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Geostatistics as a tool to study mite dispersion in physic nut plantations

J.F. Rosado[1,2], M.C. Picanço[2], R.A. Sarmento[1]*, R.M. Pereira[2], M. Pedro-Neto[1], T.V.S. Galdino[3], A. de Sousa Saraiva[1] and E.A.L. Erasmo[1]

[1]Federal University of Tocantins (UFT), PO BOX 66, Gurupi, State of Tocantins, Brazil: [2]Department of Entomology, Federal University of Viçosa, 36570-900 Viçosa, MG, Brazil: [3]Department of Plant Production, Federal University of Viçosa, 36570-900 Viçosa, MG, Brazil

Abstract

Spatial distribution studies in pest management identify the locations where pest attacks on crops are most severe, enabling us to understand and predict the movement of such pests. Studies on the spatial distribution of two mite species, however, are rather scarce. The mites *Polyphagotarsonemus latus* and *Tetranychus bastosi* are the major pests affecting physic nut plantations (*Jatropha curcas*). Therefore, the objective of this study was to measure the spatial distributions of *P. latus* and *T. bastosi* in the physic nut plantations. Mite densities were monitored over 2 years in two different plantations. Sample locations were georeferenced. The experimental data were analyzed using geostatistical analyses. The total mite density was found to be higher when only one species was present (*T. bastosi*). When both the mite species were found in the same plantation, their peak densities occurred at different times. These mites, however, exhibited uniform spatial distribution when found at extreme densities (low or high). However, the mites showed an aggregated distribution in intermediate densities. Mite spatial distribution models were isotropic. Mite colonization commenced at the periphery of the areas under study, whereas the high-density patches extended until they reached 30 m in diameter. This has not been reported for *J. curcas* plants before.

Keywords: *Polyphagotarsonemus latus*, *Tetranychus bastosi*, spatial distribution maps, *Jatropha curcas*

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Introduction

The physic nut, *Jatropha curcas* L. (Euphorbiaceae), is one of the most promising oilseed plants for biodiesel production (Kumar & Sharma, 2008). The mites *Polyphagotarsonemus latus* (Banks) (Prostigmata: Tarsonemidae) and *Tetranychus bastosi* Tuttle, Baker and Sales (Prostigmata: Tetranychidae) are the most relevant physic nut pests (Sarmento *et al*., 2011; Anitha & Varaprasad, 2012; Cruz *et al*., 2012). These mites are widely distributed geographically and attack several plant families (Zhang, 2003; Moraes & Flechtmann, 2008). However, the dynamics of colonization of these mites in crops is unknown, as well as the influence of one species over another.

Studies on the spatial distributions of crop pests help to identify the locations of their most frequent attacks on the crops (Diaz *et al*., 2012). These studies also enable us to understand and predict pest movement between plantations, as well as within the different regions of the same plantation (Hortal *et al*., 2010). Thus, sampling and control efforts can be focused on these locations (Barrigossi *et al*., 2001; Bacca *et al*., 2006).

The spatial distribution patterns of insect pests can be classified as aggregated, random or uniform (Elliott, 1983; Krebs, 1989). These spatial distribution patterns have been measured

*Author for correspondence
Phone: +55 63 3311 358 5
Fax: +55 63 3311 3501
E-mail: rsarmento@uft.edu.br

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using mathematical frequency distribution models (Elliott, 1983; Krebs, 1989). However, they are not representative of the density distribution of these organisms in space, as they are based on the relationship between the variance and the mean, irrespective of where the samples are located (Binns *et al.*, 2000). One suitable option is to use geostatistics in the spatial distribution studies of pests, which incorporates the geographic location of the samples (Rijal *et al.*, 2014; Rogers *et al.*, 2014).

Geostatistics enables the measurement of the degree of dependence among the samples over space using semivariance and permit to infer about spatial distribution patterns of insect pests (Silva *et al.*, 2011; Rijal *et al.*, 2014; Veran *et al.*, 2015). By observing the behavior of a variable in space, it can be noticed that the closer the sample points, the greater the similarity between them and thus lower the semivariance. Thus, the greater the distance between two points used to calculate the higher will be the semivariance (Matheron 1963; Gumprecht *et al.*, 2009). According to Gumprecht *et al.* (2009) the characteristics measured by geostatistics include the nugget effect (a measure of sampling error), the sill (maximum semivariance value in spatially dependent samples) and the range (the distance over which the samples are correlated).

Currently, only a few studies are available that describe the spatial distribution of mite populations (Napierała *et al.*, 2006; Yarahmadi & Rajabpour, 2013), despite their great significance for pest management. Such studies involving two species are even rarer to find in the literature (Napierała *et al.*, 2006). The aim of this work was to measure the spatial distributions of the pest mites *P. latus* and *T. bastosi* in the physic nut plantations.

Materials and methods

Experimental conditions

This study was conducted over two years in two different plantations. Crop 1 was located in Caseara (9°20′24″S, 49°50′51″W, at an altitude of 174 m) and Crop 2 in Palmas (10°9′227″S, 48°29′27″W, at an altitude of 280 m), in the state of Tocantins, Brazil.

Nine months after planting the seedlings to the field, physic nut plants start producing fruits, reaching peak production from the second year and produce viable fruit for oil production by up to four decades (Saturnino *et al.*, 2005; Arruda *et al.*, 2013; Saraiva *et al.*, 2013). At the commencement of this study, the plants were 4 years old. The fields were approximately 4 ha, and the plants were spaced approximately 2 × 3 m apart. The crops were grown according to Sato *et al.* (2009), and no pesticides were used. Air temperature and total rainfall (mm) were monitored during the whole experimental period. The mite and natural enemies' populations were monitored monthly over a period of 2 years.

Characteristics analyzed

Measurements were taken on the lower (abaxial) surface of the 4th most apical leaf of the plant branch, using a 20× magnifying glass (Rosado *et al.*, 2014). We evaluated 300 equally spaced plants to obtain systematic samplings that would ensure total coverage of the plantation without directional bias (Midgarden *et al.*, 1993).

Each plant thus analyzed was georeferenced using a global positioning system (GPS 12XL, Garmin, Othale, Kansas, USA). The density of *P. latus* was measured in the leaf blade region near the petiole, while the density of *T. bastosi* was measured in the middle region of the leaf blade (Rosado *et al.*, 2014).

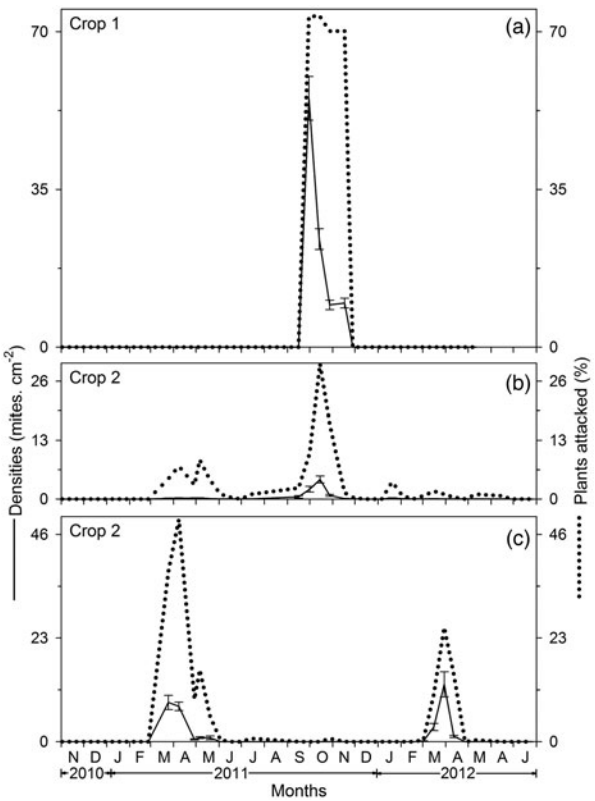


Fig. 1. Seasonal variation in the density of *Tetranychus bastosi* in Crop 1 (A) and in Crop 2 (B) and of *Polyphagotarsonemus latus* in Crop 2 (C).

Data analysis

We calculated the mean density and the percentage of the plants affected, for each species, at each location, for each date. We selected the dates (39 dates) on which the mites attacked the plants. In geostatistics, the semivariogram is the tool used to evaluate the spatial dependence between two samples (Matheron, 1963). In the semivariogram the semivariances between two points are calculated to generate the paired differences between points at different distances. Therewith, it is determined the empirical semivariogram, obtained from the sample data.

The empirical semivariogram is used to best fit the model for the theoretical semivariogram (Rijal *et al.*, 2014). When a semivariogram has a defined sill the adjusted models can be spherical, exponential and Gaussian (Isaaks & Srivastava, 1989). Because of this, we then fitted three teorical semivariogram models, namely, spherical, exponential and Gaussian, to the mite density data to choose the best model (Liebhold *et al.*, 1993). The models with the best fit were chosen by cross-validation. The models chosen were those with intercepts close to zero, slopes close to one and those having the lowest residual sum of squares. The nugget effect, range, sill and coefficient of determination were calculated for each model (Murphy & Sternitzke, 1979; Isaaks & Srivastava, 1989).

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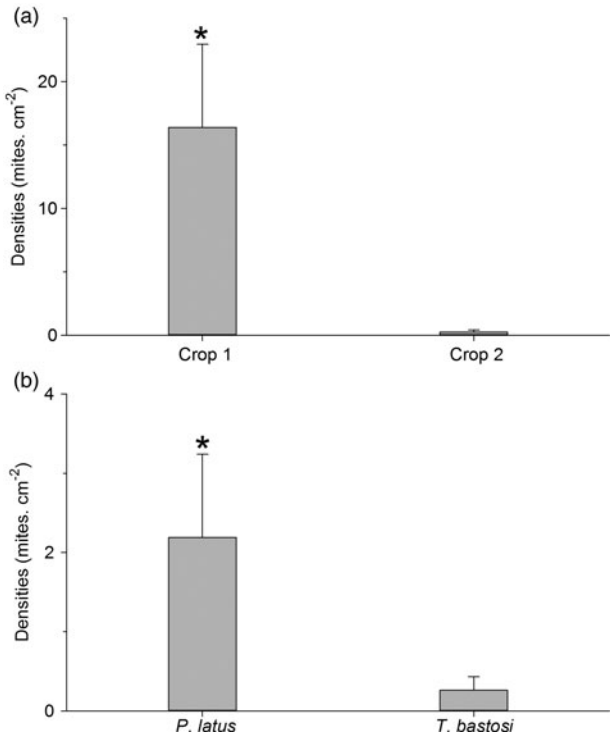


Fig. 2. (A) Total density (mean ± SD) of the mites in two locations. (B) Density (mean ± SD) of *Polyphagotarsonemus latus* and *Tetranychus bastosi* in Crop 2. Bars with an asterisk (*) are significantly higher by the *F*-test at $P < 0.05$.

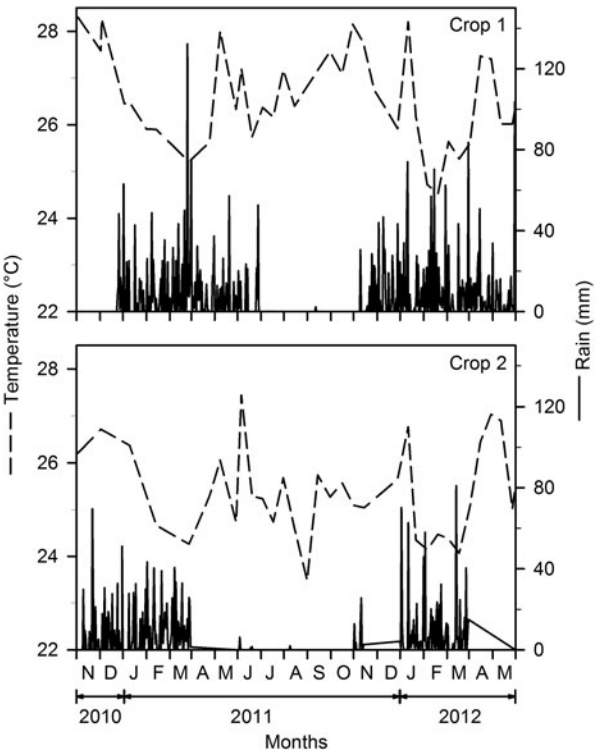


Fig. 3. Seasonal variation of climatic elements in Crops 1 and 2.

The Kriging method was used to construct maps of the spatial distributions of the mites in the plantations (Farias *et al.*, 2004). Spatial analyses were performed using the GS+ Geostatistics for the Environmental Sciences software, Version 9.0 (Robertson, 2008). We calculated the range of spatial dependence (RSD) using the following formula: $RSD = C_0/(C_0 + C)$, where C_0 = the nugget effect and $C + C_0$ = the sill (Cambardella *et al.*, 1994). Spatial dependence is considered to be strong when $RSD \leq 0.25$, moderate when $0.25 < RSD \leq 0.75$ and weak when $RSD > 0.75$ (Cambardella *et al.*, 1994; Sciarretta & Trematerra, 2006).

The average densities of both species were calculated for the studied crops. Because each field presented a different range for each mite in each sample date (spatial analysis), we set an increasing range model according to the increasing density of the mites ($P < 0.05$). These data were used to verify the influence of mites density in the spatial dependence among samples.

Results

In Crop 2, we observed the presence of both *P. latus* and *T. bastosi*. However, only *T. bastosi* was observed in Crop 1. The total mite density was higher in Crop 1 than in Crop 2. The *P. latus* density was higher than that of *T. bastosi* in Crop 2 (figs 1 and 2).

Populations peaked for a short time period (30–45 days). The mite density varied widely during peak population periods for both *P. latus* (0 to 8.7 mites cm^{-2}) and *T. bastosi* (0 to 4.3 and 0 to 73.6 mites cm^{-2} in Crops 2 and 1, respectively). In Crop 2, we observed peak *P. latus* and *T. bastosi* populations at two different time periods. During the first infestation (from March to April, 2011), the *P. latus* population peaked first, followed by *T. bastosi*. During the second infestation (from October 2011 to March 2012), the *T. bastosi* population peaked first, followed by *P. latus*. In Crop 1, we observed only a single population peak for *T. bastosi*, corresponding to the largest mite population peak (from September to November, 2011) (figs 1, 4 and 5).

The highest densities of *T. bastosi* on phisic nut coincided with warmer periods. However, this was not observed to *P. latus*. On the other hand, *P. latus* was more frequent in periods with higher rainfall, whereas *T. bastosi* in lower rainfall periods (fig. 3).

In both crops the natural enemies densities were low during the whole studied period (mean 0.01 ± SE 0.0011 for Crop 1 and 0.01 ± SE 0.0014 for Crop 2). These densities did not allow adjustment of the semivariogram. The natural enemies found were the predatory mite *Euseius concordis* Chant (Acari: Phytoseiidae), spiders, ladybirds *Stethorus* sp. (Coleoptera: Coccinellidae) and Lacewings *Chrysoperla* sp. (Neuroptera: Chrysopidae).

The spatial distribution of the mites was uniform for 30 samples (10 for *P. latus* and 20 for *T. bastosi*) and these models revealed only the pure nugget effect. However, the models showed ranges of spatial dependence of 0.17–0.51 in nine samples (four for *P. latus* and five for *T. bastosi*), indicating an aggregated mite distribution at these locations. Three of the aggregated distribution models for *P. latus* were exponential and one was Gaussian. Four of the aggregated distribution models for *T. bastosi* were exponential, while one was spherical. The spatial distribution models for the mites were isotropic (table 1).

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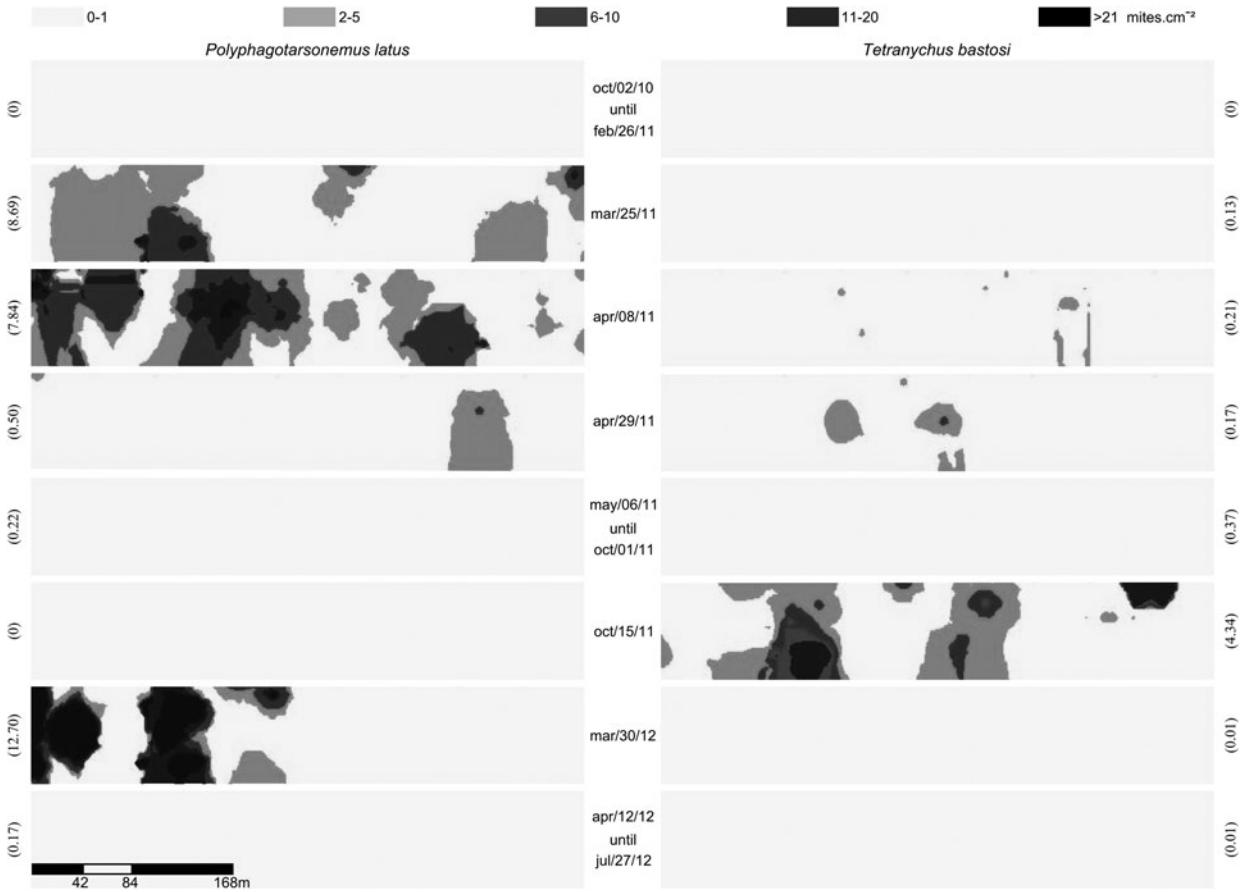


Fig. 4. Maps of the spatial distribution of *Polyphagotarsonemus latus* and *Tetranychus bastosi* in Crop 2. The mean densities in the plantation are given in parentheses (mites cm^{-2}).

The mite populations were found to be uniformly distributed under two circumstances: (i) when the densities were very low (up to 0.22 and 0.13 mites cm^{-2} for *P. latus* and *T. bastosi*, respectively) and (ii) when the densities were high (greater than 24 mites cm^{-2} for *T. bastosi*). The mite populations showed aggregated spatial distributions for intermediate densities. The patches (plantation areas) with high mite densities were seen to concentrate at the periphery of the area under study (figs 4 and 5).

The ranges in the aggregated spatial distribution models varied from 7.37 to 45 m (table 1). We did not observe any significant differences for the ranges of the aggregated spatial distribution models as a function of mite species ($F_{1;7} = 0.37$; $P = 0.5622$) or as a function of location ($F_{1;7} = 1.37$; $P = 0.2794$). However, we found that the ranges in the aggregated distribution models increased as a function of mite density until they reached a plateau at a density of approximately 3 mites cm^{-2} and a range of approximately 30 m (fig. 6).

Discussion

This study presents the first spatial distribution maps for *P. latus* and *T. bastosi* in physic nut plantations. The resulting spatial distribution maps enabled us to understand the spatio-temporal dynamics of these mite populations. The spatial distribution was uniform at the extremes of the densities (low or high), as we did not observe large differences in mite density between the plants. However, the mite spatial distribution was aggregated at intermediate population densities because we observed patches (plantation areas) of plants that revealed high mite densities, while other plants showed low mite densities.

Aggregation of the mite populations at the specific time periods may have occurred due to their high reproductive rates and their propensity to exhaustively explore their current location before migrating to other areas (Moraes & Flechtmann, 2008). Thus, the *P. latus* and *T. bastosi* populations only spread to new locations after reaching high densities in their original location.

The large variation in the distribution patterns of the *P. latus* and *T. bastosi* populations over time and space is typical of the *r*-strategist species. *R*-strategist species explore resources in temporary patches, reveal high population growth rates and minimize interspecific competition (Southwood, 1962; Begon *et al.*, 2005). Both *P. latus* and *T. bastosi* exhibit these traits, as they have high reproductive rates (Lopes, 2009; Evaristo *et al.*, 2013; Pedro-Neto *et al.*, 2013) and have characteristics that reduce the interspecific competition, including their behavior of attacking plants at different time periods.

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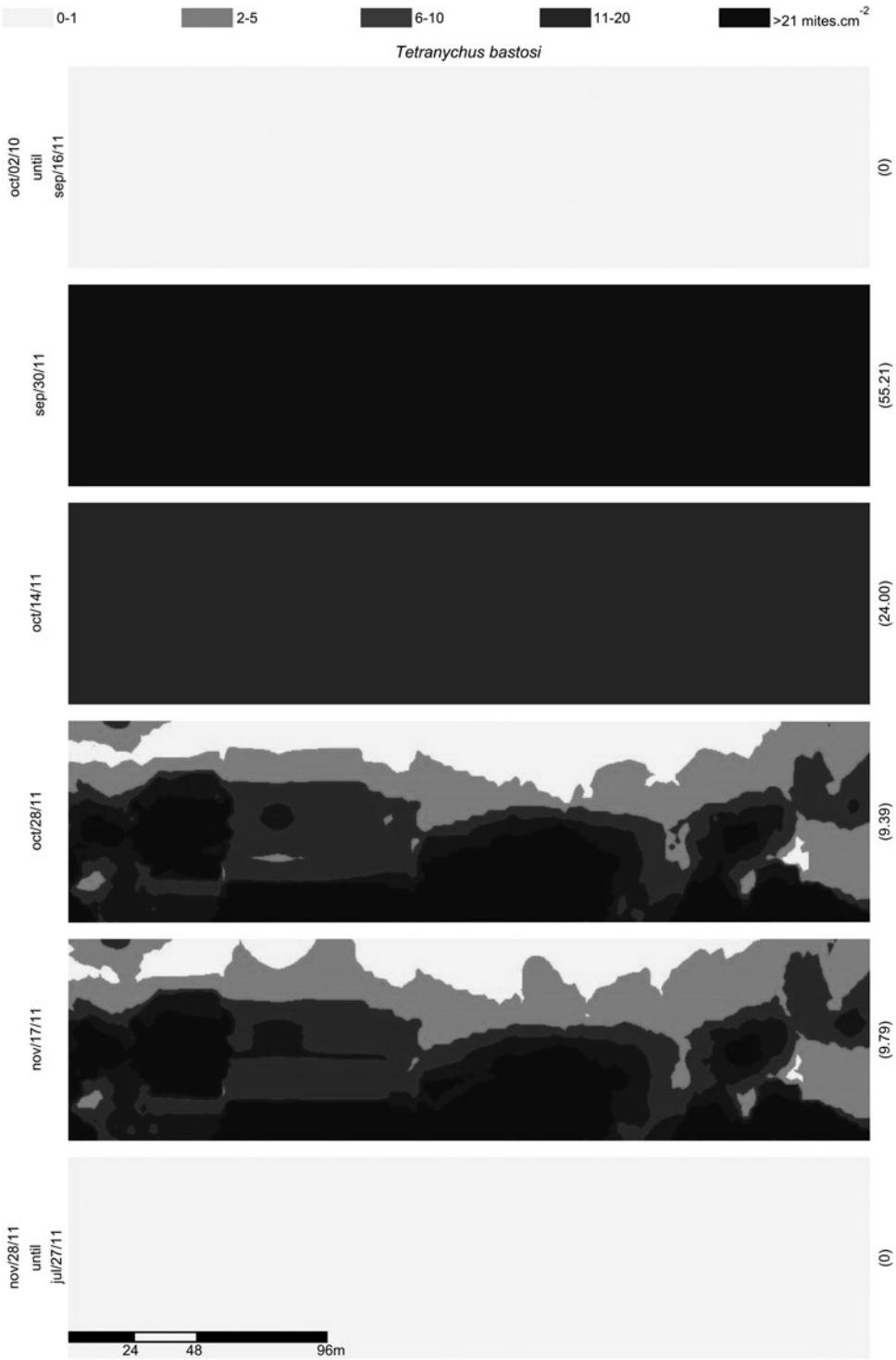


Fig. 5. Maps of the spatial distribution of *Tetranychus bastosi* in Crop 1. The mean densities in the plantation are given in parentheses (mites cm^{-2}).

During colonization, individuals identify locations favorable to their offspring (Karban & Agrawal, 2002). The fact that the spatial distribution models are isotropic indicates that the mite populations spread in all directions in the plantation. During this process, these arthropods migrate to the neighboring plants as the leaves deteriorate due to the intense infestation by them. This migration is possible because the leaves of the neighboring plants are in contact with each

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Table 1. Density (mean ± SE) and characteristics of the spatial distribution models for *Polyphagotarsonemus latus* and *Tetranychus bastosi* in Crops 1 and 2.

Local	Data	$\bar{X}$ (mites cm^{-2})	Characteristics of the selected spatial distribution model							
			Model	β_0	β_1	RSS	C_0	C_0+C	R	R^2	RSD
			Polyphagotarsonemus latus								
Crop 2	mar-25-2011	8.69 ± 1.58	Exponential	0.92	0.28	634	9.39	22.92	27.31	0.03	0.41
	apr-08-2011	7.84 ± 0.93	Gaussian	7.51	0.89	1039	27.68	57.48	19.62	0.40	0.48
	apr-29-2011	0.50 ± 0.13	Exponential	0.03	0.70	9.73	0.42	1.47	21.33	0.06	0.29
	mar-30-2012	12.70 ± 2.79	Exponential	1.62	1.00	$4.33.10^5$	140.65	420.5	17.43	0.08	0.33
			Tetranychus bastosi								
Crop 2	apr-08-2011	0.20 ± 0.06	Exponential	0.07	0.34	0.34	0.07	0.28	7.37	0.05	0.25
	apr-29-2011	0.17 ± 0.08	Exponential	−0.02	1.12	2.82	0.17	0.97	14.4	0.10	0.18
	oct-15-2011	4.34 ± 0.76	Spherical	−0.47	1.56	$1.64.10^4$	35.2	132	45.00	0.25	0.27
Crop 1	oct-28-2011	9.39 ± 1.05	Exponential	2.32	0.84	$1.44.10^5$	150	363	36.18	0.22	0.41
	nov-17-2011	9.79 ± 1.08	Exponential	2.73	0.81	$1.06.10^5$	181	354	28.50	0.15	0.51

In the heading: β_0 = intercept of the curve, β_1 = slope, RSS = residual sum of the squares, C_0 = nugget effect, $C + C_0$ = sill, R = range (cm), R^2 = coefficient of determination and RSD = Range of Spatial Dependence.

other. Thus, dispersion links the local population cycles of colonization and extinction of the individuals in ephemeral environments (Hanski, 1999). *P. latus* and *T. bastosi* colonize the leaves at their preferred site, the apex of the physic nut plants (Lopes, 2009; Evaristo *et al.*, 2013; Pedro-Neto *et al.*, 2013). Another reason for the mite migration to other plant species is that the physic nut plants are deciduous (Ulyshen, 2011). Thus, when these plants lose their leaves (from mid-June to mid-September), the mites, of necessity, need to migrate to other plant species.

Polyphagotarsonemus latus and *T. bastosi* infestations were observed to concentrate at the periphery of the plantation. The colonization process includes an infestation source and a sink. The source of the infestation could be the plantation itself or other areas. For arthropods, the most common situation is one where the source is another area (Yarahmadi & Rajabpour, 2013). In the situation studied here, both the plantations and the other areas could have been the source of the mite infestation. Mites may spread between areas via wind, transportation of contaminated plants or by phoresy on other insects (Moraes & Flechtmann, 2008). When the mites originate from the plantation itself, the source is normally the weeds in the area (Sutherland *et al.*, 2002). These two hypotheses are not mutually exclusive, as *P. latus* and *T. bastosi* have already been observed on weeds (Cruz *et al.*, 2012), and a few studies reporting mite dispersion between plantations are available in the literature (Moraes & Flechtmann, 2008). We previously found that the weeds *Sida rhombifolia, Bauhinia angulata, Calopogonium mucunoides, Urena lobata, Waltheria americana, Helicteres guazumifolia, Sida cordifolia* and *Sida urens* act as source of phytophagous mites infesting physic nut plantations (Cruz *et al.*, 2012, 2013; Saraiva *et al.*, 2015). Thus, we favor the possibility that the physic nut plants may act as a sink, whereas the other plant species, such as weeds, act as the source for the *P. latus* and *T. bastosi* populations (Hanski, 1999).

The range value obtained in the spatial distribution analysis of a pest allows the use of geostatistics in pest management programs (Rijal *et al.*, 2014). Thus, the range should be the minimum distance between the samples that make up the sampling plans. Adopting these sample distances, the data of a sample does not suffer from the pest spatial distribution (Young & Young, 1998), allowing the use of classical methodologies consisting of conventional and sequential samplings.

The evaluation of the spatial pattern by using geostatistical tools is also important to correct the flaws of methods that are traditionally used to determine the spatial distribution of pests (Young & Young, 1998; Rijal *et al.*, 2014). Such frequency distribution methods provide no information on the spatial pattern of pests in the field, for not taking into account the geographical location of the sampling points (Young & Young, 1998; Rijal *et al.*, 2014). Using geostatistics, this can be verified by semivariogram models and clearly displayed on the maps generated by the Kriging method (Liebhold *et al.*, 1993; Bacca *et al.*, 2006).

The facts that mites colonization are concentrated at the periphery and each sample depends on those located about 30 m in its diameter can affect how these arthropods need to be sampled (Barrigossi *et al.*, 2001). Mites must be sampled commencing from the edge of the plantation and the samples should be drawn from closely located plants. Next, the sampling should be extended to the whole plantation, and samples need to be taken approximately 30 m apart. In addition, a random walk is recommended in this case (Rosado *et al.*, 2014).

The spatial distribution of the mites in the plantations over time was observed to be affected by interspecific competition. Species that compete interspecifically inhabit the same ecological niche and tend to occur at lower densities when they are found in the same location (Sarmento *et al.*, 2011). Both *P. latus* and *T. bastosi* inhabit the same ecological niche, as they both suck out the cellular contents from the lower leaf surfaces and prefer to attack the young leaves (Lopes, 2009; Evaristo *et al.*, 2013; Pedro-Neto *et al.*, 2013). Another supporting piece of evidence for the existence of interspecific competition is the fact that the total mite density was higher when only one species occurred (figs 1 and 2). To reduce interspecific competition, species generally exploit the resources available at distinct time periods (Hammen *et al.*, 2012). This effect was observed in the current study, as *P. latus* and *T. bastosi* attacked the plants at different time periods, when both were found to occur in the same crop (fig. 1).

The climatic factors such as rainfall and temperature varied along the year and the mite species studied varied accordingly. Several arthropods species improve their biological performance with increasing temperature. In this context, high

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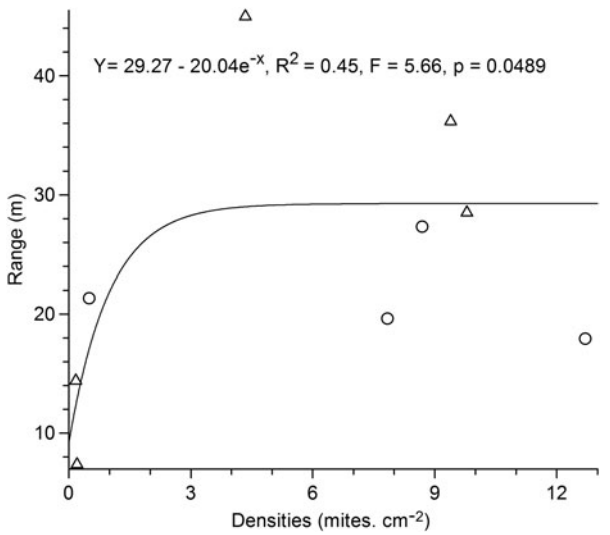


Fig. 6. Range variation in the spatial distribution models for *Polyphagotarsonemus latus* (○) and *Tetranychus bastosi* (Δ) as a function of their densities.

temperature increases reproduction, as well as, the developmental rate of several tetranichid mites, such as we found to *T. bastosi* (Liu & Tsai, 1998, Bounfour & Tanigoshi, 2001; Silva, 2002). Because *P. latus* presents large thermal limits of development (14–32°C) (Ferreira *et al*., 2006), the temperature variation in the study sites (23–28°C) should not have been enough to affect the populations size of this mite.

Among the negative effects of rain is the death of small arthropods such as mites by knocking them to the ground or drowning (Leite *et al*., 2006). The rain may also decrease the mobility of arthropods reducing encounters between sex partners for mating (Bacca *et al*., 2006) and provide conditions for development of entomopathogenic fungi that are important natural enemies of mites (Van der Geest *et al*., 2000). Some arthropods may be more susceptible to these factors and thus be adversely affected. This may explain the difference in the effect of rain on the two studied species.

Conclusion

In conclusion, our study sheds light on the spatiotemporal dynamics of the *P. latus* and *T. bastosi* mite populations in the physic nut plantations. Mite colonization begins at the periphery and spreads towards the center, in uniform patches. The spatial distribution of the mites is influenced by interspecific competition, and the total density of the mites is observed to be higher when only one species is present. When both the mite species are present, their populations peak at different times. The spatial distribution of the mites is uniform at extreme densities (low or high), although it is aggregated at intermediate densities.

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