SPATIAL QUALITY ASSESSMENT OF PESTICIDE APPLICATIONS USING A CANNON SPRAYER

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ABSTRACT

One of the critical points of the current system of crop production is the use of pesticides, which in addition to increasing the cost of production, can cause direct and indirect environmental contamination. This study aimed at evaluating the spatial variability of the quality of the pesticide applications using a cannon sprayer. Hydrosensitive paper targets were placed on the soil every two meters in the direction of the air flow until the maximum range of 30 m, and also in the direction of the tractor movement, placed every 6 m until the maximum distance of 30 m, forming a 90 m² area. Operational parameters of the Volume Median Diameter (VMD), Coefficient of homogeneity (CH), Target coverage (%C) and Density of droplets (DD) were evaluated. The data were submitted to a descriptive analysis and a subsequent geostatistical analysis in order to construct maps for the variables. The sprayer was not considered capable of performing efficient pesticide applications while maintaining good application uniformity, even in proper operating conditions.

Keywords: Geostatistics, application uniformity, spraying.

RESUMO

VARIABILIDADE ESPACIAL DA QUALIDADE DA APLICAÇÃO DE DEFENSIVOS AGRÍCOLAS UTILIZANDO PULVERIZADOR PNEUMÁTICO TIPO CANHÃO

Um dos pontos críticos do atual sistema de produção de culturas agrícolas é o uso de agrotóxicos, que, além de elevar o custo de produção, pode causar contaminações ambientais diretas e indiretas. Objetivou-se avaliar a variabilidade espacial da qualidade da aplicação de defensivos agrícolas utilizando pulverizador pneumático tipo canhão. Foram posicionadas etiquetas de papel sensível à água, no solo, a cada dois metros no sentido do fluxo de ar, até atingir o alcance máximo de 30 m e também no sentido do deslocamento do trator posicionadas a cada 6 m até uma distância máxima de 30 m, formando uma área de 90 m². Avaliou-se os parâmetros operacionais Diâmetro da Mediana Volumétrica (DMV), Coeficiente de homogeneidade (CH), Cobertura do Alvo (%C) e Densidade de Gotas (DG). Os dados foram submetidos a uma análise descritiva e a uma subsequente análise geoestatística para a construção dos mapas para as variáveis. O pulverizador analisado não foi capaz de realizar aplicações eficientes de defensivos, resultando em desuniformidade de aplicação, mesmo em condições adequadas de operação.

Palavras-chave: Geoestatística, uniformidade de aplicação, pulverização.

Recebido para publicação em 14/05/2014. Aprovado em 14/10/2015.

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INTRODUCTION

One of the critical points of the current system of crop production is the use of pesticides, which in addition to increasing the cost of production, can cause direct and indirect environmental contamination. In spraying, pesticides residues may exceed 70% of the total product applied (CHAIM *et al.*, 2000). Other authors reported losses between 30% and 50% (PERGHER *et al.*, 1997), but in some cases the deposition on plants was more than 64% of the total of product applied (PERGHER; GUBIANI, 1995).

Field monitoring data in Brazil have shown that 2 to 3% and up to approximately 1% of the volume applied is lost, adsorbed to soil particles and in solution in superficially drained water, respectively. Herbicide losses by volatilization were also found, with values from 2 to 90% with respect to the volume applied (EMBRAPA, 2012a). In bean crops, losses obtained were approximately 77% of the volume applied (EMBRAPA, 2012b).

Pesticides are most often effective in controlling the pest for which they are being employed. Trained operators use doses recommended by the manufacturers and care for their health by using personal protective equipment. Gandolfo and Antuniassi (2003) found errors in dosing the product to be added to the tank in 81.6% of the hydraulic sprayers evaluated; results indicative of lack of training for handling chemicals.

The quality of agrochemical application can be crucial to achieve the desired yield of the crop, and this operation aims to apply the correct dose for the desired target. Low-quality spraying can cause significant yield losses due to recurrence of insects, pathogens, and weeds in the area (GADANHA JÚNIOR, 2000). Therefore, monitoring the quality of the application is very important for effective control (BAIO, 2001).

Uneven distribution of the mixture over the plot treated with a cannon sprayer or atomizer is very significant and affects the effectiveness of the control. Rocamora *et al.* (2000), studying the performance of the air-assisted sprayers, stated that reduced volume of the mixture leads to a decrease in the deposition, but this reduction is not proportional and can be compensated by adjusting dosages. The reduction in mixture volume has occurred for most pesticide treatments worldwide, being advantageous both economically and environmentally. Furthermore, several studies have shown that it does not compromise the effectiveness of treatments if the application technology is properly employed (CHUECA *et al.*, 2009).

Importance is often given to the plant protection product to be applied while the application technology receives little attention. However, besides knowing the product to be applied, it is also necessary to master the appropriate application method in order to ensure that the product reaches the target efficiently, thereby minimizing losses (CUNHA *et al.*, 2005). According to Murphy *et al.* (2000), deviation of the trajectory of the particles released through the application process is influenced by wind speed, movement speed of the applicator device, and the droplet size. However, according to Ebert and Downer (2006) the size and number of droplets and the concentration influence the effectiveness of all pesticides, be it in laboratory, greenhouse, or field studies. Nevertheless, it is not possible to establish a pattern by stating that reduction in droplet size improves effectiveness.

Several factors influence the application of pesticides, causing the amount of products applied to miss the target. Holownicki *et al.* (2000) stated that application of agrochemicals in orchards (arboreal crops) is considered inefficient, since more than 50% of the products applied are lost. This causes economic loss to producers, in addition to risk of environmental contamination.

According to Fox *et al.* (2008), as the droplets move away from the sprayer there is a reduction in the speed of air flow, making it uneven during its trajectory. The smaller droplets tend to follow the air stream and are deposited on the target due to its turbulent motion, while large drops are deposited primarily due to impact. Thus, small droplets can be affected by the air stream itself, as well as by the weather conditions through the processes of drift, evaporation, or volatilization. On the other hand, larger droplets have difficulty penetrating the crown due to the wall effect produced by the leaves, in accordance with Escola *et al.* (2006), which also occurs for small drops, but not as intensely.

Understanding application uniformity is of great importance to minimize the negative impacts of agriculture on the environment, as well as to improve the efficiency of agricultural systems. In this context, geostatistics is an important tool to be considered, since it is capable of promoting the development of techniques for sampling and describing the variability of the characteristics of the physical environment of a system (SILVA *et al.*, 2011). The basic principles of experimentation, established by means of the classical statistical method, consider that the variability of the various phenomena occur entirely at random and collections are made randomly, assuming that their attributes present normal-frequency distribution; however, such phenomena do not present such spatial independence, thus requiring geostatistics (WEBSTER; OLIVER, 2008).

This study aimed to evaluate the uniformity of distribution of the spray mixture through the spatial variability of droplets using a cannon-type atomizer, commonly employed in phytosanitary control of mountain coffee plantations.

MATERIAL AND METHODS

The experiment was conducted in the experimental area of the Department of Agricultural Engineering of the Federal University of Viçosa (Minas Gerais, Brazil), located at 20º43' latitude, 42º51' longitude, and 640 meters altitude.

A cannon sprayer of the brand Berthoud, model AF 427, with tank capacity of 400 liters and hydraulic agitation system, a centrifugal pump with flow rate of 90 L min^{-1}, and a fan with curved aluminum blades and 4,000 rpm rotation was used. The applications were performed in the morning when weather conditions were suitable for application of pesticides.

The air speed at the outlet of the cannon was measured by using a digital thermo-anemometer, model TAFR-180. The sprayer was pulled by an MF 265 tractor, series 300,000, with 4 x 2 TDA (auxiliary front drive) drive. With aid of a Tachometer Minipa, model MDT-2238A, the rotation of 1,600 rpm was determined, corresponding to 540 revolutions per minute on the power take-off (PTO) axle.

The spray volume applied was 118 L ha^{-1} with the tractor operating at 5.4 km h^{-1}. To the spraying mixture, 10 g L^{-1} of Guarany dye recommended for dyeing black-colored cloth, pre-diluted in boiling water as recommended by the manufacturer, were added (RODRIGUES, 2005). The dye is of low

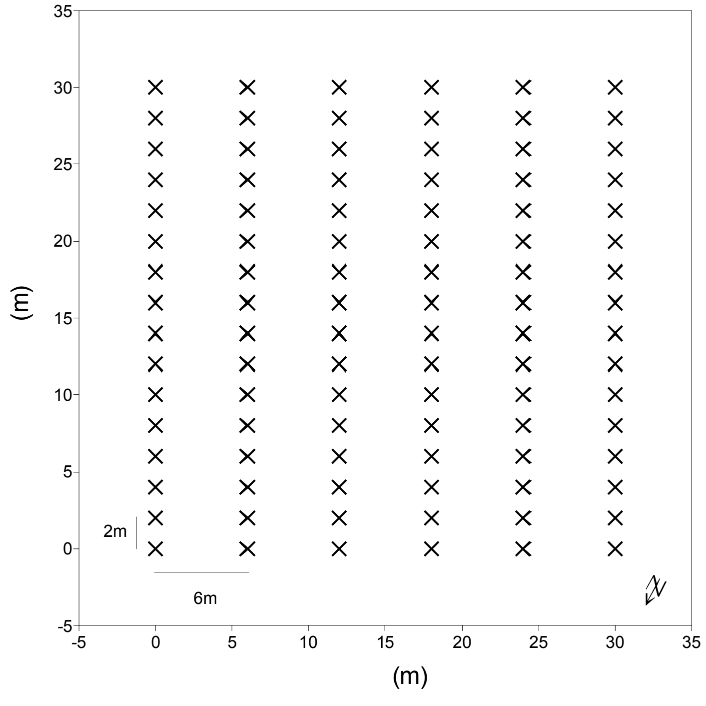


Figure 1. Spatial distribution of the sample points on the studied area.

cost and allows for the observation of drops after generating the images.

Hydrosensitive paper targets were placed on the soil every two meters in the direction of the air flow until the maximum range of application, which was determined for the aforementioned sprayer in a previous test and corresponds to 30 m. In the direction of the movement of the tractor, paper targets were placed every 6 m until the maximum distance of 30 m, forming a 90 m² area, as shown in Figure 1.

After the paper targets had dried, they were collected and photographed with a Nikon digital camera, model COOLPIX-5400. The camera was placed on a support so that all photos were obtained at a height of 0.20 m. The images were analyzed by the software Image Tool 3.0, as also used by Ruas (2007) and Magno Júnior (2008). The software allows for the study of the parameters Volume Median Diameter (VMD), Coefficient of homogeneity (CH), Target coverage (%C), and Density of droplets (DD), which are responsible for the quality of application in the field.

Before and during the work, the weather conditions were monitored. To measure wind speed and temperature, a digital Thermo-Anemometer, model TAFR-180, was used, and the measures obtained were, respectively, 3.2 km h^{-1} and 23.6°C. Relative humidity was 70%, obtained with aid of a psychrometer, model M-II, manufactured by Meteoro Instrumento.

The data were subjected to descriptive and exploratory statistics and normality was defined by the Shapiro-Wilk test, at 5% probability. Subsequently, the spatial dependence was calculated by semivariance, within which the assumed hypothesis of seasonality (Vieira *et al.*, 1983; Gonçalves *et al.*, 2001) was tested through adjustment of the variogram estimated by the following equation:

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h]^2 \qquad (1)$$

in which, N(h) is the number of pairs of values [Z (xi), Z (xi + h)] separated by a vector h, and xi is a spatial position of the variable Z.

For the point cloud, a mathematical function was adjusted [$\gamma(h)$, h], whose parameters are known as: nugget effect, corresponding to the value of the intersection in the semivariances axis; plateau, equal to the value of the variance of the data; and scope, which is the distance at which the variogram reaches the value of the plateau (VIEIRA *et al.*, 1983).

The theoretical models for adjustment of the tested variograms were spherical, exponential, and Gaussian. The choice of the model followed the criteria adopted by the GS+ software (Robertson, 2002), which uses the smallest residual sum of squares (RSS), the highest coefficient of determination (R2), and the parameters of cross-validation. The data adjustment from the variogram enabled the definition of the following parameters: nugget effect (C0), plateau (C0+C), scope (a), and spatial dependence index (SDI). The SDI is calculated by the relation [C/(C0+C)], based on criteria established by Zimback (2001), and assumes the following intervals: weak for SDI<25%; moderate between 25%≤SDI≤75%, and strong for SDI>75%.

The variograms used in this work were scaled by the variance of the data as suggested by Vieira *et al.* (1991) to facilitate comparison. The existence of spatial dependence defined by the variogram was observed, and adjacent values were so similar that allowed estimating values for any location where the variable was not measured, using the ordinary kriging, which estimates values without tendency and with minimum deviation from the known values, i.e., with minimum variance (VIEIRA, 2000).

$$\sum_{j=1}^{N} \lambda_j \gamma(xi, xj) + \mu = \gamma(xi, x_0), 1 = 1, N \qquad \sum_{j=1}^{N} \gamma_j = 1 \qquad (2)$$

in which: γ(xi, xj) is the estimated semivariance, using the model adjusted to the variogram, corresponding to the distance between the points located at position xi and xj and γ(xi, x0) is the semivariance corresponding to the distance between the points located at the position xi and x0. Values of weight λ and one value of the Lagrange multiplier (μ) associated with the minimization of variance are generated, and with the values of λ_i it is possible to estimate values (Z) in the sampled area for any position x0.

With the estimated values, isoline maps were constructed based on the geographic coordinate, allocating the values of R of the different positions, using the following equation:

$$Z^*\ (X_0) = \ \sum_{i=1}^{n} \lambda_i\ Z\ (X_i) \qquad (3)$$

in which: Z*(x0) is the estimated value for the non-sampled local x0, Z (xi) is the sampled value, n equals the number of adjacent samples used in the estimation, and λ_i is the value of the weights applied to each Z(xi).

After estimating the data by ordinary kriging, isoline maps for the variables evaluated in the study were generated. The geostatistical analyses, as well as the interpolations, were performed with the aid of the GS+ software, version 7.0 (ROBERTSON, 2002), whereas all procedures for map construction were performed using the Surfer software, version 8.0.

RESULTS AND DISCUSSION

The application conditions were considered adequate - meteorological factors, regular surface of the ground, and speed of movement - as suggested by several authors (MATTHEWS, 2002; RAMOS, 2004), which makes the results reliable.

Table 1 presents the exploratory analysis of the values found for the variables under study. Measures of central tendency (mean and median) were different for all the variables, indicating a distribution in which the data present distancing from a central value. This fact is confirmed by the positive coefficient of skewness, indicating asymmetric distribution to the right (elongation of the tail of the normal distribution curve), which led to a deviation of the data from normal distribution according to the Shapiro-Wilk test at 5% probability. In the case of the coefficient of kurtosis, the variables presented leptokurtic distribution, with positive values distant from zero, indicating an elevation of the normal distribution curve which contributed to non-normality of the data.

Data normality is not a requirement of geostatistics; it is just convenient that in the normal distribution graph, the attribute does not present very elongated tails, which could compromise the analyses (CRESSIE, 1991). More important than normality of the data is the occurrence or non-occurrence of the proportional effect, in which the mean and variability of the data are constant in the area under study, i.e., the stationarity necessary for the use of geostatistics occurs (ISAAKS; SRIVASTAVA, 1989).

Analyzing the coefficient of variation (CV), which provides a very useful measure in the dispersion assessment of the data, it is possible to observe that, according to the classification proposed by Warrick and Nielsen (1980), considering as low the CV values <12%, median for 12%<CV<60%, and high for CV>60%, all variables presented median variation with values ranging from 47.84% to 57.27%. These high values of CV can be attributed to the large scope of the data, which favors distancing of the data from a central value. Because small droplets are produced, spraying with an atomizer is strongly influenced by wind; at the moment of application winds of 7.2 km h^{-1} affected

Table 1. Descriptive statistics and frequency distribution of the variables used to characterize the application uniformity

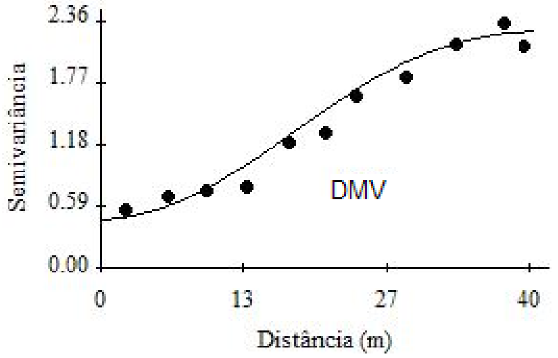
Variables	Statistics								
	Mean	Median	Minimum	Maximum	s	CV(%)	Cs	Ck	w
DMV	175	145.51	95.26	543.06	84.18	47.84	0.82	0.55	*
CH	2.4	2.00	1.41	7.38	1.17	48.50	0.66	0.72	*
%C	32.0	27.02	4.79	99.73	18.37	57.27	0.87	0.69	*
DG	16	13.82	2.83	52.61	9.31	56.46	0.99	0.73	*

VMD (Volume Median Diameter) - µm; %C (percentage of coverage) - %; DD (density of droplets) - droplets cm^{-2}; SPAN (relative amplitude), and CH (coefficient of homogeneity) – dimensionless; s – standard deviation; CV(%) – coefficient of variation; Cs – asymmetry; Ck – kurtosis; * non-normal distribution according to Shapiro-Wilk test at 5% probability.

the sedimentation of droplets, which presented sizes of 175.9 µm, being considerably harmful.

Analysis of the spatial variability of the variables was measured by variogram analysis. In Table 2 and Figure 2, which illustrate the results of this analysis, it is observed that two models proved more suitable to explain the structure of the spatial variability of the variables, the Gaussian model adjusting to the VMD and CH data, and the exponential model, with ranges varying from 15 to 38 m, adjusting to the %C and DD data.

The degree of spatial dependence, which measures the relationship between the nugget effect and the plateau, was considered strong for the variables VMD and DD according to the classification proposed by Zimback (2001), while the other variables presented moderate spatial dependence. According to Vieira (2000), the greater the proportion of structural variance (C) for the plateau ($C_0 + C$), the greater the similarity between adjacent values, the continuity of the phenomenon and smaller estimation of variance, and therefore the greater the reliability of the estimation of values in locations not measured by the method of interpolation by ordinary kriging.



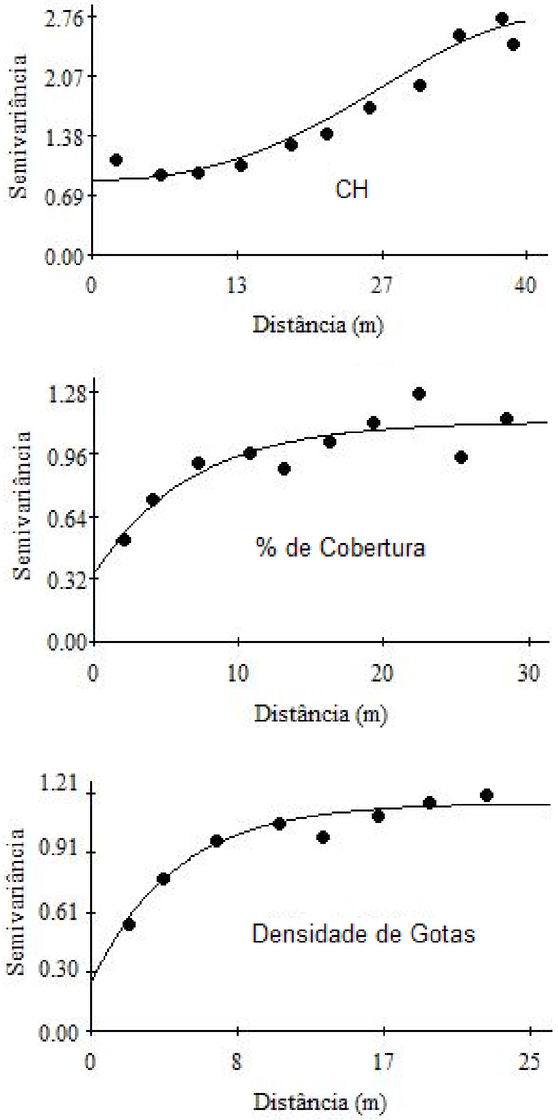


Figure 2. Median variograms of the variables that characterize the application uniformity.

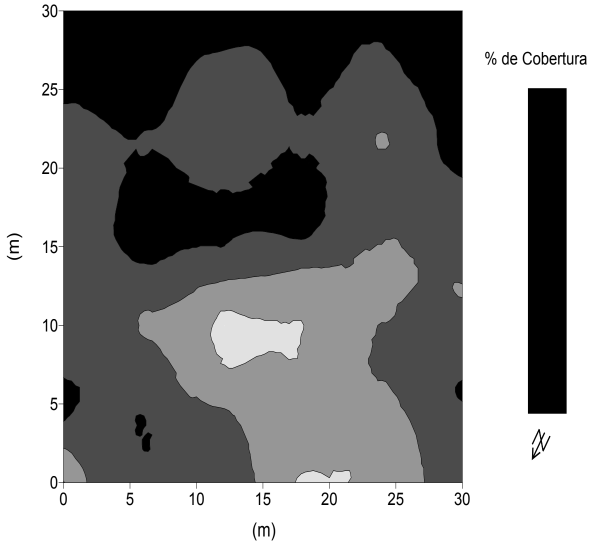
Table 2. Models and parameters of the median variograms adjusted to the variables under study

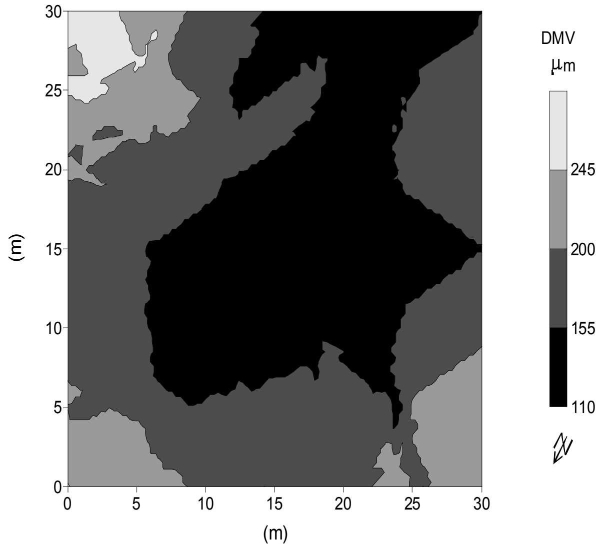
Variables	Models and Parameters							
	Model	C_0	C_0+C	IDE	a	R^2	RMSE	R^2(VC)
DMV	Gaussian	0.48	2.07	79	38	84	2.28	25.5
CH	Gaussian	0.74	2.66	72	35	85	2.26	32.3
%C	Exponential	0.31	1.08	71	24	82	0.87	36.9
DG	Exponential	0.27	1.14	76	15	79	0.99	23.7

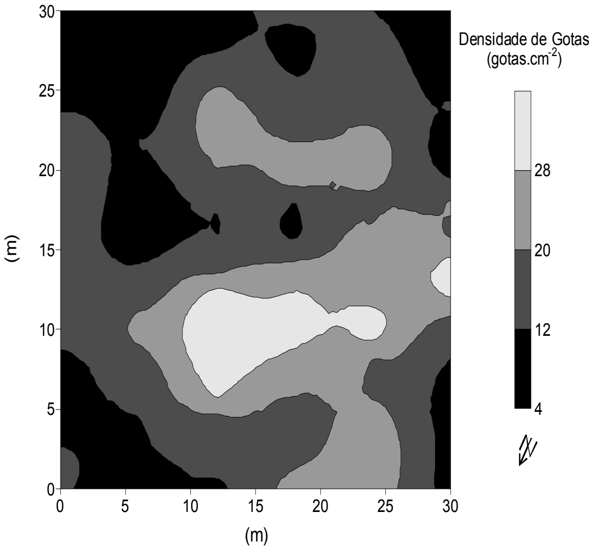
C_0 – nugget effect; C_0+C – plateau; SDI – spatial dependence index (C/ C_0+C); a – range; R^2 – coefficient of determination of the model; RMSE – mean squared error; R^2(CV) – coefficient of determination of cross-validation.

After the variogram parameters for the variables under study were obtained, maps were produced by the ordinary kriging method. They are presented in Figure 3.

It is possible to observe in the maps that the distribution pattern of the variables VMD and Coefficient of Homogeneity is similar, i.e., at locations where the first is smaller and the second is also decreased. This occurred because, at most times, the smaller the droplet size the larger their quantity, reducing the CH, which is the ratio of the Volume Median Diameter and the Number Median Diameter.







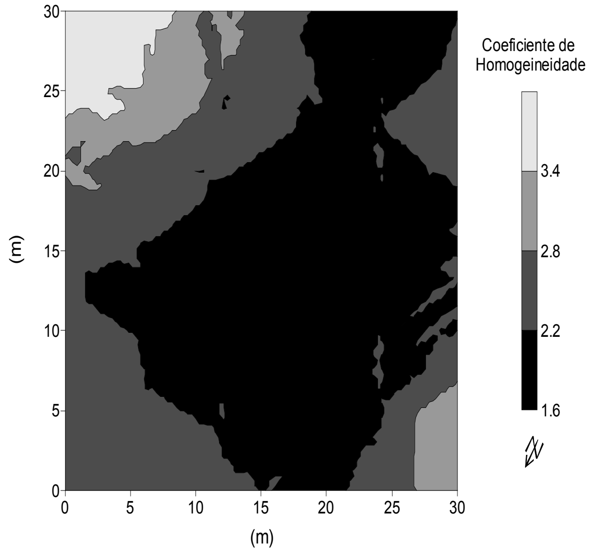


Figure 3. Thematic maps of the variables that characterize the application uniformity.

Analyzing the Percentage of Coverage and the Density of Droplets, it is observed that they also follow a similar pattern of spatial distribution. These two parameters have a close relationship with the droplet size, because the smaller the droplets, the higher the percentage of coverage and the density of droplets. This similarity in distribution behavior is expected, since these variables are interrelated and should be considered together for the evaluation of spraying quality.

For the Percentage of Coverage, as expected, as the horizontal distance from the sprayer increases there is lower coverage of droplets, i.e., in a real application scenario, considering the results of this study, plants located at a distance greater than 15 m would receive a volume lower than that received by those situated in distances smaller than 15 m. This problem is even greater when wind conditions are critical.

Despite the possible precautions at the time of application, as discussed above, the variation of distribution was considerably great. The sprayer was not able to maintain uniformity for any of the variables evaluated, demonstrating its inefficiency in pesticide application. The maintenance of uniformity of distribution of the spray mixture over a plot undergoing treatment is one of the most significant problems of this type of equipment; this aspect is enhanced when wind gusts push the air and mixture in the opposite direction, in the same direction, or sideways to the launch, continually altering the extent of the plot subjected to treatment, making it difficult to establish the volume of mixture sprayed and the plot of reentry for the machine, making this a very inefficient control method.

The most critical result of the application was observed for the density of droplets, which despite the wide variation in values, show values that in their entirety are much lower than those recommended for the control of various diseases. Azevedo (2001) reported the range of 50 to 70 drops per cm^{-2} as the minimum range of target coverage in order to obtain good control of diseases with contact fungicides.

The variation found in the horizontal application distribution can be attributed to the technology of the application used. According to Correa *et al.* (2004), using cannon sprayers offers a number of operational constraints due to problems of topography, soil condition, operational hazards, and mainly due to problems inherent to the equipment, such as the turbulence generated by the sprayer mechanism that tends to promote uneven deposition of droplets.

CONCLUSIONS

- From a technical point of view, the atomizer promoted inefficient spraying for application of insecticides and fungicides on mountain coffee culture;
- The application of spatial statistics allowed for understanding of the droplet distribution behavior along the plot under treatment.

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