

Field data and prediction models of pesticide spray drift on coffee crop

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Abstract – The objective of this work was to generate drift curves from pesticide applications on coffee plants and to compare them with two European drift-prediction models. The used methodology is based on the ISO 22866 standard. The experimental design was a randomized complete block with ten replicates in a 2x20 split-plot arrangement. The evaluated factors were: two types of nozzles (hollow cone with and without air induction) and 20 parallel distances to the crop line outside of the target area, spaced at 2.5 m. Blotting papers were used as a target and placed in each of the evaluated distances. The spray solution was composed of water+rhodamine B fluorescent tracer at a concentration of 100 mg L⁻¹, for detection by fluorimetry. A spray volume of 400 L ha⁻¹ was applied using a hydropneumatic sprayer. The air-induction nozzle reduces the drift up to 20 m from the treated area. The application with the hollow cone nozzle results in 6.68% maximum drift in the nearest collector of the treated area. The German and Dutch models overestimate the drift at distances closest to the crop, although the Dutch model more closely approximates the drift curves generated by both spray nozzles.

Index terms: *Coffea arabica*, drift curves, environmental contamination, hydropneumatic sprayer, nozzles.

Dados de campo e modelos de estimação de deriva nas aplicações de agrotóxicos na cultura do café

Resumo – O objetivo deste trabalho foi gerar curvas de deriva a partir de aplicações de agrotóxicos em cafeeiro e compará-las a dois modelos europeus de simulação de deriva. A metodologia utilizada baseia-se na norma ISO 22866. Utilizou-se o delineamento experimental de blocos ao acaso, com dez repetições, em arranjo fatorial 2x20 com parcelas subdivididas. Os fatores avaliados foram: dois tipos de pontas de pulverização (cone vazio com e sem indução de ar) e 20 distâncias paralelas à linha de cultivo fora da área-alvo, espaçadas em 2,5 m. Foram colocados papéis filtrantes como alvo, em cada uma das distância avaliadas. A calda foi composta por água+corante fluorescente rodamina B na concentração de 100 mg L⁻¹, para detecção por fluorimetria. Aplicou-se volume de calda de 400 L ha⁻¹, por pulverizador hidropneumático. A ponta com indução de ar reduz a deriva até 20 m de distância da área tratada. A aplicação com ponta de jato cônico resulta em deriva máxima de 6,68% no ponto de coleta mais próximo da área tratada. Os modelos Alemão e Holandês superestimam a deriva nas distâncias mais próximas à cultura, embora o modelo Holandês se aproxime mais das curvas de deriva geradas por ambas as pontas de pulverização.

Termos para indexação: *Coffea arabica*, curvas de deriva, contaminação ambiental, pulverizador hidropneumático, pontas de pulverização.

Introduction

Coffee (*Coffea arabica* L.) production represents an important agricultural activity in South America, and Brazil is the world's largest coffee producer and exporter (Companhia Nacional de Abastecimento, 2013). The crop is subject to attack by several pests and diseases that, in many cases, require chemical control. However, there is little information about technology for the application of insecticides and fungicides on coffee. Knowledge of the performance of pesticide-spraying equipment is fundamental for

appropriate application, ensuring both biological efficacy and environmental safety (Cunha, 2008).

The type of spray nozzle and its working characteristics are some of the main factors that affect losses of pesticides to the environment. Hollow cone nozzles are traditionally recommended for applications on crops with broad leaf mass, in which penetration and coverage are essential. These nozzles produce very small droplets with a high risk of drift. Spray drift is defined as the quantity of plant protection product carried out of the sprayed (treated) area by air currents during application. It persists as one of the major

problems in modern agriculture (Tsai et al., 2005; Nuyttens et al., 2011).

Due to this risk, an air-induction variant of this nozzle, which produces droplets of a larger diameter, was released onto the market (Figueroa et al., 2012). By producing large to extremely large droplets, these nozzles have reduced risks of drift. Therefore, some producers envision the possibility of substituting hollow cone nozzles with other more environmentally safe ones, as long as the nozzles do not compromise the efficacy of the application.

Research on drift aims to determine the appropriate measures to minimize the negative effects of spray application on the environment (Baetens et al., 2009). In this sense, some prediction models have been developed to evaluate drift (Lebeau et al., 2011). The most commonly used model worldwide was created in the 1990s in Germany (Ganzelmeier et al., 1995). However, it is not known whether these models can be applied in tropical conditions, since they were developed for important plants in the European climate.

In some countries, one solution to reduce pesticide drift was to establish buffer zones, stipulated by drift-prediction models associated with toxicological studies (De Schampheleire et al., 2007). These zones involve rows of vegetation that cannot receive the application of pesticides, in order to avoid contamination of a specific sensitive area, such as water course regions.

However, the size of the buffer zone is variable and depends on the application conditions. Therefore, it is necessary to study the horizontal distance that a droplet can travel under different operational spraying conditions, for the establishment of buffer zones with the correct size and for more effective and environmentally safe applications.

Despite the environmental risk from pesticides, few studies assess pesticide drift in coffee production, especially under tropical conditions.

The objective of this work was to generate drift curves from pesticide applications on coffee plants and to compare them with two European drift-prediction models.

Materials and Methods

The experiment was performed at the Coffee Production Sector of Universidade Federal de Uberlândia, MG, Brazil (18°58'52"S, 48°12'24"W, at an average altitude of 912 m).

For pesticide applications, a Arbo 360 hydropneumatic airblast sprayer was used (Montana, São José dos Pinhais, PR, Brazil), with 12 nozzles (six on each side) coupled to the hydraulic system of a 265E Massey Ferguson tractor (Massey Ferguson, Itu, São Paulo, Brazil). Two hollow-cone jet nozzles with and without air induction, respectively, were evaluated: ATR 80° Orange 3.0 nozzle (Albuz, Gragny, France), with traditional application; and TVI 8002 nozzle (Albuz, Gragny, France), using low-drift application.

A spray volume of 400 L ha⁻¹ was used. The displacement velocity of the machine was 8.2 km h⁻¹. The working pressures for the ATR and TVI spray nozzles were 1.567 MPa (227.5 lb in⁻²) and 1.447 MPa (210 lb in⁻²), respectively. According to the manufacturer, at these pressures, the ATR and TVI nozzles produce very fine (lower than 100 µm) and very course (between 375 and 450 µm) droplets, respectively. The manufacturer used the ASAE S-572 standard to classify the volume median diameter.

Prior to the applications, the sprayer was calibrated by determining the flow rate from each nozzle; then, the best angle for the nozzles, along with the arc of the sprayer, was determined using a patternator to reduce the loss of spray above the crop canopy and to prevent the jet formed by the lowest nozzles of the arc from spraying directly into the soil. The coefficients of variation (CV) for the flow rates from the ATR and TVI nozzles were 3.99 and 6.40%, respectively. Wolf & Smith (1979) concluded that a CV less than 15% is desirable.

The air flow rate from the fan was determined using air velocity and outlet area, according to the methodology proposed by Rodrigues et al. (2008). The flow rate from the left side was 1.64 m³ s⁻¹ and from the right side was 1.58 m³ s⁻¹.

For the drift study, a rhodamine B tracer was used (Synth, Diadema, SP, Brazil) at a concentration of 100 mg L⁻¹, added to the spray for later quantification by fluorimetry.

The applications were conducted in an area planted with 'Catuaí Vermelho' coffee spaced at 3.8 m between lines and 0.7 m between plants of three years of age and average height of 2.5 m. The average lower diameter of the tree crown was 1.2 m. The leaf area index (LAI) of the coffee plant was estimated indirectly through measurements of the lower diameter and the height of the crown, following Favarin et al. (2002). The estimated LAI was 4.38.

The experimental design was a randomized complete block with ten replicates in a 2x20 split-plot arrangement in space. Two factors were evaluated: two spray nozzles – standard and air-induction hollow cone; and 20 distances in relation to the last line sprayed.

The drift to the soil was determined according to the ISO 22866 standard (International Organization for Standardization, 2005). Prior to the applications, polyethylene plates with dimensions of 0.40x0.08x0.006 m were placed at ground level in an area adjacent to the crop outside of the target area, perpendicular to the direction of the sprayer application and in the main direction of the wind (downwind). The plates, spaced at 2.5 m from each other, were placed at a distance of 2.5 m from the center of the last spray application up to 50 m, totaling 20 distances in relation to the last line sprayed. This same arrangement was repeated in four lines spaced at 1.5 m from each other, perpendicular to the direction of the displacement of the sprayer.

For statistical analysis, the average from these four collectors was used for each distance. The four lines of plants adjacent to the drift-evaluation area were sprayed, for a total length of 50 m, constituting one replicate. On the last spray of the equipment, only the side of the sprayer arc aimed toward the lines of coffee plants was used. Each application during one replicate took approximately 3 min.

Blotting papers (J. Prolab, Ind. e Comércio de Produtos para Laboratório Ltda., São José dos Pinhais, PR, Brazil) with a neutral pH, 65 g m⁻² of weight, and dimensions of 0.38x0.07 m were fixed onto the polyethylene plates.

Once the application was performed, the papers were collected and placed in a heat- and light-insulated container. The samples were kept in a refrigerator at 10°C in a laboratory until the end of the field data collection.

Meteorological conditions were monitored during the applications, including velocity and direction of the wind, temperature and relative humidity of the air. For this analysis, a meteorological station with automatic data acquisition was used, installed next to the experimental area. Data acquisition was conducted targeting temperatures between 5 and 35°C, wind speeds between 1 and 5 m s⁻¹, and wind direction within a limit of 90±30° from the spray line and in the direction of the sampling area. There were no specifications for the relative humidity of the air in the ISO standard. In all of the applications, the wind direction was within the range of angles permitted by the ISO 22866 standard. The temperature and wind velocity also met the standard (Table 1).

In the laboratory, rhodamine B was extracted from the blotting papers according to Scramin et al. (2002).

Table 1. Date and hour of meteorological conditions during pesticide spraying on coffee (*Coffea arabica*) crop to evaluate drift caused by hollow cone nozzles with (ATR) and without air induction (TVI).

Replicate	Nozzle	Date	Hour	Temperature (°C)	Relative humidity of air (%)	Wind velocity (m s ⁻¹)	Wind direction
1	ATR	4/17/2013	09:01	19.7	71	0.83	ESE
	TVI		09:39	20.5	66	0.83	ESE
2	ATR	4/17/2013	15:33	27.6	39	2.50	ESE
	TVI		16:04	27.4	36	2.65	ESE
3	ATR	4/18/2013	08:52	19.6	73	1.22	SE
	TVI		09:26	21.3	74	1.00	SE
4	ATR	4/18/2013	09:52	22.7	65	2.80	E
	TVI		10:10	22.8	64	2.45	E
5	TVI	4/18/2013	10:30	23.4	60	2.77	E
	ATR		10:52	24.7	52	3.15	E
6	ATR	4/19/2013	08:20	19.4	82	1.90	E
	TVI		08:46	19.4	83	2.45	E
7	TVI	4/19/2013	09:11	20.4	83	3.70	E
	ATR		09:35	22.1	78	3.35	E
8	ATR	4/23/2013	08:15	16.8	85	4.12	E
	TVI		08:43	17.2	84	3.80	E
9	TVI	4/23/2013	09:10	18.9	80	3.43	E
	ATR		09:34	19.3	75	3.80	E
10	ATR	4/23/2013	09:58	20.6	73	4.33	ESE
	TVI		10:22	22.0	66	7.13	ESE

A total of 100 mL of a solution composed of distilled water and Tween 80 – polyoxyethylene sorbitan monooleate – at 0.2% (Synth, Diadema, SP, Brazil) was added to each plastic bag, which was subjected to constant agitation at 120 rotations per minute for 15 min on a pendulum shaker TE-240/I model (Tecnal Equipamentos para Laboratórios, Piracicaba, SP, Brazil). The samples were left to rest for 10 min. For tracer quantification, the samples were placed in borosilicate cuvettes with four polished faces for reading in a fluorimeter model FM109515 with a halogen lamp (Thermo Fisher Scientific Inc., Waltham, MA, USA). The excitation and emission wavelength filters were 540 and 585 nm, respectively.

The tracer deposit per unit area of drift collectors was determined, expressed in microliters per square centimeter ($\mu\text{L cm}^{-2}$), using the data on rhodamine B concentration extracted from the blotting papers, as well as the spray volume and the real spray concentration. With the deposition data from the collectors, the percentage of drift for each distance was calculated, relating the deposit to the quantity applied to the field.

For analysis of the assumptions for the drift percentage data, the Kolmogorov-Smirnov, Levene, and Tukey tests were applied to analyze the normality of the residuals, homogeneity of the variances, and additivity of the blocks, respectively, using the SPSS statistical software, version 17.0 (SPSS Inc., Chicago, IL, USA). If the assumptions were not met to 1% probability, the data were transformed using the arc sine of the square root of $x/100$ and subjected to a new analysis.

The data were subjected to analysis of variance using the Sisvar statistical software, version 5.3 (Ferreira, 2008). When a significant difference was found, the nozzles were compared to each other for each distance using Tukey's test, at 5% probability, whereas regression analysis was performed for the distances.

The drift curves obtained for each spray nozzle were compared using the confidence interval of the equation parameters. For this comparison, the data were linearized using the $\log(x)$ function and subjected to regression analysis. The upper and lower limits of each equation parameter were identified, and, if the intervals were not superimposed at the 95% confidence level, the curves were considered different.

Additionally, the obtained curves were prepared as a function of distance and compared to the curves from the German (Ganzelmeier et al., 1995) and Dutch (Holterman & Van de Zande, 2003) drift-prediction models using the 90th percentile of the drift data. For the German model, the application to fruit trees with good leafiness (late-fruit application conditions) was considered. For the Dutch model, the application to fruit trees with leaves was considered.

In the German model, the drift values, expressed as a percentage of the application dose, in function of the z distance downwind the field, were calculated by the equation: $\%drift = Az^B$, in which A and B are coefficients that depend on the crop and distance. For distances lower than 10.3 m, the coefficients are 60.3960 and -1.2249, respectively. For distances higher than 10.3 m, they are 210.7000 and -1.7599, respectively (Ganzelmeier et al., 1995).

In the Dutch model, the drift values, expressed as a percentage of the application dose, in function of the z distance downwind the field, were calculated by the equation: $\%drift = A_0e^{-z \times A_1} + B_0e^{-z \times B_1}$, in which A_0 , A_1 , B_0 , and B_1 are equal to 48, 0.45, 2.70, and 0.091, respectively, for fruit trees in leaf (Holterman & Van de Zande, 2003).

Results and Discussion

The applications made on coffee plants with the TVI nozzle caused less drift than those with the ATR nozzle up to 20 m of distance from the last line sprayed (Table 2). Beyond this distance, there was no difference between the nozzles. Therefore, the TVI nozzle reduced spray drift to the areas closest to the crop.

In some cases, an increase in drift can occur with air-induction nozzles at distances closer to the treated area due to the passage of large droplets through the lower part of the plants. However, in this experiment, the crowns of the plants were near soil surface, which prevented this process from occurring.

Combella et al. (1996), while evaluating drift potential in a wind tunnel, observed that the air-induction nozzle reduced the risk of drift by 262% in relation to the same nozzle without air induction.

Therefore, the TVI nozzle may be a good option for spraying when the coffee crop is located near regions where drift must be reduced as much as possible, such

as neighboring crops that are sensitive to the applied product, water courses, and inhabitable areas. However, in recommending a nozzle, the deposition of spray on the leaves of the crop must be taken into account.

It is important to emphasize that although the TVI nozzle produces very large drops, it results in 5.06% drift at a distance of 2.5 m, a value considered high, considering the spectrum of the generated droplets. This drift may have been caused by the association between the strong air turbulence from the propellers of the sprayer and the larger mass of the droplets, which may pass directly through the coffee plants through inertia, especially on the second-to-last spray of the sprayer, in areas closest to the last line of plants.

The drift generated by the ATR nozzle was greater than that by the TVI nozzle at a distance from 2.5 m until 20 m (Table 2), which was expected because very

small droplets are more easily carried by the wind. Between 2.5 and 5 m, there was an abrupt drop in the drift caused by both nozzles – 3.45% for the TVI nozzle and 3.93% for the ATR nozzle. This change may be explained by the physical barrier imposed by the coffee plants, associated primarily with the good regulation of the angle of the upper nozzles of the sprayer arc. Therefore, the drift in the areas closest to the crop is caused primarily by air flow from the sprayer, while the drift in more distant areas is caused by the atmospheric wind. This reinforces the importance of adequately regulating the spraying equipment, which can reduce drift even during applications under adverse meteorological conditions.

Based on regression analysis, the power model showed good fit to the data for both of the sprayer nozzles, although the R^2 for the TVI nozzle was lower than that for the ATR nozzle, which is probably attributed to the difference between the values observed and estimated for the 2.5 m distance (Figure 1). A power model was selected due to the availability of the German model as a reference (Ganzelmeier et al., 1995).

The largest drift percentages were obtained at the collection point closest to the crop, and the drift decreased as the collection points moved away from the target area. This pattern was also observed by Yarpuz-Bozdogan & Bozdogan (2009), who obtained largest drift values at a distance of 1 m from the crop, using an application rate of 200 L ha⁻¹ on grassland.

Beyond 20 m, the drift percentage was less than 1%. However, this value was not zero at any distance, not even at 50 m, using the air-induction nozzle. This finding may be related to the lower limit of detection of rhodamine B on the fluorimeter. Working with distances greater than 50 m does not necessarily result in a more complete analysis if the power of detection of the tracer is low enough that such differences cannot be detected.

The A coefficients of the drift curves were between 12.0918 and 19.1333 for the ATR nozzle and between 2.8155 and 9.1434 for the TVI nozzle, whereas the B coefficients were between -1.1491 and -1.0027 for the ATR nozzle and between -1.0007 and -0.6249 for the TVI nozzle. Because there was no superposition of the values for both the A and B coefficients, the curves were considered to be mathematically different. This difference can be better observed in the regions closest

Table 2. Drift percentage resulting from pesticide application with standard (ATR) and air-induction (TVI) hollow cone nozzles on coffee (*Coffea arabica*) plants⁽¹⁾.

Distance from the treated area (m)	Spray nozzle	
	ATR	TVI
2.5	6.68b	5.06a
5.0	2.75b	1.59a
7.5	1.67b	0.85a
10.0	1.33b	0.63a
12.5	1.03b	0.47a
15.0	0.82b	0.40a
17.5	0.69b	0.35a
20.0	0.52b	0.30a
22.5	0.45a	0.29a
25.0	0.41a	0.31a
27.5	0.37a	0.30a
30.0	0.35a	0.29a
32.5	0.33a	0.28a
35.0	0.32a	0.30a
37.5	0.30a	0.30a
40.0	0.30a	0.33a
42.5	0.30a	0.30a
45.0	0.28a	0.31a
47.5	0.29a	0.30a
50.0	0.29a	0.32a

$F_{\text{nozzle}} = 8.282^*$; $F_{\text{dist}} = 108.860^{**}$; $F_{\text{int}} = 2.965^*$

OR: $F_{\text{Levene}} = 23.267^{**}$; K-S = 0.272^{**}; $F^*_{\text{Tukey}} = 858.318^{**}$

T: $F_{\text{Levene}} = 13.567^{**}$; K-S = 0.164^{**}; $F^*_{\text{Tukey}} = 351.741^{**}$

⁽¹⁾Means followed by equal letters, in the rows, do not differ by Tukey's test, at 5% probability. F_{nozzle} , F_{dist} , and F_{int} , values of F calculated for nozzle, distance, and interaction, respectively. F_{Levene} , K-S, and F^*_{Tukey} , values of the F statistic for the Levene test, K-S for the Kolmogorov-Smirnov test, and F for Tukey's test for the additivity of the blocks, respectively, which test the assumptions of the original data (OR) and of the data transformed (T) by arc sine $(x/100)^{0.5}$. ** and *Significant at 1 and 5% probability, respectively.

to the sprayed area. Therefore, it would be interesting if the preparation of drift-prediction models included the nozzle type used in the application, since drift was shown to be dependent on this factor in the present study.

The curves obtained for the ATR and TVI nozzles were compared with the German and Dutch models using the 90th percentile of the drift data resulting from applications on coffee plants (Figure 2). The 90th percentile is a widely used representation in studies of ecological and toxicological risks (Wang & Rautmann, 2008). According to these authors, a part of the drift, beyond that measured in the field, is omitted due to combination effects, such as the velocity of the wind and agricultural practices. Because the models do not take into consideration all of the effects, the expression of drift in the 90th percentile, used in pesticide records in the European Union, is a way of compensating for these omissions and increasing the safety of the information, especially for recommendations.

The German and Dutch models estimated a drift of 19 and 17%, respectively, for fruit tree crops at 2.5 m from the last line sprayed, which are values higher than those observed in the present study. At distances greater than 20 m, the drift curves from the nozzles began to have a similar behavior. This similarity allows for the drift data estimated by Ganzelmeier et al. (1995) to be used on coffee trees without suffering large distortions in studies on the risk for residents exposed to pesticide products. The same is expected for the determination of buffer zones. However, in studies that involve smaller

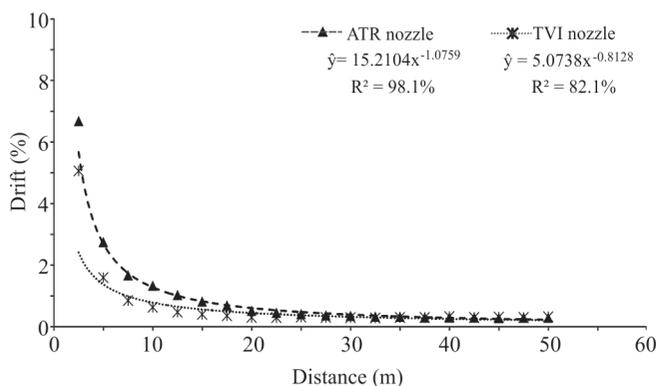


Figure 1. Drift curves from pesticide applications on coffee (*Coffea arabica*) plants with standard (ATR) and air-induction (TVI) hollow cone spray nozzles.

distances, such as those to bystanders, preference must be given to the models developed specifically for coffee.

In the regions closest to the application area (up to 5 m), the German model generated the largest drift values, indicating the greatest differences between the data, which can affect the calculation of the total amount of product lost to drift. Therefore, the largest product losses are observed in those regions.

This pattern possibly occurred because regions closest to the treated are the most affected by the spraying process. The coffee plant, in general, is denser than the fruit-bearing crops used in Germany (Ganzelmeier et al., 1995), forming a physical barrier to the passage of the droplets, decreasing the loss of product that passes between the plants of the same line. In the most distant areas from the crop, losses are most likely caused by droplets that pass over the plants, mainly due to the action of the spray fan, and are less influenced by the type of crop.

The German model was prepared based on studies with apple (*Malus domestica* Borkh.) and pear (*Pyrus communis* L.) trees, which are crops that differ anatomically and morphologically from coffee. Coffee plant architecture is different from that of most common orchard crops – it is a cylindrically-shaped woody, perennial dicotyledon, with a high leaf area index. Although the Dutch model is considered to be more complete than the German one because it encompasses a larger number of variables, both

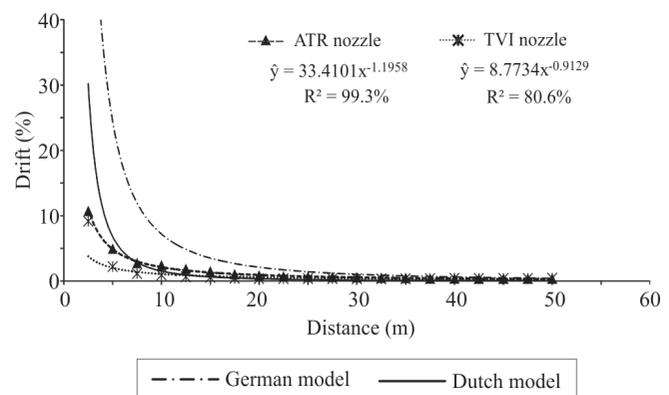


Figure 2. The 90th percentile of the drift percentage from pesticide applications on coffee (*Coffea arabica*) plants using standard (ATR) and air-induction (TVI) hollow cone nozzles, including a representation of the German and Dutch drift-prediction models for fruit crops.

models were developed for European conditions of temperate climate and, therefore, must be used with caution to estimate drift in coffee crops in tropical climates. In general, the Dutch model more closely approximated the drift curves obtained in the present study. Furthermore, it is important to note that the physical-chemical properties of the spray mix can change the droplet spectrum and, in this way, affect drift values.

In areas of citrus trees (*Citrus* spp.) in Italy, the German model overestimated the field data and should not be used for drift prediction in citrus orchards in that region (Meli et al., 2003). Similar results were found by Vischetti et al. (2008), who studied drift-reduction methods in vineyards, comparing a drift-prediction model with field data. The authors concluded that there was agreement between the data only at greater distances, approximately 24 m from the treated area.

The determination of environmental risk from pesticide application is highly dependent on the drift models employed because they use values that are close to those of the treated areas. This shows the importance of the selection of a drift model, given that evaluations made up to 5 m, to estimate worst-case scenarios, are less accurate than those made at greater distances because of the larger data variability.

Conclusions

1. The air-induction hollow cone nozzle results in lower drift than the nozzle without air induction, up to 20 m from the treated area.

2. The application with the hollow cone nozzle results in 6.68% maximum drift in the nearest collectors of the treated area.

3. The German and Dutch drift-prediction models overestimate the drift at the distances closest to the treated area.

4. The Dutch model more closely approximates the drift curves generated by the hollow cone nozzles, with and without air induction.

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