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Population fluctuation and distribution of *bemisia tabaci* MEAM1 (Hemiptera: Aleyrodidae) in soybean crops

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Studies on the spatiotemporal dynamics of crop pests enable the determination of their colonization pattern and dispersion in the landscape. Geostatistics is an efficient tool to determine the spatial distribution pattern of the pest in the crops and to visualize them in appropriate maps. Analysis of these maps across the crop developmental stages can be a helpful tool in precision agriculture programs. The aim of this study was to determine the spatiotemporal distribution of *Bemisia tabaci* whitefly adults and nymphs in commercial soybean crops from planting to harvest. Infestation by the whitefly adults and nymphs started between 30 and 50 days after plant emergence. The maximum population density of ten adults per plant and two nymphs per leaf occurred between 90 and 101 days after plant emergence. In Kriging maps, it was possible to observe the distribution pattern for both adults and nymphs. The colonization of soybean plants by *B. tabaci* may be divided into three stages: beginning infestation (at the outermost parts of the crop), whole area colonization, and dispersion colonization (when the whole crop area is infested). The density of adult insects was positively correlated with rainfall and relative humidity. Wind speed positively affected the dispersion of adult whiteflies. The distribution pattern of *B. tabaci* in the soybean crop was aggregated. Climatic factors, such as wind speed, increase the dispersion radius of the whitefly in the crop. Contribution to the field.

KEYWORDS

aleyrodidae, dispersion, geostatistics, *glycine max*, hemiptera, whitefly

Introduction

Bemisia tabaci (Gennadius) Middle East -Asia Minor 1 - MEAM1 (Hemiptera: Aleyrodidae), commonly known as whitefly, is one of the most destructive pests for global agriculture, causing significant yield losses in commercial crops (Oliveira et al., 2013; Lima et al., 2017). This insect has high fecundity and fertility rates, it is polyphagous and occurs in areas of temperate, subtropical, and tropical climates (Byrne et al., 1997; De Barro et al., 2011; Cruz and Baldin, 2017). The whitefly has a wide host range; thus, crops such as cotton, beans, squash, melon, and tomato may serve as alternate host plants for *B. tabaci* infesting soybean crops.

The whitefly causes several problems in Brazilian crops, and the insect may cause direct damage by sucking phloem sap. Indirect damage is linked to the excretion of honeydew, which serves as a substrate for the growth of opportunistic fungi *(Capnodium* sp.) (Stansly and Naranjo, 2010; Li et al., 2011). *B. tabaci* may inhibit the gathering of carotenoids and chlorophyll, affecting the photosynthetic rate of plants (Masuda et al., 2016). In soybean [*Glycine max* (L.) Merr., Fabaceae], *B. tabaci* is the vector for the cowpea mild mottle virus (CpMMV) (Marubayashi et al., 2010).

In recent years, soybean has been highly attacked with high whitefly populations, mainly in the reproductive stages of the plant. Until very recently, this species was only seen as an occasional pest; however, it is now considered a key pest in soybean. Although the importance of the whitefly *B. tabaci* MEAM1 has increased its incidence in soybean cultivars (Vieira et al., 2011; Czepak et al., 2018; Da Silva Oliveira et al., 2018), there is no sampling method currently defined for this pest in this crop. The recommendations do not specify the sample numbers, area size to be sampled, location of the different stages, or the most suitable evaluation forms. In general, management is based on information obtained from other countries and in other crops, such as cotton (Naranjo and Flint, 1995; Ellsworth et al., 1995; Ellsworth and Martinez-Carrillo, 2001) and melon (Palumbo et al., 1994), in the state of Arizona, USA, in the cucumber and watermelon crop in Brazil (Moura et al., 2003; Lima et al., 2017; Lima et al., 2018).

The spatiotemporal dynamics of insects using geostatistics can provide important information about the pattern of colonization, aggregation, and dispersion of pests in the field (Pias et al., 2017; Galdino et al., 2017; Lima et al., 2018; Suekane et al., 2018; Martins et al., 2018; Felicio et al., 2019). This statistical tool uses a method that characterizes spatial variation by comparing similarities between distant and proximal points. This technique provides results that allow colonization maps to be produced, zoning the different densities, and determining the pattern of spatial distribution of the insects in the field (Pias et al., 2017; Lima et al., 2018). A sequence of these maps during crop development may indicate areas that demand greater attention to pest sampling and control in time and space (Sciarretta and Trematerra, 2014; Macfadyen et al., 2015; Martins et al., 2018).

In the context of precision agriculture, spatiotemporal dynamics studies of crop pests facilitate the reduction of the following: 1) production costs; 2) economic losses; and 3) environmental impacts of the unnecessary use of pest control methods. These advances come as a consequence of these studies, which indicate the places and times more favorable to the pests, and in which parts of the crops it is necessary to control these organisms. Considering the importance of studying the spatiotemporal dynamics of insect pests and to the best of our knowledge, there are few published studies on *B. tabaci* in soybean. Thus, the aim of this study was to determine the spatiotemporal distribution of adults and nymphs of *B. tabaci* in soybean crops from planting to harvest by using geostatistics and verifying abiotic factors (temperature, relative humidity, wind, and rainfall) that affect the dispersion of these insects.

Materials and methods

The experiment was carried out at Celeiro Seeds Farm, where grains and soybean seeds are produced. The experiment was conducted in two seasons, the first, from November 2017 to the end of March 2017, and the second start in from November 2018 to the end of March 2019. The farm is located in the municipality of Monte Alegre do Piauí and Serra do Quilombo, in the Brazilian state of Piaui (09°21'12" S; 45°07'42" W, 642 m) (Figure 1A).

The region's soil is characterized as a yellow Latosol (Oxisol), and the climate is tropical with a dry winter season, Aw, according to the Köppen-Geiger classification 29 (Kottek et al., 2006). Climatic data such as the mean air temperature (°C), relative humidity (%), wind speed (m/s) and wind direction were obtained from NIMET (National Institute of Meteorology), and rainfall data were obtained with a rainfall meter during the period of execution of the experiment in each field (Figure 2).

During the first season the work was conducted (2017/2018), the cultivars Brasmax Bonus IPRO® and BRS 9180IPRO® were used; in the second season (2018/2019), the cultivars were Brasmax Bonus IPRO® and Brasmax Extreme IPRO®. The characteristics of the cultivars are shown in Table 1. In the first season, the distance the fields the Brasmax Bonus IPRO® and BRS 9180IPRO® between was 12.347 meters (Figure 1B). In the second season, the distance the fields the Brasmax Bonus IPRO® and BRS 9180IPRO® between was 4.454 meters (Figure 1B).

An area of 1.6 ha (16,000 m²), with 100 m length and 160 m width, was divided into 160 sampling units, with 10 m² (Figure 1). In the center of each sample unit, sets of four ordered points, equally spaced 2 m from a central point, were used to improve the estimate of the nugget effect (Figure 1). Each sampling point was georeferenced using a GPS device model GPSMAP 60CS®x (Garmin). The distance from each field to the nearest native vegetation is described in Table 1.

Whitefly population

The population density of insects was evaluated in the sampling grid of 160 points previously georeferenced (Figure 1B). At each georeferenced point, 12 plants were

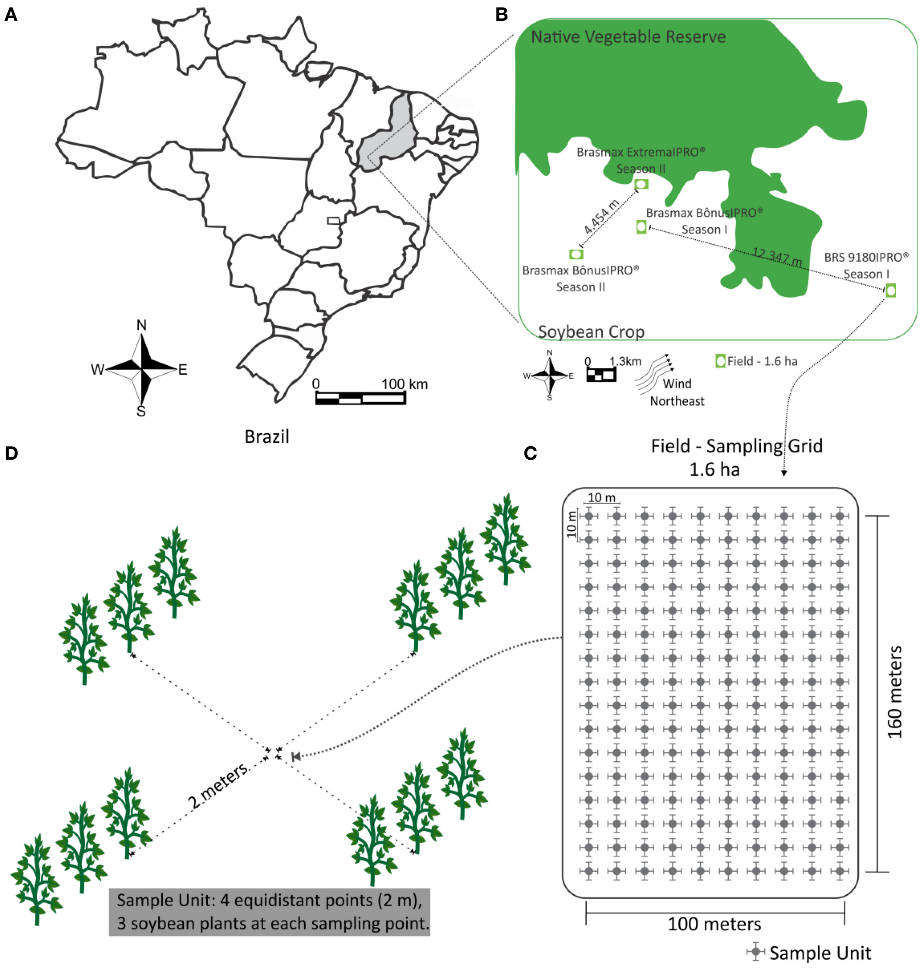

FIGURE 1
Location where the research was conducted **(A)** Brazil map showing *Monte Alegre do Piauí, Piauí.* **(B)** Location of field within the area, the distance between each field within an inside season. **(C)** Sample grid of the evaluated points and geographic location. **(D)** Sampling unit (3 plants equidistant from the central point, total of 12 plants per unit).

evaluated; 4 subsamples of 3 plants were taken (sampling unit). The subsamples were 2.0 m equidistant from the central point (Figure 1C). The evaluated plants were positioned along a regular grid pattern throughout the crop cycle to obtain systematic sampling points and avoid directional trends.

The third leaflet from top to bottom (apical third) of each plant was evaluated by direct counting (Naranjo and Flint, 1995; Pereira et al., 2004). Leaves were handled with care, and the nymphs and adults of *B. tabaci* were counted. A magnifying glass (40x) was used to count the number of nymphs. We evaluated these leaves using a direct counting method because these are appropriate technique for assessing the density of *B. tabaci* nymphs and adults in soybean crops (Naranjo and Flint, 1995; Pereira et al., 2004). The sampling schedule was standardized; the evaluations started at 7 am and ended at 11 am. The sampling schedules for each cultivar are described in Table 1.

Analysis of the whitefly spatial distribution

Phytosanitary management

The crop management practices were used in the region, including the application of pesticides against stinkbugs and whiteflies. In the 2017/2018 season, Field I received applications of Imidacloprid and Acetamiprid + Bifenthrin, while Chlorpyrifos and Bifenthrin + Carbosulfan were applied in the other field (Table 1). In the 2018/2019 season, Chlorpyrifos, Imidacloprid, or Imidacloprid + Beta-cyfluthrin were applied as needed in the fields. The insecticide label rate was used in all applications.

Data analysis

The data on adult and nymph densities of *B. tabaci* were submitted to statistical analysis. Subsequently, principal

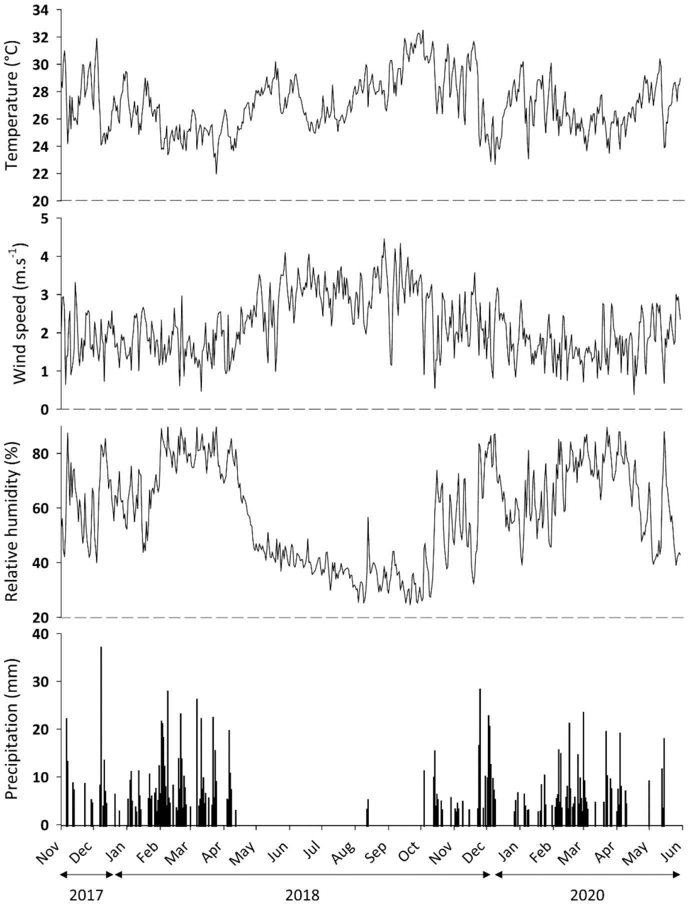

FIGURE 2
Daily variation in the mean air temperature, mean wind speed, mean relative air humidity, and total rainfall at Celeiro Seed Farm, Serra do Quilombo, Monte Alegre do Piauí. National Institute of Meteorology (INMET) data.

component analysis was performed between the range and density of whitefly adults with climatic parameters (temperature, relative humidity, wind speed, and rainfall). The PCA was used to analyze the interrelationships between the variables studied, and if there is any effect of climatic parameters on the distribution and density of whitefly adults and nymphs. These analyses were performed using Package 'psych' in R® software (R Core, 2020). All geostatistical procedures were performed using the Geostatistical Analyst Tool for ArcGIS 10.5 (ESRI). The steps in this procedure are follows: map and examination of data; preprocess of data if necessary (transform, detrend, decluster); definition of spatial structure model; definition of search strategy; prediction of values at unsampled locations; quantification of uncertainty of the predictions; checking if the model produces reasonable results for predictions and uncertainties, and using the information in risk analysis and decision making.

Subsequently, geostatistical analysis was performed; the spatial patterns and interpolations were determined using the parameters of adjusted experimental semivariograms and ordinary kriging, respectively. The semivariograms were calculated from the primary collected data, allowing us to detect differences between pairs of sampled points in relation to the distances (this procedure was used to adjust the theoretical semivariogram). Once the semivariance increases, there is a spatial dependence relationship between the densities of *B. tabaci* and the sampled points. The nugget effect and the sill value were calculated for each of the adjusted models (spherical, exponential, and Gaussian).

The experimental semivariograms were adjusted to the theoretical models, and the selection was made based on the cross-validation parameters, in which the measured and estimated values were compared using the standard mean error (SME) and the root mean square standardized error (RMSSE).

The kriging indicator was applied to spatial distribution maps of the insect in the crops, with the objective of modeling the probability of unsampled locations exceeding the quality reference values (QRVs). The kriging indicator does not use normal distribution assumptions, because it transforms the

TABLE 1 Phenological cycle, fertilization, plant population, planting date, distance from cultivars to the nearest native forest, and evaluation days by cultivar in the two seasons studied.

Season	I (November 2017 - April 2018)		II (November 2018 - April 2019)	
Variety	Brasmax BonusIPRO ®	BRS 9180IPRO®	Brasmax BonusIPRO ®	Brasmax ExtremaIPRO ®
Field	Field I	Field II	Field III	Field IV
Planting date and characteristics	Maturity group 7.9 - average cycle of 108 days. Planting on November 11, 2017	Maturation group 9.1 - average cycle 119 - 139 days. Planting on November 18, 2017.	Planting on November 27, 2018.	Maturation group 8.1 - average cycle of 110 days. Planting on December 4, 2018
Stand and spacing	390 thousand plants/ha. Spacing between lines of 0.50 m	200 thousand plants/ha. Spacing between lines of 0.45 m	390 thousand plants/ha. Spacing between lines of 0.50 m	200 thousand plants/ha Spacing between lines of 0.45 m
Fertilization	620 kg/ha of Simple SuperPhosphate, 200 kg/ha of Potassium Chloride, 3 kg/ha of copper sulphate, 2.5 kg/ha of Manganese Monoxide, 3 kg/ha of Ulexite and 20 kg/ha of MIB Granary.	200 kg/ha Simple SuperPhosphate, 200 kg/ha of Potassium Chloride and 20 kg/ha of MIB Granary in the planting line.	630 kg/ha of Simple SuperPhosphate, 200 kg/ha of Potassium Chloride, 20 kg/ha of Manganese Monoxide, 6 kg/ha of Ulexite and 13 kg/ha of Zinc Sulphate, by haul.	
Nearest native forest	1.79 km to the North	4.09 km to the West	4.22 km North	0.32 km Northwest
Assessment's days	14, 28, 42, 56, 70 and 84 DAE[a]	17, 31, 45, 59, 73, 87 and 101 DAE.	13, 27, 41, 55, 69, 83 and 87 DAE	20, 34, 48, 62, 76, 90 and 104 DAE
Geographic coordinates	9°23'27.21"S 45° 6'56.62"W	9°25'3.54"S 45° 0'23.63"W	9°24'10.88"S 45° 8'37.50"W	9°22'25.27"S 45° 6'56.69"W

[a]= Days After Emergence.

original data into binary values and, consequently, into cumulative distribution functions from pre-established values, in this case the QRVs (Chakraborty et al., 2017; Richer-de-Forges et al., 2017). The data were transformed into log-normal values to minimize distribution errors and meet the requirements of common kriging based on the rejection of the null hypothesis of the Kolmogorov-Smirnov test for normal distribution. Spatial variability was determined from isotropic and anisotropic semivariograms. Anisotropic calculations were performed in four directions (0, 45, 90 and 135°).

To obtain reliable estimates, the theoretical model needs to show SME values close to 0 and RMSSE close to 1 (Bahrami Jovein and Hosseini, 2017). The Akaike information criterion (AIC) was used as the last selection criterion. The spatial dependence rate (SDR) was calculated according to the formula: [C0/(C0 + C1) × 100] (Cambardella et al., 1994). A nugget effect less than or equal to 25% of the plateau was considered strong. The value was considered moderate when it was between 25 and 75% and weak when it was above 75%. Variables that showed SDR less than one unit were not considered. Spatial distribution maps of *B. tabaci* adults and nymphs were prepared for each crop.

Results

The variance values were within the range 0 to 7.52 and were predominantly positive. Where the peak of the normality curve of the results was higher than the standard value, the distribution curves were classified with positive asymmetries, and the coefficient of variation values were predominantly greater than 30%. In the two seasons evaluated, the infestation by adults and nymphs of *B. tabaci* generally started between 30 and 50 days after the emergence of the plants. The maximum population density of ten adults per plant in the BRS 9180IPRO® were recorded 101 days after plant emergence, and approximately four nymphs per leaflet in Brasmax ExtremaIPRO® were recorded 90 days after plant emergence (Figure 3).

The results that showed a strong or moderate degree of spatial dependence (SDR) were subjected to geostatistical models and chosen based on cross-validation parameters using the standard mean error (SME) and the root mean square standardized error (RMSSE). Of the 126 models that were processed, 33 were selected, of which 13 were exponential, 10 Gaussian, 10 spherical, and 36 pure nugget effects (Table 2). All selected models were isotropic (i.e., the spatial autocorrelation was the same in all directions).

Differences in the variogram parameters (nugget, sill, and range) were observed in the three cultivars in the two sampled seasons. A nugget effect was observed in the variograms, always at a low density of *B. tabaci* adults or nymphs (Figures 4, 5). The SDR of the models ranged from 0 to 100. This shows a significant effect of the nugget effect on the interpolation for some sampled days. These proportions showed that the spatial component accounted for 66% of the total spatial variance. From the selected models, 15.15% showed a strong SDR (<0.25),

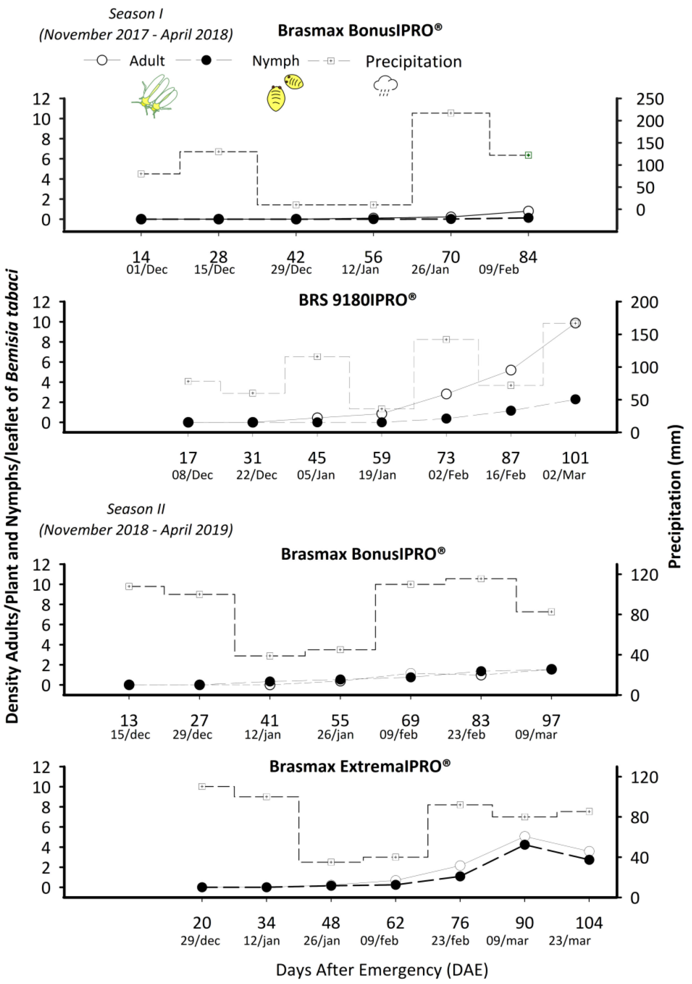

FIGURE 3
Population density of *Bemisia tabaci* adults and nymphs in the Brasmax Bonus IPRO®, BRS 9180IPRO® and Brasmax ExtremaIPRO® cultivars in seasons I and II and rainfall.

51.52% moderate SDR (between 0.25 and 0.75), and 33.33 weak SDR (Table 2).

The ranges of the models varied from 13.03 to 132.53 m, and the maximum range obtained for adults was 67 m at 104 DAE in the Brasmax ExtremaIPRO® cultivar and approximately 130 m for nymphs 101 DAE in the BRS 9180IPRO® cultivar (Table 2).

We observed that colonization of soybean plants by *B. tabaci* may be divided into three stages: the start of infestation, colonization of the area, and dispersion in the area. The adults of *B. tabaci* began to infest the experimental area from the outermost area; in season I, the insects came from the west, and in season II, the insects originated from the north (Figure 4).

Colonization by *B. tabaci* nymphs occurs as adults disperse in the area. Near the end of the crop cycle, adults, and nymphs of *B. tabaci* had already colonized the whole experimental area. With the colonization of the total area, adults began the process of migration to nearby areas (Figures 4, 5).

The soybean cultivars may be divided into three groups according to the density of the pest. In the first group (Brasmax BonusIPRO®), the lowest densities of the pest (2 adults and 1 nymph per leaf) were observed. In the second group (Brasmax ExtremaIPRO®), lands with a higher density of nymphs (up to 10 nymphs per leaf) were observed. In the third group (BRS 9180IPRO®), plants exhibited the highest densities of adults (up to 15 adults per leaf) (Figures 4, 5).

We observed two patterns of variation in the densities of *B. tabaci* throughout the development of the plants. The first occurred in Brasmax BonusIPRO®, where the pest population varied little over time and remained at low density. The second pattern occurred in Brasmax ExtremaIPRO® and BRS 9180IPRO®, where the pest population increased over time and was distributed throughout the crop area (Figures 4, 5).

The mean air temperature was high (29-33°C) during the cropping period. On the other hand, rainfall ranged from 10 to

TABLE 2 Models and parameters estimated by semivariogram for *Bemisia tabaci* adults and nymphs in the cultivars Brasmax BonusIPRO®, BRS 9180IPRO® and Brasmax ExtremaIPRO.

Variety	**Stages**	**SAD**	**Model**	**C_0[a]**	**C_0+C_1[b]**	**RDS (%)[c]**	**RDS**	**Range (m)**	**RMSSE[d]**	**SME[and]**
Season I (November 2017 - April 2018)										
Brasmax BonusIPRO ®	Adult	56	Exponential	0.06	0.08	72.02	Moderate	24.91	0.98	0.29
		70	Exponential	0.09	0.12	74.19	Moderate	24.91	0.98	0.35
		84	Exponential	0.14	0.24	60.06	Moderate	45.41	1.07	0.46
	Nynph	70	Exponential	0.00	0.00	97.83	Weak	34.40	1.00	0.05
		84	Exponential	0.00	0.02	0.00	Strong	27.01	0.96	0.11
BRS 9180IPRO®	Adult	45	Exponential	0.00	0.16	0.00	Strong	27.74	0.99	0.33
		59	Exponential	0.00	0.25	0.00	Strong	52.13	1.02	0.32
		73	Exponential	0.00	2.01	0.00	Strong	41.37	0.81	1.02
		87	Exponential	0.00	2.89	0.00	Strong	33.73	0.94	1.33
		101	Exponential	2.28	8.20	27.78	Moderate	52.59	0.98	2.29
	Nymph	73	Exponential	0.04	0.11	40.00	Moderate	20.50	0.96	0.33
		87	Exponential	0.12	0.42	27.87	Moderate	54.50	0.96	0.52
		101	Exponential	0.53	1.27	41.24	Moderate	132.53	0.99	0.86
Season II (November 2018 - April 2019)										
Brasmax BonusIPRO ®	Adult	41	Spherical	0.00	0.00	100.0	Weak	72.82	1.06	0.03
		55	Spherical	0.04	0.06	70.0	Moderate	128.48	1.00	0.22
		69	Spherical	0.51	0.92	55.4	Moderate	45.18	0.96	0.83
		83	Spherical	0.28	0.53	52.8	Moderate	42.39	0.94	0.62
		97	Spherical	1.38	2.51	55.2	Moderate	25.20	0.89	1.48
	Nymph	41	Spherical	0.00	0.00	98.2	Weak	25.34	1.10	0.06
		55	Spherical	0.03	0.03	95.1	Weak	24.94	1.04	0.18
		69	Spherical	0.12	0.16	74.6	Moderate	20.82	0.96	0.40
		83	Spherical	0.54	0.55	96.5	Weak	45.18	0.94	0.76
		97	Spherical	0.73	0.73	100.0	Weak	128.48	0.94	0.88
Brasmax ExtremaIPRO ®	Adult	48	Gaussian	0.064997639	0.08	80.48	Weak	83.89	1.01	0.26
		62	Gaussian	0.108601774	0.17	65.00	Moderate	21.62	1.01	0.39
		76	Gaussian	1.167979313	1.75	66.74	Moderate	41.45	0.96	1.17
		90	Gaussian	2.574639589	3.34	77.07	Weak	24.10	0.99	1.79
		104	Gaussian	1.444284816	5.23	27.64	Moderate	67.53	1.02	1.32
	Nymph	48	Gaussian	0.01394965	0.02	87.38	Weak	13.03	0.95	0.13
		62	Gaussian	0.033389883	0.03	95.60	Weak	29.94	0.98	0.19
		76	Gaussian	0.167840405	0.41	41.16	Moderate	19.93	0.98	0.65
		90	Gaussian	1.675549944	2.05	81.93	Weak	35.23	0.99	1.38
		104	Gaussian	0.823629539	1.81	45.55	Moderate	22.01	0.96	1.18

[a]: Nugget Effect; [b]: Threshold; [c]: (C0/C0 + C1) * 100) = Spatial Dependence Rate; [d]: Root Mean Square Standardized Error; [and]: Standard Mean Error.

127 mm per month during the cropping period (Figure 2). The winds during the experimental periods occurred predominantly in the northeast direction in 70% of cases with a maximum speed of 2.1 m/s. Performing the main component analysis, it was observed that the two axes explained 74.79% and 86.99 of the date variance for adults and nymphs respectively. There were positive correlations between the range and wind speed, and positive correlations were also observed between adult whitefly densities and rainfall and relative humidity (Figure 6A). Furthermore, there were positive correlations between nymph density with range, as well as precipitation and relative humidity (Figure 6B).

Discussion

The data presented here provide information on the spatiotemporal dynamics of *B. tabaci* in commercial soybean crops. The initial foci of colonization by adults occurred near the end of the vegetative stage of the crop, and it is common to observe the occurrence of nymphs and adults of *B. tabaci* at this stage of plant development. Thus, in regions of similar conditions, whitefly monitoring should be intensified from the end of the vegetative stage and the beginning of the reproductive stage (R1). The peak infestation by adults and nymphs recorded in the present study was relatively low

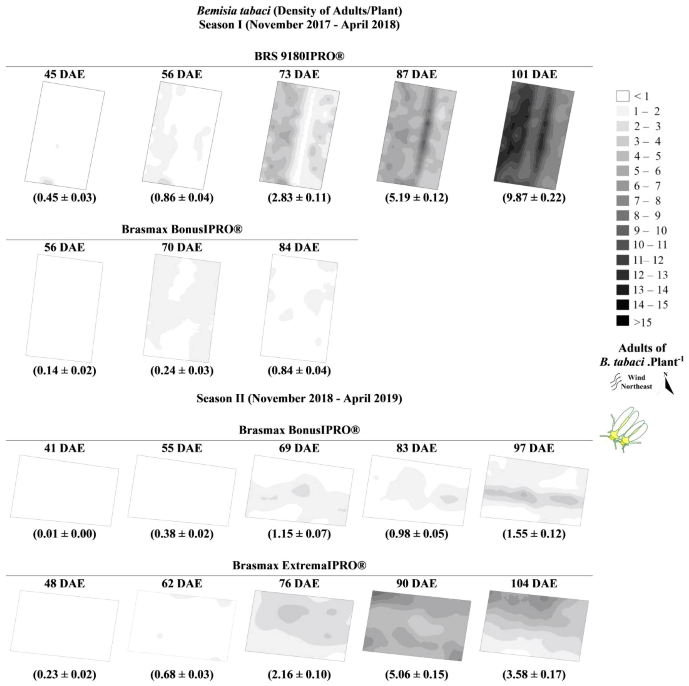

FIGURE 4
Kriging maps for the spatial variability of *Bemisia tabaci* adults in the Brasmax BonusIPRO®, BRS 9180IPRO® and Brasmax ExtremaIPRO® cultivars in 2017/2018 seasons I and 2018/2019 season II.

compared to other studies (Vieira et al., 2013; Suekane et al., 2018).

In previous experiments in the greenhouse, the cultivar Brasmax BonusIPRO ® had greater attractiveness for adults, colonization by nymphs and oviposition by *B. tabaci*, when compared to the cultivar BRS 9180IPRO® (Rodrigues et al., 2021). In our study, there was low infestation in the two evaluated seasons, which may indicate that cultivars of an early cycle with early planting may escape the whitefly attack (Ameen et al., 2019) and as mentioned above *B. tabaci* infestation was more severe in late February and early March. Whereas the attractiveness of the cultivars in relation to the whitefly, reconciles with the fact that there is a large number of cultivars available on the market, the variations of cultivars planted over the years by the producers, the planting time in each region, are issues that should be considered.

Bemisia tabaci showed an aggregated distribution in the soybean crops, indicating that there were factors that influenced this outcome. Information about the type of distribution and range of the whitefly is essential for the elaboration of the monitoring plans, mainly in the definition of the distance between the sampling points. Because depending on the number of points per hectare, the population can be underestimated or overestimated. Here we found that: (1) the distribution max range is related to the level of infestation by adults and nymphs of *B. tabaci*; (2) the type of aggregate distribution indicates that the level of infestation shows little variation within the area of infestation, and (3) the maximum range of 130 m was observed for adults and nymphs. This distance should be considered in monitoring plans. The spatial distribution of pest insects in crops is a consequence of the colonization and dispersion of these organisms at these sites (Rosado et al., 2015; Martins et al., 2018). Climate elements, terrain topography, characteristics of insect species, and landscapes are among the factors influencing the spatial distribution of pest insects in crops (Silva et al., 2011; Rusch et al., 2013; Carrière et al., 2017; Ludwig et al., 2017; Czepak et al., 2018; Martins et al., 2018).

Some results obtained for *B. tabaci* adults and nymphs showed a weak degree of spatial dependence. This finding is characterized as a pure nugget effect (total absence of spatial dependence), probably due to the low infestation by adults and whitefly nymphs in each evaluation, making the in geostatistical analyses imperceptible (Reay-Jones et al., 2010; Pias et al., 2017). These results are a common finding in this type of study; other authors with experiments on the spatial distribution of *Euschistus heros* (Fabricius, 1798) (Hemiptera: Pentatomidae) in soybean have made similar observations (Pias et al., 2017; De Souza et al., 2018).

According to the semivariograms, whitefly adults and nymphs had an isotropic distribution. This finding confirms

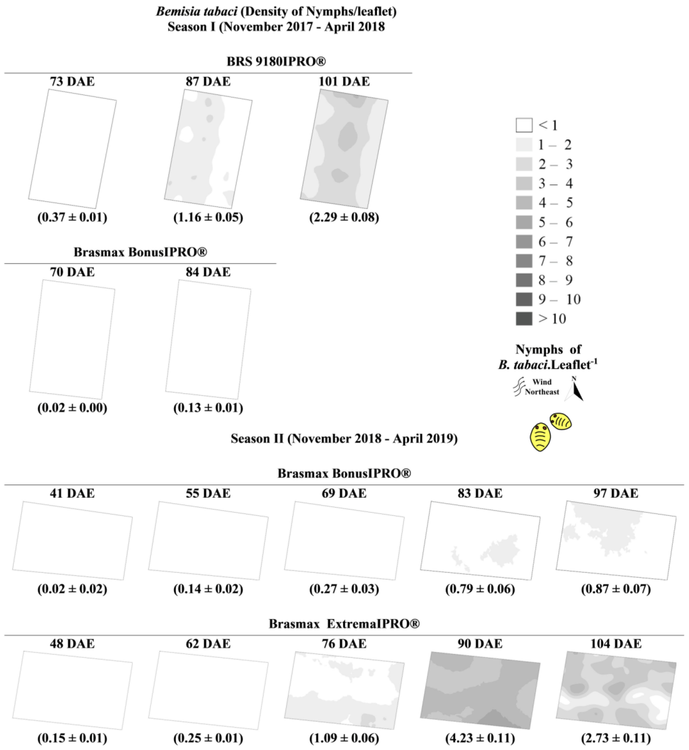

FIGURE 5
Kriging maps referring to the spatial variability of *Bemisia tabaci* nymphs in the Brasmax BonusIPRO®, BRS 9180IPRO® and Brasmax ExtremaIPRO® cultivars in 2017/2018 seasons I and 2018/2019 season II.

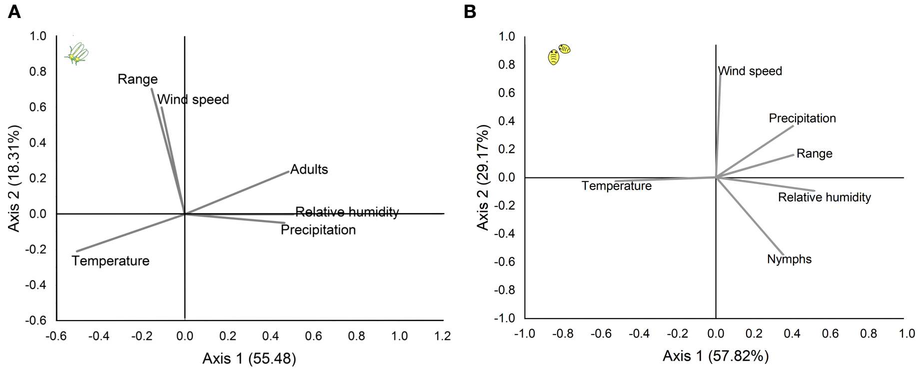

FIGURE 6
Principal component analysis of the effects of rainfall and climate elements on the range and abundance of **(B)** *tabaci* in soybean crops **(A)** for adults and **(B)** for nymphs. The first and second axes explained 74.79% and 86.99 of the date variance for adults and nymphs, respectively.

the premise that *B. tabaci* disperses across the field in a diffusion pattern, achieving an equal or similar number of adults throughout the sampling points regardless of direction, with the center of origin as the beginning of the evaluation (Byrne et al., 1997). Isotropic and aggregate pattern distributions were observed for adults and nymphs, and a reduction in range (dispersion radius) was observed as the density of adults per plant increased, while for nymphs, the opposite effect was verified. Other authors have observed the same pattern of whitefly distribution in soybean and other crops (Byrne et al., 1997; Lima et al., 2018; Suekane et al., 2018). The spatial distribution of *B. tabaci* in commercial watermelon crops, established that the dispersion of the insect was not influenced by a physical barrier or height gradient (Lima et al., 2018).

The kriging maps made possible to verify that colonization of the area by *B. tabaci* proceeded in the western and northern regions. Near the experimental area, there is a permanent preservation area, native forest. Therefore, when favorable environmental conditions existed, the infestation of *B. tabaci* in soybean crops was to be expected. Migration from the native vegetation to the crop occurs when there is abundant food and shelter (Macfadyen et al., 2015). However, the northeast winds were predominant in both seasons; the adults of *B. tabaci* may fly upwind searching for food or be dispersed by the wind given their small body size (Reinecke and Hilker, 2014)."

Geostatistics allowed us to verify the movements of *B. tabaci* adults and nymphs during the evaluations and soybean cycle. As previously explored, there are factors that can affect the distribution of pests in the field, features linked to insect characteristics such as population growth (reproduction, mortality) and dispersion (immigration, colonization, emigration) (Byrne et al., 1997; Sciarretta and Trematerra, 2014; Pias et al., 2017; Suekane et al., 2018; De Souza et al., 2018). *B. tabaci* may fly to a height of up to 7 m and a distance of 7 km (Isaacs and Byrne, 1998). Climatic factors such as rainfall and the relative humidity of the air favored an increase in the density of whitefly adults and nymphs, while wind speed favored the dispersion of adults, according to the literature (Byrne et al., 1997; Lima et al., 2018). Perhaps it is possible to manage the insect pest accurately before weather conditions favor the spread of the insect throughout the site; if the climatic conditions of the region always favor the distribution of the insect pest, control can be chosen as early as the presence of the insect in the place is verified. The present study provides important information about the pattern of aggregation and distribution of *B. tabaci*, which may be used in future work to assist in the sampling method in soybean grown in tropical or subtropical regions.

Conclusion

The results of this research help in the understanding of the spatiotemporal dynamics of *B. tabaci* populations in soybean crops. The colonization of *B. tabaci* had two patterns. In the first, colonization started at end of the vegetative phase at the outermost parts of the crop. In the second, the insects occupied the whole area of the crop since the beginning of cultivation. The adult whitefly density on soybean crops was positively correlated with rainfall, relative humidity, and wind speed. *Bemisia tabaci* adults and nymphs have an aggregate distribution, with a dispersion radius dependent on the density of the insects and the stage of crop development.

Data availability statement

The datasets presented in this article are not readily available because there are no restrictions. Requests to access the datasets should be directed to Luciana Barboza Silva, lubarbosabio@ufpi.edu.br.

Author contributions

RR: conceptualization, data curation, and writing- original draft preparation. LS: supervision and writing- original draft preparation. MS: visualization and investigation. JL: software and validation. EL: software and validation; RB: software and validation; LA: data curation, and writing- original draft preparation. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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