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Application of geostatistics tools to evaluate droplets spectrum of a common spray atomizer using several additives

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Abstract

The objective of this work was to evaluate the spectrum of droplets and syrup deposition of motorized costal atomizer, using additives in spraying solution. For this purpose geostatistical approach was applied. The treatments such as water (witness) and different additives (mineral oil, siliconized polymer and ethoxylated nonylphenol) were applied. Just before application, collectors (glass plates and hydrosensitive labels) were distributed at seven distances from the center of the spray circumference with different radius (3.0, 6.0, 9.0, 12.0, 15.0, 18.0 and 20.0 m), in the directions of the cardinal and collateral points, totaling 56 sample points. The deposition parameters, volumetric median diameter (VMD), relative amplitude (RA) and coverage were evaluated by means of aqueous solution (spray liquids + dye) to verify deposition by spectrophotometry and hydrosensitive paper label for the spectrum of drops. Descriptive analysis of the data was performed and geostatistics used as a tool for the analysis of spatial variability. The values for non-sampled locations were estimated using the ordinary kriging interpolation method. It allowed mapping that defined the application zones for the calculation of drift. The results showed that the VMD of the droplets was 136 µm. The application maps showed that there was a drift of 71.50% of the volume of syrup applied. The geostatistical tool made it possible to evaluate the droplet and deposition spectrum by means of the application maps. The proposed climatic recommendations for the application of agricultural pesticides do not apply to cost atomizers.

Keywords: additives; air assistance; deposition; drift; application technology.
Abbreviations: RA_Relative Amplitude, VMD_Volumetric Median Diameter, ISD_Index of Spatial Dependence.

Introduction

Spraying technology of formulations (such as insecticides, fungicides, etc.) is mainly based on the most efficient and safe mix pulverization, using the lowest volume of calcium available to obtain the highest coverage with the lower drift loss and human contamination (Baetens et al., 2009). Spryaing under climatic conditions with relative reduction to 50% and a wet bulb temperature above 30 °C stimulate early evaporation of spray droplets. The wind velocity above 3 m s^{-1} can blow away lighter droplets characterizing a spray derivate (Minguela e Cunha, 2010; Boller et al., 2011). Additives are compounds that are usually added to formulations or to the spray mixtures to improve wetting, adherence, non-spreading, foaming reduction and dispersion of spray mixtures (Cunha et al., 2010). However, according to Antuniassi et al. (2008), misuse of additives may lead to unknown negative effects, including non-expected effects or drift decrease on pulverization agriculture. The use of the pneumatic costal spray (sprayer) in cultures with high leaf density has been commonly approved since the air flow produced by the internal combustion engine promotes the movement of the leaves of the plants, facilitating the penetration of the drops into the canopy. Unlike hydraulic sprayers, the assistance of air over the formed droplets allows a greater spray jet range, allowing more homogeneous applications (Paixão, 2016). The study of spatial variability through geostatistics allows interpretation of the results based on the structure and natural variability of the evaluated attributes. The spatial dependence within the sampling interval (Souza et al., 2009) is an alternative, allowing a better understand of variability of the attributes and their influence on the environment (Silva Neto et al., 2012). Cokriging is a geostatistical procedure, according to which several regionalized variables can be estimated together based on the spatial correlations. It is a multivariate extension of the kriging method, when in each sampled location a vector of values is obtained instead of a single value (Angelico, 2006). The intercorrelation between variables is called coregionalization, which describes the spatial correlation between the variables in different locations. This correlation may be positive or negative, and the negative value indicates inverse correlation (Duarte, 2015). In this way, this work has the objective of evaluating the droplet spectrum and deposition of motorized costal atomizer spray using adjuvants in the pulverization applying the geostatistical method.

Results and Discussion

Descriptive analysis of the studied variables

There was no normal distribution of data for all the studied variables. The descriptive analysis (Table 1) showed the presence of high coefficients of variation for deposition, between 146.15 and 252.46%. Analyzing kurtosis, addition of silicone polymer, vegetable oil and nonylphenol ethoxylate obtained 5.14, 13.42 and 12.97 of spray mix deposition, respectively, demonstrating high data elevation compared to normal curve, characterizing spray mix deposition contrast within study area. For water and additives deposition variables, there were high skewness index, according to Figueiredo et al. (2009) and Pearson coefficient. Kriging does not require normality and low skewness of the data. However, kriging is better executed with data, which present normality due to semivariogram adjustment and facilitate kriging process (Machado et al., 2007). Descriptive analyses of VMD, RA and air coverage were the only positive deposition points. VMD for different types of additives showed values between 128 and 143 µm; thus, classified as fine droplets, according to Doble et al. (1985); and relative amplitude between 0.81 and 0.92. Rodrigues (2005) found that VMD can vary between 187 and 476 µm in hydropneumatic sprayers with JA-2 nozzles, depending on ventilator air speed. However, Reis et al. (2010) studied spray mix deposition using rotative atomizers on air plane and VMD was 144.5 µm and relative amplitude was lower than 1.0 for the upper canopy of the plants, values close to those found in this study.

Maps of studied spray variables

Table 2 shows the best results fitted to experimental semivariances for droplets characteristics and deposition. When deposition maps created from a theoretical model and ordinary kriging are analyzed (Fig. 1), predominance of deposition spray mix is noticed in northwest direction. Even according to climatic recommendations for application of pesticides, spray droplets transportation was affected by the wind. The use of air handling equipment to propel spray droplets are more sensitive to wind speed variation and recommendations for application of pesticides are not suitable for use, suggesting more studies to determinate the best use for these equipments. Jamar et al. (2010) studied deposition of different nozzles in hydropneumatic sprayer at orchards. Deposition on wind direction was significant between droplet size and wind speed in horizontal displacement (drift) of agriculture pulverization. Spatial variability can analyze open-air droplets spectrum characteristics as droplet size and application form, speed of electric energy production and pesticides expectation of deposition using terrestrial atomizers. Analyzing variability maps of VMD, RA and coverage (Fig. 2, 3 and 4), deposition of droplets bigger than 100 µm is concentrated on the first 10 m far from the equipment and coverage as well. Meanwhile, VMD lower than 100 µm is related to the most distant location from pulverization center, proving droplets susceptibility to wind transportation. Higher values on the relative amplitude maps (Fig. 4) are related to higher VMD and coverage, these regions represent nominal deposition of the equipment. Regions further than 10 m from the pulverization center have low values of VMD and RA. Deposition on this location consisted of droplets predominantly shorter than 100 µm. According to Cunha et al. (2010), these droplets are too thin and have high drift potential. Hydrosensitive paper labels located at 20 m, responsible to indicate drift direction out of study area showed that there was spray drift to northwest and west in all used adjuvants. Analyzing droplet spectrum on hydrosensitive paper labels at 20 m points, mean VMD and RA was 84.35 µm 0.63, respectively, characterizing droplets of high potential drift and difficult control. For a better sizing of pesticides droplets, it is essential to know that extra quantity of deposited spray may mix with wind, reducing application time per area; therefore, maximizing operational capacity of the equipment. Change in direction of spray droplets was southwest to northwest on the same way as equipment. In this situation, the applier receives deposition. Several authors reported the lack of individual protection equipment (IPE) and correct use of appliers, as well as environmental and human contamination index coming from pesticides drift explosion (Cunha, 2008; Gebler, 2011; Quirino et al., 2013). Therefore, besides the drift loss factor it is important to avoid application of pesticides against the wind as much as possible. This will reduce the exposure of the applicator to the pesticide used. Total mean deposition was calculated by sum of each distance mean at their respective influence area. It was 1.140 L of deposition on study area, which was 71.5% of volume of spray mix applied (4.0 L). At 18-20 meters distance, there was 1.8% of drift deposition on the soil. The hydrosensitive paper located at twenty meters points, indicated drift towards north and northwest. Cunha (2008) studied different droplets sizes and horizontal speeds and found that horizontal distance travelled is affected by droplets release height. Several authors reported drift difficulties using equipments that produce small droplets, mainly in unfavourable weather conditions (Balan et al., 2008, Cunha et al., 2010, Boller et al., 2011, Rodrigues et al., 2012, Quirino et al,. 2013). High initial speed utilized by equipment to spray propulsion and low pulverized droplets (VMD) promoted acceleration of the evaporation, maximizing the drift and reducing life time during the application.

Correlation

For all additives there was a strong correlation between deposition and coverage, as shown on Table 3. According to Fritz et al. (2012), droplets size is a decisive factor related to deposition both inside and outside of the target. Fine droplets can increase spray coverage, consequently, the products efficiency (Derksen et al., 2007). However, Schneider et al. (2013) claimed that droplets evaporation must be disregarded; because once droplets evaporated they will not be deposited on the target. Volumetric Median Diameter (VMD) and correlation index (r) of water reduced compared to Nonylphenol ethoxylate. The results corroborate with Scheneider et al. (2013). Correlation decrease can be related to interference of random factors inserted by wrong adjuvant dosage for atomizer application (Antuanissi et al., 2008; Durigen et al., 2008).

Table 1. Descriptive analysis of spray mix deposition data, VMD (Volumetric Median Diameter), RA (relative amplitude) and coverage for water, and additives silicone polymer, vegetable oil and ethoxylated nonylphenol.

Variable	M	SD	SV	Min	Max	Kurt.	AC	VC %
Deposition*								
Water	0.26	0.38	0.142	0	1.44	1.40	1.53	146.15
Silicone polymer	0.20	0.49	0.236	0	1.88	5.14	2.56	245.00
Vegetable oil	0.71	1.75	3.058	0	10.04	13.42	3.41	246.48
Ethoxylated nonylphenol	0.61	1.54	2.363	0	8.69	12.97	3.42	252.46
VMD								
Water	143.07	43.26	1871.82	84.42	243.18	0.18	0.68	30.24
Silicone polymer	141.84	40.01	1600.85	73.55	204.62	-1.05	-0.27	28.20
Vegetable oil	135.96	38.58	1488.47	79.32	237.35	1.08	0.82	28.38
Ethoxylated nonylphenol	127.94	35.84	1284.53	81.35	204.37	-0.75	0.48	28.01
RA								
Water	0.92	0.17	0.028	0.66	1.21	-1.13	0.28	18.48
Silicone polymer	0.81	0.23	0.054	0.43	1.20	-0.81	-0.07	28.87
Vegetable oil	0.89	0.27	0.075	0.44	1.57	0.74	0.46	30.50
Ethoxylated nonylphenol	0.82	0.16	0.026	0.53	1.05	-1.18	-0.20	19.78
Coverage								
Water	12.79	7.87	61.87	0.30	23.3	-1.43	0.01	61.53
Silicone polymer	12.62	8.20	67.29	0.30	23.80	-1.49	-0.17	65.00
Vegetable oil	13.84	8.66	74.99	0.10	24.30	-1.43	-0.54	67.44
Ethoxylated nonylphenol	10.33	7.81	61.00	0.30	23.50	-1.42	0.34	75.58

M = mean; SD = standard deviation; SV = sample variance; Min = minimum; Max = maximum; Kurt = Kurtosis coefficient; AC = asymmetry coefficient; VC = variation coefficient. *Units of measurements: Deposition: µl/cm²; VMD: µm; RA --; Coverage: %.

Table 2. Theoretical models of semivariance adjusted for deposition and characteristics of the droplet spectrum and spray for water and the different types of formulation of agricultural adjuvants.

Variable	Model	Nugget Effect (Co)	Sill (Co+C)	Range* (Ro)	R²	ISD (Co/(Co+C))	Residue
Deposition**							
Water	Gaus.	0.0001	0.172	5.86	0.887	0.999	0.0044
Silicone polymer	Gaus.	0.0001	0.283	4.44	0.716	1	0.0339
Vegetable oil	Gaus.	0.01	3.706	3.49	0.529	0.997	9.44
Ethoxylated nonylphenol	Gaus.	0.001	2.877	4.28	0.721	1	3.37
VMD							
Water	Gaus.	10	5080	4.58	0.823	0.998	5176207
Silicone polymer	Gaus.	10	5178	5.44	0.937	0.998	2110788
Vegetable oil	Gaus.	10	4971	5.28	0.877	0.998	3390481
Ethoxylated nonylphenol	Gaus.	10	4826	5.94	0.874	0.998	3176534
RA							
Water	Gaus.	0.0001	0.201	6.65	0.951	1	0.00251
Silicone polymer	Gaus.	0.0001	0.170	6.72	0.956	0.999	0.0017
Vegetable oil	Gaus.	0.0001	0.218	5.58	0.887	0.998	0.00662
Ethoxylated nonylphenol	Gaus.	0.004	0.190	6.80	0.880	0.979	0.00484
Coverage							
Water	Gaus.	0.1	54.160	4.95	0.811	0.998	747
Silicone polymer	Gaus.	0.1	57.510	5.81	0.916	0.998	399
Vegetable oil	Gaus.	0.1	70.430	5.60	0.898	0.999	606
Ethoxylated nonylphenol	Gaus.	0.1	51.240	4.84	0.791	0.998	761

* Range in meters. ISD - Index of Spatial Dependence; R² - coefficient of determination. ** Units of measurements: Deposition: µl/cm²; VMD: µm; RA --; Coverage: %.

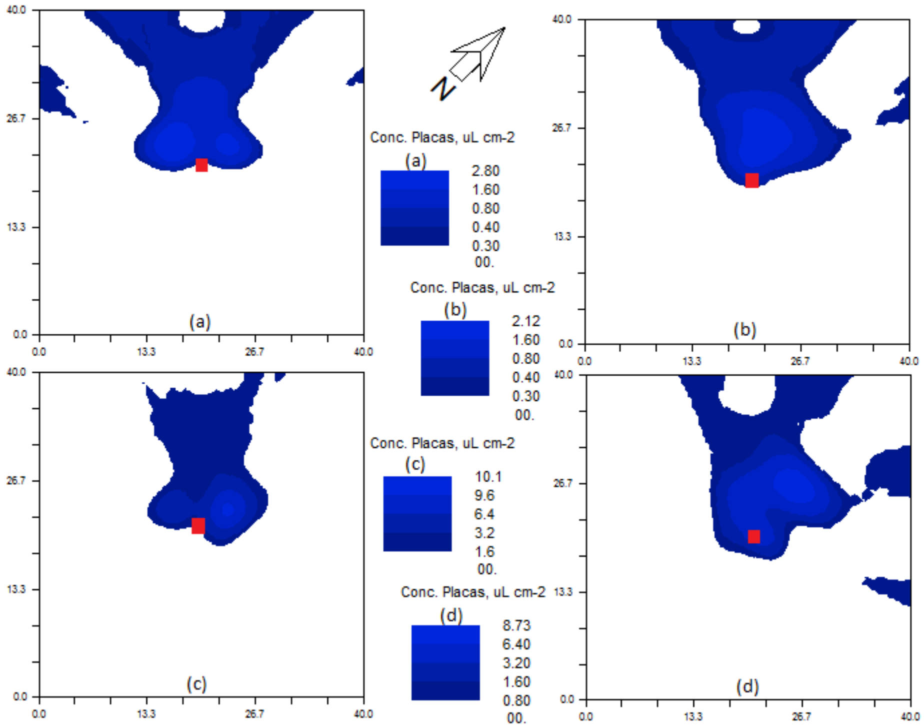

Fig 1. Map of spray mixture deposition using backpack atomizer. (a) water, (b) siliconized polymer, (c) mineral oil and (d) nonylphenol ethoxylate, for application of spray mix volume of 0.4 µL cm^{-2}. Darker blue tones are the lowest deposition values and the red dot shows the location of the sprayer.

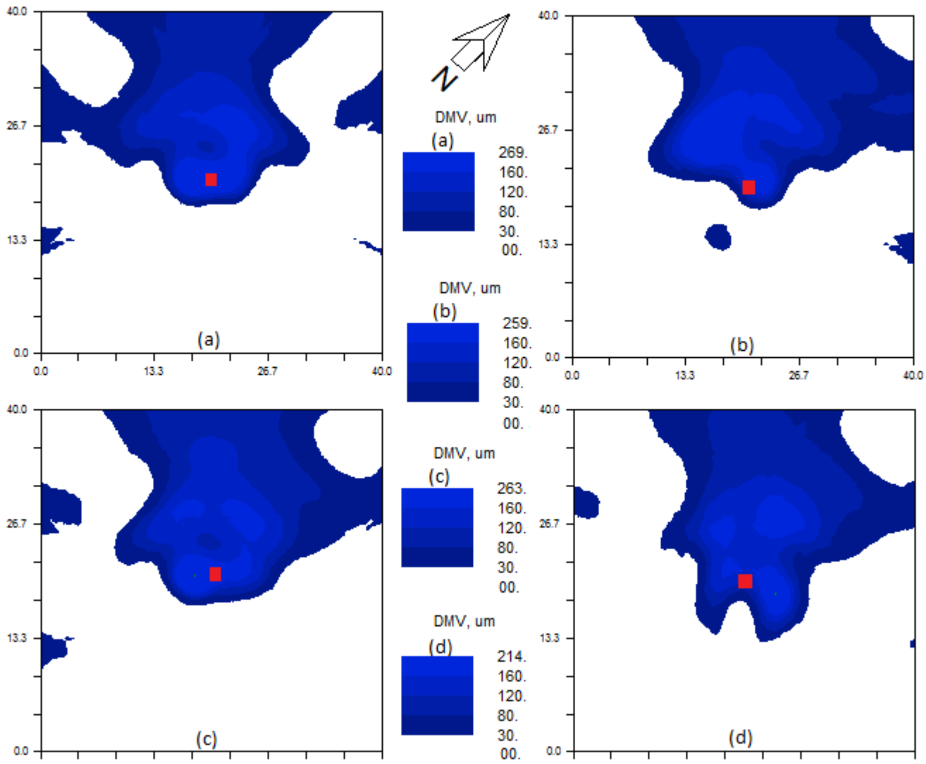

Fig 2. Map of spacial variability for VMD using backpack atomizer. (a) water, (b) silicone polymer, (c) mineral oil and (d) nonylphenol ethoxylated, for spray mix volume application of 0.4 µL.cm^{-2}. Darker blue tones are the lowest deposition values and the red dot shows the location of the sprayer.

Table 3. Interpretation of Pearson correlation index to spray mix deposition data and coverage.

Additive	Correlation index to deposition and coverage (r)	Interpretation
Water	0.9222	High correlation
Silicone polymer	0.9205	High correlation
Vegetable oil	0.8534	High correlation
Ethoxylated nonylphenol	0.8410	High correlation

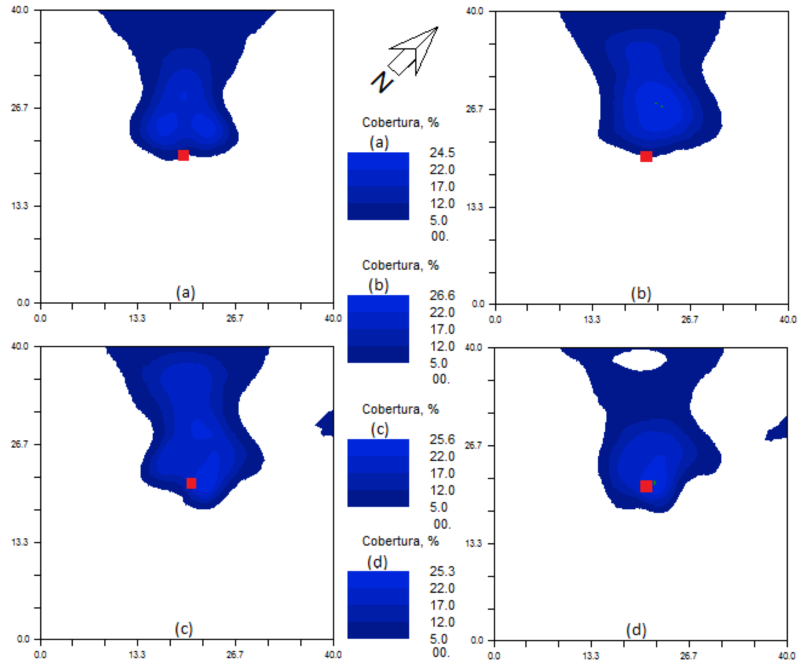

Fig 3. Map of spatial variability coverage using backpack atomizer. (a) water, (b) siliconized polymer, (c) mineral oil and (d) nonylphenol ethoxylate, for application of spray mix volume of 0.4 µL cm^{-2}. Darker blue tones are the lowest deposition values and the red dot shows the location of the sprayer.

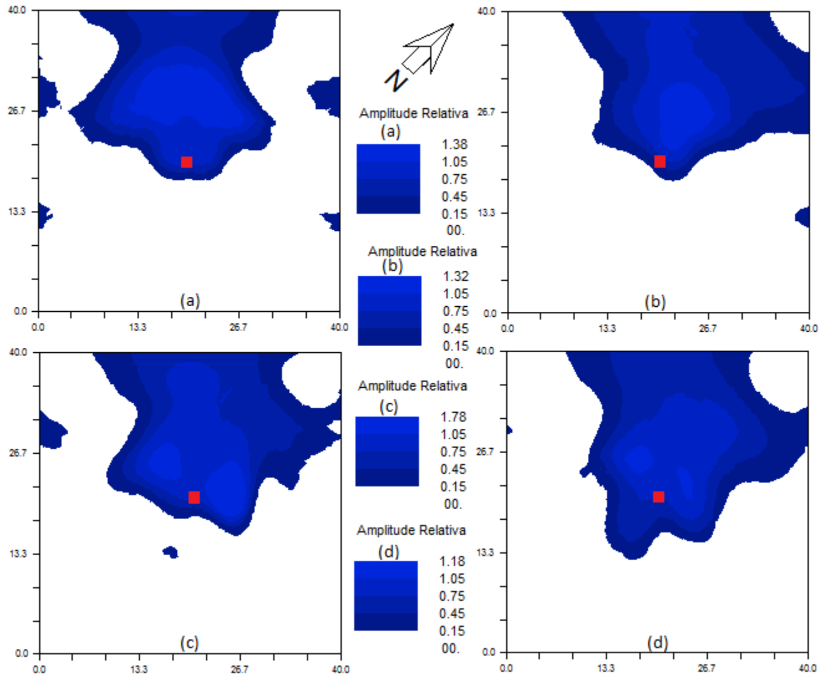

Fig 4. Spacial variability map for relative amplitude (RA) using backpack atomizer. (a) water, (b) siliconized polymer, (c) mineral oil and (d) nonylphenol ethoxylate, for application of spray mix volume of 0.4 µL cm^{-2}. Darker blue tones are the lowest deposition values and the red dot shows the location of the sprayer.

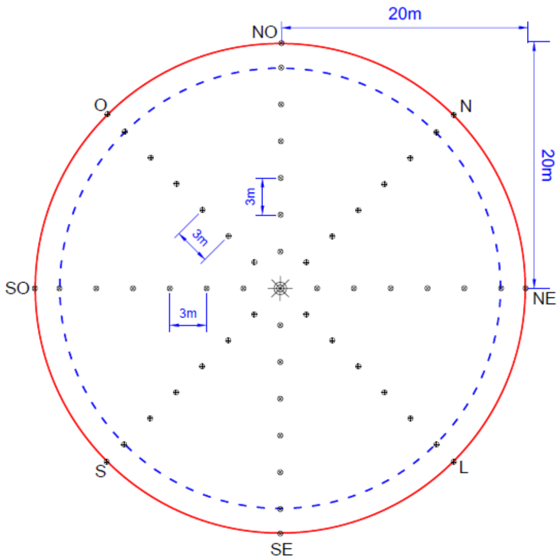

Fig 5. Drift collectors distribution on study area in platform rotating, spaced 3 meters each towards cardinal and collateral points. Where; NO = northwest; N = north; NE = northeast; L = east; SE = southeast; S = south; SO = south-west; O = west.

Materials and methods

General information

Study area comprised of a circle with 20 meters radius (Fig 5) without vegetation and maximum spray range of atomizer was considered 18 meters, as described in the manufacturer's manual, taken as expected deposition in the circle radius. A motored atomized backpack with 18L of capacity, ACM 18L-AT75 model with 3.48 KW sprayer motor, model TK065D – AT75E, single-cylinder with two strokes to pulverization was used. The sprayer's nozzle had flow of 1.33 L min^{-1} and stirrer in position 2 (maximum).

Implementation and conduction of study

The atomizer was fixed on a rotating platform, 0.60 meters from the ground. The spray's nozzle was fixed at 1 meter from the ground in 45° angle. The platform was powered by a motor and controlled by a frequency inverter, with angular velocity of 0.011 rad s^{-1}, resulting in application of 4 liters of spray mixture on the area. Sampling grid was established in 8 directions, spaced in 3 meters in each direction until 18 m and an extra collector in 20 m with atomizer in the center, as shown in Fig. 5, totally 56 sampling points. In each point deposition was collected using collector plaques and droplets spectrum utilizing hydrosensitive labels. Temperature, relative humidity, wind velocity and direction were monitored randomly. Experiments were performed at 6:45 a.m. and temperature varied from 16.5 to 22.8 °C; relative humidity, 62 to 72%; wind velocity, 1.00 to 1.35 m s^{-1}, and wind direction was predominantly to northwest. Formulations for the additives were made with commercial products BreakThru® (Silicone Polymer - 100%), Assist® (Mineral Oil - 75.6%) and Haiten® (Nonylphenol ethoxylate - 20%), using recommended doses of the manufacturer for application. In every collection point a hydrosensitive paper label was fixed (Wolf and Frohberg, 2002) and a glass plate 0.10 x 0.10 x 0.002 m (Bauer et al., 2000), both located at 0.20 m in height from the ground. At the laboratory, labels were scanned and analyzed using the "CIR" software (Conteo y tipification de impactos de pulverización) to characterize the droplet spectrum, evaluating VMD, RA and coverage. To Study spray mix deposition, a spectrophotometer analysis was performed, according to Palladini et al. (2005).

Drift quantification was performed by difference between actual volume applied and deposition volume calculated by means of deposition in each distance and its area of influence, according to Equation 1 and 2.

$$A_i = \pi(D_i^2 - D_a^2)$$
(1)

$$P_t = A_i \times C_d \times 0.01$$
(2)

Where:

Ai –Área of influence, m²;
Di – Distance analyzed , m;
Da – Previous distance analyzed, m;
Cd – Deposition concentration, µL cm^{-2};
Pt – Total depositon, L.

Data analysis

Data analysis consisted of a descriptive analysis, verification of spatial variability and Pearson correlation index between spray mix deposition and coverage. For descriptive analysis of data, kriging calculations, semivariograms creation and maps of spatial variability software GS + 7.0 (Gamma Design Software®) was used. Hypothesis of normality of the data was verified by the Shapiro-Wilk test at 5% probability, and computer program Excel 2007®. A total of 42 pairs of points were used to calculate the semivariogram with a minimum distance of 3 m and maximum of 20 m. Analysis of spatial dependence was determined by the SDI, according to Zimback (2001).

Conclusion

The results showed that the DMV of the droplets was 136 µm. According to the application maps, there was a drift of 71.50% of the volume of the syrup applied. The geostatistical tool made the evaluation of the droplet spectrum and deposition possible by means of the preparation of the application maps. The proposed climatic recommendations for the application of agricultural pesticides do not apply to cost atomizers.

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