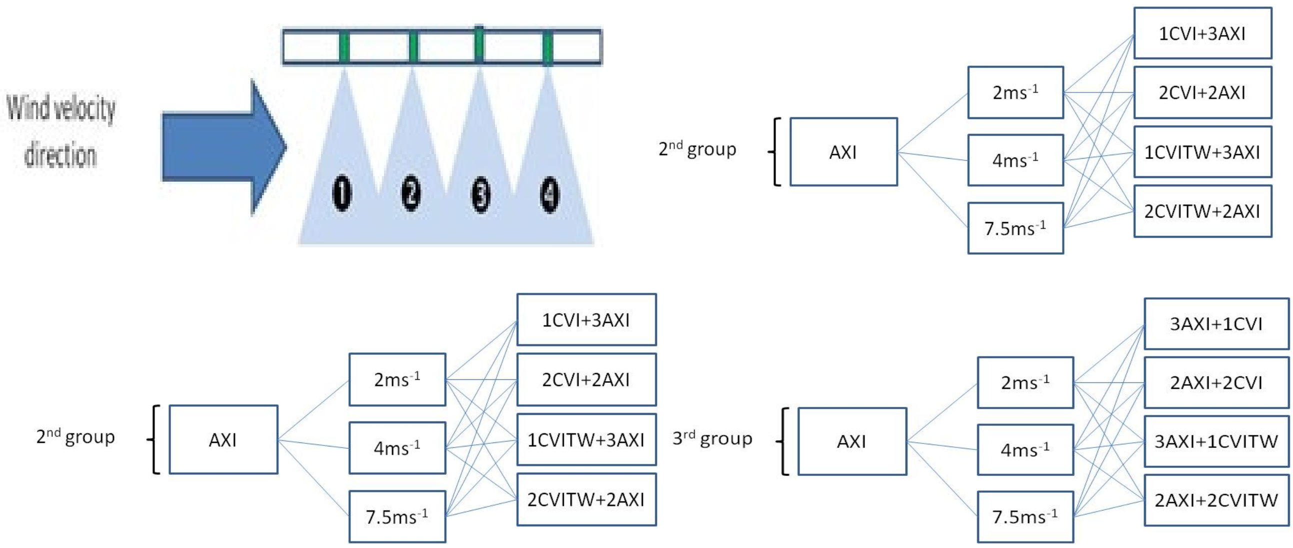

Figure 3 Experimental setup

2.6 Experimental procedure

Determination of spray drift in IRSTEA- Montpellier wind tunnel is calculated by measuring flowrate sedimentation through a distribution test bench at different distances up to 9 m from the nozzle orifice. Four nozzles are tested in this study at the same setting conditions as the wind speed of 2, 4, and 7.5 m s^{-1} in a lateral boom. We used these speed values by following the French protocol for measuring spray drift. The half reference distance of the last nozzle is considered (Figure 4).

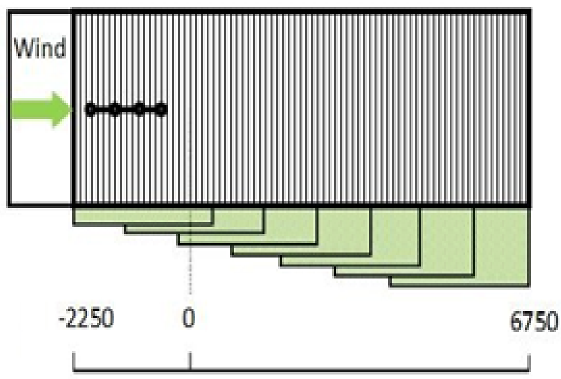

Figure 4 Reference distance (all units in mm)

2.7 Nozzle arrangements on the boom

At first, the tests were achieved with a complete boom with a single nozzle model Flat Fan, Air injection (single jet), and air injection twin jet as shown in Figure 3 (1st group) using 9 modalities (3 nozzles – 3 wind speeds). Secondly, a combination of one or two air injection nozzles placed at the beginning of boom counteracting the wind as shown in Figure 3 (2nd group) using 12 models (4 combinations - 3 wind speeds). Thirdly, air induction nozzles are placed at the end of the boom far from the wind source (3rd group) using 12 models.

2.8 Data analysis

Raw data consisted of relative flowrate at each distance along the distribution test bench. First, these data are cumulated which defined as sedimentation flowrate, then the opposite value of sedimentation flowrate called spray drift ratio is calculated following Equation 1 (Douzals and Alheidary, 2014).

$$Dr_i = 1-\sum_i q_i \ldots \quad (1)$$

Where Dr_i is drift ratio at each distance position i (%), q_i is the relative sedimentation flowrate at the position i (%).

A second step consisted of the calculation of an integrated criteria DR 5 m corresponding to the drift ratio value at 5 m representing the remaining fraction of emitted droplets that did not deposit 5 m beyond the boom.

2.9 Statistical analysis

All drift values were expressed as a percentage. Statistical analysis for Data collected from the experimental study was performed using Excel Software®.

3 Results and discussion

3.1 Effect of nozzle type and wind velocity on sedimentation amount

Figures 5, 6, and 7 showed the correlation between nozzle type and sedimentation flowrate amount at different distances and wind speeds when the boom consists of the type of the same nozzle.

The results showed statistically significant differences (P-value <0.0001) between nozzle types and sedimentation amount at different wind speeds. Although the different nozzles have the same flowrate, the values of VMD were different that led to differences in spray sedimentation values.

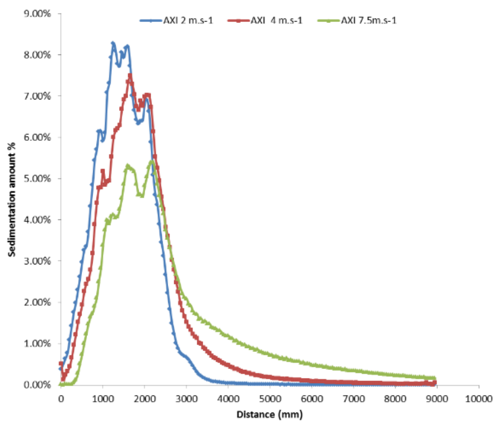

Figure 5 Deposition amount at different wind velocities using Flat Fan nozzle (AXI)

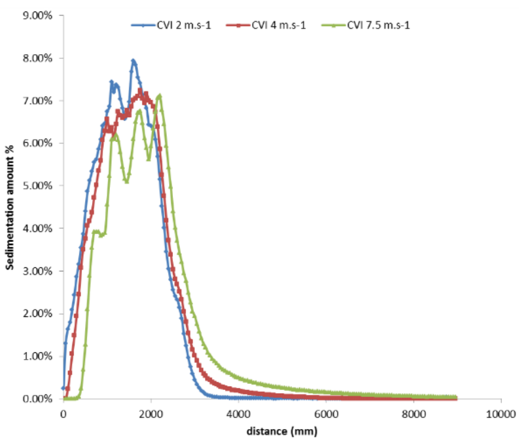

Figure 6 Deposition amount at different wind speeds using Flat Fan nozzle air induction single jet (CVI)

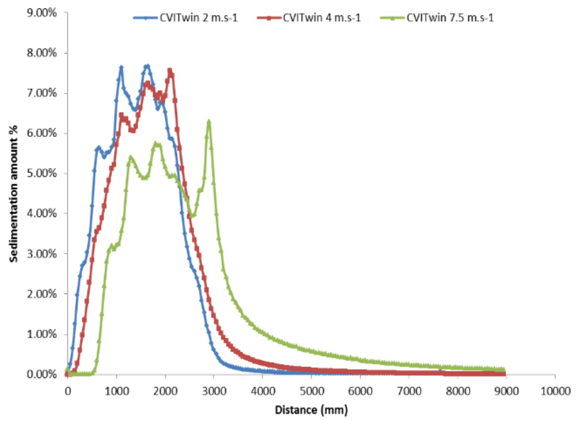

Figure 7 Deposition amount at different wind speeds using Flat Fan nozzle air induction Twin jet (CVITwin)

Sedimentation amount data analyses showed small value in coefficient variance of 1.74%, 1.52%, 1.02% for AXI nozzle; 1.78%, 1.67%, 1.39% for CVI nozzle; 1.75%, 1.58%, 1.12% for CVITwin nozzle at 2, 4, and 7.5 m s^{-1} respectively. Minimum sedimentation value for all nozzles tested observed at 7.5 m s^{-1} wind speed. The percentage nozzle amount average was 0.015%, 0.016%, and 0.016% for AXI, CVI, and CVITwin nozzles respectively. The nozzle of AXI showed a lower nozzle amount compared to air induction nozzles. Wind speed has a great influence on the values of the sedimentation amount for all nozzles tested. The effect of increasing wind speed was clearly on the peak values and in the shifting in peak position.

3.2 Effect of nozzle type and wind velocity on drift ratio using same nozzle type on the boom

As shown in Figures 8, 9, and 10 introduced the effect of nozzle type on drift ratio at different wind velocities using the same fill nozzle on the boom.

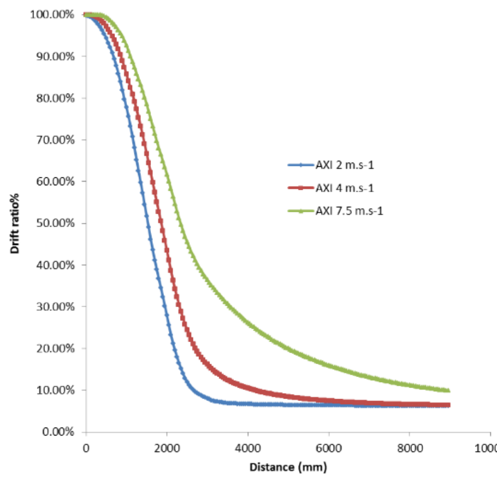

Figure 8 Effect of nozzle type on drift ratio- Flat fan nozzle (AXI)

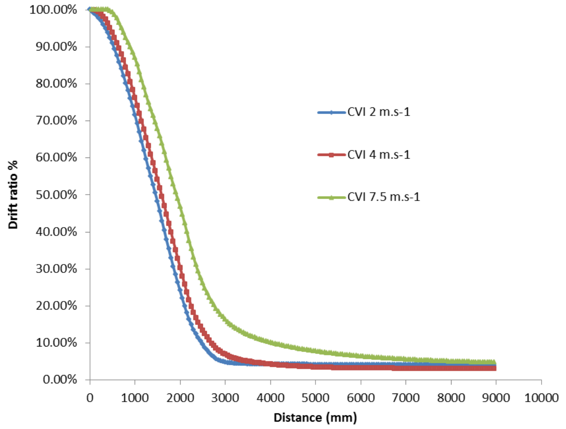

Figure 9 Effect of nozzle type on drift ratio- Flat Fan air induction nozzle (CVI single jet)

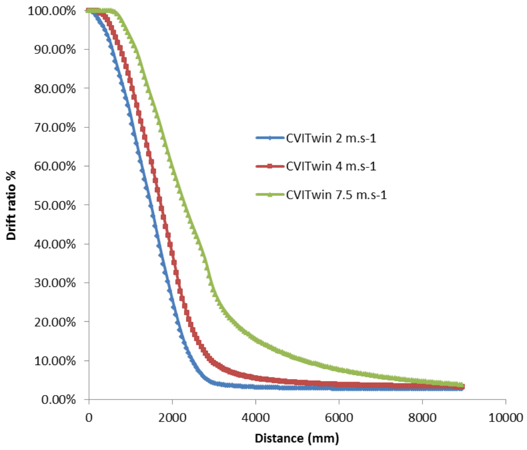

Figure 10 Effect of nozzle type on drift ratio- Flat Fan air induction Twin nozzle (CVITwin)

Nozzle type has a significant effect (P-value <0.0001) on the drift ratio. Lower drift percentage 3% observed with air induction nozzles compared to flat fan nozzle. Besides the differences in drift ratio depending on the nozzle type, it is a visible effect of wind speed on the drift ratio for all nozzles tested in this study. There is variation in drift between the results of the flat fan nozzle as a reference nozzle in this study and air induction nozzles. For example, drift ratio at 5 m (reference distance) for AXI, CVI, and CVIT win varied was 6.45%, 8.38%, and 19.99%; 3.38%, 4.04%, and 7.64%; 2.95%, 4.37%, and 10.69% at 2, 4, and 7.5 m s^{-1} respectively. It is acceptable that the differences in drift caused in the increase of wind speed at the time of measuring spray drift.

3.3 Effect of nozzle substitution and wind speed on drift ratio

Figures 11, 12, and 13 introduced the effect of nozzle substitution and wind speed on the drift ratio. The results showed significant differences (P-value <0.0001) in the effect of both of these nozzle substitutions and wind speed on the drift ratio. Wind velocity has an obvious effect on the drift ratio for all nozzle substitutions. The drift ratio increases with increasing of the wind speed when the flat fan nozzle placed on the boom either in front of or away from the direction of wind speed.

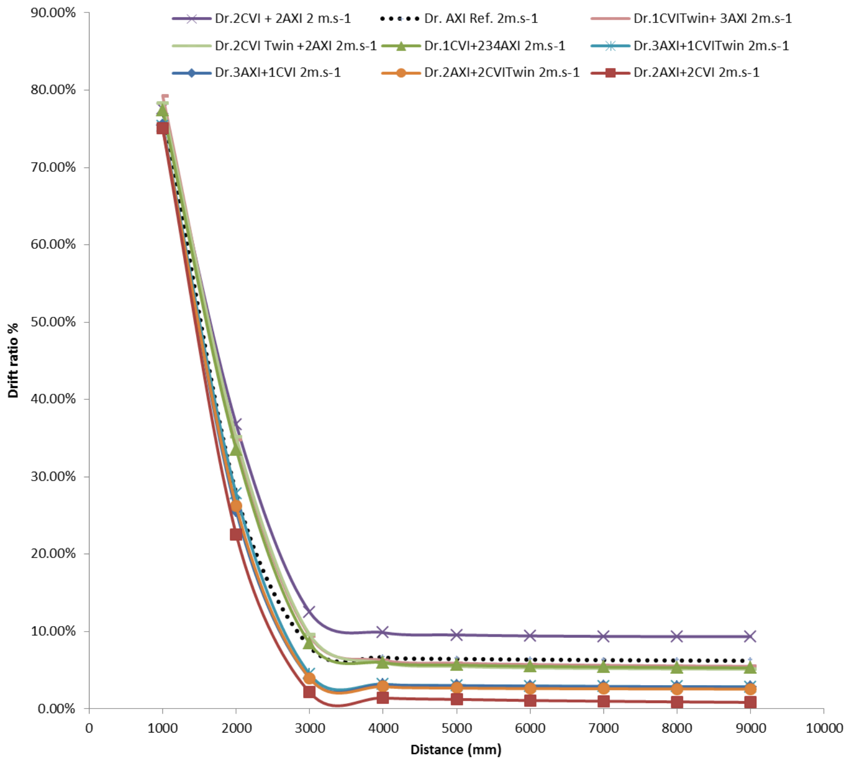

Figure 11 Effect of nozzle substitution on drift ratio at 2 m s^{-1} wind speed compared to reference nozzle

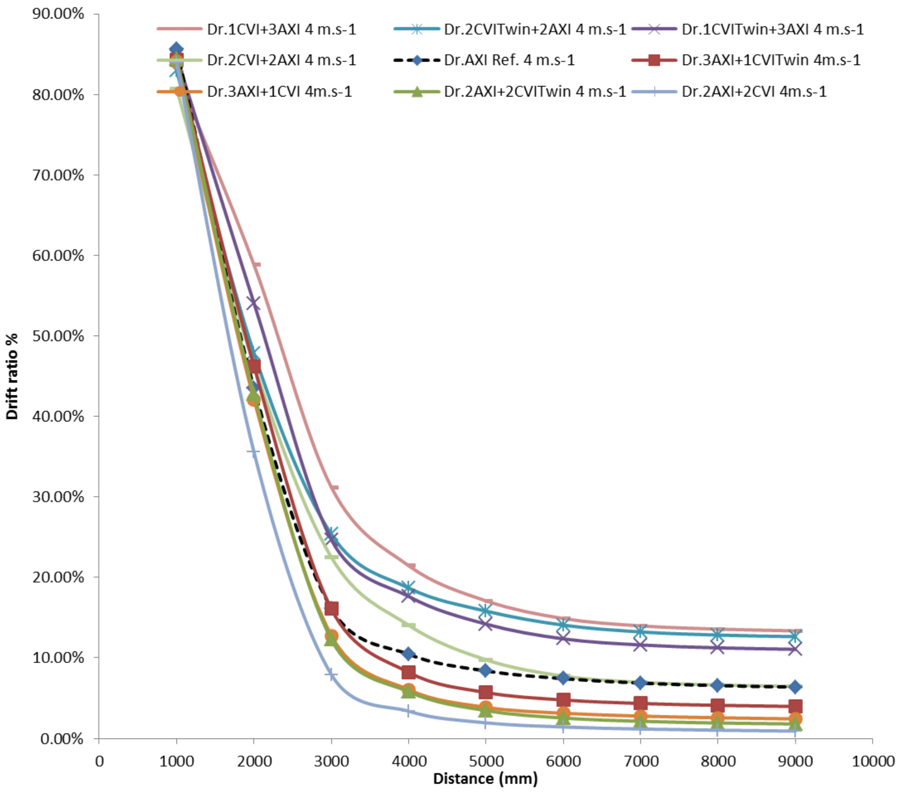

Figure 12 Effect of nozzle substitution on drift ratio at 4 m s^{-1} wind speed compared to the reference nozzle

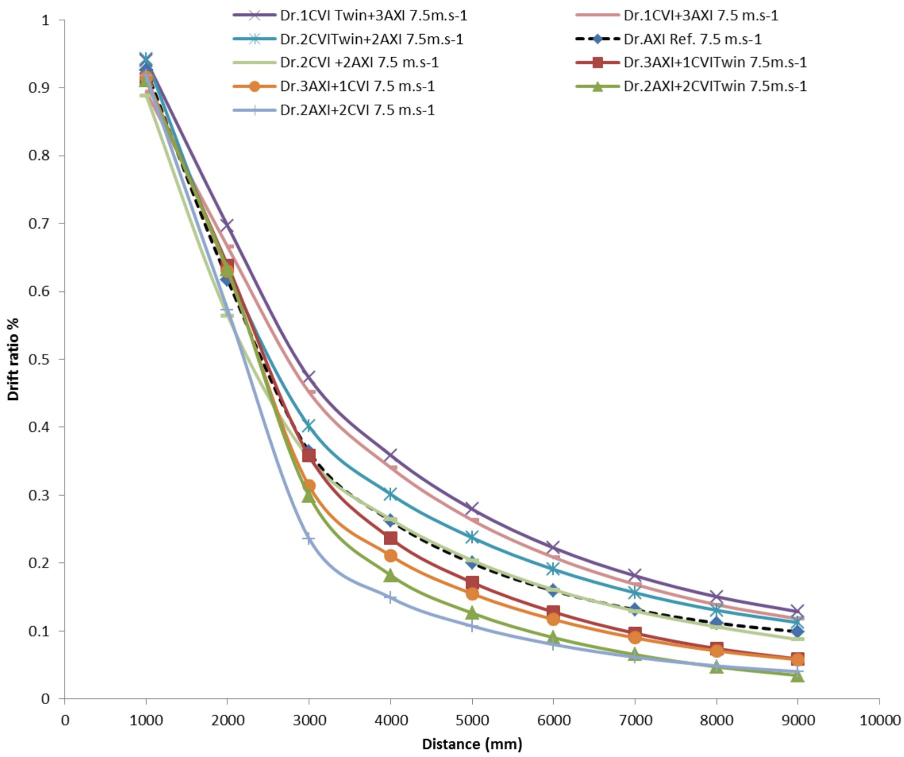

Figure 13 Effect of nozzle substitution on drift at 7.5 m s^{-1} wind speed compared to the reference nozzle

Figure 13 illustrates a reduction in drift ratio when two nozzle types (AXI and CVI) were used in drift measurement. Particularly, mounting two nozzles of AXI at the beginning of the boom followed by two nozzles of CVI for all tested wind velocities compared to one nozzle type.

4 Conclusions

The main objective of this study was to introduce the effect of substitution nozzle mounted on the boom in the lateral position towards wind direction. In this present paper, different models tested using different nozzle types, nozzle substitutions, and wind speeds on the spray drift ratio as measured in a wind tunnel. The results obtained by this experimentation influence on spray drift values. It has been shown significant differences in the amount of spray drift when used substitution nozzles compared to fill nozzle and reference nozzle.

The present results indicated a complex relationship between flowrate sedimentation and drift ratio with distance due to the interaction between sprays nozzle in lateral position especially with substitution nozzles. Also, results showed a lower drift ratio observed when used air induction nozzle at the end of boom far to wind source especially the combination of 2 AXI+2CVI at all wind speeds studied.

The present findings will pave the way using developed models for future studies to calculate spray drift. Also, this study will contribute to mitigating spray drift values.

References

AlHeidary, M., J. P. Douzals, A. Vallet, and C. Sinfort. 2014a. Influence of spray characteristics on potential spray drift of field crop sprayer: A literature review. *Crop Protection*, 6: 120-130.

AlHeidary, M., J. P. Douzals, C. Sinfort, and A. Vallet. 2014b. Influence of nozzle type, nozzle arrangement and side wind speed on spray drift as measured in a wind tunnel. In *AgEng International Conference of Agricultural Engineering - Zurich*, 7. Switzerland, 6-10 July.

ASAE Standards. 2009. S572.1. Spray nozzle classification by droplet spectra. St. Joseph, Mich.: ASAE.

Butler, E., M. C. Lane, A. G. O'Sullivan, C. M. Alanis, R. Harris, A. H. Stallinga, and J. C. Van De Zande. 2014. Bystander and Resident exposure to spray drift from orchard applications: field measurements, including a comparison of spray drift collectors. *Aspects of Applied Biology*, 122: 187-194.

Douzals, J. P., and M. Alheidary. 2014. How spray characteristics and orientation may influence spray drift in a wind tunnel. *Aspect of Applied Biology*, 122: 271-278.

EPA. 2019. Introduction to pesticide drift. Available at: https://www.epa.gov. Accessed June 6.

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

Hewitt, A. J. 2000. Spray drift: impact of requirements to protect the environment. *Crop Protection*, 19(8-10): 623-627.

ISO. 2005. 22866: Equipment for crop protection - Methods for field measurement of spray drift.www.iso.org: International Organization for Standardization.

ISO. 2008. 22856: Equipment for crop protection-Methods for the laboratory measurement of spray drift- Wind tunnels. www.iso.org: International Organization for Standardization.

Londo, J. P., N. S. Bautista, C. L. Sagers, E. H. Lee, and L. S. Watrud. 2010. Glyphosate drift promotes changes in fitness and transgene flow in canola (Brassica napus) and hybrids. *Annals of Botany*, 106(6): 957-965.

Miller, P. C. H. 1993. Spray drift and its measurement. In *Application Technology for Crop Protection,* eds G. A. Matthews, and E. C. Hislop. E.C.: CABI.

Miller, P. C. H., E. Butler, M. C. Lane, A. G. O'Sullivan, and C. M. Tuck. 2011. Methods for minimizing drift and off-target exposure from boom sprayer applications. *Aspect of Applied Biology*, 106:281-288.

Murphys, D., P. E. H. Milier, and S. Parkinc. 2000. The effect of boom section and nozzle configuration on the risk of spray drift. *Journal of Agricultural Engineering Research*, 75(2):127-137.

Nuyttens, D., K. Baetens, M. De Schampheleire, and B. Sonck. 2007. Effect of nozzle type, size and pressure on spray droplet characteristics. *Biosystems Engineering*, 97(3): 333-345.

Nuyttens, D., W. A. Taylor, M. De Schampheleire, P. Verboven, and D. Dekeyser. 2009. Influence of nozzle type and size on drift potential by means of different wind tunnel evaluation methods. *Biosystems Engineering*, 103(3): 271-280.

Nuyttens, D., B. Sonck, M. De Schampheleire, W. Steurbaut, K. Baetens, P. Verboven, B. Nicolai, and H. Ramon. 2005. Spray drift as affected by meteorological conditions. *Communications in Agricultural and Applied Biological Sciences*, 70(4): 947-959.

Parkin, C. S., and J. J. Spillman. 1980. The use of wing-tip sails on a spraying aircraft to reduce the amount of material carried off-target by a crosswind. *Journal of Agricultural Engineering Research*, 25(1): 65-74.

PMRA. 2019. Proposed special review decision PSRD2019-01, special review for bromoxynil and its associated end-use products. Available at: www.pmra-arla.gc.ca. Accessed May 7, 2019.

Parkinc, S., and N. Wheelerp. 1996. Influence of spray induced vortices on the movement of drops in wind tunnels. *Journal of Agricultural Engineering Research*, 63(1): 35-44.

Reddy, K. N., W. Ding, R. M. Zablotowicz, S. J. Thomson, Y. Huang, and L. J. Krutz. 2010. Biological responses to glyphosate drift from aerial application in non-glyphosate-resistant corn. *Pest Management Science*, 66(10): 1148-1154.

Stainier, C., M. F. Destain, B. Schiffers, and F. Lebeau. 2006. Droplet size spectra and drift effect of two phenmedipham formulations and four adjuvants mixtures. *Crop Protection*, 25(12): 1238-1243.

Van De Zande, J. C., E. Butler, M. Wenneker, P. Walklate, and M. Kennedy. 2014. Spray drift and bystander risk from fruit crop spraying. *Aspects of Applied Biology*, 122:177-186.

Walkatep, J., P. C. H. Milier, and J. Gilberta. 2000. Drift classification of boom sprayers based on single nozzle measurements in a wind tunnel. *Aspects of Applied Biology*, 57:9-56.