



General Entomology

Spatial behavior of corn leaf aphid and syrphid flies in corn crop in the northeast of Pará

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Abstract. The aim of this study was to verify the spatial and temporal behavior of corn leaf aphid (*Rhopalosiphum maidis* Fitch.) and hoverflies in corn crop in the municipality of Igarapé-Açu, northeast of Pará, Brazil, as well as the influence of adjacent areas on the occurrence of these insects. An experimental area of 1.0 ha (100 x 100 m) was used in the years 2015 and 2016, adjacent areas consisted of mango agroecosystem, pasture and secondary forest. The area was divided into grid with 100 plots of 100 m² (10 x 10 m). Ten plants were randomly selected, totaling 1,000 plants per sampling date. Corn leaf aphid colonies (= or > 15 aphid) and syrphid flies adult was visually analyzed throughout the aerial parts of the plants. The spatial behavior was analyzed by semivariogram modeling and kriging interpolation maps. The semivariograms and kriging maps were made by the R software for Windows. Gaussian, spherical and exponential models were the best fit for corn leaf aphid in both harvests, showing aggregate behavior. The weak and moderate spatial dependence index prevailed, with range ranging from 12.46 to 93.04 m for *R. maidis*. The syrphids flies showed spatial interaction with the corn leaf aphid and they also show aggregate behavior, confirmed by most adjustments in the spherical and exponential models. The spatial dependence index of the prevailing syrphids flies were moderate and weak, ranging from 14.00 to 101.33 m. Adjacent areas showed influence on occurrence and dispersal of both corn leaf aphid and syrphids flies.

Keywords: Aphids; Geostatistics; Kriging; *Rhopalosiphum maidis*; Syrphidae.

Corn is one of the most important cereal in Brazil, reaching an expressive production of 85 million tons in the 2017/2018 harvest (CONAB 2018). The high production of corn is stimulated by the versatility in its commercial use, mainly aimed at animal feed and social aspect (CRUZ *et al.* 2006).

Brazil has an extensive corn cultivated area, with production in the first crop (summer) and second crop (autumn/winter), varying the period according to the region (CONAB 2018). This extensive and intense cultivation of corn favors and offers food for insects throughout the year, pests appear from germination to harvest, attacking all parts of the plants (VALICENTE 2015).

The productive potential of the corn crop can be significantly reduced due to the action of insect pests (CRUZ 2008). Among the insects that cause injury and damage in the corn crop stand out a variety of caterpillars, stick bugs, leafhoppers, beetles, termites and the corn leaf aphid (*Rhopalosiphum maidis* Fitch) (CRUZ 2008; VALICENTE 2015).

The corn leaf aphid is considered a secondary pest of the corn crop, however, infestations that occur from the vegetative stage to the corn tasseling are the ones that cause greater productivity losses, which means, the more initial the infestation occurs on the crop, the greater the damage. (AL-ERYAN & EL-TAABBAKH 2004; PEREIRA *et al.* 2006). Depending on the aphid abundance and the phenological stage of corn, production losses may be increased (AL-ERYAN & EL-TAABBAKH

2004).

Corn pest management strategies and actions vary, the effectiveness depends on the target insect, injured plant part and the plant's phenological stage (WAQUIL *et al.* 2003; CRUZ 2008). For the corn leaf aphid, chemical control is often the best recommendation, mainly depending on population density and the presence of natural enemies in the field (CRUZ 2008). However, this aphid hardly reaches high populations due to the presence of a complex of natural enemies such as coccinellids, earwigs, chrysopids and syrphids (CRUZ 2008; SWAMINATHAN *et al.* 2015). Species of coccinellids and syrphids are predators commonly associated with the presence of *R. maidis* in the corn crop (KUMAR & AHMAD 2017).

The relationship in the occurrence and spatio-temporal distribution between aphids and their predators can generate benefits for pest management. SHAYESTEHMEHR & KARIMZADEH (2019) verified in alfalfa the overlap in some periods of occurrence of aphids and ladybugs. Insect monitoring has been facilitated using geostatistical tools that show their spatio-temporal behavior (AMORIM *et al.* 2004). Analysis of spatial and temporal distribution check the presence of a species of insect in which you are interested and how its behavior is being in relation to the crop, facilitating Integrated Pest Management (IPM) (DIONISIO *et al.* 2016).

Therefore, this study aimed to verify the spatial and temporal behavior of the corn leaf aphid (*R. maidis*) and syrphid flies in corn crop in the municipality of Igarapé-Açu, northeast

of Pará and to verify the influence of areas adjacent to the occurrence of the corn leaf aphid.

MATERIAL AND METHODS

The study was developed during the years 2015 and 2016 at the Experimental Farm of Igarapé-Açu - FEIGA, located in the municipality of Igarapé-Açu - PA, Brazil, belonging to the Federal Rural University of the Amazon (UFRA), which is situated at 39 m altitude and with geographical coordinates of 01° 07 '33" South and 47° 37 '27" West.

The region climate, according to Köppen, is of the Ami type, with an annual rainfall of 2,500 mm and an average annual temperature of 25 °C. The region soil consists of a Dystrophic Yellow Argisol with a medium sandy texture.

The study was carried out in an experimental area of 1.0 ha (100 x 100 m), adjacent to mango agroecosystem areas (1.7 ha), an experimental pasture area with a predominance of *Panicum maximum* Jacq. (0.6 ha), secondary forest areas (Figure 1).



Figure 1. Experimental area with grid plots, highlighting the sampling points of the corn leaf aphid and adjacent areas: mango agroecosystem (MG), pasture (P) and forest fragment (C). Experimental farm, UFRA/FEIGA, Igarapé-Açu, Pará, Brazil. Source: Adapted from Google Earth (2019).

The area was divided into a grid with 100 plots of 100 m² (10 x 10 m) (Figure 1), in this area, conventional corn (Al Piratininga) was mechanically sown on March 30, 2015, and hybrid corn (Priorizi) on April 4, 2016, with spacing between lines of 0.90 m and between plants 0.15 m without chemical control intervention. In this same experimental area, cowpea [*Vigna unguiculata* (L.) Walp] was cultivated, and after harvesting, the area was in fallow state until 2015, where the site was screened and prepared for sowing corn.

Ten plants were selected at random, totaling 1,000 plants per sampling date. For the occurrence of colonies of corn leaf aphids, all aerial parts of the plant were visually analyzed. Colony was considered when more than 15 individuals were found in a given part of the plant, regardless of its distribution.

The occurrence of natural enemies was also assessed visually, but in this case only the number of adult individuals per plant was noted. Specimens were collected for identification, and forwarded to the UFRA/Capanema Biodiversity Laboratory and with the help of dichotomous keys it reached the possible taxonomic level.

The study period was from April 10, 12 days after sowing (DAS) to May 29 for the year 2015 and April 16 (12 DAS) on June 25 (maize maturation) for the year 2016, sampling took place weekly.

To verify the spatial behavior and influence of adjacent areas, the geostatistics tool was used, through semivariogram modeling. The graph of the experimental semivariogram, $\gamma(h)$ versus h , shows a series of discrete points of $\gamma(h)$ that correspond to each value of h , in which a continuous function must be adjusted.

Depending on the behavior of $\gamma(h)$ for high values of h , the models can be classified into models with sill and models without sill (VIEIRA *et al.* 1981). In models with sill, C_0 is the nugget effect, $C_0 + C_1$ is the sill, and 'a' is the range of the semivariogram. The tested models were: spherical model, exponential model, Gaussian model, and random model (Nugget effect).

Kriging interpolation maps were constructed, which showed the values of the frequency observed at the sampling points and the interpolation between the points. To obtain semivariograms and kriging maps, R software for Windows was used.

This study also evaluated the spatial dependence index (FDI) by calculating the index k , where k values <0.25 considered strong spatial dependence, $0.25 \leq k \leq 0.75$ is considered moderate spatial dependence and $k > 0.75$ indicated weak spatial dependence (CAMBARELLA *et al.* 1994).

RESULTS AND DISCUSSION

In 2015, there were 76 colonies of corn leaf aphids and 425 specimens of adult syrphids, however, in the 2016 harvest the number of colonies of corn leaf aphids and syrphids was greater than 2015 with 258 colonies and 1,046 adults of syrphids. This difference, between the 2015 and 2016 harvests, may be related to the subsequent planting, with two consecutive corn harvests, prior to 2015 the area was left fallow for three years. Subsequent cultivation in the same area with a productive system without diversification and cultivating the same plant type can contribute to the increase of specialized phytophagous insect communities (ALTIERI *et al.* 2003).

When analyzing the semivariograms of the spatial distribution, to the data set of the parameter R^2 , it was verified that the spherical and random models (nugget effect), were the best adjustments for the corn leaf aphid in the year 2015. The spherical model was best fit for two analysis dates (04/29/2015 and 05/29/2015), thus, as well as the random model was adjusted in two evaluations (04/24/2015 and 05/08/2015) (Table 1 and Figure 2).

In the evaluations of the 2015 harvest in which the corn leaf aphid adjusted to the spherical model, the spatial dependence was moderate (Table 1). FARIAS *et al.* (2008) report that when the spherical model is adjusted there is spatial dependence, the opposite is observed in the random model, when there is no spatial dependence on pests.

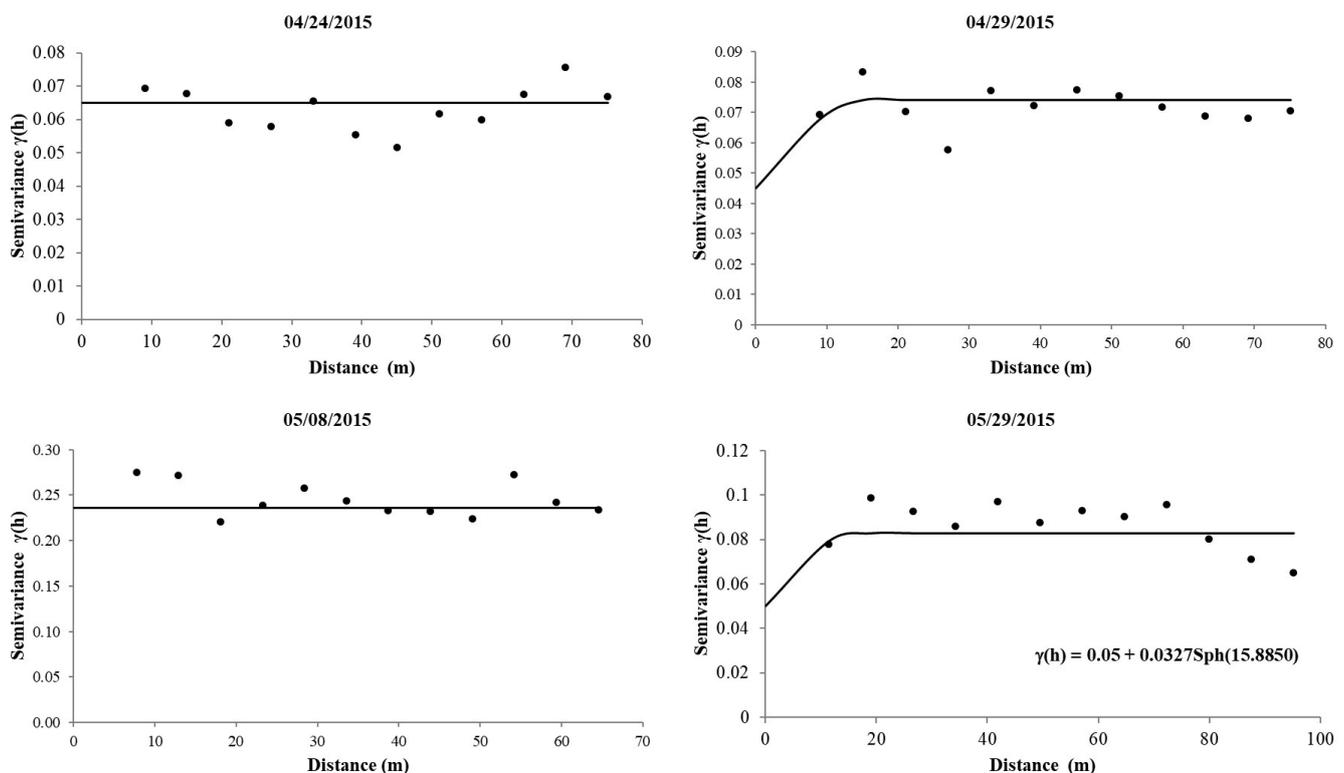
The range is represented by the radius of influences that are the points sampled before your neighborhood, that is, the range can be used to determine the appropriate distance between the samples (VALERIANO & PRADO 2001). The maximum range of *R. maidis* in 2015 was 15.89 m with an area of influence of 0.08 ha (792.83 m²) and the minimum was 15.25 m with an area of influence of 0.07 ha (730.07 m²) (Table 1).

The Gaussian, spherical and exponential models best fit the corn crop in the 2016 harvest, to the data set using the

Table 1. Semivariogram parameters, range (a), coefficient of determination (R²) spatial dependence index (K), the experimental model and influence area (ha) of *Rhopalosiphum maidis* in corn in the Experimental Farm of Igarapé-Açu-PA, Brazil.

Year/Date	Semivariogram parameters			Models	R ²	Area (ha)	K	
	C ⁰	C ¹	a(m)					
2015	4/24/2015	0.07	0.00	0.00	Random	-	-	-
	4/29/2015	0.05	0.03	15.25	Spherical	0.97	0.07	Moderate
	5/8/2015	0.24	0.00	0.00	Random	-	-	-
	5/29/2015	0.05	0.03	15.89	Spherical	0.98	0.08	Moderate
2016	5/28/2016	0.10	0.03	19.21	Gaussian	0.97	0.12	Weak
	6/4/2016	0.10	0.06	12.46	Gaussian	0.97	0.05	Moderate
	6/11/2016	0.08	0.03	31.72	Spherical	0.92	0.32	Moderate
	6/18/2016	0.18	0.05	93.04	Gaussian	1.00	2.72	Weak
	6/25/2016	0.05	0.20	31.91	Exponential	0.98	0.32	Strong

Area calculated by πr^2 , where $\pi = 3.14$ and $r = a$, (1 ha = 10.000 m²); K = C⁰/C⁰+C¹

**Figure 2.** Adjusted models of Semivariograms for *Rhopalosiphum maidis* in corn crop (2015). Experimental farm in Igarapé-Açu-PA, Brazil.

parameter R². In three evaluations, the Gaussian model best fit, whereas the spherical model fit in one assessment, as well as the exponential model that also fit one assessment (Table 1 and Figure 3). The index of weak and moderate spatial dependence was those that prevailed, with only one evaluation showing a strong index.

The maximum range detected for *R. maidis* in the 2016 harvest was 93.04 m with an area of influence of 2.72 ha (27,181.23 m²) and the minimum of 12.46 with an area of influence of 0.05 ha (487.33 m²) (Table 1).

The aggregate spatial distribution for corn leaf aphid in periods of higher occurrence and random in periods of low occurrence seems to be the trend for this insect. The spherical, Gaussian and exponential models are found for corn aphids and the reach of this insect does not reach great distances (PARK & OBRZYCKI 2004).

The range of insect pests is influenced by their way of life and behavior. PINHO *et al.* (2016), when studying the spatial distribution of *Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae), they found a maximum range of 710 m with an area of influence of 158.4 ha (1,584,675.5 m²). This low range found for the corn leaf aphid is explained by the fact that it is not an insect that has a good precision in its flight.

For the Syrphidae fly, the spherical and random models (nugget effect), fit better for 2015, to the data set using the parameter R². The spherical model fit in 3 evaluations and the random model with only one analysis date (Table 2 and Figure 4). The spatial dependency index that prevailed was weak (Table 2).

The maximum range obtained in 2015 was 81.66 m with an area of influence 2.09 ha (20,938.64 m²) with a minimum of 14.00 m with an area of influence 0.06 ha (615.69 m²). The wider range of natural enemies can benefit and increase

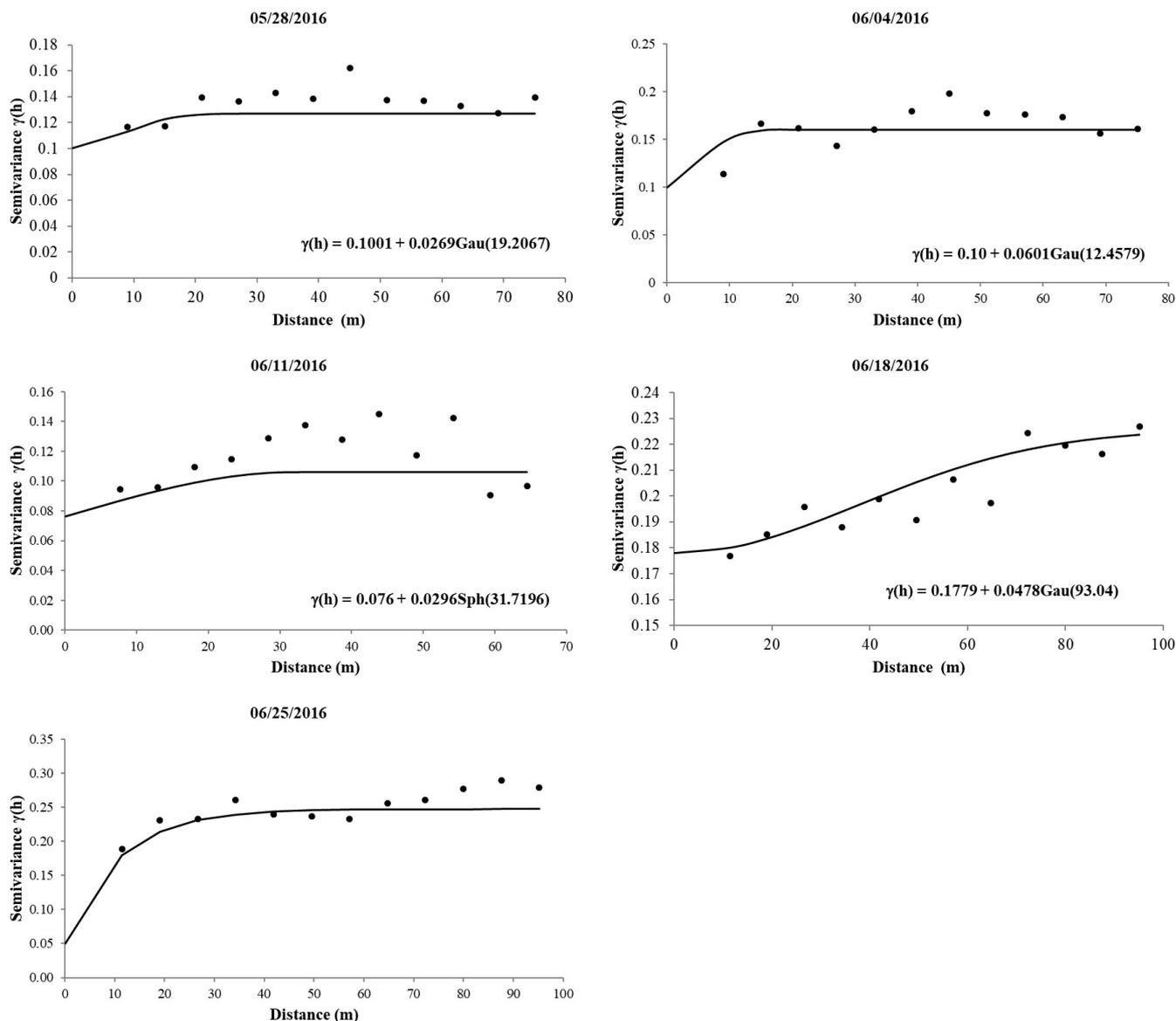


Figure 3. Adjusted models of Semivariograms for *Rhopalosiphum maidis* in corn crop (2016). Experimental farm in Igarapé-Açu-PA, Brazil.

Table 1. Semivariogram parameters, range (a), coefficient of determination (R²) spatial dependence index (K), the experimental model and influence area (ha) of Syrphidae in corn in the Experimental Farm of Igarapé-Açu-PA, Brazil.

Year/Date	Semivariogram parameters			Models	R ²	Area (ha)	K	
	C ⁰	C ¹	a(m)					
2015	5/8/2015	0.16	0.01	36.93	Spherical	0.99	0.43	Weak
	5/15/2015	0.12	0.01	81.66	Spherical	0.99	2.09	Weak
	5/22/2015	0.25	0.00	0.00	Random	-	-	-
	5/29/2015	0.20	0.03	14.00	Spherical	0.99	0.06	Weak
2016	5/6/2016	0.10	0.10	20.51	Spherical	0.99	0.13	Moderate
	5/14/2016	0.17	0.04	47.63	Spherical	0.99	0.71	Weak
	5/21/2016	0.19	0.00	0.00	Random	-	-	-
	5/28/2016	0.05	0.11	101.36	Exponential	0.96	3.23	Moderate
	6/4/2016	0.21	0.04	28.17	Spherical	1.00	0.25	Weak
	6/11/2016	0.11	0.01	32.93	Spherical	0.99	0.34	Weak

Area calculated by πr^2 , where $\pi = 3.14$ and $r = a$, (1 ha = 10.000²); $K = C0/C0+C1$

their range of action. PARK & OBRZYCKI (2004) found that ladybugs have greater range when compared to their prey, aphids, in the corn crop.

The spherical, exponential and nugget effect models were the best fit in 2016. The spherical model fit into four evaluations, the exponential model fit into one evaluation, as well as the

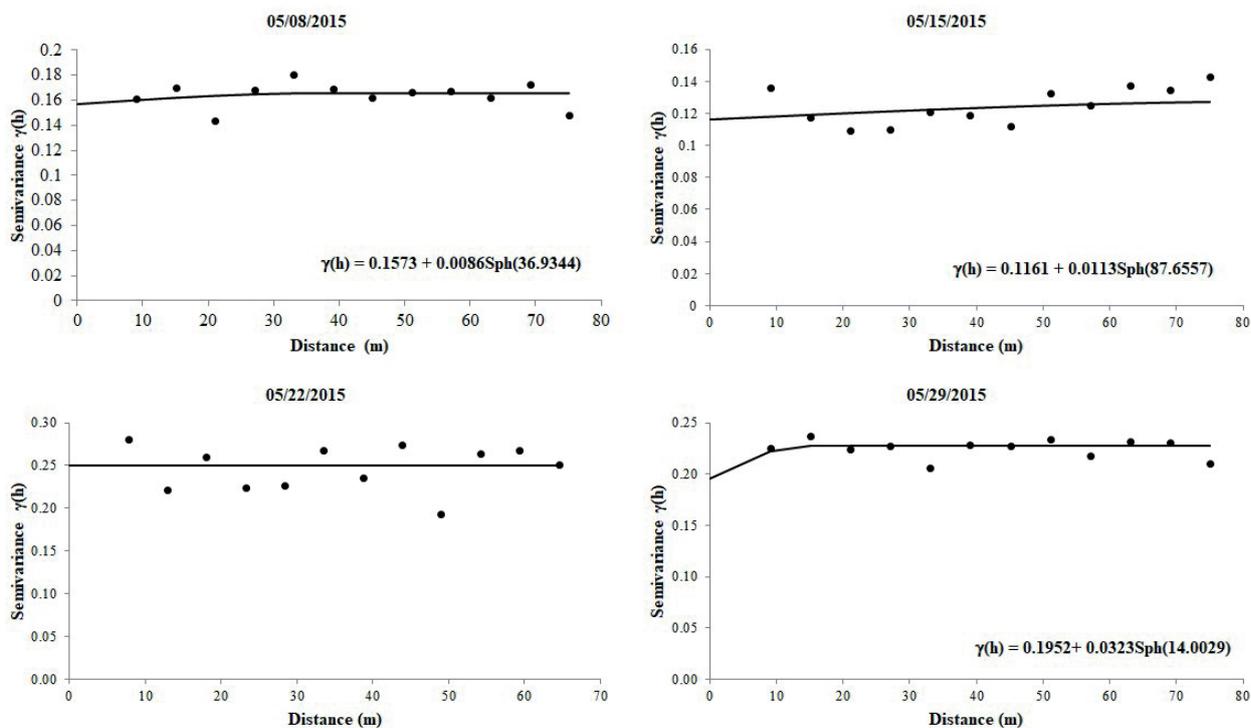


Figure 4. Adjusted models of Semivariograms for *Rhopalosiphum maidis* in corn crop (2016). Experimental farm in Igarapé-Açu-PA, Brazil.

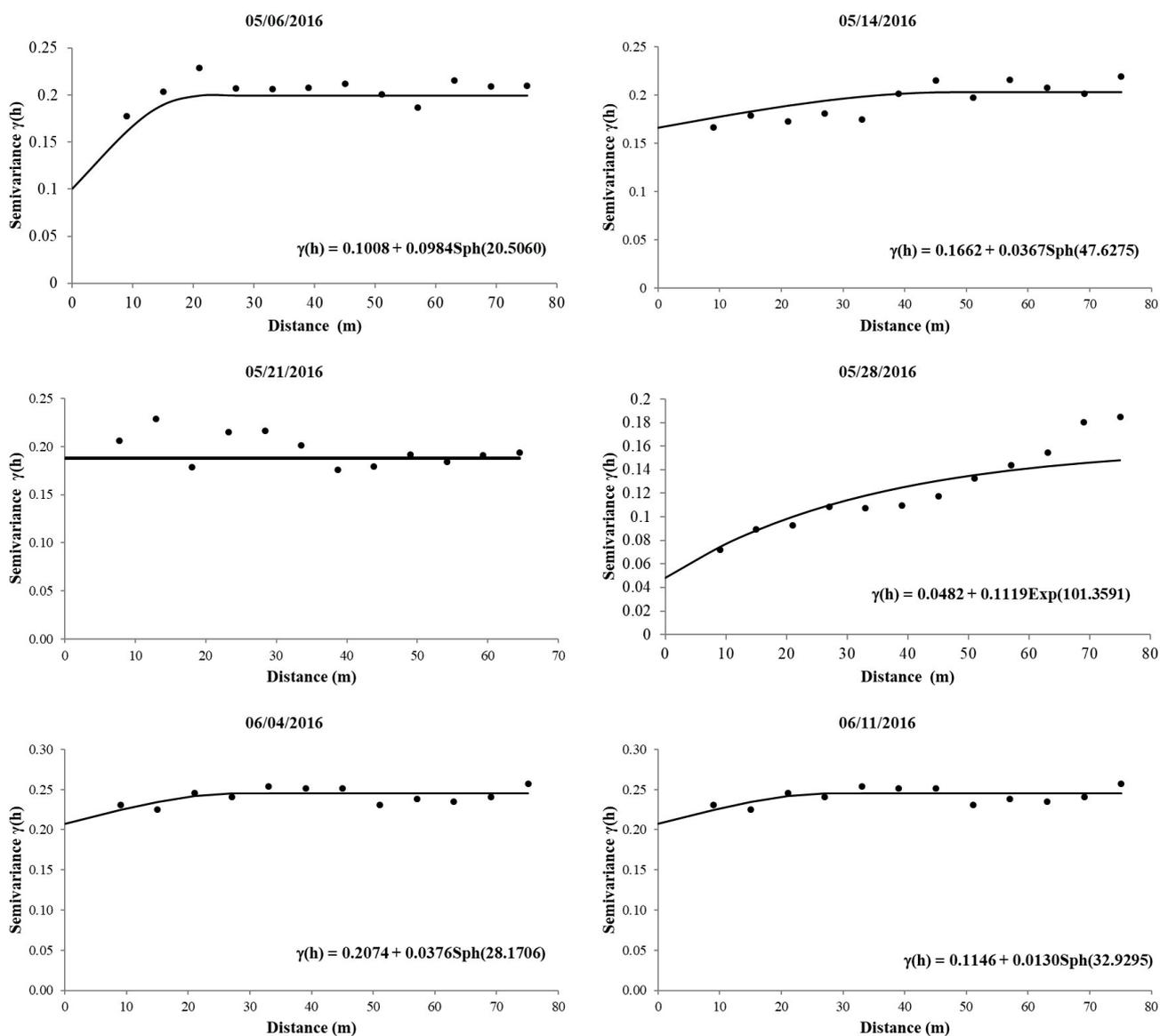


Figure 5. Adjusted models of Semivariograms for Syrphidae in corn crop (2016). Experimental farm in Igarapé-Açu-PA, Brazil.

nugget effect adjusted into one evaluation (Figure 5). The moderate and weak spatial dependence index were those that prevailed (Table 2).

The maximum range detected in these samples of the Syrphidae fly was 101.33 m with an area of influence 3.23 ha (32,259.89 m²) with a minimum of 20.51 m with an area of influence 0.13 ha (1,320.36 m²) (Table 2). According to MORALES & KOHLER (2006), this greater reach occurs due to the fact that the Syrphidae fly has a good flight capacity, unlike the corn aphid, syrphids control their flight perfectly.

In 2015, the kriging maps for *R. maidis*, showed infestation with initial aggregations close to the pasture area and in the center of the corn crop, over the days a considerable aggregation was obtained at the limits of the adjacent area of mango agroecosystem (Figure 6).

Analyzing the 2016 aphid maps, there was an aggregate behavior for *R. maidis*, and this aggregation started at the edge adjacent to the pasture area. As the crop progressed, it was infested from the edge with proximity of pasture to the center. It was also observed that during the samples there was low aphid infestation near the area of mango agroecosystem, suggesting, therefore, that this environment functioned as an ecological barrier (Figure 7). The edges and adjacent plants of agricultural areas can interfere with the distribution of insect communities. These environments function as natural or artificial barriers affecting insect mobility and dispersion (NGUYEN & NANSEN 2018; PENN 2018). Trees on the edge of agricultural areas act as windbreaks, preventing insects that need wind to disperse to colonize these agricultural areas (NGUYEN & NANSEN 2018).

Adjacent, non-agricultural areas, close to cultivated areas, can

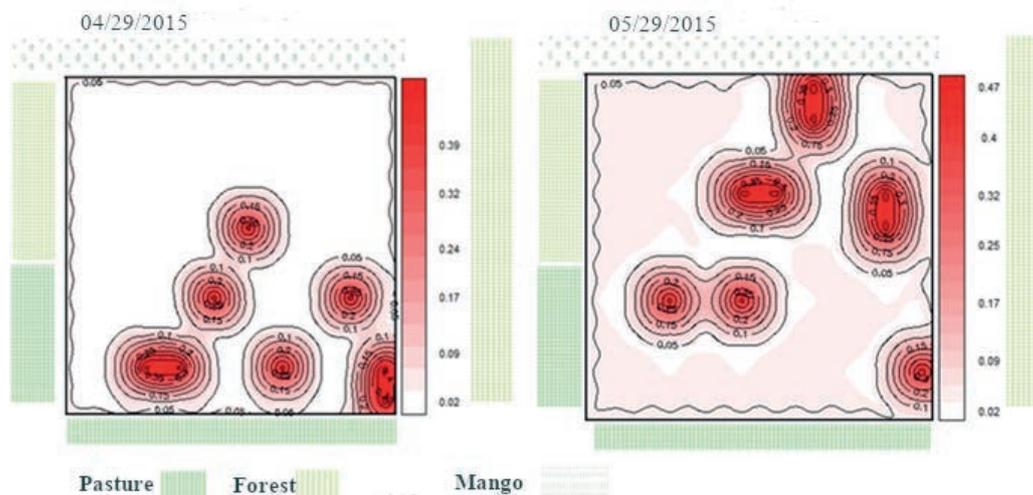


Figure 6. Maps of spatial distribution (kriging) of *Rhopalosiphum maidis* in corn crop (2015). Experimental farm in Igarapé-Açu-PA, Brazil.

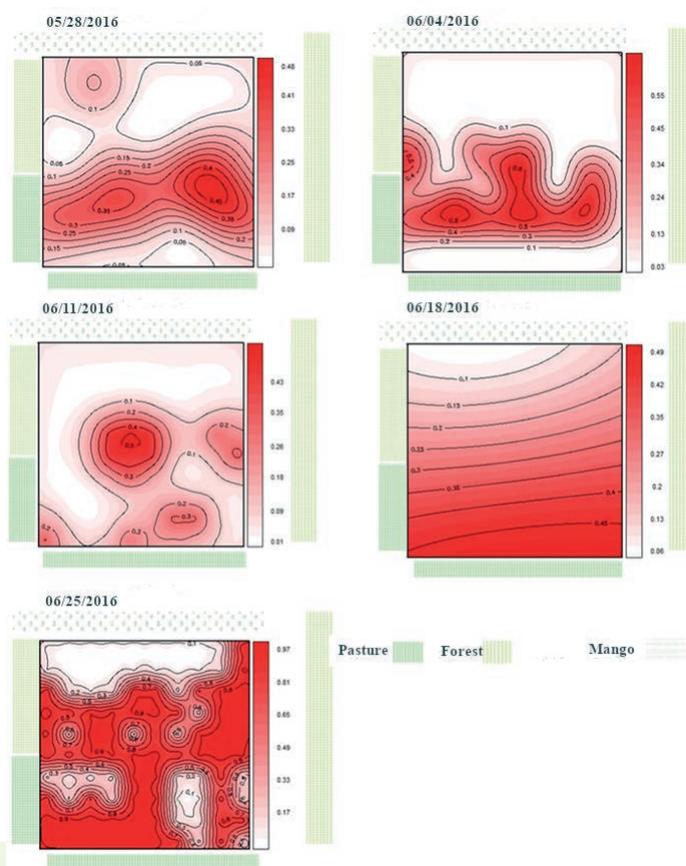


Figure 7. Maps of spatial distribution (kriging) of *Rhopalosiphum maidis* in corn crop (2016). Experimental farm in Igarapé-Açu-PA, Brazil.

benefit the occurrence of aphid populations and consequently their dispersion. When implementing agricultural areas, the landscape must be taken into account and analyzed (YANG *et al.* 2019). However, the presence of natural enemies in natural or semi-natural areas adjacent to agricultural land can decrease the presence of aphids, especially on the edge of the crop that is close to these areas (ALIGNIER *et al.* 2014).

According to the 2015 Syrphidae fly maps, the dispersion started close to the adjacent area of mango agroecosystem. During the corn crop, the syrphids dispersed towards the pasture, expanding over almost the entire corn crop area (Figure 8).

In 2016, Syrphidae flies aggregated and dispersed near the adjacent pasture area, also with aggregation in the center of the corn crop. During the harvest, their dispersion was from the center towards the edge of the pasture, occupying this whole area of corn. On the last analyzed date, it was observed that the corn area close to the mango agroecosystem area was completely dominated by the fly, which may be the reason for the low colonization of the corn aphid (Figure 8).

A positive spatial interaction was observed between the occurrence of Syrphidae flies and the corn leaf aphid, as AUAD *et al.* (1997) confirm in their study that syrphids are more attractive to aphids, these are part of their diet in the larval

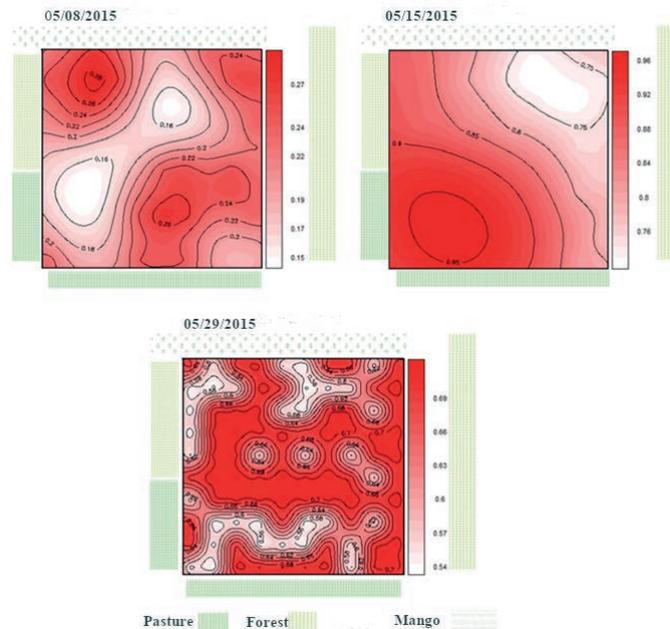


Figure 8. Maps of spatial distribution (kriging) of Syrphidae in corn crop (2015). Experimental farm in Igarapé-Açu-PA, Brazil.

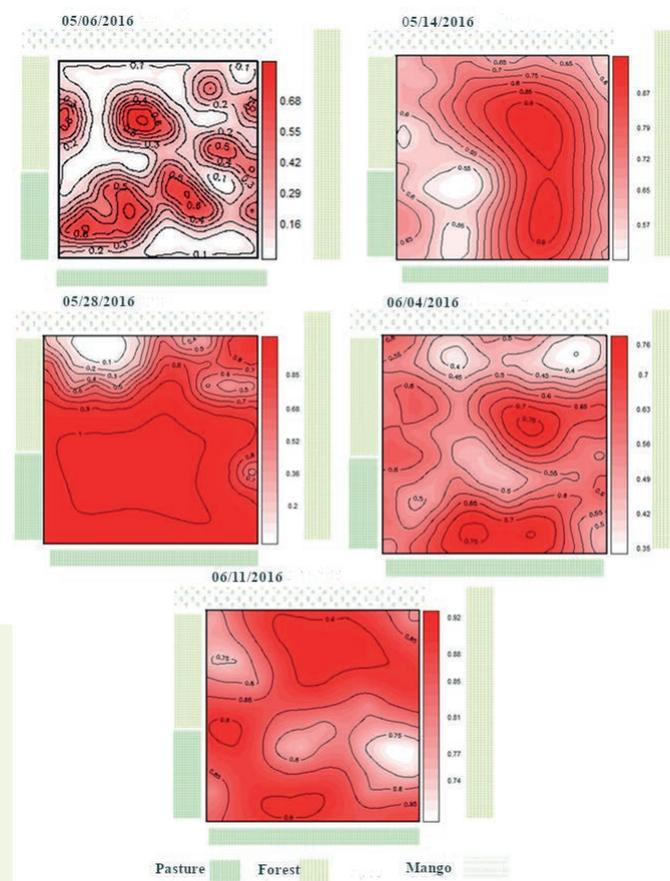


Figure 9. Maps of spatial distribution (kriging) of Syrphidae in corn crop (2016). Experimental farm in Igarapé-Açu-PA, Brazil.



phase. These syrphids, when adults, have a remarkable ability to fly, and preferably oviposit close to aphid colonies.

In addition to the positive spatial interaction between syrphids and corn leaf aphids, the spatial analysis showed a positive interaction of adjacent natural and semi-natural areas on the aggregation and dispersion of aphids and syrphids. YANG et al. (2019) described that natural and semi-natural areas benefit the occurrence and dispersion of syrphids over aphid populations and consequently increase biological control.

It is concluded that the corn leaf aphid, *R. maidis*, and its natural enemy, Syrphidae flies show, in periods of greater occurrence, an aggregated distribution, observed by the models of semivariograms.

The spatial dependence that prevails for the corn leaf aphid is moderate with a range of up to 93 m, on the other hand, the syrphids have a weak spatial dependence, with a range of up to 101 m.

The aggregations of *R. maidis* occur initially close to the adjacent pasture areas, dispersing towards the center of the corn crop.

The spatial distribution of the Syrphidae fly has a positive interaction with the spatial behavior of the corn leaf aphid. Syrphids can benefit from the presence of natural or semi-natural areas close to the corn agricultural area.

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