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CROP PROTECTION

Mapping of the time available for application of pesticides in the state of Paraná, Brazil

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ABSTRACT. Spraying practices are highly sensitive to variations in climatic conditions, so it the spatial variability of the number of monthly hours available for the application of pesticides in the state of Paraná, Brazil, was determined and analyzed. An hourly time series of the climatic data obtained from 54 meteorological stations from the Paraná, for the years 2004-2014 was analyzed. To determine the number of monthly hours available to perform the applications, the following conditions were established: temperature < 30°C, relative air humidity > 55%, wind speed between 3 and 12 km h^{-1}, and rainfall less than 0.2 mm h^{-1}. After being cross-referenced, these data were analyzed using descriptive statistics and geostatistics. A high variability of availability for the performance of the applications was found, with 46.59 hours in June and 285 hours in August. A spatial dependence existed in the time available to perform pesticide applications in the state of Paraná, with variation occurring as a function of the month of the year. The Paraná geographic regions of the Central East, Metropolitan Curitiba, and Southwest are less favorable to perform the application. The mapping allows the management of spraying practices.

Keywords: application technology; spraying; climatic conditions; geostatistics.

Mapeamento do tempo disponível para aplicação de produtos fitossanitários no Estado do Paraná, Brasil

RESUMO. As práticas de pulverização são altamente sensíveis as variações das condições climáticas, assim foi determinado e analisado a variabilidade espacial do número de horas mensal disponíveis para realizar a aplicação de produtos fitossanitários no Estado do Paraná, Brasil. Foi analisado uma série horária de 2004-2014 de dados climáticos obtido em 54 estações meteorológicas do Paraná. Para determinar o número de horas mensal disponível para realizar as aplicações foi estabelecido a seguinte condição: temperatura < 30°C, umidade relativa do ar > 55%, velocidade do vento entre 3 e 12 km h^{-1} e precipitação menor que 0,2 mm h^{-1}. Após o cruzamento destas informações, os dados foram analisados pela estatística descritiva e pela geoestatística. Existe alta variabilidade de disponibilidade para realizar as aplicações com mínimo de 46,59 horas em junho e máximo de 285 horas em agosto. Existe dependência espacial do tempo disponível para realizar aplicações de produtos fitossanitários no estado do Paraná com variação em função do mês do ano. As regiões geográficas Centro Oriental, Metropolitana de Curitiba e Sudeste Paranaense são menos favoráveis para realizar a aplicação. O mapeamento permite a gestão das práticas de pulverização considerando a variabilidade espacial da disponibilidade em horas em cada mês e região do Paraná.

Palavras-chave: tecnologia de aplicação; pulverização; condições climáticas; geoestatística.

Introduction

The state of the atmosphere directly affects the evaporation, deposition of spray droplets and can increase the risk of losses through drift and run-off. Thus, the appropriate time for spraying can vary considerably with climatic variables from place to place and during the year in the same area of cultivation, constituting phenomena with spatio-temporal indexing.

Natural phenomena, such as climatic variables, often present with a certain structure in the variations between neighbors; therefore, the variations are not random, and thus, they have some degree of spatial and/or temporal dependence. Spatio-temporal variability can be studied using geostatistical tools, based on the theory of regionalized variables, where the values of a variable are related to its spatio-temporal arrangement.

To characterize the variability of climatic data, an analysis of their distribution is necessary. Spatial variability can be studied with geostatistical tools, based on the theory of regionalized variables, where the values of a variable are related to their spatial arrangement. The observations made over a short space resemble one another more than those made over larger spaces (Vieira, Nielsen, & Biggar, 1981).

For pesticide spraying to be successful, several factors related to the application technology must be considered, including climatic conditions (Cunha, Pereira, Barbosa, & Silva, 2016). Often, the active ingredient is lost due to environmental conditions and inappropriate application times. The results of 15 field experiments under varying climatic conditions, boom heights, and driving speeds indicated that for the most-evaluated spraying conditions, the most decisive factors influencing total spray drift were boom height and wind speed, followed by temperature, driving speed, and relative air humidity (Arvidsson, Bergström, & Kreuger, 2011).

The meteorological conditions considered favorable for spraying are widely reported in the literature and are characterized by temperatures between 15 and 30°C, relative air humidity greater than 55%, and wind speeds varying from 2 to 10 km h^{-1} (Ruedell, 2002; Minguela & Cunha, 2010; Raetano, 2011). However, in various situations, these requirements are not met due to the need to spray under unfavorable conditions. Previous knowledge about the spatial distribution of the monthly number of hours available to perform applications can be used in the decision-making process for the best time/condition for the application of pesticides.

The spatial analysis of the availability in hours to perform the application of pesticides under an ideal state of atmospheric conditions is fundamental for labor management, planning, and sizing of the sprayer fleet in agricultural properties. In addition, spatial analysis provides a more complex analysis to diagnose the regions that need more attention when choosing the application technology to reduce the risk of environmental impact, increase efficiency, and achieve the expected benefits of spraying practices.

The objective of this study was to analyze the spatial variability of the time available under appropriate conditions to perform pesticide applications in the state of Paraná, Brazil.

Material and method

The main meteorological elements that affect the quality and loss of pesticides during spraying are rainfall, air temperature, relative air humidity, and wind speed. This work was conducted through the analysis of historical data schedules of the meteorological variables air temperature (°C), air humidity (%), rainfall (mm), and wind speed (km h^{-1}) collected by the weather stations of the State of Paraná in southern Brazil (Figure 1).

The study included the entire territory of Paraná State, located between 22°29′30″ and 26°43′00″ south latitude and 48°05′37″ and 54°37′08″ west longitude. According to the Köppen classification, the climate in the state includes the types Cfa (subtropical) in the north, west, southwest, and coastal regions and Cfb (temperate) predominantly in the southern and southeastern portions of the state (Caviglione et al., 2000).

A map of the state of Paraná with the spatial distribution of the meteorological stations that collected the data is presented in Figure 1. Data were obtained from 54 stations encompassing the Pioneer North (4), Central North (5), Central West (2), Central East (4), Central South (6), Northwest (7), West (11), Southeast (4), Southwest (5), and Metropolitan Curitiba (6) regions. The data cover the period from 2004 to 2014.

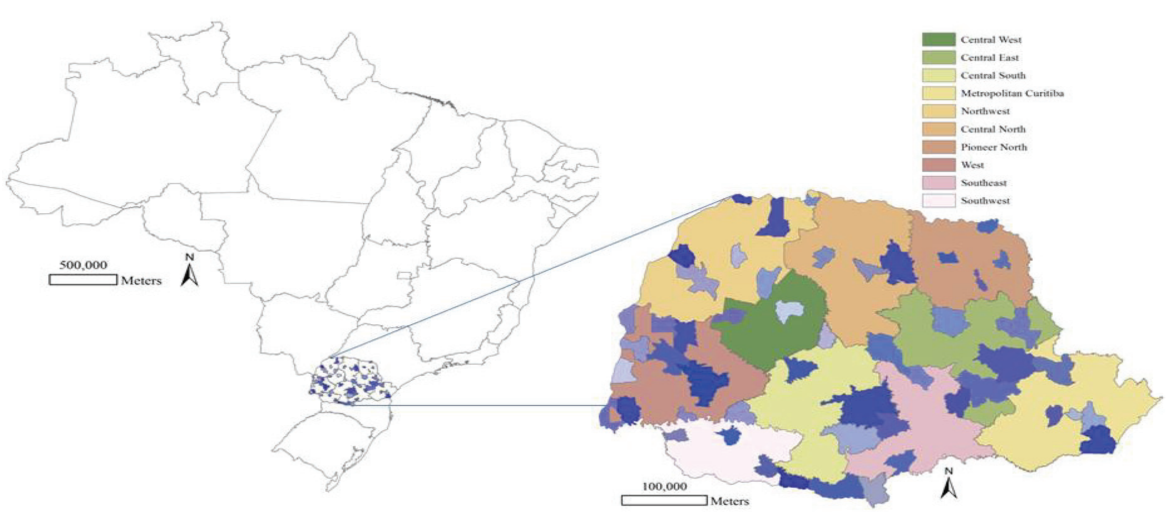

Figure 1. Spatial distribution of the agrometeorological data collection stations in the State of Paraná, Brazil.

Historical data on the studied variables were acquired from the National Institute of Meteorology (Instituto Nacional de Meteorologia – INMET) website (http://www.inmet.gov.br) and the Meteorological System of Paraná (Sistema Meteorológico do Paraná – SIMEPAR). The data were tabulated in an electronic spreadsheet (Excel®), followed by daily verification of the consistency of the available information. Data for those days whose information was inconsistent or had missing variables were eliminated.

With the aid of an electronic spreadsheet (Excel®) and using the ideal meteorological conditions for conducting pesticide applications as the parameter, a temperature below 30°C, a relative air humidity above 55%, wind speed between 3 and 12 km h^{-1} and rainfall less than 0.2 mm h^{-1} (ANDEF, 2004; Alvarenga et al., 2014), the data were cross-referenced to determine the times of day that all four weather conditions were within the intervals recommended in order to obtain better efficiency in the application. Next, the hours available for pesticide application were summed for each month, and the monthly mean for the 2004-2014 period was considered.

The data were analyzed using descriptive statistics of measures of central tendency (mean) and variability (standard deviation and coefficient of variation). Variographic analysis was applied to verify the existence and quantify the degree of spatial dependence by fitting the theoretical functions to the experimental variogram models, based on the assumption of stationarity of the intrinsic hypothesis, proposed by Vieira, Hatfield, Nielsen, and Biggar (1983), according to equation 1:

$$\gamma = \frac{1}{2N_h}\sum_{i=1}^{N_h}[Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

where: γ(h) = experimental variogram or variogram of samples; N(h) = number of experimental pairs of observations $Z(x_i)$, $Z(x_i + h)$, separated by a vector h; and $Z(x_i)$ and $Z(x_i + h)$ = pairs of data belonging to a distance class. The nugget effect (C_0), plateau (C_0 + C), and range (R_0) coefficients were determined from the fitting of the theoretical models to the experimental variograms. Ordinary kriging was used to estimate values at nonsampled sites and to create the isoline maps.

For the descriptive statistics and geostatistical analysis of the data, the program geoMS v. 1.0 was used (CMRP, 2000).

Result and discussion

Table 1 shows the results of the descriptive analysis of the number of hours available to carry out the application of pesticides in each month for the period 2004-2014.

For these 54 stations, the central tendency represented by the mean indicates that the month of February had less time available for applications (113.32 hours) and that October had more time available (152.74 hours). High variability existed in the ability to carry out the applications, which were intrinsically influenced by the months and geographical location. The highest coefficient of variation (22.20%) was observed in the month of June and the lowest in the months of April and September (16.80%). The data presented normal distribution according to the Kolmogorov-Smirnov test (Table 1).

Table 1. Descriptive measures of hours available for pesticide application in each month in Paraná State, southern Brazil.

Variables	Mean	Standard deviation	Minimum	Maximum	CV (%)	K-S test Max D (p > 0.02)
January	142.74	31.46	56.48	264.18	22.00	0.08
February	113.32	20.79	53.74	197.80	18.30	0.09
March	129.84	28.28	46.65	253.22	21.70	0.08
April	120.25	20.18	54.19	206.07	16.80	0.10
May	125.47	23.10	55.11	205.82	18.40	0.10
June	118.85	26.38	46.59	259.34	22.20	0.09
July	132.03	24.76	57.49	267.64	18.75	0.09
August	131.22	24.18	54.57	285.00	18.43	0.08
September	140.42	23.62	65.58	282.12	16.80	0.07
October	152.74	25.93	77.69	242.31	16.98	0.09
November	152.11	31.55	60.61	272.14	20.74	0.07
December	144.04	29.13	64.53	248.75	20.23	0.09

The variographic analysis (Table 2) revealed that all months presented spatial dependence with the fitting of variograms to the spherical model, with a minimum range of 79,792.82 m (August) and maximum of 179,990.49 m (October). Several studies indicate this model is best adapted to describe the behavior of the variograms of soil attributes and of the different slope gradients and relief shapes (Trangmar, Yost, & Uehara, 1985; Sanchez, Marques Júnior, Pereira, & Souza, 2005; Lima, Oliveira, & Silva, 2012). The variogram shows the measure of the degree of spatial dependence among samples along a specific support (Landim, 2006), that is, the zone of influence or distance around a station to perform the mapping.

The month with the highest spatial dependence index (SDI) was August, with 65.96%. In practice, this indicates that the mean number of hours available for pesticide application is not random in the area, that the structure is spatially dependent, and that these variogram parameters allow the values in unmeasured locations to be estimated using ordinary kriging.

The availability to perform applications was not uniform over time or among stations and varied with geographic location, with the nearest stations presenting more similar results than the more distant stations (Figures 2 and 3). The same pattern was observed among the months, with the highest number of hours available for applying pesticides in all the months occurring in the Pioneer North, Central North, West, Central South, and Southeast geographical regions.

The greatest availability for pesticide application occurred in the months of March and April in the Pioneer North and Central North regions; in the months of May, June, July, and August in the West region; and in the months of September, November, December, and January in the Central South and Southeast regions of Paraná. Therefore, variation is necessary in the application technique and the number of machines to perform the sprays at the appropriate time for control in the months with less availability and to meet the local demand of each region.

Table 2. Models and parameters of hours available for pesticide application in each month.

Variables	Model	C_0	$C+C_0$	Range (m)	SDI (%)
January	Spherical	3224.71	8957.61	172658.40	64.00
February	Spherical	2652.86	5478.53	159431.53	51.58
March	Spherical	3169.42	8319.76	122280.19	61.90
April	Spherical	5267.18	8778.64	125049.61	40.00
May	Spherical	3585.79	8366.61	87614.40	57.14
June	Spherical	3479.64	8654.36	102651.20	59.79
July	Spherical	3920.37	9025.73	91223.23	56.56
August	Spherical	2713.55	7970.89	79792.82	65.96
September	Spherical	2691.59	6930.75	92626.67	61.16
October	Spherical	4341.82	8857.11	179990.49	50.98
November	Spherical	3256.78	9118.59	143134.09	64.28
December	Spherical	4091.02	9304.64	169824.11	56.03

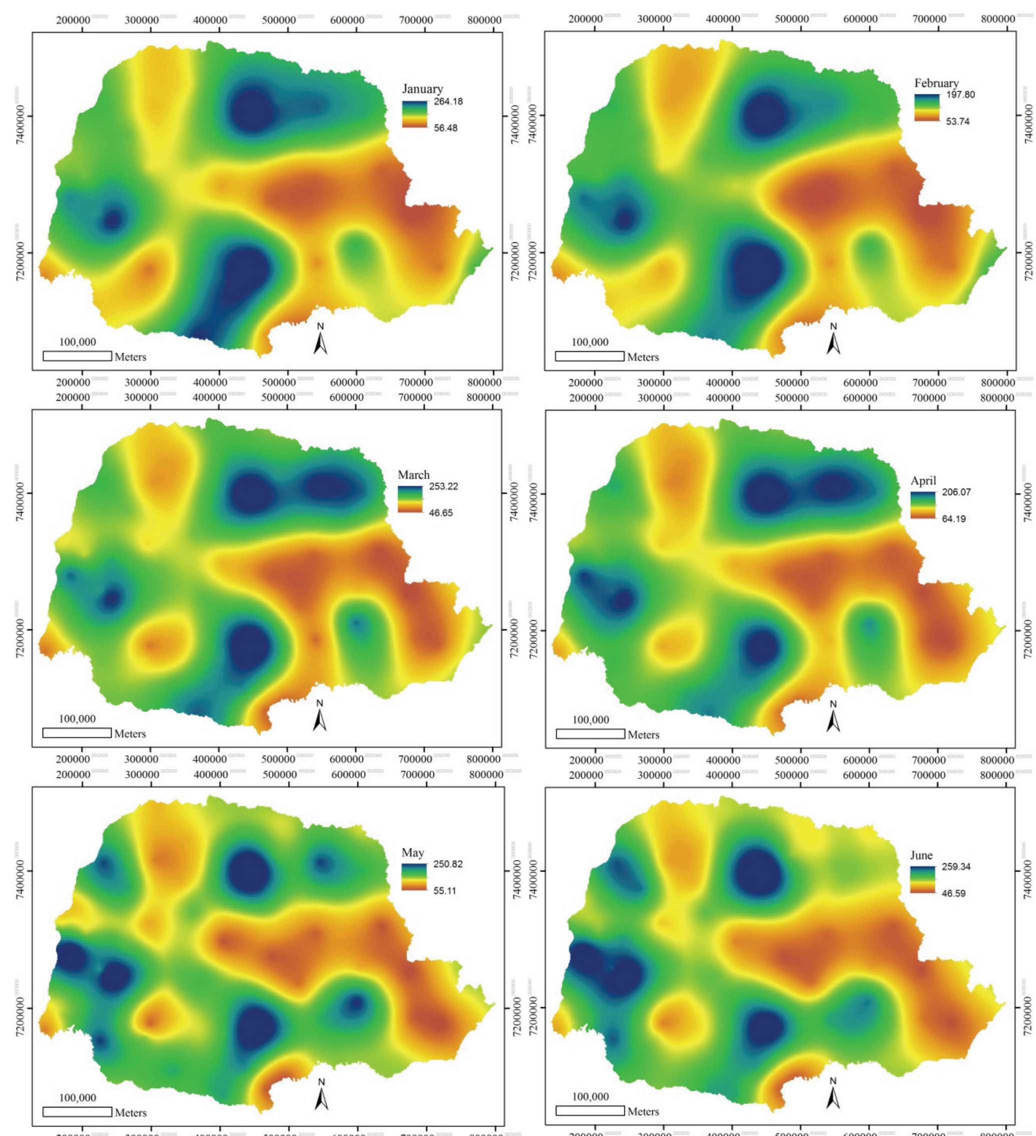

Figure 2. Spatial distribution of hourly availability for pesticide applications in the State of Paraná in the different months of the year.

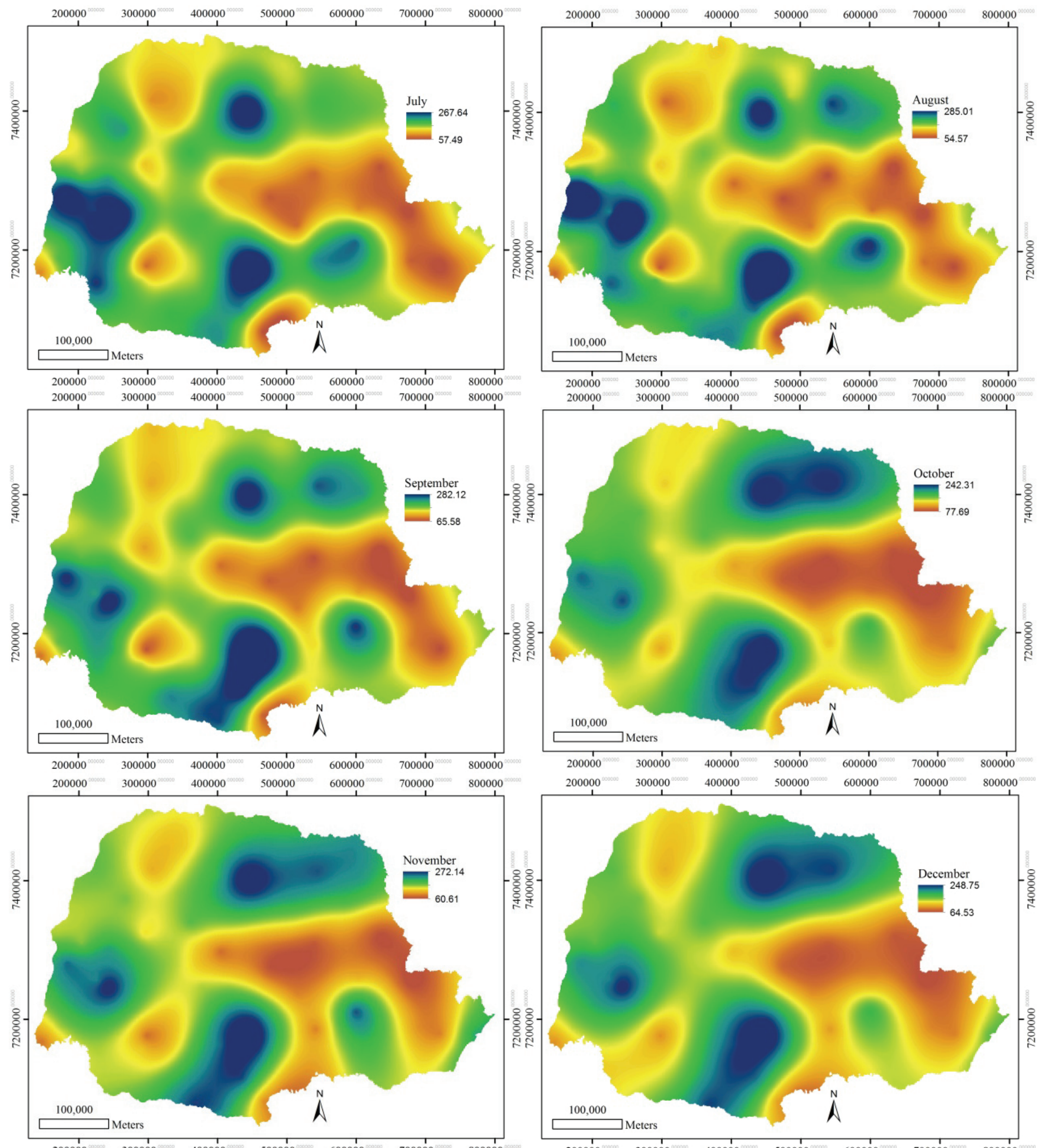

Figure 3. Spatial distribution of hourly availability for pesticide application in the State of Paraná in the different months of the year.

The availability in hours for application varies with the month, and the most appropriate months to apply pesticides are January, September, and November for the main summer crops, such as corn and soybean, and the least appropriate months are February and April, which is when the planting of the main winter crops begins (wheat and oats). The availability of hours for application also depends on the Brazilian region; in the southeast region, in the city of Uberlândia, state of Minas Gerais, a greater availability of times for pesticide application under the appropriate conditions were found for the months of November, December, January, and February, and less availability of appropriate hours for pesticide application was found in the months of August and September (Cunha et al., 2016).

Due to the continental proportions of Brazil and the size of many agricultural properties in Brazil, however, the ideal time for pesticide spraying, considering the climatic conditions, is very variable in the different production regions (Alvarenga et al., 2014). In this case, the mapping and knowledge of the hourly availability to perform the applications under suitable climatic conditions allows the professionals involved with the application technology to plan ahead and size the fleet of machines and the most appropriate application techniques for each time of application in the month and region to achieve success and reduce the probability of failure when performed under unsuitable climatic conditions due to underestimating the size of the sprayer fleet needed.

The maps express regions with lower and greater restriction in the number of viable hours per month, indicating the need for variation in the pesticide application in the state of Paraná to meet the demand of each region and in the respective months in which spraying activities are conducted. Knowing the spatial variability allows analysis with more accuracy of the regional demands of the state and thus better definition of the type, timing, and movements of machines; an understanding of the technological levels; the selection of drift reduction and safety techniques for each region; and the adjustment of the droplet size and use of adjuvants to reduce the percentage of droplets smaller than 100 μm, which are the spray droplets that can cause environmental damage.

Wind speed showed a stronger correlation with the number of hours available to perform pesticide application; that is, wind speed is the climatic variable that most limited or affected the spatial distribution of availability for pesticide application in the state of Paraná in all months, with lower affects in the month of February (Table 3). Thus, wind speed serves as an alert, so that, in these regions and months, the application techniques and schedules can be adjusted to minimize the effects of very strong wind or absence of wind during spraying. In field experiments under variable climatic conditions, boom height and wind speed were the most decisive factors influencing total spray drift (Arvidsson et al., 2011).

Wind is very important, and pesticide application is not recommended in its absence and in situations of high speed (strong winds). In the absence of wind, very fine droplets remain suspended in the air; in very strong winds, the very fine droplets can be transported away from the target of action and dispersed with other pollutants up to hundreds of kilometers from the application site (Miller & Stoughton 2000). In addition to wind, other variables such as rainfall, temperature, and air humidity are also equally important for pesticide application.

Relative air humidity presented a weaker correlation with the number of hours available to perform the pesticide applications, thus indicating that in the state of Paraná, the relative air humidity does not limit pesticide application, which is more dependent on wind speed, temperature, and rainfall (Table 3).

Table 3. Pearson correlation between the number of hours available for pesticide application (NHAPA) and climatic variables.

NHAPA	Precipitation (mm)	Temperature (°C)	RH (%)	Wind (m s^{-1})
January	0.33*	0.30*	0.23	0.99*
February	0.27*	0.27	0.12	0.31*
March	0.45*	0.36*	0.16	0.98*
April	0.50*	0.42*	0.24	0.99*
May	0.33*	0.38*	0.23	0.99*
June	0.31*	0.40*	0.19	0.99*
July	0.30*	0.38*	0.12	0.97*
August	0.25	0.27	-0.01	0.92*
September	0.19	0.15	-0.10	0.91*
October	0.24	0.19	-0.05	0.96*
November	0.15	0.16	-0.06	0.98*
December	0.21	0.26	0.14	0.99*

* Significant correlation ($p < 0.05$).

Conclusion

Spatial dependence exists in the time available to perform pesticide applications in the state of Paraná, with variation occurring as a function of the month of the year.

The Pioneer North, Central North, West, Central South, and Southeast regions of Paraná are the most favorable to perform applications.

Wind speed is the climatic variable that most influences the mapping of the time available for the application of pesticides in the state of Paraná.

The mapping allows the management of spraying practices while taking into consideration the spatial variability of the availability in hours in each month and region of Paraná.

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