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Spatial and temporal distribution of *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) and *Euxesta* spp. (Diptera: Otitidae) in the corn crop

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Abstract: The aim of this study was to verify the pattern and the spatial and temporal behavior of the corn earworm and corn-silk fly in the corn crop. Hybrid corn was planted without chemical insect control in one hectare, this area was divided into 100 plots of 100 m^2. For the occurrence of *Euxesta* spp. all parts of the plants were visually analyzed, whereas for *Helicoverpa zea* (Boddie) 10 ears were removed at random from each plot, totaling 1,000 ears per sample. Population fluctuation was related to the phenological stages of corn. For spatial behavior, the dispersion indices, frequency distribution models and geostatistics (Krigagem) were analyzed. The corn earworm (small and large) and corn-silk fly showed aggregate pattern and spatial behavior. The reach of caterpillars < 1 cm had an area of influence greater than caterpillars > 1 cm, with spatial dependence being considered moderate. The corn-silk fly had a maximum area of influence of 1.33 ha with moderate and weak spatial dependence. The maps demonstrated that these insects occur dispersed throughout the corn area, but with aggregations influenced by the adjacent areas and edges of the crop. The largest occurrence of corn earworms was at the R3 stage. It was also found that the corn-silk fly followed the occurrence of the corn earworm. It is concluded that the studied pests have an aggregate spatial tendency in the corn crop and with the influence of adjacent areas, in addition to presenting related population peaks in the reproductive period of the corn crop.

Keywords: Aggregate; Corn-silk fly; Corn earworm; Geostatistics, Population fluctuation.

The corn (*Zea mays* L.) is important in world agricultural production, due to its widespread use, such as for human and animal food, even the production of biofuels. Brazil has an area of approximately 17 million hectares with production of more than 92 million tons and occupies the third place in world production (CONAB 2019). Therefore, the use of extensive areas allows pests to appear on crops, which causes losses to the producer (Venâncio & Costa 2012).

There are several insects that affect the corn crop, the corn earworm [*Helicoverpa zea* (Boddie)] and the corn-silk fly of the genus *Euxesta* (Diptera: Otitidae) can cause injuries to the ear and become potential pests. Both pests oviposit in stigma-styles, interfering with pollination and grain formation, due to their mode of feeding (Cruz *et al.* 2011a).

The attack of *H. zea* starts in the stigmas, which compromises fertilization, the caterpillar penetrates the ear epically to consume the milky grains, leaving holes that facilitate the entry of microorganisms that cause diseases to the plant (Goyal *et al.* 2012; Valicente 2015).

The appearance of stigmas-style and the filling of grains leads to an increase in the population of *Euxesta*, indicating that the insect has the potential for a key pest in areas of commercial corn production (Cruz *et al.* 2011a). This fly has an intense movement of opening and closing its wings when walking. In the larval phase, it can cause injuries and damage to the ears, causing losses in productivity. At this stage, the larvae feed on the grains during their development, which can cause direct and indirect damage by facilitating the entry and colonization of microorganisms (Lima *et al.* 2016).

It is necessary to know what factors can influence the management of insect pests, so it is important to know the spatial and temporal behavior and carry out sampling correctly. Geostatistical analyzes have shown adequate responses to the spatial behavior of insect pests, in addition to providing an understanding of insect interpolation and dispersion, facilitating the application of management practices (Dal Prá *et al.* 2011; Dionisio *et al.* 2016).

Insects have variations in space and time, and analyzing this population dynamics, together with the influence of biotic and abiotic factors in agricultural ecosystems, makes it possible to infer the greatest occurrence preference, as well as to determine the main factors involved in this occurrence (Ennis & Philpott 2019).

Therefore, this study aimed to verify the pattern and the spatial and temporal behavior of the corn earworm (*H. zea*) and corn-silk flies (*Euxesta* spp.) in the corn crop in Igarapé-Açu, Northeast Pará, Eastern Amazon.

MATERIAL AND METHODS

The study was conducted at the Experimental Farm of Igarapé-Açu - FEIGA (01º07'33" South and 47º37'27" West, 39 m), municipality of Igarapé-Açu - PA, belonging to the Universidade Federal Rural da Amazônia - UFRA. The region has soil with a predominance of dystrophic Yellow Argisol with sandy texture (Guerino *et al.* 2017). The climate is defined as Ami, with an average annual rainfall of 2,500 mm and an average annual temperature of 25 °C, according to the Köppen classification.

The area used for the implantation of the study was of 10,000 m^2 (1.0 ha) divided into 100 plots of 100 m^2 (10 m x 10 m), with adjacent areas composed by an experimental area of grassland, *Megathyrsus maximus* (Jacq.) BK Simon & SWL Jacobs (0.6 ha); mango agroecosystem, *Mangifera indica* L. (1.7 ha); and fragments of secondary forest. The hybrid corn Priorizi M274 Morumbi was used, with an early cycle that presents rusticity and tolerance to the main corn diseases; with the aid of a seeder-fertilizer, it was sown without chemical control for insects, with a spacing of 0.90 m between rows and 0.15 m between plants. Sampling was carried out weekly, randomly selecting 10 plants per plot, for a total of 1,000 plants/sampling.

To evaluate *Euxesta* spp. the presence of adults in all parts of the plants was visualized, the number of individuals per plot was noted, from April 16 to June 25, 2016, starting the visualization seven days after the emergency (DAE).

To check for the presence of the *H. zea* caterpillar, sampling started at the reproductive stage of corn R2 (56 DAE), 10 ears of corn were randomly removed per plot with a total of 1,000 ears/samples, afterwards the material was sent to the Biodiversity Laboratory the UFRA Capanema *campus*.

In the laboratory, the husks of the ears were removed, the occurrence was visually analyzed in all parts of the ear, mainly in the ear tip and in the corn silks, and the number of caterpillars per plot was noted. To verify the spatial behavior of the different stages of development of the caterpillars, these were separated into small (< 1 cm) and large (> 1 cm) caterpillars, there were four evaluations during the reproductive period that corresponded to the period from 04 to 25 June 2016.

To determine the temporal distribution, the total values of the individuals sampled over time were plotted, and related to the phenological stages of corn to determine which stage with the highest occurrence of insects. For the phenological stages of corn, it was considered the predominant stage in most plants on the sampling day. Phenological stages were considered according to the name and description of the study by Weismann (2008).

The spatial distribution pattern was analyzed by dispersion indices, and adjustment to the probabilistic models of frequency distribution. For this, the mean ($\hat{m}$) and variance (s^2) were analyzed, and later the dispersion indices were calculated: variance/mean (I), Morisite index (Iδ), Green coefficient (Cx) and K exponent of negative binomial distribution (k). The randomness deviation was tested by the chi-square test for variance / mean and Morisite index. The data were also tested for Poisson distribution and negative binomial distribution.

To verify the spatial behavior and influence of adjacent areas, geostatistical analysis was used with the application of kriging maps. The data were analyzed using semivariogram modeling. In models with landing, C0 is the nugget effect, C0 + C1 is the landing, and 'a' is the range of the semivariogram. The tested models were: spherical model, exponential model, Gaussian model and random model (nugget effect).

Subsequently, Kriging interpolation maps were constructed, showing the observed frequency values and the interpolation between the values. The R software for Windows was used to obtain semivariograms and kriging maps. The semivariogram function is used in geostatistics to express spatial variability in a predefined direction (Sturaro 2015). To adjust the semivariogram models, the maximum likelihood method was used. The Akaike criterion (AIC) was used to select the most appropriate model, that is, the model with the lowest AIC was selected.

In this study, the Spatial Dependency Index (SDI) was also evaluated through the result calculated by the k index ($k=C_0/C_0+C_1$) in which k values < 0.25 are considered strong dependencies, $0.25 \leq k \geq 0.75$ is considered moderate dependence and, of k > 0.75, there is weak spatial dependence (Bastos *et al.* 2019).

RESULTS AND DISCUSSION

For *Euxesta* spp. a total of 165 individuals were observed throughout the sampling period. There was a low occurrence of adults of corn-silk flies until the beginning of the tassel stage (VT 49 DAE), from the reproductive period (R2) with 56 DAE, an increase in those of adults of corn-silk fly was observed. The highest occurrence was verified on the last day of sampling with 48 dipterans already in the R5 stage (Table 1). Cruz *et al.* (2011b) reported that adults from *Euxesta* have been found in the corn crop since the early stages, with a significant increase during the reproductive stages R1 and R2. The attraction of adults from *Euxesta* to ears attacked by other pests can be related to the attractiveness of this fly by volatile semiochemicals (Owens *et al.* 2017).

For this study, 4,000 ears of corn were analyzed, a total of 2,755 individuals of *H. zea* was observed, corresponding to 68.88% of the ears sampled with infestation (Table 1). In the reproductive period (R2) there was a predominance of small caterpillars < 1 cm (672 caterpillars), but in this period also caterpillars > 1 cm were observed, demonstrating that since the appearance of the style-stigmas oviposition should occur.

According to the development of corn, there was a greater observation of caterpillars > 1 cm at the stage of R3 (Table 1). The highest incidence of caterpillars occurred exactly in the kernel milky stage R3 with 847 ears infested out of a total of one thousand, corresponding to 84.70% of ears. These infestations decreased in the following samples, being 53.50% in R4 and 61.60% in R5. There are several factors that can decrease the occurrence of *H. zea*, among them climatic factors and natural enemies (Olmstead *et al.* 2016).

The behavior of H. zea was analyzed separately for small caterpillars (< 1 cm) and large caterpillars (> 1 cm) allowing results for better management strategies. Caterpillars < 1 cm when submitted to the variance/mean ratio (I) and the Morisite index (Iδ) showed an aggregate behavior. Having the Chi-square (χ^2=I; Iδ) significant at 5%, proving the departure from randomness and confirming the aggregation of the sampled individuals.

Green Coefficient (Cx) values indicated contagious distribution. The values of K (K mom) confirmed aggregation of corn earworms, verified on the dates 04 and 06/25/2016 positive values and less than two, suggesting a highly aggregated behavior, already for the dates 11 and 06/18/2016 this parameter indicates moderate aggregation.

For *H. zea* > 1 cm, the distribution pattern verified by the

Table 1. Occurrence of Helicoverpa zea caterpillars and adults of the corn-silk fly sampled in the corn crop during 2016, in Igarapé-Açu, Pará, Brazil.

Dates	DAE	Corn stages	*H. zea* < 1cm	*H. zea* > 1cm	Total *Helicoverpa*	Infestation %	Adults *Euxesta* spp.
04/16/2016	7	V1	0	0	0	0	6
04/23/2016	14	V3	0	0	0	0	1
04/30/2016	21	V6	0	0	0	0	5
05/06/2016	27	V7	0	0	0	0	0
05/14/2016	35	V8	0	0	0	0	6
05/21/2016	42	V9	0	0	0	0	3
05/28/2016	49	VT	0	0	0	0	9
06/04/2016	56	R2	672	85	757	75.70	34
06/11/2016	63	R3	423	424	847	84.70	30
06/18/2016	70	R4	153	382	535	53.50	23
06/25/2016	77	R5	162	454	616	61.60	48
Total			**1.410**	**1.345**	**2.755**	**68.88**	**165**

DAE: dates after emergency. % infestation = (total *Helicoverpa**100)/total ears analyzed.

variance/mean ratio (I) was of the aggregate type, showing results greater than the unit. The Morisite Index (Iδ) showed higher values than the unit indicating population aggregation or contagious type distribution. The Chi-square test for randomization (χ^2 = I; Iδ), shows the aggregation of individuals, so that all dates showed a 5% significance, excluding randomness. The Green Coefficient (Cx), in turn, indicates a contagious type distribution and the K (K mom) parameter confirmed aggregation, this parameter infers highly contagious aggregation for the dates of June 4, 11 and 25, 2016, and moderate aggregation on 06/18/2016 (Table 2).

The spatial behavior of the aggregate type of caterpillars in agricultural corn crops tends to prevail, this aggregation behavior was observed in Southern Ethiopia with dispersion indexes for *Busseola fusca* Fuller (Lepidoptera: Noctuidae) (Taddele *et al.* 2020), and in *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) smaller than 1 cm (Rios *et al.* 2014), caterpillars between 1 and 1.5 cm (Melo *et al.* 2014) and larger than 1.5 cm (Rios *et al.* 2014).This aggregate behavior of corn earworm may be related to the appearance of stigmas-styles, Foresti *et al.* (2013) found that the number of eggs of *H. zea* is high and follows the period of emission of ears and style-stigmas in the corn crop. So, according to the appearance of stigmas-styles in the plots, they tend to favor the aggregation and infestation of *H. zea*.

For the analysis of spatial distribution of *Euxesta* spp., the first sampling dates were discarded, due to the low occurrence. Therefore, the dispersion indices were analyzed from the VT stage on 05/28/2016. Cruz *et al.* (2011b) observed that the corn-silk fly occurred since the beginning of the corn crop. In this study, the occurrence of *Euxesta* has also occurred since the initial stages and these flies may have migrated from adjacent areas such as natural areas, pastures and cultivated with mango trees.

The spatial distribution of *Euxesta* spp. analyzed by the variance/average ratio (I) shows aggregate behavior, with all variances being higher than the means. The Morisita

Table 2. Means, variances and dispersion indices for the occurrence of corn earworm (*Helicoverpa zea*) in Igarapé-Açu, Pará, Brazil.

***Helicoverpa zea* < 1 cm** **Indexes**	**06/04/2016**	**06/11/2016**	**06/18/2016**	**06/25/2016**
M	6.72	4.23	1.53	1.62
s^2	605.07	127.85	22.52	67.03
I= s^2/m	9.00	30.22	14.72	41.37
Iδ	21.81	14.75	13.07	29.29
X^2=I; Iδ	891.39*	299.22*	145.69*	409.61*
K mom	0.84	20.92	3.24	0.52
Cx	0.01	0.00	0.00	0.02
***Helicoverpa zea* > 1 cm** **Indexes**	**06/04/2016**	**06/11/2016**	**06/18/2016**	**06/25/2016**
M	0.85	4.24	3.82	4.54
s^2	17.65	310.33	60.89	233.82
I= s^2/m	20.77	7.32	15.94	51.50
Iδ	22.69	24.79	11.54	1.91
X^2=I; Iδ	205.58*	724.59*	157.79*	509.88*
k mom	0.79	0.67	64.33	10.94
Cx	0.01	0.01	0.00	0.01

m = sample mean; s^2 = variance; I = variance/mean ratio; Iδ = Morisite index; X^2 I = chi-square test to deviate randomness from the variance / mean ratio; X^2 Iδ = chi-square test for deviating from the randomness of the Morisita index; k mom = k calculated by the method of moments; Cx = Green's coefficient; * = Significant at 5% probability; NS = Not significant at 5% probability.

Index (Iδ) presented values higher than the unit, indicating contagious behavior, as demonstrated by the Chi-square test (χ^2 = I; Iδ), where the results were significant at 5%. The Green Coefficient (Cx) varied between positive values and less than 1, considered an aggregate distribution. The parameter of k (k mom) showed positive values and < 2, a tendency to high aggregation (Table 3). The aggregate occurrence of ear flies was related to the appearance of stigmatic styles in the plots and also to the occurrence of corn earworm.

In Table 4, it was observed that the sampling data of small and large caterpillars adjusted on two dates to the negative binomial model, not adjusting to the Poisson model, confirming the tendency of aggregation of caterpillars. Similar behavior was observed in a study with adults of *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and *Aphis gossypii* Glover (Hemiptera: Aphididae) in cotton crop, which did not fit the negative binomial model at all times (Rodrigues *et al.* 2010).

When the adjustments to the Poisson and negative bionomial models were tested for the distribution of *Euxesta* spp., it was found that both models showed adjustments, with three dates each model (Table 5). These adjustment results for both models tested, are probably due to the low number of flies occurring, leaving the analyzes with low degree of freedom values.

Using R^2 as a parameter in geostatistical analyzes, he verified the spatial distribution of the aggregated type, adjusting to the spherical model on three dates for *H. zea* < 1 cm. The spatial dependency index (k) was of the moderate type. On the second sampling date, a pure nugget effect was observed, showing a tendency towards the random distribution of *H. zea* in this sample (Table 6). The maximum distance between the samples or the maximum range found in the samples ranged from 23.39 to 71.37 meters with an area of influence from 0.17 ha to 1.6 ha (Table 6). The analyzed data allowed to estimate the influence of the aggregation points of the corn earworms and their infestation in the experimental area of the corn crop.

The spherical model, presents itself as more adequate to exemplify the spatial behavior of insects. Machado *et al.* (2015) found in the spherical model with moderate spatial dependence for *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), and *Chrysodexis includens* (Walker) (Lepidoptera: Noctuidae), in soybean crop. A similar result was observed in the spatial distribution of the coffee borer *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) in coffee conilon, with data adjusted to the spherical model and moderate spatial dependence (Silva *et al.* 2017).

The data from the *H. zea* caterpillar > 1 cm, shows adjustment to three models, with the Gaussian model standing out with adjustment in two of the four evaluations. The moderate spatial dependency index prevailed on all dates analyzed (Table 6). Similar spatial distribution was found by Santi *et al.* (2014), when they evaluated the spatiotemporal distribution of *Anticarsia gemmatalis* Hübner (Lepidoptera: Noctuidae) and *C. includens* in soybean crop, where they occurred aggregates in the area, with moderate spatial dependence.

The maximum range for *H. zea* was obtained on 11/06/2016 with 43.33 meters and 0.59 ha of area of influence, whereas the minimum range was found on the first sampled date with

Table 3. Means, variances and dispersion indices for the occurrence of corn-silk fly (*Euxesta* spp.) in Igarapé-Açu, Pará, Brazil.

	***Euxesta* spp.**				
Indexes	**05/28/2016**	**06/04/2016**	**06/11/2016**	**06/18/2016**	**06/25/2016**
M	0.09	0.34	0.30	0.23	0.48
s^2	0.14	0.51	0.45	0.26	0.66
I= s^2/m	15.93	14.99	15.15	11.29	1.37
Iδ	83.33	24.96	27.59	1.58	1.77
X^2=I; Iδ	157.67*	148.35*	150.00*	111.78*	135.33*
K mom	0.15	0.68	0.58	17.81	13.08
Cx	0.07	0.02	0.02	0.01	0.01

m = sample mean; s^2 = variance; I = variance/mean ratio; Iδ = Morisite index; X^2 I = chi-square test to deviate randomness from the variance / mean ratio; X^2 Iδ = chi-square test for deviating from the randomness of the Morisita index; k mom = k calculated by the method of moments; Cx = Green's coefficient; * = Significant at 5% probability; NS = Not significant at 5% probability.

Table 4. Results of the chi-square test to adjust the Poisson distributions, and Binomial negative to data from *Helicoverpa zea* <1cm and *Helicoverpa zea* > 1cm.

Dates	**Poisson**			**Binomial Negative**		
	X^2	**df**	**P**	**X^2**	**df**	**P**
***Helicoverpa zea* < 1 cm**						
06/04/2016	1132,0155**	12	0,0000	42,7848**	16	0,0003
06/11/2016	77,0874**	8	0,0000	13,0656^{NS}	10	0,2200
06/18/2016	15,0287**	4	0,0046	6,5730^{NS}	4	0,1603
06/25/2016	28,7190**	4	0,0000	18,5443**	6	0,0050
***Helicoverpa zea* > 1 cm**						
06/04/2016	17,8600**	2	0,0001	4,6645^{NS}	3	0,1981
06/11/2016	157,9057**	8	0,0000	36,9526**	12	0,0002
06/18/2016	23,0417**	8	0,0033	157,7906^{NS}	8	0,3577
06/25/2016	66,1437**	9	0,0000	42,5626**	12	0,0000

X^2 = Chi-square test statistics; df = number of degrees of freedom of the chi-square; p = level of probability of the chi-square test; * Significant at 5% probability; ** Significant at 1% probability; NS Not significant at 5% probability; IDF = insufficient number of degrees of freedom.

Table 5. Results of the chi-square test to adjust the Poisson distributions, and Binomial negative to data from *Euxesta* spp.

Dates	Poisson			Binomial negative		
	X^2	Df	P	X^2	df	P
05/28/2016	IDF	IDF	IDF	IDF	IDF	IDF
06/04/2016	2,4998^{NS}	1	0,1139	0,5640^{NS}	1	0.4526
06/11/2016	2,8053^{NS}	1	0,0940	1,2171^{NS}	1	0.2699
06/18/2016	1,9303^{NS}	1	0,1647	IDF	IDF	IDF
06/25/2016	13,2179**	2	0,0013	2,0229^{NS}	1	0.1549

X^2 = Chi-square test statistics; df = number of degrees of freedom of the chi-square; p = level of probability of the chi-square test; * Significant at 5% probability; ** Significant at 1% probability; NS Not significant at 5% probability; IDF = insufficient number of degrees of freedom.

Table 6. Semivariogram parameters, area of reach, coefficient of determination (R^2), spatial dependency index and experimental model for geostatistical analysis of *Helicoverpa zea* <1 cm and *Helicoverpa zea* > 1 cm in one hectare of corn crop.

***Helicoverpa zea* < 1 cm**							
Analysis dates	**Semivariogram parameters**			**Models**	**R^2**	**Area (ha)**	**K**
	C_0	C_1	*a (m)*				
06/04/2016	0.06	0.04	71.37	Spherical	0.94	1.60	Moderate
06/11/2016				Random			
06/18/2016	0.10	0.12	23.39	Spherical	0.98	0.17	Moderate
06/25/2016	0.17	0.06	28.39	Spherical	0.99	0.25	Moderate
***Helicoverpa zea* > 1 cm**							
Analysis dates	**Semivariogram parameters**			**Models**	**R^2**	**Area (ha)**	**K**
	C_0	C_1	*a (m)*				
06/04/2016	0.16	0.09	20.56	Gaussian	0.99	0.13	Moderate
06/11/2016	0.04	0.07	43.33	Gaussian	0.97	0.59	Moderate
06/18/2016	0.04	0.04	30.08	Exponential	0.97	0.28	Moderate
06/25/2016	0.05	0.03	39.27	Spherical	0.97	0.48	Moderate

C_0: nugget effect; C_1: contribution; a: reach (m); K: spatial dependency index; Area calculated by πr^2, where $\pi = 3.14$ and r = a (1 ha = $10,000^2$); $K = C_0 / C_0 + C_1$.

20.56 meters and 0.13 ha of reach area (Table 6). The range demonstrates the distance at which the samples correlate within space (Oliveira & Antônio 2017). The range results are important, because they demonstrate the influence of infested areas on the rest of the area, it is noted that smaller caterpillars tended to reach larger areas in relation to large caterpillars, showing the relevance of controlling this caterpillar early in the detection.

The *H. zea* adults can disperse over great distances (Olmstead *et al.* 2016) which can facilitate the distribution of eggs and consequently a greater range of distribution for small caterpillars. On the other hand, eggs and small caterpillars are more susceptible to the action of biotic and abiotic controllers (Olmstead *et al.* 2016), perhaps justifying the aggregation with less distribution of larger caterpillars that are concentrated in more favorable areas.

For the corn-silk fly, semivariograms were better adjusted by the spherical model, fitting into five evaluations. The spatial dependence alternated between weak and moderate, the range obtained varied from 13.62 to 65.20 m with a maximum area of influence of 1.33 ha (Table 7). The corn-silk fly tends to increase the area of reach depending on its incidence, on the dates of greatest occurrence were the largest ranges. The pure nugget effect seen on two dates shows the randomness and non-spatial dependence on dates of low occurrence of this fly. *Euxesta* eggs and larvae are found with aggregation in reproductive stages of corn (Kalsi *et al.* 2014), this immature aggregation may reflect the aggregate behavior of adults.

Krigagem maps of *H. zea* < 1 cm showed aggregations distributed throughout the corn crop area. On the first date analyzed, the concentration is mostly close to the edges with adjacent pasture areas. Nguyen & Nansen (2018) report that the edges and adjacencies of agricultural areas influence the distribution of insects, largely caused by abiotic and biotic factors. The distribution of *H. zea* started with migrations from the edges with pasture to corn, this area was open without high barriers as in other areas adjacent to the corn crop.

On the second date, the caterpillar occurred with aggregations at the edges and centralized in the study area, on the last analysis date the caterpillar presented aggregations concentrated in the central region of the area (Figure 1). According to Machado *et al.* (2015) the abundance of caterpillars is a decisive factor for its dispersion in the field, since, with the population peak, the spatial dependence in the samples will decrease.

Looking at maps referring to *H. zea* > 1 cm, results similar to that of small caterpillars are observed. The plots on the edges have high concentrations and centralized colonization may be due to dispersion. The mango agroecosystem may be influencing as a physical barrier to pests, since the concentration and aggregation occurred less in the areas close to the mango crop (Figure 2).

The edges and adjacent plants of agricultural areas can interfere with the distribution of insect communities. These environments function as natural or artificial barriers that affect insect mobility and dispersion (Nguyen & Nansen 2018; Penn 2018). The trees on the margins of agricultural areas act as windbreaks, preventing the dispersion of insects that need the wind to colonize these agricultural areas (Nguyen & Nansen 2018). The maps also help to verify the uniformity of

Table 7. Semivariogram parameters, area of reach, coefficient of determination (R^2), spatial dependency index and experimental model for geostatistical analysis of *Euxesta* spp. in one hectare of corn crop.

Analysis dates	Semivariogram parameters			Models	R^2	Area (ha)	K
	C_0	C_1	*a (m)*				
04/16/2016	0.03	0.03	13.62	Gaussian	0.97	0.06	Moderate
04/23/2016				Random			
04/30/2016				Random			
05/14/2016	0.02	0.04	17.78	Spherical	0.87	0.10	Moderate
05/21/2016	0.01	0.02	18.77	Gaussian	0.91	0.11	Moderate
05/28/2016	0.06	0.01	47.84	Spherical	0.88	0.72	Weak
06/4/2016	0.12	0.07	65.20	Spherical	0.92	1.33	Moderate
06/11/2016	0.10	0.06	23.84	Spherical	0.97	0.18	Moderate
06/18/2016	0.15	0.01	54.78	Spherical	0.99	0.94	Weak
06/25/2016	0.19	0.03	45.95	Gaussian	0.99	0.66	Weak

C_0: nugget effect; C_1: contribution; a: reach (m); K: spatial dependency index; Area calculated by πr^2, where $\pi = 3.14$ and r = a (1 ha = $10{,}000^2$); $K = C_0 / C_0 + C_1$.

the infestation on dates with high occurrence.

On the maps of *Euxesta* spp. demonstrate the aggregations, confirming the results of the dispersion analyzes. The corn-silk flies started occurring in the area close to the mango agroecosystem and in the secondary forest fragment area, dispersing to the center of the corn crop. On the following dates (05/28 and 06/04 of 2016) the aggregations were concentrated in the center of the corn crop, and the last analyzes showed that the spatial distribution of corn-silk flies followed the spatial distribution of corn earworms (Figure 3). The corn-silk fly shows an opportunistic behavior benefiting from the attack of other insects on the ear (Moreira & Aragão 2009), the adults of *Euxesta* spp. demonstrated, through aggregations, that they were influenced and attracted by plants that had ears with the presence of *H. zea* caterpillars.

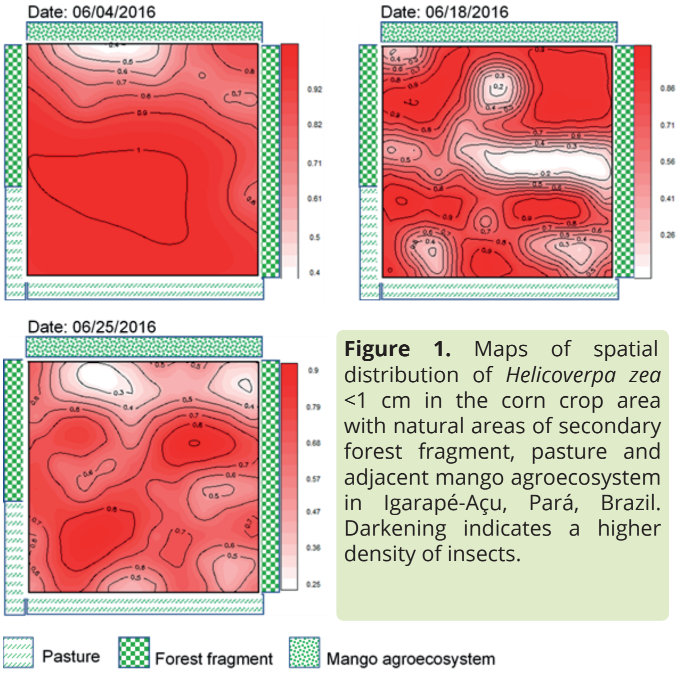

Figure 1. Maps of spatial distribution of *Helicoverpa zea* <1 cm in the corn crop area with natural areas of secondary forest fragment, pasture and adjacent mango agroecosystem in Igarapé-Açu, Pará, Brazil. Darkening indicates a higher density of insects.

When verifying the population fluctuation of *H. zea* it was observed on 06/04/2016 (stage R2, kernel blister stage) the caterpillars < 1 cm presented a total of 672 individuals, while the caterpillars > 1 cm presented 85. In the R3 kernel milky stage (06/11/2016) amount of *H. zea* < 1 cm and > 1 cm were 423 and 424 individuals, respectively. From this date on, the presence of caterpillars < 1 cm decreased and the occurrence of caterpillars > 1 cm increased, with a population peak of 454 individuals in stage R5, kernel dent stage (Figure 4). This fluctuation demonstrates what is expected, where the development of the caterpillar is related to corn, since the eggs of *H. zea* are deposited in the appearance of stigma-styles.

The presence of *Euxesta* spp. started on 04/16/2016 with the first developed corn leaf, however the occurrence stood out only in the reproductive stages of the crop, reaching a peak population with 48 individuals on 06/25/2016 (R5 - kernel dent stage), transition from kernel milky stage to maturity (Figure 5).

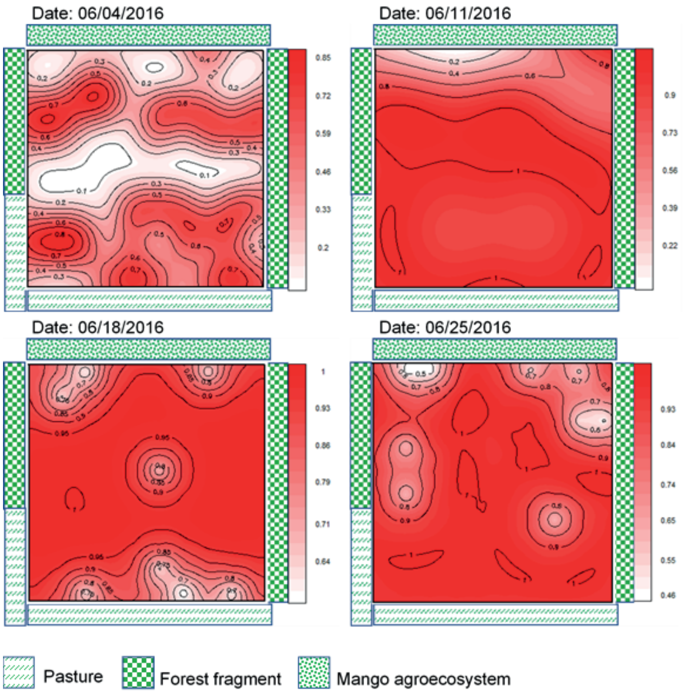

Figure 2. Maps of spatial distribution of *Helicoverpa zea* >1 cm in the corn crop area with natural areas of secondary forest fragment, pasture and adjacent mango agroecosystem in Igarapé-Açu, Pará, Brazil. Darkening indicates a higher density of insects.

Population peaks of the corn-silk fly occur coinciding with the reproductive phenological stage of the corn (Cruz *et al.* 2011a). One factor that can be attributed to this event is the presence of *H. zea*, because its damages facilitate the entry, oviposition and establishment of *Euxesta* spp. (Cruz *et al.* 2011b).

A total of 68.88% of the ears of corn were infested with *H. zea* caterpillars in this study, and in the R3 stage with milky kernels the infestation reaches 84.7% of the ears. *Euxesta* adults are found at all stages of corn development, but there is an increase in the population with the appearance of stigma-styles.

Both *H. zea* and *Euxesta* flies exhibit aggregate spatial behavior during the reproductive stage of corn. However, caterpillars < 1 cm have a greater reach and area of influence than caterpillars > 1 cm, with spatial dependence being considered moderate. The corn-silk fly has a maximum area of influence of 1.33 ha and with moderate and weak spatial dependence.

Kriging maps demonstrate that these insects can occur throughout the corn area, but with aggregations mainly influenced by the adjacent areas and edges of the crop.

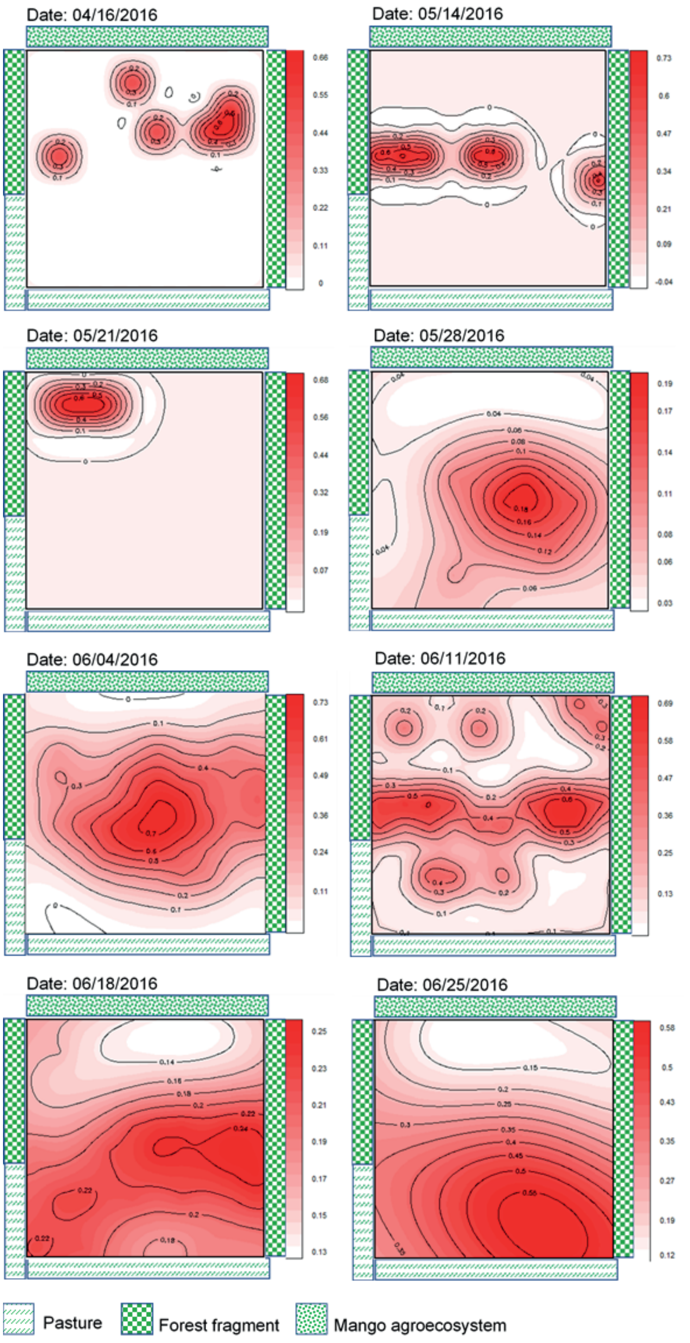

Figure 3. Maps of spatial distribution of *Euxesta* spp. in the corn crop area with natural areas of secondary forest fragment, pasture and adjacent mango agroecosystem in Igarapé-Açu, Pará, Brazil. Darkening indicates a higher density of insects.

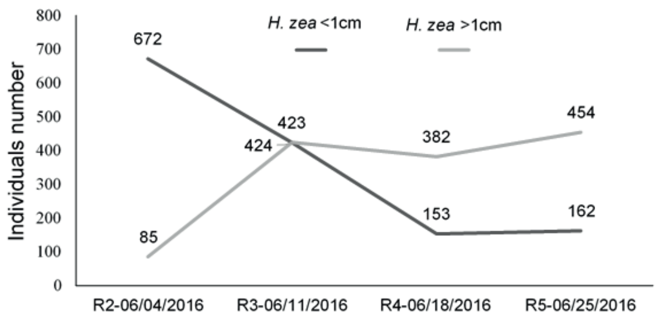

Figure 4. Population fluctuation and the relationship between the phenological stages of the corn crop and the *Helicoverpa zea* caterpillar, Igarapé-Açu, Pará, Brazil.

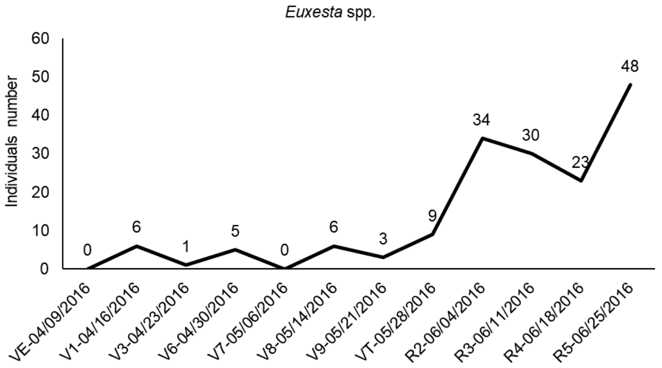

Figure 5. Population fluctuation and the relationship between the phenological stages of the corn crop and the *Euxesta* spp., Igarapé-Açu, Pará, Brazil.

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