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Full Length Article

Spatial Distribution of Citrus Leprosis Associated with its Vector and Abiotic Factors in Different Cropping Systems

Fabio Júnior de Oliveira[1], Paulo Roberto Silva Farias[2], Aloyséia Cristina da Silva Noronha[2], Walter Maldonado Junior[3] and Luiz Antonio Soares Cardoso[4*]

[1]*Federal Rural University of the Amazon (UFRA), Capitão Poço Campus, Pará, Brazil*
[2]*Federal Rural University of the Amazon (UFRA), Belém Campus, Pará, Brazil*
[3]*Paulista State University (UNESP), Jaboticabal Campus, São Paulo, Brazil*
[4]*Federal Institute of Pará (IFPA), Bragança Campus, Pará, Brazil*
[*]For correspondence: luizcardoso.geologo@gmail.com
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Abstract

Citrus leprosis stands out as one of the main phytosanitary problems found in citrus growing, being transmitted by the citrus leprosis mite *Brevipalpus* spp. The objective of this work was to characterize the spatial distribution of citrus leprosis and its vector associated with abiotic factors in two orange cultivation systems. The areas were selected from a previous survey of the occurrence of the vector and the disease in orange groves in the municipality of Capitão Poço, State of Pará. Estimates were performed on 112 georeferenced plants in a citrus plot in a monoculture system and 112 plants in a plot intercropped with teak from September 2015 to August 2016, at monthly intervals. Using a pocket magnifying glass with 10x magnification, the mite (*Brevipalpus* spp.) was counted on 3 fruits, 3 branches and 3 leaves of the inner and outer part of each plant. The symptoms of citrus leprosis were visually evaluated throughout the canopy of the plant. Most of the abiotic factors were associated with the occurrence of the leprosis mite in the region. Climatic variables influence citrus leprosis mite infestation and were not associated with disease incidence in both cropping systems. Higher maximum temperatures favored the infestation of mites, while precipitation was not the most determining factor in the population of mites. Citrus leprosis and its vector showed aggregated distribution in both areas. The kriging maps indicated that there was no association between citrus leprosis infection and its vector infestation in the two cropping systems.

Keywords: *Brevipalpus* spp.; CiLV; Geostatistics; Semivariogram; Kriging

Introduction

Brazil is currently the world's largest producer of oranges (*Citrus sinensis* L. Osbeck), with a production of approximately 16,214,982 tons for the year 2021, accounting for approximately 32.8% of world production of the fruit in the 2020/2021 harvest, with an estimate for a 12% increase in production in the 2021/2022 harvest (Vidal 2021; IBGE 2021). Agricultural production would be even greater were it not for the damage caused by citrus leprosis (*Citrus Leprosis Virus* – CiLV), transmitted by the citrus leprosis mite of the genus *Brevipalpus* spp., found in all regions of the world (Beard *et al.* 2015), with emphasis on species B. *phoenicis* (Geijskes, 1939), B. *californicus* Banks, B. *obovatus* Donnadieu (Rodrigues and Childers 2013) and B. *yothersi* (Nunes *et al.* 2020). This virus is considered the most devastating for Brazilian citrus (Leastro *et al.* 2020; Chabi-Jesus *et al.* 2021).

CiLV has stood out considerably in the last decade, occurring in 22 Brazilian states where citriculture is important, including the state of São Paulo, which has the greatest economic importance for the culture in the country, responsible for about 77% of national production (Bastianel *et al.* 2010; IBGE 2021). In the state of Pará, specifically in the citrus region of the municipality of Capitão Poço, there are reports of the occurrence of the disease (Boari *et al.* 2007).

The drop and depreciation of damaged fruits vary from 0 to 2%, when the disease is efficiently controlled, and from 40 to 100%, when control measures are not adopted, depending on the level of mite infestation, disease incidence, age and plant variety, climatic conditions and other factors (Fernandes *et al.* 2004).

The leprosis mite can occur throughout the year, but dry periods favor an increase in the mite population (Oliveira 1986). The adult stage of the mite deserves to be highlighted in the transmission of the disease due to its greater mobility and longevity, also increasing the chances of contamination (Chiavegato 1986).

The disease causes the appearance of chlorotic and/or necrotic lesions, smooth or raised, circular or elongated when

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close to the leaf veins, which result in premature drop of fruits, leaves and death of branches and buds (Rodrigues *et al.* 2003). The main way of managing the citrus leprosis mite has been through the use of synthetic acaricides, which generates a significant increase in production costs (Bastianel *et al.* 2010; Della Vechia *et al.* 2022). Citrus intercropping with tree species can help to minimize production costs. Teak (*Tectona grandis* Linn. F.: Verbenaceae) stands out as a tree species of high commercial value (Moreira *et al.* 2006).

According to Childers and Rodrigues (2011), determining the distance and dispersion of the vector is essential to provide information that can optimize pest management. In this sense, geostatistics can be used to model the space-time pattern of pests.

Due to the importance of citrus growing in the region, basic knowledge is needed to characterize the spatial distribution of the incidence of citrus leprosis and its vector infestation in order to establish adequate management. The objective of this work was to characterize the spatial distribution of citrus leprosis and the leprosis mite, associated with local abiotic factors in citrus planting systems in monoculture and intercropped with teak in commercial orchards of sweet orange, variety "Pêra rio", in the municipality of Capitão Poço, PA, in the Northeast of Pará.

This study represents a breakthrough in understanding the spatial behavior of citrus leprosis and its vector in orange plantations in the eastern Brazilian Amazon. The use of geostatistics made it possible to visualize the spatial dependence of both the virus and the mite studied, resulting in more robust and relevant results in relation to the subject.

Materials and Methods

The study areas are located in the municipality of Capitão Poço, PA, belonging to the mesoregion of Northeast Pará and the microregion of Guamá, with geographic coordinates 01º44'54" south latitude and 47º03'42" west longitude of the Greenwich meridian. The climate is classified as AMI according to Koppen (1948), with an average annual temperature of approximately 25ºC and annual precipitation close to 2,250 mm, with the highest concentration from January to June, representing about 80% of the total. The relative humidity of the air is around 85% (Fig. 1).

Two plots were selected in an area with a history of occurrence of citrus leprosis: the first with 1,586 plants, in a monoculture planting system, planted at 4 x 10 m spacing, arranged in 26 rows with 61 plants each, with a density of 250 plants per hectare. The second plot with 1,508 plants, in a planting system combined with Teak (Tectona grandis Linn. F.), planted at 4 x 7 m spacing, arranged in 26 rows with a number of 58 plants each, with a density of 357 plants per hectare. Cultural treatments, such as fertilization and mowing with mechanical brush cutters, were applied in both experimental areas, without the use of any type of pesticide in the areas of the plots under study during the evaluation period, so as not to affect the population of leprosy mites and allowing the natural infestation of mites.

For the evaluation of the citrus leprosis mite in the field, 112 plants were considered in the monoculture area and 112 plants in the consortium area, from September 2015 to August 2016, with an interval between evaluations of approximately one month, totaling twelve collections. On each plant, 3 inner fruits, 3 outer fruits, 3 inner branches, 3 outer branches, 3 inner leaves and 3 outer leaves were randomly sampled from the central part of the plant canopy, counting the number of mites found in each segment, with the pocket magnifier with 10x magnification. In the absence of fruits during the evaluation period, this was replaced by a branch, as indicated by Gravena (2005).

To evaluate citrus leprosis, samples were taken from the same 112 plants evaluated for mite count, in both planting systems, also at intervals of approximately one month. Each plant had its crown visually evaluated in all quadrants (north, south, east and west) at all heights of the plant, observing characteristic symptoms of citrus leprosis in the fruits, branches and leaves, registering 1 (one) for presence and 0 (zero) for absence of disease.

Climatic data with monthly values of accumulated precipitation (mm), minimum, maximum and average temperature (°C) and relative humidity (%) were obtained from the automatic station of the National Institute of Meteorology – INMET in the municipality of Capitão Poço/PA, at 6 .3 km from the center of the monoculture area and 6.5 km from the consortium area. Due to technical problems at the station, which resulted in the absence of precipitation, temperature and relative humidity data for the month of January 2016, the averages observed in the months of January of the year 2012 to 2015 were used.

The percentage of plants infested by the leprosis mite (%) and the percentage of plants with incidence of citrus leprosis (%) were submitted to Pearson's simple linear correlation analysis.

The semivariograms were adjusted for the total number of mites and presence/absence of citrus leprosis for each planting system, in order to identify the type of spatial dependence in each evaluated month. The semivariogram was estimated by the following equation:

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

Where $N(h)$ is the number of pairs of measured values $Z(xi) - Z(xi + h)$, separated by a vector h. $\gamma^*(h)$ is the semivariance given as a function of distance, therefore it depends on the direction of h. Theoretical adjustments were made by the following isotropic models:

Spherical models

$$\gamma^*(h) = C_0 + C_1 \left[\frac{3}{2}\left(\frac{h}{a}\right) - \frac{1}{2}\left(\frac{h}{a}\right)^a\right], \ for\ 0 < h < a$$

$$\gamma^*(h) = C_0 + C_1, \quad for\ h \geq a$$

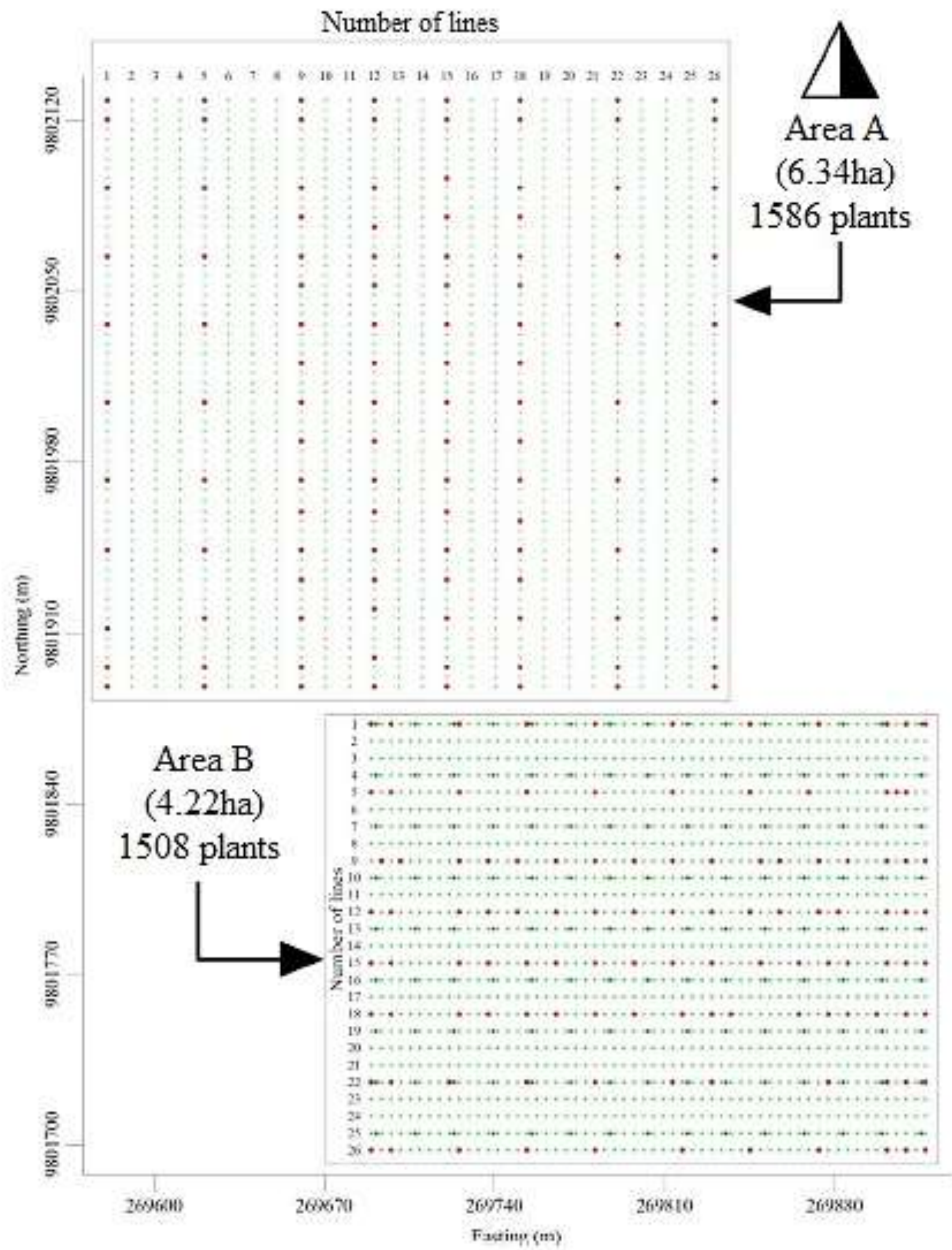

Fig. 1: Plant location map: Area A - with 1,586 plants and spacing of 10×4 meters and Area B - with 1,508 plants with spacing of 7x4 meters and intercropping with teak. Red dots indicate the sampled plant, light green dots indicate citrus plants and dark green dots indicate teak plants

Exponential model

$$\gamma^*(h) = C_0 + C_1\left[1 - exp\left(-3\frac{h}{a}\right)\right], \quad for\ 0 < h < d$$

Gaussian model

$$\gamma^*(h) = C_0 + C_1\left[1 - exp\left(3 - \left(\frac{h}{a}\right)^2\right)\right], \quad for\ 0 < h < d$$

Random model

$$\gamma^*(h) = C_0 + C_1, \quad for\ 0 < h < d$$

Where, C_0 is the nugget effect, $C_0 + C_1$ is the threshold, a is the range and h is the distance.

For the choice of models, the coefficient of determination (R^2) was evaluated. Then, the spatial dependence index (parameter k) was calculated from the ratio C0/(C0+C1), to determine the spatial dependence, classified as strong dependence if $k < 0.25$, moderate if $0.25 \leq k \geq 0.75$ and weak if $k > 0.75$ (Cambardella *et al.* 1994).

The number of mites per plant and the incidence of citrus leprosis were interpolated using the kriging method, generating kriging maps using the equation:

$$Z^*(x_0) = \sum_{i=1}^{N} \lambda_i Z(x_i)$$

Where, Z^* = estimated value; x_0 = linear combination of measured neighboring values; N = number of measured values involved in estimating $Z(x_i)$; and λ_i = weight associated with each measured value. Both in the elaboration and adjustments of the semivariograms and in the creation of the kriging maps, Surfer 8.0 software was used.

Results

As a result of what was proposed in the methodology of this work, it was possible to create graphs for the analysis of citrus leprous mite infestation in monoculture (MM) and intercropped (MI) systems, as well as for the analysis of the incidence of citrus leprosis in the same conditions, monoculture and intercropping, allowing the correlation between the variables maximum temperature, minimum temperature, average temperature, temperature range, precipitation and relative humidity, for the months of September 2015 to August 2016 (Fig. 2A–C).

Then, correlation analyzes were performed between these variables, using simple linear correlation (r), where it was possible to better observe the variables that were or were not related, the magnitude of this correlation and whether it would be positive or negative (Table 1).

After the correlation analyses, the use of geostatistics began, through the construction of semivariograms and definition of its theoretical model, making it possible to measure the magnitude of the possible spatial dependence present in the collected data. These analyzes were carried out both for the citrus leprosis mite and for the citrus leprosis disease itself, from September 2015 to August 2016 (Table 1–2).

Then, after adjusting the semivariograms, it was possible to create kriging maps, also for the leprosis mite and for citrus leprosis, from September 2015 to August 2016 (Fig. 3–4).

The initial hypothesis of this research was that the intercropping system would reduce mite infestation and consequently, citrus leprosis. However, it was observed that there was no reduction in the infestation of mites or diseases in both systems, both in monoculture and in consortium, which did not reflect in differences in the parameters of productivity and fruit quality in the areas studied.

It is important to point out that cultural practices such as fertilization and mechanical mowing can affect the infestation of mites in orchards, due to the possibility of their dispersion in the planting rows, hence the importance of optimizing these practices, as a way to minimize the future use of pesticides, preserving the health and productivity of plantations.

Table 1: Simple linear correlation coefficients (*r*) between leprosis mite infestation in monoculture (MM) and intercropped (MI), incidence of citrus leprosis in monoculture (LM) and intercropped (LI), minimum, maximum and average temperature of the months, monthly thermal amplitude, monthly accumulated precipitation and relative humidity in the city of Capitão Poço, PA

Variable	*r*			
	MM	MI	LM	LI
MI	0.8443^{**}	-	-	-
	0.0006	-	-	-
LM	0.3607^{NS}	0.4907^{NS}	-	-
	0.2494	0.1053	-	-
LI	0.2734^{NS}	0.3943^{NS}	0.2414^{NS}	-
	0.3899	0.2047	0.4496	-
Monthly minimum temperature	0.0200^{NS}	-0.2476^{NS}	0.1398^{NS}	0.2350^{NS}
	0.9509	0.4377	0.6647	0.4621
Monthly maximum temperature	0.8821^{**}	0.7567^{**}	0.4838^{NS}	0.1772^{NS}
	0.0001	0.0044	0.1110	0.5816
Monthly average temperature	0.5856^{*}	0.6128^{*}	0.5600^{NS}	0.2594^{NS}
	0.0454	0.0341	0.0583	0.4156
Thermal amplitude	0.5912^{*}	0.6799^{*}	0.2402^{NS}	-0.0319^{NS}
	0.0429	0.0150	0.4520	0.9216
Monthly precipitation	-0.5415^{NS}	-0.5675^{NS}	-0.3587^{NS}	0.1703^{NS}
	0.0690	0.0543	0.2523	0.5967
Relative humidity	-0.7346^{**}	-0.7399^{**}	-0.4025^{NS}	-0.0469^{NS}
	0.0065	0.0059	0.1946	0.8850

^{NS} not significant ($p \geq 0.05$); * significant at the 5% probability level ($0.01 \leq p < 0.05$); ** significant at the 1% probability level ($p < 0.01$)

Discussion

Based on the results of the evaluations, it was observed that the leprosis mite was always present in both planting systems during the evaluation period, as well as the incidence of the disease in both areas, regardless of climatic conditions. From September 2015 to February 2016, the leprosy mite infestation was always above 50% and values below 50% were observed from March to August 2016, in both cropping systems, but a pattern was not verified in the disease occurrence.

The maximum temperature ranged from 33.00 °C to 37.80°C, corresponding to the months of July 2016 and December 2015, respectively (Fig. 2A). For the average temperature, there was a variation from 25.70°C to 27.80°C, which refer to the months of June/July 2016 and December 2015, respectively. For the thermal amplitude (difference between maximum and minimum temperature), the variation was from 10.30°C to 16.30°C, in the months of March 2016 and December 2015. Precipitation ranged from 0.80 mm in November 2015 to 257.80 mm in March 2016 (Fig. 2B). Relative air humidity was always above 80% from February to July 2016 and below 80% in the other evaluated months (Fig. 2C).

In the periods when the maximum temperature, average temperature and thermal amplitude were lower, there was less citrus leprosis mite infestation, which corresponded to the period from February to August for MM and from January to August 2016 for MI. When these variables were at higher levels, there were peaks of leprosis mite infestation,

Table 2: Parameters of the theoretical models adjusted to the experimental semivariograms, range area, coefficient of determination (R^2) and *k* parameter for geostatistical analysis in a monoculture plot of the orange variety "Pêra rio" (*Citrus sinensis*), in the municipality of Capitão Poço, PA

Sampling month/year	Model	Semivariogram parameters			Range area (km^2) [a]	R^2	k[b]	Spatial dependence
		C_0	C_1	a (m)				
Citrus leprosis mite								
Sep/2015	Exponential	50.00	110.000	40.00	5024.00	0.97	0.31	Moderate
Oct/2015	Exponential	55.00	82.000	40.00	5024.00	0.91	0.40	Moderate
Nov/2015	Pure nugget effect	-	-	-	-	-	-	-
Dec/2015	Exponential	50.00	270.000	15.00	706.50	0.89	0.16	Strong
Jan/2016	Spherical	98.00	91.000	38.00	4534.16	0.89	0.52	Moderate
Feb/2016	Exponential	3.00	9.000	34.00	3629.84	0.87	0.25	Strong
Mar/2016	Exponential	1.70	1.300	18.00	1017.36	0.67	0.57	Moderate
Apr/2016	Gaussian	1.40	7.200	28.50	2550.47	0.98	0.16	Strong
May/2016	Spherical	1.80	0.730	40.00	5024.00	0.80	0.71	Moderate
Jun/2016	Exponential	1	20	42.00	5538.96	0.85	0.05	Strong
Jul/2016	Spherical	11.5	9.5	80.00	20096.00	0.75	0.55	Moderate
Aug/2016	Pure nugget effect	-	-	-	-	-	-	-
Citrus leprosis								
Sep/2015	Spherical	0.160	0.054	57.00	10201.86	0.84	0.75	Weak
Oct/2015	Spherical	0.100	0.083	65.00	13266.50	0.81	0.55	Moderate
Nov/2015	Exponential	0.180	0.074	40.00	5024.00	0.73	0.71	Moderate
Dec/2015	Spherical	0.090	0.110	75.00	17662.50	0.95	0.45	Moderate
Jan/2016	Exponential	0.110	0.145	25.00	1962.50	0.95	0.43	Moderate
Feb/2016	Spherical	0.120	0.133	33.00	3419.46	0.87	0.47	Moderate
Mar/2016	Spherical	0.150	0.091	60.00	11304.00	0.90	0.62	Moderate
Apr/2016	Spherical	0.110	0.130	41.00	5278.34	0.95	0.46	Moderate
May/2016	Spherical	0.100	0.067	44.00	6079.04	0.83	0.59	Moderate
Jun/2016	Spherical	0.175	0.600	45.00	6358.50	0.74	0.74	Moderate
Jul/2016	Exponential	0.070	0.210	35.00	3846.50	0.95	0.25	Strong
Aug/2016	Spherical	0.095	0.120	55.00	9498.50	0.95	0.44	Moderate

[a] Calculated by $\pi.r^2$, where $\pi = 3.14$ e r = a; a = range
[b] Ratio between $C_0/(C_1 + C_0)$; C_0 = Pure nugget; C_1 = spatial variance

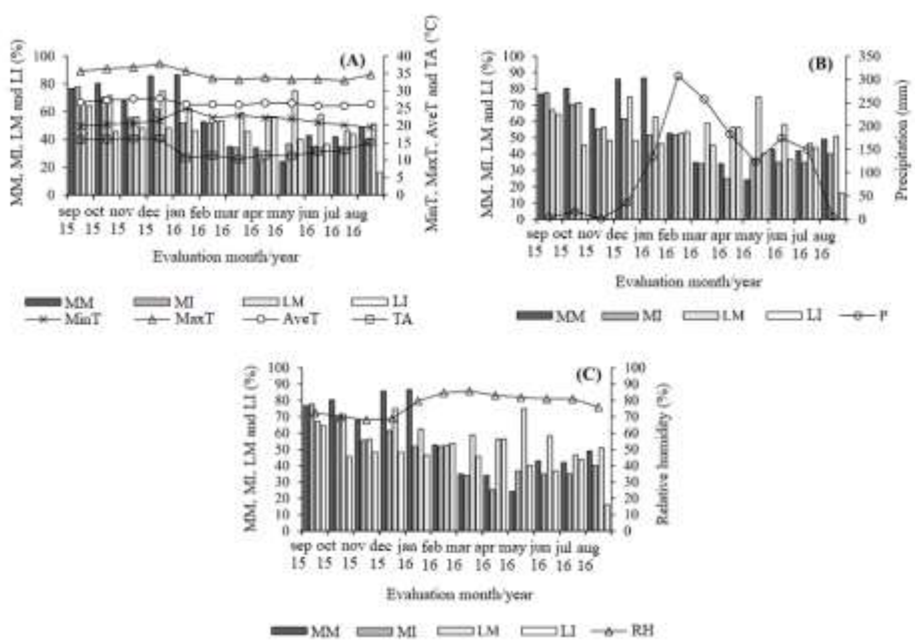

Fig. 2: Citrus leprosis mite infestation in monoculture (MM) and intercropping (MI) systems and incidence of citrus leprosis in monoculture (LM) and intercropping (LI) systems. A: minimum temperature (MinT), maximum temperature (MaxT), average temperature (AveT) and thermal amplitude (TA); B: precipitation (P); C: relative humidity (RH), in the municipality of Capitão Poço, PA, from September 2015 to August 2016

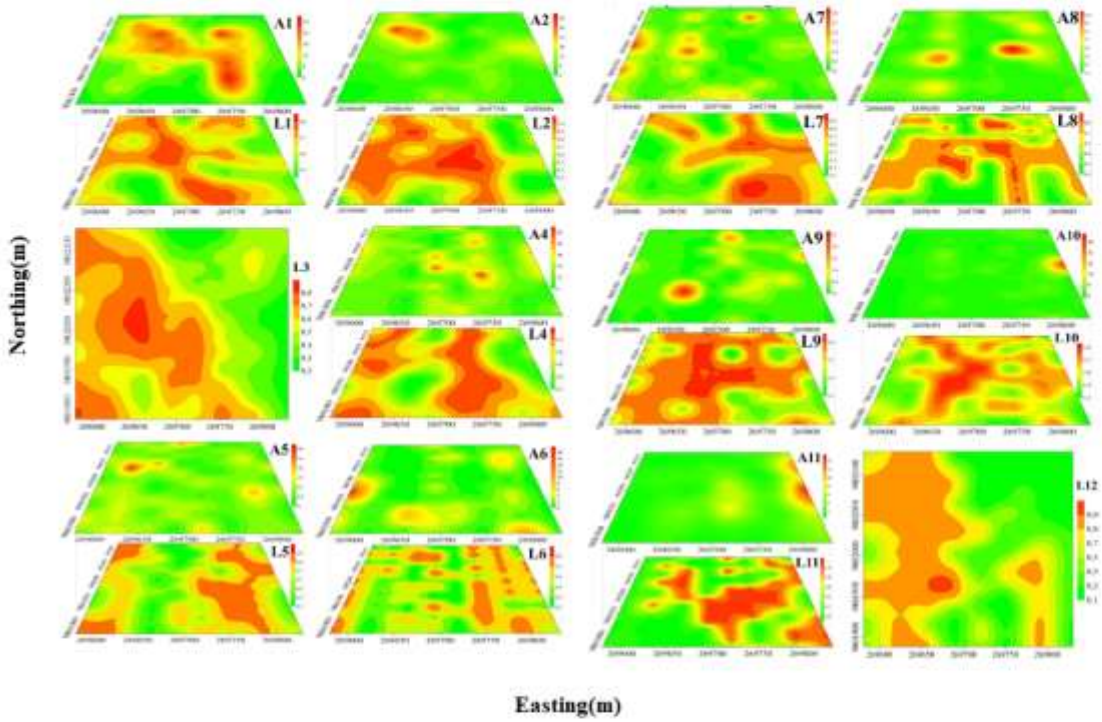

Fig. 3: Kriging maps of mite infestation (A) and incidence of citrus leprosis (L) in a citrus monoculture system in the municipality of Capitão Poço, PA. A1/L1: September 2015; A2/L2: October 2015; L3: November 2015; A4/L4: December 2015; A5/L5: January 2016; A6/L6: February 2016; A7/L7: March 2016; A8/L8: April 2016; A9/L9: May 2016; A10/L10: June 2016; A11/L11: July 2016; L12: August 2016

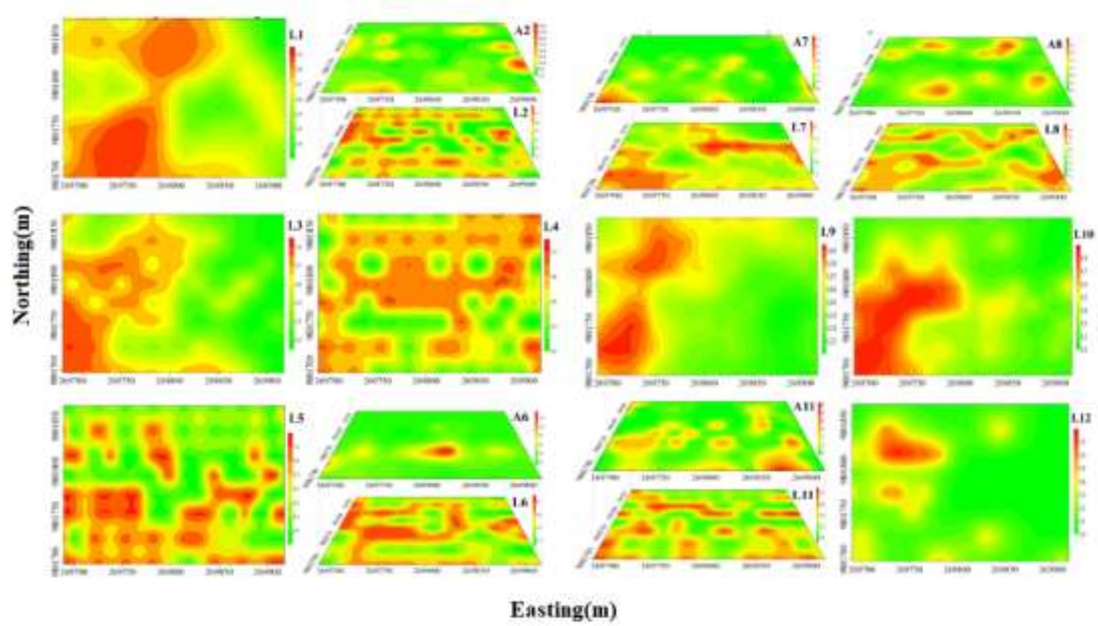

Fig. 4: Kriging maps of mite infestation (A) and incidence of citrus leprosis (L) in citrus intercropped system. A1/L1: September 2015; A2/L2: October 2015; L3: November 2015; A4/L4: December 2015; A5/L5: January 2016; A6/L6: February 2016; A7/L7: March 2016; A8/L8: April 2016; A9/L9: May 2016; A10/L10: June 2016; A11/L11: July 2016; L12: August 2016

which corresponded to the period from September 2015 to January 2016. In the variation of precipitation, the influence of the variable on the mite infestation is not clear (Fig. 2B). As a result of the rains, lower values of relative humidity also favored the infestation (Fig. 2C).

There was a significant positive correlation for the occurrence of the leprosis mite in both cultivation systems (r = 0.8443; P-value = 0.0006), considering the correlation magnitude parameters of Rumsey (2016), indicating that the occurrence of the vector in both areas was equivalent, that is, when there was an increase in vector infestation in the monoculture area, there was also an increase in the consortium area (Table 1). The magnitude of the Rumsey correlation considers that the correlation is weak when Pearson's r has a value of up to 0.30; the correlation is moderate when Pearson's r is up to 0.50 and the correlation is strong when Pearson's r is above 0.70.

There was no correlation between the percentage of plants infested by the leprosis mite with the incidence of citrus leprosis in the two planting systems. This was to be expected, as after the emergence of the infection caused by the virus, this plant may show symptoms after several days. The constant presence of the inoculum in the area and in high percentages contributed to the spread of the disease in the area, regardless of whether the number of mites was low or high, corroborating Czermainski *et al.* (2007), who observed that they found no correlation between the incidence of diseased plants and the number of mites on the plants.

For citrus leprosis, no correlations were observed with any climatic variable in the two planting systems studied (Table 1). This can be explained by the period between plant infection by the viruliferous mite and the appearance of symptoms in the plants, which can vary from 17 to 60 days, with a predominance of symptoms appearing between 21 and 30 days (Colariccio *et al.* 1995). The harvest or fruit drop and the fall of infected leaves may have influenced the observations. It is noteworthy that the mite becomes viruliferous only after feeding on disease lesions in adjacent or asymptomatic areas, which previously served as food for infected mites (Oliveira 2004).

For the average monthly temperature and the thermal amplitude, there was a significant positive correlation, of moderate magnitude, according to Rumsey (2016), for the leprous mite infestation in both cultivation systems, at a significance level of 5%. Regarding the maximum monthly temperature and relative humidity, the first showed a positive correlation and the second a negative correlation, both with strong magnitude for Rumsey (2016) and probability of 1% for both cropping systems.

Temperature is a determining factor in leprosy mite infestation, and when temperature is high, it shortens the disease and mite cycle, which may explain the peaks of leprosy mite infestation and the significant correlations for months of higher occurrence, with maximum temperatures in the region reaching between 35.7°C to 37.8°C, extending from September to December 2015. Several works show the importance of temperature in the development of the leprosis mite (Czermainski *et al.* 2007).

Monthly precipitation and monthly minimum temperature were not associated with mite infestation in both systems (Table 1), probably because the sampling of mite infestation considered fruits, branches and leaves of the plant, differing from other studies that, working only with fruits, showed that rain was a determining factor in the population of the mite. Although several works show a negative correlation between the amount of rain and the occurrence of the mite (Salinas-Vargas *et al.* 2013; Laranjeira *et al.* 2015), there is probably a migration of mites to less exposed places.

The mite always remained above the control level, which is 10% of the sampling with mites for areas with occurrence of the citrus leprosis virus, as recommended by Gravena (2005). This occurred due to the non-use of any method aimed at controlling this pest, which, therefore, sustains that the incidence of citrus leprosis has always remained at high levels. Abiotic factors such as low rainfall and high temperatures favor an increase in the population density of the mite on the plant (Oliveira *et al.* 2007). These factors may have contributed to keeping the mite at levels above control in the months of lower rainfall and higher temperatures, and reduced its infestation in the wettest periods (February to May), when precipitation ranged from 122.0 mm to 496.6 mm, being the wettest evaluation period.

Large-scale dust mite problems may be spurred by climate change (Bebber *et al.* 2013). This can result in infestation problems in orchards in regions where control would not yet be necessary (Leeuwen *et al.* 2015). Changes in annual rainfall in Amazonia, especially in the dry season, tend to exacerbate the drought in northern Amazonia that has been occurring since the mid-1970s (Marengo 2004), which can result in mite outbreaks.

The adjustments of the spherical, exponential and Gaussian models characterized the spatial distribution with the formation of furrows in both cultivation areas in most evaluations. The occurrence of the pure nugget effect was low, with a greater appearance of the leprosis mite in a system intercropped with teak, which can be explained by the high infestation and high incidence in all evaluations. Webster and Oliver (2007) report that the spherical model is the most used to explain the aggregated distribution pattern of several plant diseases.

In monoculture, the semivariograms reached a plateau, corresponding to their amplitude, both for citrus leprosis and its vector, with the exception of November 2015 and August 2016 for the leprosis mite, which showed a pure nugget effect. In this cropping system, the range ranged from 15 m (December 2015) to 80 m (July 2016) for the leprosis mite, with adjustment for the exponential and spherical models. For citrus leprosis, the amplitude ranged from 25 m (January 2016) to 75 m (December 2015), with adjustment for the exponential and spherical models, respectively, in all evaluations (Table 2).

In a consortium system, there was adjustment of the

Table 3: Parameters of the theoretical models adjusted to the experimental semivariograms, area range, coefficient of determination (R²) and parameter k for geostatistical analysis of the leprosis mite and citrus leprosis itself in intercropped plots of the orange variety "Pêra Rio" (*Citrus sinensis*) and Teak (*Tectona grandis*), in the municipality of Capitão Poço, PA

Evaluation month	Model	Semivariogram parameters			Range area (km^2) [a]	R^2	k^b	Spatial dependence
		C_0	C_1	*a* (m)				
Citrus leprosis mite								
Sep/2015	Pure nugget effect	-	-	-	-	-	-	-
Oct/2015	Spherical	110.000	100.000	30.00	2826.00	0.49	0.52	Moderate
Nov/2015	Pure nugget effect	-	-	-	-	-	-	-
Dec/2015	Pure nugget effect	-	-	-	-	-	-	-
Jan/2016	Pure nugget effect	-	-	-	-	-	-	-
Feb/2016	Exponential	6.000	18.000	40.00	5024.00	0.87	0.25	Forte
Mar/2016	Exponential	0.750	2.600	28.00	2461.76	0.46	0.22	Forte
Apr/2016	Spherical	1.800	1.000	44.00	6079.04	0.79	0.64	Moderate
May/2016	Pure nugget effect	-	-	-	-	-	-	-
Jun/2016	Pure nugget effect	-	-	-	-	-	-	-
Jul/2016	Spherical	1.300	2.000	35.00	3846.50	0.93	0.39	Moderate
Aug/2016	Pure nugget effect	-	-	-	-	-	-	-
Citrus leprosis								
Sep/2015	Exponential	0.190	0.050	35.00	3846.50	0.69	0.79	Fraca
Oct/2015	Spherical	0.140	0.100	25.00	1962.50	0.56	0.58	Moderate
Nov/2015	Exponential	0.130	0.085	25.00	1962.50	0.64	0.60	Moderate
Dec/2015	Spherical	0.070	0.185	28.00	2461.76	0.92	0.27	Moderate
Jan/2016	Spherical	0.018	0.213	25.00	1962.50	0.90	0.08	Forte
Feb/2016	Spherical	0.185	0.058	30.00	2826.00	0.65	0.76	Fraca
Mar/2016	Exponential	0.180	0.083	20.00	1256.00	0.62	0.68	Moderate
Apr/2016	Spherical	0.160	0.093	25.00	1962.50	0.56	0.63	Moderate
May/2016	Exponential	0.195	0.045	40.00	5024.00	0.56	0.81	Fraca
Jun/2016	Exponential	0.140	0.075	30.00	2826.00	0.88	0.65	Moderate
Jul/2016	Spherical	0.150	0.094	27.00	2289.06	0.78	0.61	Moderate
Aug/2016	Exponential	0.065	0.070	30.00	2826.00	0.92	0.48	Moderate

[a] Calculated by $\pi.r^2$, where $\pi = 3.14$ e r = a; a = range
[b] Ratio between $C_0/(C_1 + C_0)$; C_0 = Pure nugget; C_1 = spatial variance

theoretical models for citrus leprosis mite infestation only in the months of October 2015 and February, March, April and July 2016, with the spherical and exponential models, with range ranging from 28 m to 44 m. In the other evaluations, there was a pure nugget effect. For the incidence of citrus leprosis, spherical and exponential models were fitted, with amplitude ranging from 20 m to 40 m.

The largest area occupied by the leprous mite in monoculture was 2,0096.00 m² (Table 2), while in consortium it was 6,079.04 m² (Table 3). This greater amplitude of infestation in monocultures is already expected, since in this system the infestation of mites can be favored by the arrangement of orange trees. In the intercropping system, however, *T. grandis* can be used as a host plant for a greater number of predators, resulting in a concentration of leprosis mites in a more restricted area, limiting the area of biological control.

The high values in the range of areas by the monoculture reflected in the incidence of the disease, since in the monoculture area the maximum range was 17,662.50 m², while in the intercropping system it was 5,024.00 m². Oliveira Júnior *et al.* (2016) found an aggregate distribution of the disease, with amplitude ranging from 18 m to 30 m, corresponding to the months of May and August 2012.

The fact that the citrus leprosis mite is considered a polyphagous and cosmopolitan species may explain the behavior of the mite in an intercropping system of citrus with teak, because even in the rainiest periods, the mite population remained at high levels. The cultivation of citrus with a forest species, which is characterized as a simple agroforestry system, can increase the diversity of herbivores that can be beneficial to the system. Additionally, the teak canopy can serve as a barrier reducing direct rain contact with the plants. However, the intercropped system may not result in a decrease in the mite population, which justifies the presence of the leprosis mite always at high levels throughout the evaluations, in both planting systems (Fig. 3–4), causing the frequent transmission of citrus leprosis from year to year.

The work in question represents a contribution on the disease of citrus leprosis and its vector in plantations in the Brazilian Eastern Amazon. However, future work on the subject is of paramount importance, so that the topic can be further explored, taking into account, for example, other factors such as soil conditions or correlation with other pests.

Conclusion

There was no association between the presence of the citrus leprosis mite and the incidence of citrus leprosis in the two cropping systems (monoculture and intercropping). Climatic variables influence citrus leprosis mite infestation and were not associated with the incidence of citrus leprosis in the two cropping systems. Higher maximum temperatures favored mite infestation, while precipitation was not the most determining factor in the mite population. The spatial distribution of citrus leprosis and its vector is aggregated, with concentration in both planting systems for most evaluations. It was not possible to observe a reduction in the infestation of mites or diseases in the intercropped system in relation to the monoculture. Citrus leprosis showed larger coverage areas in the monoculture system than in the intercropping system, indicating higher concentrations in these cases. It was not possible to observe a reduction in the infestation of mites or the disease in the intercropped system in relation to the monoculture. Citrus leprosis showed larger coverage areas in the monoculture system than in the intercropping system, indicating larger furrows in these cases.

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Author Contributions

FJO participated in all stages of the research, ending with the writing of the article, PRSF guided the stages of the research, ACSN carried out the co-supervision of the research, WMJ carried out the interpretation and discussion of the data and LASC carried out the discussion and final revision of the text to be subject.

Conflicts of Interest

All authors declare no conflict of interest.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable in this paper.

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