Spatial distribution of *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae) in oil palm, Roraima State, Brazil

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ABSTRACT: Oil palm (*Elaeis guineensis* Jacq.) is an African palm that is distinguished by its elevated oil production per unit area, however, fitossanitary problems are one of its the main drawbacks. Thus, this study aimed to evaluate the spatial distribution pattern of the *Rhynchophorus palmarum* (L) (Coleoptera: Curculionidae) in oil palm plantations with geo-statistical procedures in the south of the state of Roraima, Brazil. The 25 ha of experimental area is located in the municilaity of São João da Baliza, RR, where 24 samples were carried out in the period from September 2013 to August 2014. For the insects collection, a bucket-type trap with food attractant (sugarcane) was placed in each one of the 100 sampling points. Analyses of spatial variability and spatial dependence were held by the incorporation of geo-statistical procedures based on spatial modeling techniques by semivariagrams. The spatial distribution of the *R. palmarum* is aggregated with spatial dependence described by the spherical model, forming clusters of 100 to 210 m radius. It was observed that *R. palmarum* infestation takes place both in the center just as on the edges of the plantation, with later dissemination to the entire area. The maximum range found in the study was of 210 m, with an area of influence of 13.9 ha.

Key words: *Elaeis guineenses*; Kriging; oil palm; population dynamics; semivariogram

Distribuição espacial de *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae) em palma de óleo em Roraima, Brasil

RESUMO: *Elaeis guineensis* Jacq (Arecaceae) é uma palmeira de origem africana que se destaca por possuir elevada produção de óleo por unidade de área, porém, entre os principais entraves, destacam-se os problemas fitossanitários. Assim, o presente trabalho objetivou avaliar o padrão de distribuição espacial de *Rhynchophorus palmarum* (L) (Coleoptera: Curculionidae) em um plantio de dendê, no sul do estado de Roraima, Brasil. A área experimental de 25 ha está localizada no município de São João da Baliza, RR, onde foram realizadas 24 amostragens, quinzenalmente, no período de setembro de 2013 a agosto de 2014. Para coleta dos insetos foi instalada uma armadilha do tipo balde com atrativo alimentar (cana-de-açúcar), em cada um dos 100 pontos amostrais. As análises da variabilidade espacial e da dependência espacial foram realizadas através de incorporação de procedimentos geoestatísticos baseados em técnicas de modelagem espacial por semivariogramas. Observou-se que a infestação do *R. palmarum* é agregada com dependência espacial descrita pelo modelo esférico formando aglomerados tanto no centro quanto nas bordas do plantio, com posterior disseminação para toda a área. O alcance máximo encontrado no estudo foi 210 m com área de influência de 13,9 ha.

Palavras-chave: *Elaeis guineenses*; krigagem; dendezeiro; dinâmica populacional; semivariograma

Introduction

Oil palm, macaw-palm or "dendezeiro", the *Elaeis guineensis* Jacquin (Arecales: Arecaceae) is a palm of African origin, grown in different tropical countries. In Brazil, the largest oil palm cultivated areas are found in the Amazon region (Brazilio et al., 2012), where it is a species of great agroecological-industrial importance, contributing to the development through jobs and income generation (Cordeiro et al., 2009), vegetable oil production and by settling man on the field (Abdalla et al., 2008). Just as in other regions of the Amazon, oil palm shows potential to be cultivated in Roraima, especially in its southern region, which has adequate edaphoclimatic conditions for the species adaptation (Morais et al., 2012).

Long-term exploitation of this crop in the region can lead to positive environmental impacts, such as carbon fixation in agricultural systems, and recovery of degraded and altered areas (Chia et al., 2009; Cordeiro et al., 2009; Tan et al., 2009).

However, with monoculture, phytosanitary problems are limiting factors in the exploitation of oil palm farming, as they are of relevant economic expressiveness (Duarte et al., 2008). The insect *Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae) is considered one of the main pests of Oil Palm (Correia et al., 2015; Pinho et al., 2016), since its adults can cause direct physical damage to palm trees, such as stem puncture. The larvae make galleries in the plants tissues, mainly in the apical bud, in the petiole of new leaves, in inflorescences and in the soft stem, destroying the sap-conducting tissues, which in turn can leand to the death of the plant (Moura et al., 2006; Ambrogi et al., 2009). In seed production plantations, the damage can be irreversible (Cysne et al., 2013).

Mass collection of *R. palmarum* through the use of traps, in addition to the application of phytosanitary products, has been the most used control methods. However, it is necessary to use other tools that can complement or assist these said methods (Pinho et al., 2016). Knowing the spatio-temporal dynamics of the insects in agricultural ecosystems is important for developing management strategies and reducing the use of pesticides (Brandão et al., 2017). Maps of occurrence and distribution of pest insects in agricultural areas contribute to improve the sampling methods and correct application of the control method (Duarte et al., 2015; Brandão et al., 2017), optimizing operations and reducing costs. Therefore, geostatistics can be used as a complementary tool to help, when necessary, in the combat against this pest (Pinho et al., 2016).

Capture methods (Costa-Carvalho et al., 2011; Miguens et al., 2011; Cysne et al., 2013) and spatial distribution of *R. palmarum* (Pinho et al., 2016) rely on using aggregation pheromone and the sugarcane as a food attractant, in order to verify the spatial behavior. It was observed a tendency among the insect populations of distributing themselves in na aggregate way, which is common in populations of phytophagous insects in certain ecological niches (Hall & Branham, 2008; Ray et al., 2009).

This present study had as its objective the determination of spatial distribution of *R. palmarum* in oil palm plantation in the Southern Roraima, using the sugarcane as food attractant.

Materials and Methods

Study area

The experiment was performed in an 25-ha area of a 5 years-old commercial oil palm plantation, propriety of the Brazil BioFuels company, located in the municipality of São João da Baliza (0°57'22.7"N, 59°56'11.1"W) (Figure 1A), approximately 370 km from the capital Boa Vista, state of Roraima.

The region has a relief that goes from flat to undulating, with an average altitude of 117 m, also with Submontane Dense Ombrophilous Forest as the predominant vegetation (IBGE, 2012). According to Köppen classification, the climate in southern Roraima is of the Ami type, characterized as rainy tropical, with an average temperature between 25 and 28 °C and annual rainfall ranging from 1,800 to 1,900 mm. The air relative humidity is considered high, with the annual average ranging between 85 and 90%, and the luminosity in the region varies from 1500 to 3000 hours per year of solar radiation (Barbosa, 1997).

Plants were arranged in the form of an equilateral triangle (quincunx), with a 9 m spacing between plants and 7.8 m between lines (Figure 1A). The definition of the area perimeter was carried out aided by a navigation GPS (Garmin,
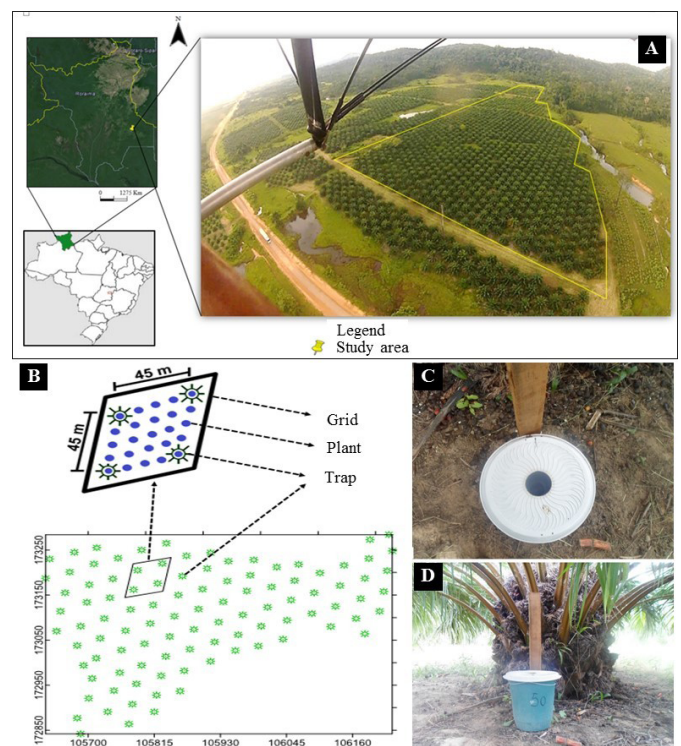
Figure 1. Location of the study area, in the municipality of São João da Baliza, RR. A) experimental area; B) sampling grid; C) view of the hole in the top part of the cover; and, D) trap ready for catching insects.

GPSmap76CSx model) and, afterwards, the experimental area was divided into regular sampling grids. The sampling grid dimension was 45 m x 45 m, making up 100 sample units, each consisting of about 25 plants, totaling 2,500 plants in the useful area (Figura 1B).

Insects colection

For the mass collection of *R. palmarum*, bucket-type traps containing the food attractant sugarcane were used. These traps were made up of 15 liters plastic buckets, with their bottom perforated in order to facilitate the rainwater draining. In the bucket lid, in its ventral part, a hole was opened and a 10 cm in diameter plastic funnel was placed in it, without the narrow tube that was removed to allow the insects passage into the bucket (Figure 1C and Figure 1D).

Within each trap, 15 sugarcanes setts (food attractant) were placed, previously cut into 20 cm long pieces and crushed to facilitate the odor volatilization to attract insects. The aggregation pheromone was not used, as it could influence the insects distribution, causing aggregation in the traps. Every fifteen days, between September 2013 and August 2014, *R. palmarum* individuals were removed from the traps and taken to the Plant Protection Laboratory from the Federal University of Roraima – UFRR, where the insects were then counted and discarded. On the collection dates, the sugarcane setts were also replaced.

Geostatystical analysis

After the data was tabulated, the spatial distribution of *R. palmarum* was analyzed through geostatistics by using the semivariogram, fitting the data to one of the four possible models: Gaussian, spherical, power or exponential.

In the analysis first stage, the semivariograms were obtained. Afterwards, the semivariogram model that best fitted the data was chosen based on the coefficient of determination (R^2), and that same model was used in the Kriging process (contour maps). The semivariogram was estimated by using Equation 1.

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

In which N(h) is the number of the experimental pairs from measured values $Z(x_i)$, $Z(x_i + h)$, separated by a h vector. The graph of $\gamma^*(h)$ versus the corresponding h values, is function of the distance (h), and thus, dependant on the magnitude and direction of the distance (Farias et al., 2008).

For a better definition of the variographic parameters, several attempts were made to fit the spherical, exponential, Gaussian and power models. In this study, the semivariogram model fitted to the data was the spherical one (Equation 2).

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

In which C_0 is the pure nugget effect or minimum semivariance; $C_0 + C_1$ is the threshold or the maximum semivariance; a is the range or aggregation radius.

In all analyzes was used information on the sample position and the assumed value of the variable at each point. The assumed variable was the incidence of *R. palmarum* and the point represented by the trap. As such, from each sampling point the value of the variable and the coordinates (latitude and longitude) were obtained, which were then used to make *R. palmarum* incidence maps thorugh the Kriging interpolation method. (Silva et al., 2011).

Parameters related to the semivariogram were defined: the threshold ($C_0 + C_1$), the nugget effect (C_0) and the range (a). Threshold is the value of the semivariogram corresponding to its range, that is, from that point onwards there is no more spatial dependence between the samples. Nugget effect is the semivariance at very close points, when the distances between the sample units are very small, and the range (a) represents the distance at which there is spatial dependence between the samples (Pinho et al., 2016) and its value have been used to determine the adequate distance between the sampling points (Silva et al., 2011).

It was also calculated the Spatial Dependency Index k (ratio between $C_0/(C_0+C_1)$) according to Cambardella et al. (1994), who considers as 'strong spatial dependence' the semivariogram that has the value of the pure nugget effect less than 25% of the threshold, as 'moderate dependence' when the value is between 25 and 75% and, as of 'low dependence' when this value is greater than 75% .

For the analysis of the data and creation of the spatial distribution maps of *R. palmarum*, the software SURFER Version 11.0 was employed (Golden Software, 2002).

Results and Discussion

Spatial distribution of *R. palmarum*

There was spatial dependence among the analyzed data and the distribution of *R. palmarum* occurred in an aggregated manner in all evaluations. The spherical model was the one that best fit the semivariograms and its fittings verified the formation of clustering spots that varied from 100 m to 210 m in radius (Table 1). The aggregate distribution, established by the spherical model, has been the most common in studies of insects in Oil Palm in the Amazon region (Pinho et al., 2016; Brandão et al., 2017), characterizing the formation of clustering spots called "reboleiras" in the field , where these insects group themselves.

The coefficient of determination (R^2) indicates the quality of the semivariogram model fitting (Figure 2). Values close to one indicate a good fit of the model (Silva et al., 2011), as how was verified for the present study, in which this parameter ranged from 0.91 to 0.99.

The range of spatial dependence is of great importance, because in addition to indicating the aggregation radius of *R. palmarum*, it allows recommending the eradication radius of these insects. Through the aggregation radius, it can be

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Table 1. Parameters of the *R. palmarum* spatial distribution semivariograms, from September/2013 to August/2014, São João da Baliza, RR.

| Date of sampling	Parameters*			Model	Area (m²)[a] of clustering spots	K[b]	R²	Spatial dependance
	C_0	C_1	a (m)					
14/09/2013	0.200	0.425	206.0	Spherical	133.317	0.32	0.99	Moderate
28/09/2013	0.150	0.120	133.0	Spherical	55.572	0.56	0.98	Moderate
12/10/2013	0.035	0.088	186.0	Spherical	108.687	0.28	0.98	Moderate
26/10/2013	0.130	0.100	100.1	Spherical	31.479	0.57	0.95	Moderate
09/11/2013	0.075	0.072	159.0	Spherical	79.423	0.51	0.96	Moderate
23/11/2013	0.340	0.270	110.0	Spherical	38.013	0.56	0.94	Moderate
07/12/2013	0.301	0.524	180.5	Spherical	102.354	0.36	0.99	Moderate
21/12/2013	0.349	0.282	210.0	Spherical	138.544	0.55	0.99	Moderate
04/01/2014	0.120	0.240	165.0	Spherical	85.530	0.33	0.99	Moderate
18/01/2014	0.181	0.300	112.9	Spherical	40.044	0.38	0.99	Moderate
01/02/2014	0.360	0.225	161.6	Spherical	82.041	0.62	0.98	Moderate
15/02/2014	0.130	1.177	102.6	Spherical	33.071	0.42	0.91	Moderate
01/03/2014	0.070	0.170	155.0	Spherical	75.477	0.29	0.99	Moderate
15/03/2014	0.170	0.188	133.0	Spherical	55.572	0.47	0.92	Moderate
29/03/2014	0.080	0.290	155.9	Spherical	76.356	0.22	0.98	Strong
12/04/2014	0.380	0.264	137.7	Spherical	59.569	0.59	0.94	Moderate
26/04/2014	0.186	0.180	108.1	Spherical	36.711	0.51	0.92	Moderate
10/05/2014	0.235	0.370	145.0	Spherical	66.052	0.39	0.99	Moderate
24/05/2014	0.235	0.142	185.5	Spherical	108.103	0.62	0.97	Moderate
07/06/2014	0.320	0.190	128.9	Spherical	52.198	0.63	0.94	Moderate
21/06/2014	0.180	0.124	119.0	Spherical	44.488	0.59	0.96	Moderate
05/07/2014	0.100	0.233	100.0	Spherical	31.416	0.30	0.95	Moderate
19/07/2014	0.220	0.161	167.0	Spherical	87.616	0.58	0.95	Moderate
03/08/2014	0.199	0.208	111.6	Spherical	39.127	0.49	0.95	Moderate

*Nugget effect (C_0), spatial variance of contribution (C_1), range (a), [a] area calculated by πr^2, where $\pi = 3.14$ and r = a, and [b] is the ratio of $C_0/(C_0+C_1)$.

affirmed that, in the evaluated conditions, the *R. palmarum* eradication radius varied from 100 m to 210 m. After determining the aggregation radius of a pest, it is possible to develop a field sampling plan, facilitating the localized pest control (Brandão et al., 2017).

The maximum range found in this study was of 210 m, with an influence area of 13.9 ha, and the minimum range was of 100 meters, with an influence area of 3.1 ha. Employing the

sample grid (45 m x 45 m) proved to be adequate. Thus, it is recommended for the next studies to employ a grid of at least 100 m x 100 m, reducing the number of traps per unit area and, consequently, the costs from integrated management of this pest insect.

Aggregate distribution was also evidenced by Faleiro et al. (2010) in Saudi Arabia, by using mathematical models of frequency distribution for *R. ferrugiensis* (Coleoptera:

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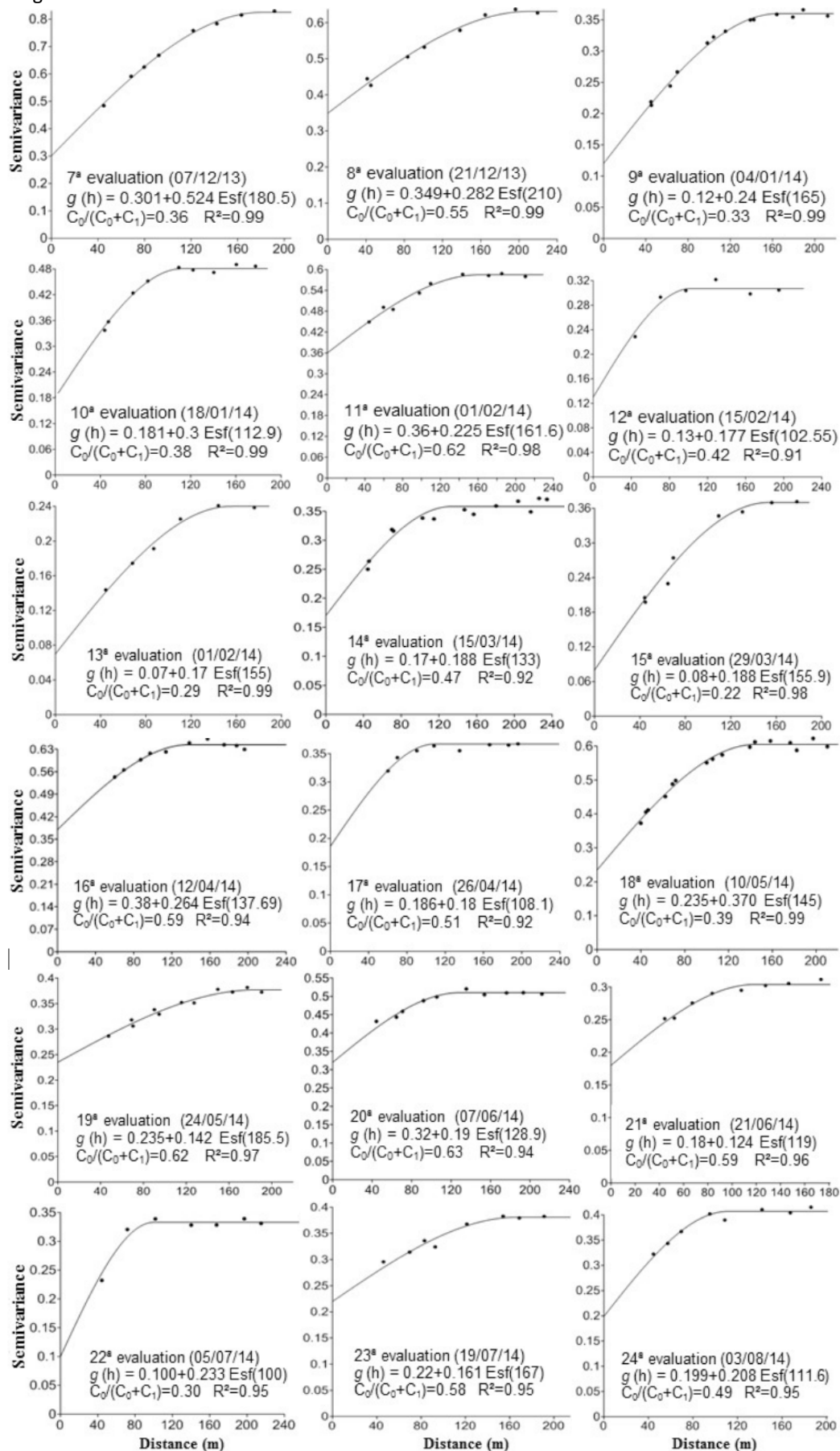
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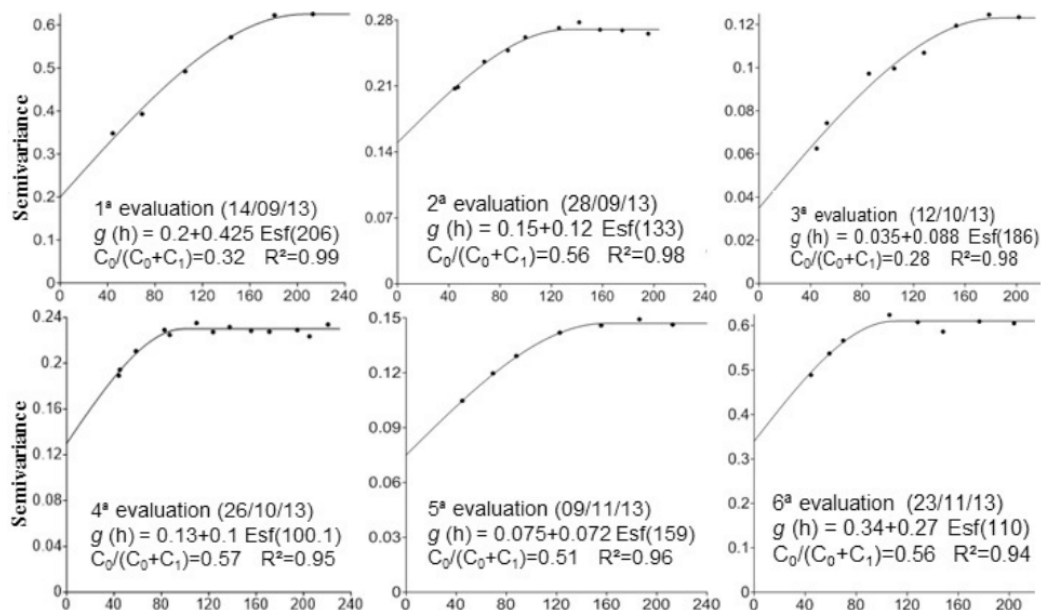
Continued from Figure 2

Figure 2. Semivariograms of the *R. palmarum* spatial distribution in the period from Sep/2013 to Aug/2014, São João da Baliza, RR.

Curculionidae) (Olivier, 1790). Pinho et al. (2016), on the other hand, concluded that the population of *R. palmarum* in Oil Palm plantations in the state of Pará follows an aggregate pattern.

The *K* ($C_0/(C_0+C_1)$) relation, an important parameter for providing na estimate measure on how much randomness exists in the surveys, ranged from 0.22 to 0.63 on the different sampling dates (Table 1), indicating maximum variation of 63% in *R. palmarum* surveys. Such values are within the range recommended by Journel & Hijbregts (1978), who cite that values below 0.80 indicate an aggregated distribution of the variable while when greater than 0.80 indicate a tendency towards randomness and that there is no spatial dependence among the samples.

Spatial dependence was classified as strong (less than 25%) in only one out of the 24 evaluations, according to the classification by Cambardella et al. (1994). In the other samples, spatial dependence was classified as moderate because the value of the nugget effect was greater than 25% and less than 63% of the threshold value.

For a better visualization of the *R. palmarum* spatial distribution, Kriging maps were elaborated where it is possible to visualize the infestation dynamics of the pest (Figures 3, 4, 5 and 6). It was initially observed that there were some *R. palmarum* outbreaks, and later, formation of pest clustering spots ("reboleiras"), which then expanded towards the planting edges. However, *R. palmarum* tends to change its infestation site over time. In some evaluations, its presence could be verified both at the edges and at the center of the plantation (Figures 3 and 6).

In the lower incidences of *R. palmarum*, larger size "reboleiras" were formed. This occurred in the following samplings: from the first to the fifth; thriteenth to the twelfth; and twenty-second to the twenty-frouth (Figures 3, 5 and 6), which correspond to the evaluations from September/2013 to November/2013 and March/2014 to August/2014. However, when the *R. palmarum* incidence in the area was higher, there were the formation of several smaller pest "reboleiras" (samples from 6 to 12 and 21) (Figures 3, 4 and 6).

The highest population densities of *R. palmarum* occurred from November 2013 to February 2014. In these months, the highest densities coincided with the period when the plantation underwent cultural treatments (mechanized weeding, straw cutting and the glyphosate herbicide application).

With the help of the Kriging maps, it was observed that the pest has a strong tendency in infesting the neighboring plant, forming "reboleiras". It is noteworthy that without the use of the semivariogram, information such as the aggregation radius are not shown. Employing geostatistics allowed a more accurate visualization of the *R. palmarum* spatial distribution, which can be used in a monitoring program, reducing production costs with more effective control. Results obtained will assist in the integrated management and monitoring of the pest in future evaluations by demonstrating the predominance of the infestation site, its spatial distribution and the infestation evolution in the study area.
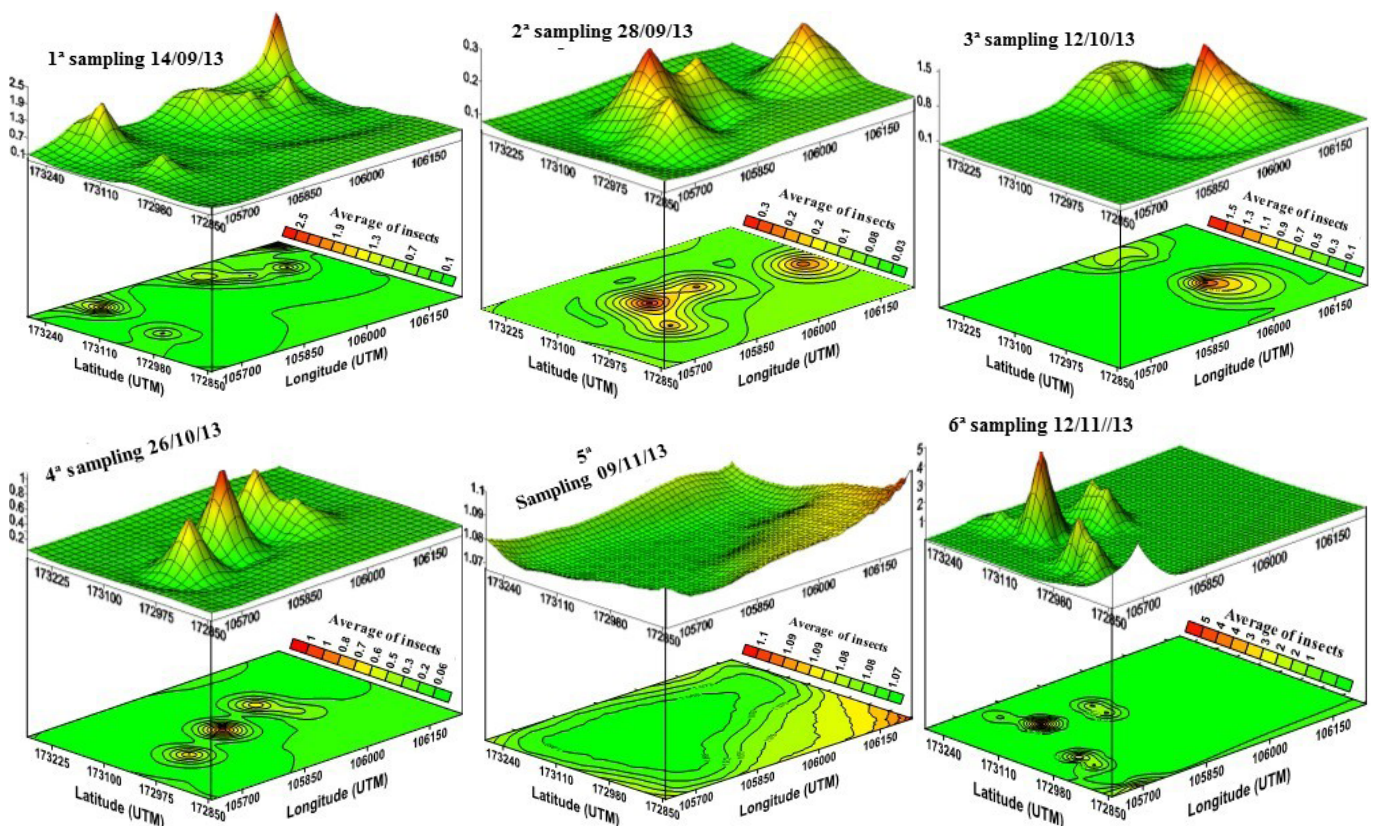
Figure 3. Spatial distribution maps of *R. palmarum*, captured in traps, from August/2013 to November/2013 in oil palmplantation, São João da Baliza, RR.
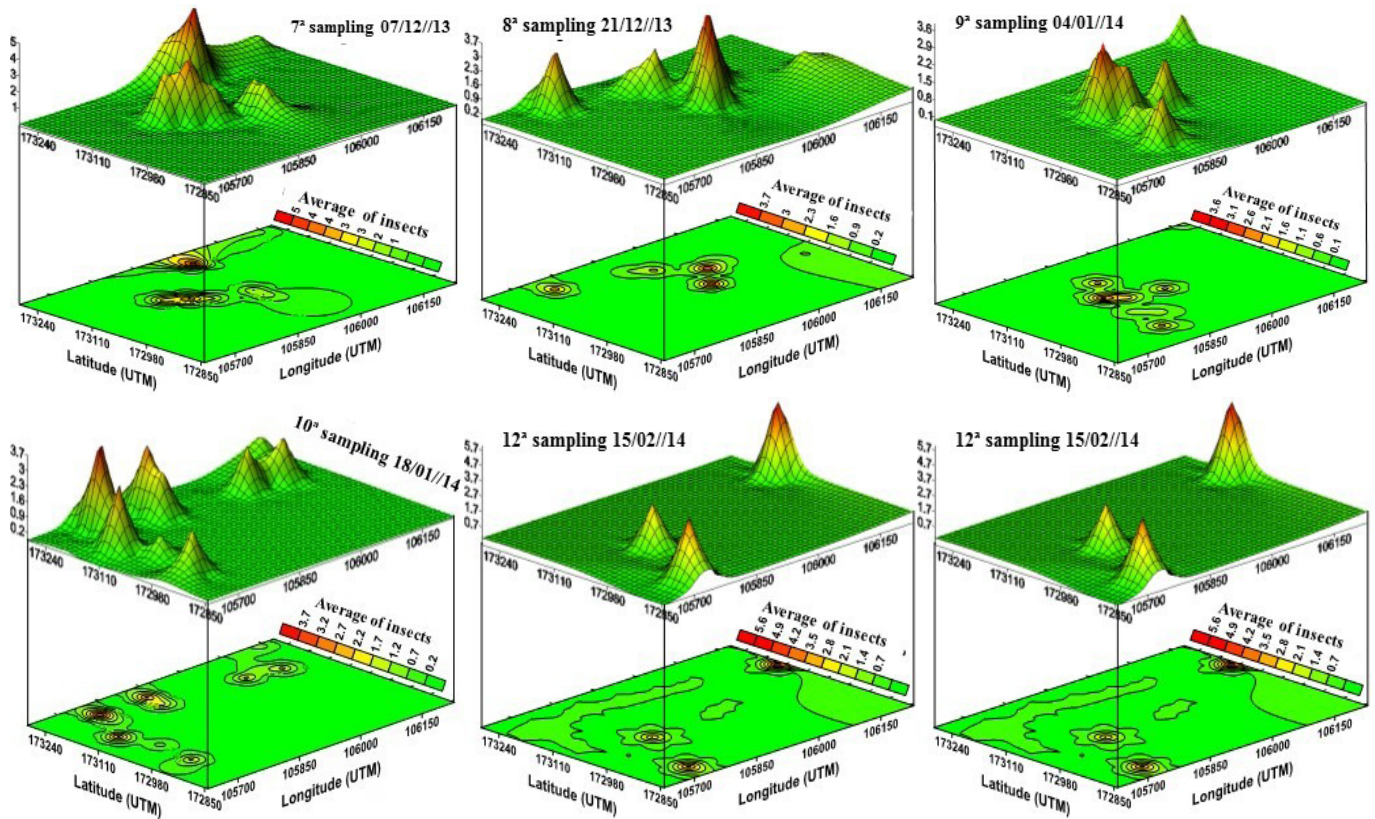
Figure 4. Spatial distribution maps of *R. palmarum*, captured in traps, from December/2013 to February/2014 in oil palm plantation, São João da Baliza, RR.

Figure 5. Maps of spatial distribution of *R. palmarum*, captured in traps, from March/2014 to May/2014 in oil palm plantation, São João da Baliza, RR.
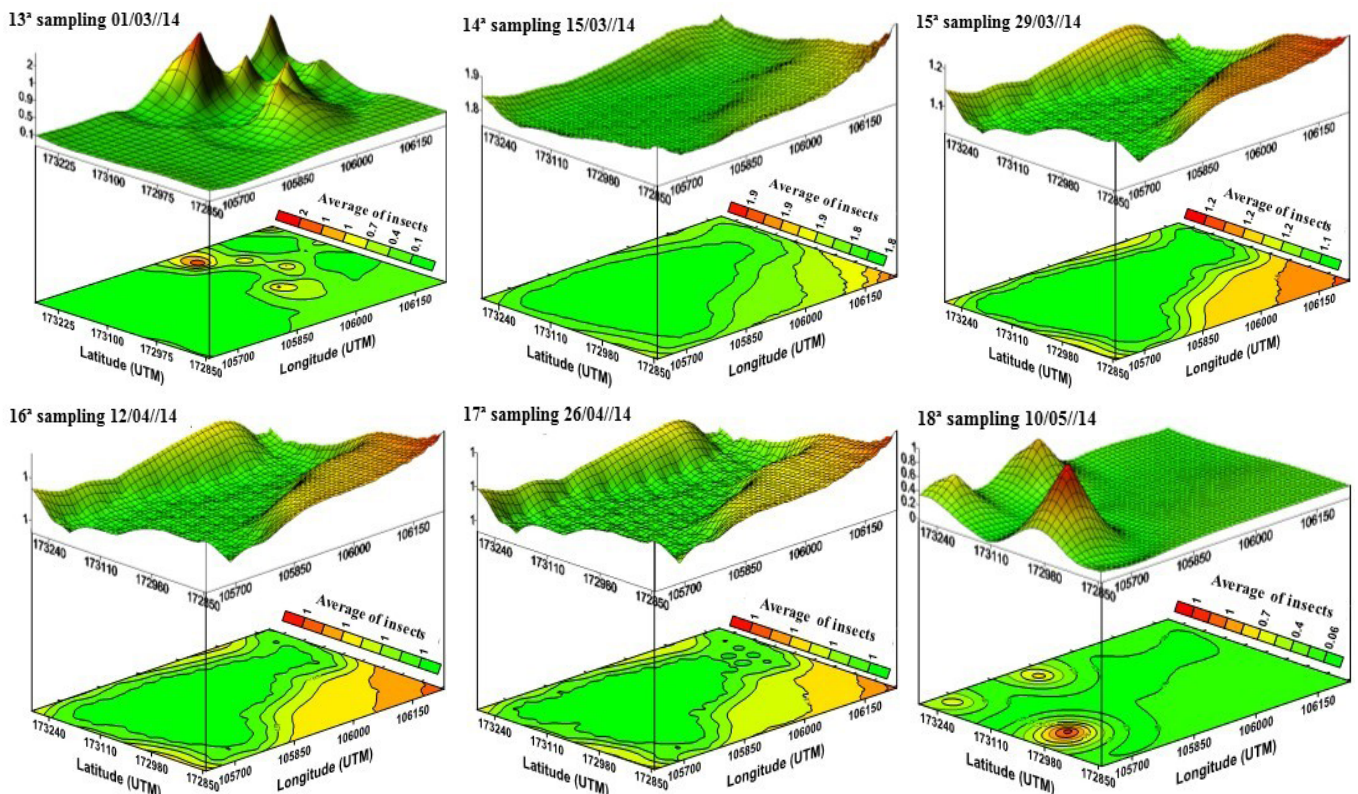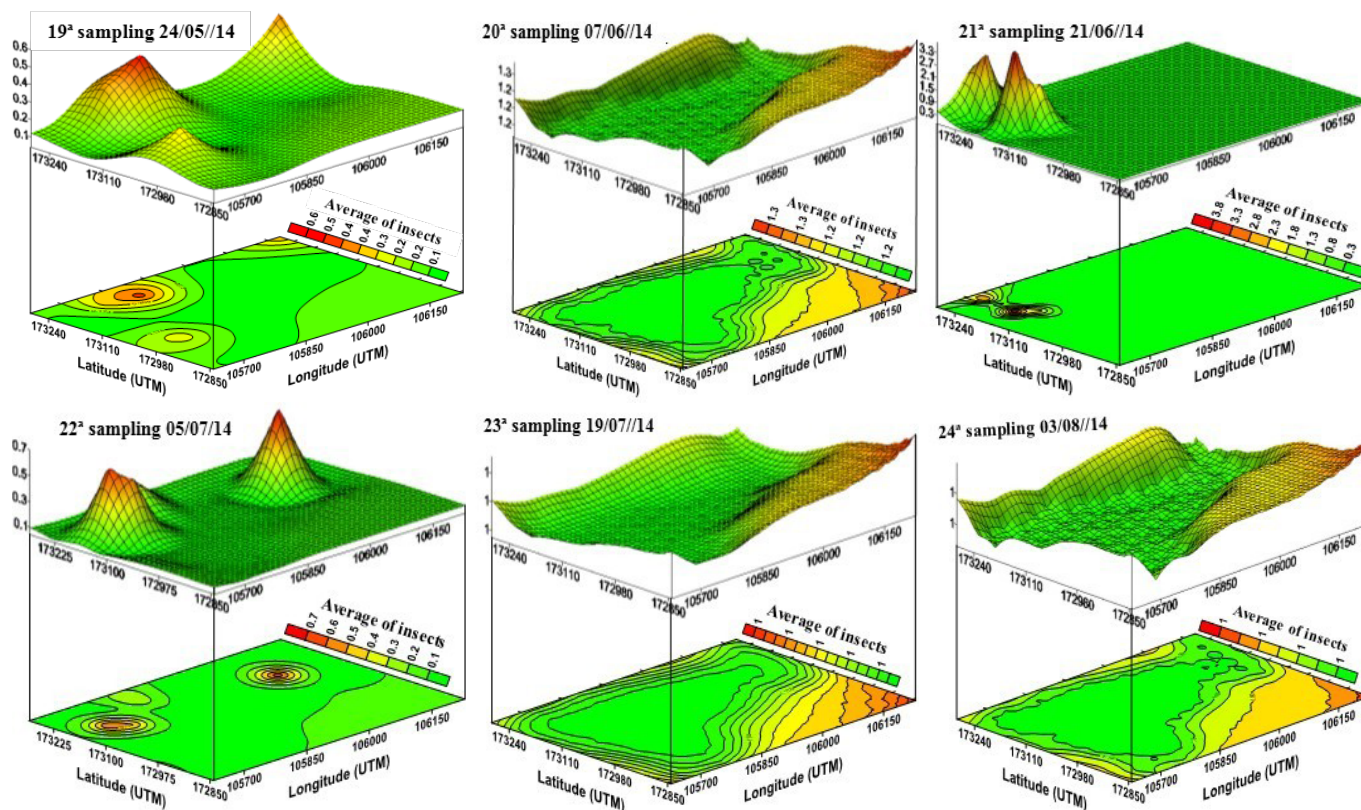
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Figure 6. Spatial distribution maps of *R. palmarum*, captured in traps, from May/2013 to August/2014 in oil palm plantation, São João da Baliza, RR.

Conclusion

The spatial distribution of *R. palmarum* in Oil Palm plantation is aggregated, forming "reboleiras" of 100 to 210 m radius, with infestation occuring both in the center and at the edges of the plantation and later spreading to the entire area.

For developing safe sampling methods for *R. palmarum* it is recommended to distribute a trap for each 13.9 ha, using sugarcane as food attractant.

Using sugarcane was efficient to determine the *R. palmarum* spatial distribution, however, when the objective is controlling (mass capture), the use of agregation pheromone is recommended due to it being more attractive to the insects.

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