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ORIGINAL ARTICLE

Spatial distribution of *Spodoptera frugiperda* in the wasteland of southern Pernambuco state, Brazil

Distribuição espacial da lagarta-do-cartucho nas condições do Agreste Meridional de Pernambuco

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ABSTRACT: The fall armyworm (*Spodoptera frugiperda)* causes damage and reduction in maize production and is considered a pest difficult to control, thus determining its spatial distribution pattern contributes to the development of suitable sampling and control strategies. The aim of this study was to evaluate the spatial distribution of *Spodoptera frugiperda* in maize culture under the conditions of the wasteland of southern Pernambuco state. The experiment was conducted at the Experimental Station of Brejão - 'Instituto Agronômico do Pernambuco' (IPA) from April to May 2012. The study area consisted of 100 plots of 60 m^2, where 10 plants per plot were weekly sampled at random. In each plant, the number of small and large larvae of *S. frugiperda* was counted on the leaves and the husk of ears. According to the data observed, the aggregation indices (variance/mean ratio, Morisita's index, Green's Index, and Exponential k of a negative binomial distribution) indicated aggregate distribution for both small and large caterpillars, and the negative binomial distribution was the most appropriate model to represent the distribution pattern of small larvae of this pest in the field. In maize crop in the wasteland of southern Pernambuco state, *S. frugiperda* presents aggregate pattern of distribution and tends to spread from the points of aggregation and colonize form the border into the center of cultures.

RESUMO: *A lagarta-do-cartucho (Spodoptera frugiperda) causa danos e redução na produção de milho, e é considerada uma praga de difícil controle; portanto, a determinação do padrão de distribuição espacial contribui para a elaboração de amostragens adequadas e estratégias de controle. O objetivo deste trabalho foi avaliar o padrão de distribuição espacial de Spodoptera frugiperda na cultura do milho, nas condições do Agreste Meridional de Pernambuco. O experimento foi conduzido na Estação Experimental de Brejão-PE, do Instituto Agronômico de Pernambuco (IPA), no período de abril a maio de 2012. A área foi composta de 100 parcelas de 60* m^2*, tendo sido amostradas semanalmente, de forma aleatória, dez plantas por parcela. Em cada planta, contava-se o número de lagartas pequenas e grandes de S. frugiperda, nas folhas e no cartucho. Os índices de agregação (Razão Variância/Média, Índice de Morisita, Índice de Green e Exponente k da binomial negativa) indicaram disposição agregada tanto para as lagartas pequenas quanto para as grandes, sendo a distribuição binomial negativa o modelo mais adequado para representar o padrão de distribuição de lagartas pequenas desta praga no campo. Na cultura do milho, no Agreste Meridional de Pernambuco, S. frugiperda apresenta padrão agregado de distribuição; essas lagartas tendem a se distribuir a partir dos pontos de agregação e colonizar das bordas para o interior da cultura.*

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1 Introduction

The cultivation of maize (*Zea mays* L.) is of great economic and social importance, being used both in human and animal nutrition (Garcia et al., 2006). Besides this economic significance, this crop plays a very important agricultural role in allowing increased production of other crops due to crop rotation, which can minimize problems with intensive production systems (CIB, 2010).

Brazil is third largest maize producer in the world, only falling behind the USA and China. Considering that two maize crops are harvested in Brazil, it is estimated that the area of production for the 2012/13 season should be between 14.59 and 14.80 million hectares with production reaching between 71.5 and 72.8 million tons; it is estimated that in Pernambuco state the total area of maize production will be approximately 205 thousand hectares with total production of 133 thousand tons (CONAB, 2012).

Pest insects are a key factor among those that can cause damage to maize crop and consequent decrease in yield. A large number of insects are associated with maize culture, but few species reach pest status. The fall armyworm, *Spodoptera frugiperda* (Smith), is considered one of the main maize pests in Brazil (Sarmento et al., 2002; Cruz, 1995, 2010).

The fall armyworm can cause reduction of 17 to 55% in maize production in Brazil, and these losses may vary according to the plant developmental stage and the genotype used (Cruz, 2010).

Greater understanding of the population dynamics of insect communities in production systems that integrate the maize crop can provide great benefits for the management of insect pests in these systems (Waquil, 2006). Knowledge on the behavior of the fall armyworm and its bioecology are of major importance for the development of strategies to manage this pest (Sarmento et al., 2002).

The study of the spatial distribution of the fall armyworm in maize cultivation is essential to the development of a plan of integrated pest management, thereby ensuring the optimization of sampling and control strategies (Farias et al., 2001a). The objective of this research is to study the pattern and behavior of spatial distribution of the fall armyworm in maize crop under the conditions of the wasteland of southern Pernambuco state.

2 Materials and Methods

The study was developed at the experimental unit of ‘Instituto Agronômico de Pernambuco’ (IPA) in the municipality of Brejão, Pernambuco state, located in the mesoregion of the wasteland, microregion of Garanhuns, (09° 01’ 49” S; 36° 34’ 07” W; altitude 850 m), with average annual temperature of 22.3 °C and average annual rainfall of 1404 mm.

The experimental area was approximately 0.5 ha large. Seeding of a hybrid maize cultivar was performed on 03/21/2012 with an inter-row spacing of 0.90 m and 0.20 m between plants. Chemical control of this pest in the study area was carried out only when its population was above the control level. Applications of Macth (active ingredient: Lufenuron) together with a spreader were conducted on 03/30; 04/10; 04/16; 05/04 and 05/11 in 2012, and the herbicide Paraquat (2 L ha^{-1}) was applied on 04/24/12.

The experimental area was divided into 100 plots of 60 m^2 (6 × 10 m). Ten plants were randomly analyzed in each plot, totaling 1000 plants per sampling. The sampling unit was the ear husk; it was opened and the number of caterpillars was counted on its leaves and inside it. The fall armyworm caterpillars were classified as small (< 1 cm) and large (> 1 cm).

The study was carried out from 04/18 to 05/30, 2012. Counting was performed weekly on 04/18; 04/24; 05/04; 05/08; 05/17 and 05/30/2012, always during the morning, between 08:30 and 11:30 am. According to the results obtained regarding the number of small and large caterpillars, the spatial distribution of the fall armyworm was determined through the calculation of the aggregation/dispersion indices: variance/mean ratio, Morisita’s index, Green’s Index, Exponential k of a negative binomial distribution, and fitting to the probabilistic models of frequency distribution (Poisson and Negative Binomial), for all samples.

Variance/mean ratio (I): used to measure the deviation of a random arrangement of conditions. According to Rabinovich (1980), values equal to one indicate random spatial distribution; values lower than one indicate uniform distribution; and values higher than one indicate aggregate distribution. This index is estimated by Equation 1:

$$I = \frac{s^2}{\hat{m}} = \frac{\sum_{i=1}^{n}\left(x_i - \hat{m}\right)^2}{\hat{m}(n-1)} \quad (1)$$

where:
s^2 = sample variance;
$\hat{m}$ = sample mean;
x_i = number of fall armyworm caterpillars found in the sample units;
n = number of sample units.

Morisita’s Index ($I\delta$): indicates that the distribution is random when equals to 1, contagious when higher than 1, and regular when lower than one. Morisita (1962) developed the following formula (Equation 2):

$$I_\delta = n\frac{\sum_{i=1}^{n}\left[x_i\left(x_i - 1\right)\right]}{\sum_{i=1}^{n}x_i\left(\sum_{i=1}^{n}x_i - 1\right)} = \frac{\sum_{i=1}^{n}x_i^2 - \sum_{i=1}^{n}x_i}{\left(\sum_{i=1}^{n}x_i\right)^2 - \sum_{i=1}^{n}x_i} \quad (2)$$

where:
n = number of sample units;
x_i = number of fall armyworm caterpillars found in the sample units;
$\sum x_i$ = sum of individuals present in the sample units.
Test for randomness is given by Equation 3:

$$\chi_\delta^2 = I_\delta\left(\sum_{i=1}^{n}x_i - 1\right) + n - \sum_{i=1}^{n}x_i \sim x^2_{(n-1)} \quad (3)$$

If $\chi_\delta^2 \geq X^2_{(n\text{-}1\ g.l.;\ 0.05)}$, the randomness hypothesis is rejected.

Green’s Coefficient (Cx): this index ranges from negative for uniform distribution, 0 for random distribution, to 1 for maximum contagion (Green, 1966). It is based on the distribution of variance/mean and is given by Equation 4:

$$Cx = \left[\left(\frac{s^2}{\hat{m}}\right) - 1\right] / \left[\sum_{i=1}^{n} x_i - 1\right] \quad (4)$$

Exponential k of a negative binomial distribution: estimation of k by the method of moments: negative values indicate uniform distribution; low positive values (k < 2) show highly aggregated distribution; k values ranging from 2 to 8 indicate moderate aggregation, and values higher than 8 (k > 8) show random distribution (Elliott, 1979) (Equation 5).

$$k = \frac{\hat{m}^2}{s^2 - \hat{m}} \quad (5)$$

Data of each sample were tested to verify their fit to the Poisson distribution. The hypothesis is that all individuals are equally likely to occupy a certain space, and the presence of an individual does not affect the presence of another, with the variance equal to the mean, but when the variance is higher than the mean, there is aggregation of individuals, that is, the presence of an individual increases the chance of another individual occur in the same unit, fitting the negative binomial distribution (Barbosa; Perecin, 1982).

The models fit properly when the data of the observed and expected frequencies show close values. The proximity of these data is compared by the chi-square test (χ^2), which is given by Equation 6:

$$\chi^2 = \sum_{i=1}^{N_c} \frac{(FO_i - FE_i)^2}{FE_i} \quad (6)$$

where:
FOi = frequency observed in the i=nth class;
FEi = frequency expected in the i=nth class;
nc = number of classes of the frequency distribution.

The number of degrees of freedom in the X^2 test is calculated as Equation 7:

$$G.L = N_C - N_P - 1 \quad (7)$$

where:
N_C = number of classes of the frequency distribution;
N_P =number of parameters estimated in the sample.

The criterion of the test adopted was to reject the fitness of the distribution level studied at the level of α% if:

$$X^2 \geq \chi^2_{(N_C - N_P - 1; \alpha = 0,05)}$$

Several indices of dispersion/aggregation were used to assess the spatial distribution of the fall armyworm caterpillars. They were used to determine the degree of randomness in the spatial arrangement and their application is essential in ecological studies (Green, 1966). There is no perfect index that satisfies all requirements and conditions of aggregation studies; therefore, multiple indices should be used (Rabinovich, 1980).

After analysis of the parameters (indices), linear interpolation maps were prepared for illustration and verification of fall armyworm spatial aggregation. The values for frequency observed at the sampling points and the interpolation between these points were demonstrated. The darkening of the gray shade shows an increase in population density. More intense and lighter gray shading indicates locations with higher and lower densities, respectively.

The licensed software Surfer 11.5 (Golden Software, 2011) for Windows was used to obtain the linear interpolation maps.

3 Results and Discussion

According to the values obtained (Table 1), it was possible to observe that the sample means of small fall armyworm larvae (< 1 cm) ranged from 0.1800 to 1.5800, where the population peak occurred 44 days after planting, on 05/04/2012.

Regarding the analysis of the spatial distribution of small caterpillars, the variance/mean ratio (I) showed values higher than one in all samplings, demonstrating aggregation behavior of the fall armyworm (Table 1). These results corroborate those presented by Fernandes et al. (2002) who, while working with the spatial distribution of *S. frugiperda* in cotton crop, reported aggregate distribution model regardless of caterpillar size (small, up to 1.5 cm in length; medium, between 1.5 and 2.5 cm; and large, longer than 2.5 cm). In the same study, the authors reported that the aggregate distribution of small caterpillars was expected, because females of this species lay eggs in masses, with large number of eggs being laid, so that newly hatched and second instar larvae remain near the oviposition site. According to Farias et al. (2008), small larvae present aggregate behavior, which favors their survival because they are vulnerable to biotic and abiotic conditions in their initial phases; aggregation is considered a form of protection.

Table 1. Means, variances and indices of dispersion for the occurrence of caterpillars (< 1 cm).

Indices	4/18/12	4/24/12	5/4/12	5/8/12	5/17/12	5/30/12
Fall armyworm						
m	0.6100	1.1500	1.5800	0.8500	0.1800	-
s^2	0.9070	2.7551	6.6097	1.4015	0.5127	-
I = s^2/m	1.4868	2.3957	4.1834	1.6488	2.8485	-
Iδ	1.8033	2.2121	3.0073	1.7647	11.7647	-
X^2Iδ	147.20	237.17	414.15	163.24	282.00	-
k mom	1.2530	0.8240	0.4963	1.3100	0.0974	-
Cx	0.0081	0.0122	0.0203	0.0077	0.1087	-

m = sample mean; s^2 = variance; I = variance/mean ratio; Iδ = Morisita's index; X^2 Iδ = chi-square test for departure from randomness of the Morisita's index; k mom = *k* calculated by the method of moments; Cx = Green's coefficient.

Several indices of dispersion/aggregation can be used to measure the spatial distribution of insects; Farias et al. (2001b), while studying the spatial distribution of small (<1 cm) and large (> 1 cm) fall armyworm larvae, found results similar to those of this study for small caterpillars using Taylor's law, with index value of 1.57 and significant t-test, which according to the authors indicate aggregate larval distribution.

Observing the results of the Morisita's index ($I\delta$), it is possible to notice that the values were also higher than one, which confirms that the population of small caterpillars in fact presents aggregate distribution in the field. This distribution trend is also observed for the assessment of the Exponential K (Kmom); according to Pielou (1977), Southwood (1978), Elliott (1979) cited by Melo et al. (2006), this parameter is an inverse measure of the degree of aggregation, and negative values indicate regular or uniform distribution, positive values close to 0 indicate aggregate distribution, and values higher than 8 indicate random distribution; as shown in Table 1, the values indicated aggregate distribution in all samples. The Green's index (Cx) confirms maximum contagion (aggregate distribution) for fall armyworm larvae < 1 cm, since all the values are higher than zero.

For fall armyworm larvae < 1 cm, five of the six samples presented degree of freedom sufficient to fit the Poisson distribution, which describes random spatial arrangement (Table 2). Only the sampling performed on 05/08/2012 presented non-significant fit, all the others showed significant chi-square test values (1% and 5%), that is, these figures indicate that the count data obtained in the field do not fit the theoretical distribution model considered (Poisson), showing that the distribution is not random. The results indicate that the fit to the negative binomial distribution model is quite satisfactory, because, among the six samples evaluated, only the counting performed on 05/04/2012 showed significant values, not rejecting randomness (Table 2).

This frequency distribution (negative binomial) is characterized by having above average variance, indicating that caterpillars < 1 cm in length present aggregate spatial distribution in maize crop, confirming the previous results of the indices of dispersion.

On the last sampling (05/30/2012), it was not possible to perform the fit test because of the insufficient number of frequency classes, probably owing to the life cycle: caterpillars that were previously classified as shorter than 1 cm, on this date must have been classified as longer than 1 cm.

For the fall armyworm larvae > 1 cm, it was not possible to perform the fit test on the first sampling (04/18/2012) due to insufficient number of classes. The indices of aggregation for caterpillars > 1 cm indicate that the variance/mean ratio (I) showed values lower than one in all samplings performed (Table 3). Thus, it is clear that caterpillars > 1 cm in length present aggregate distribution in the field; by the Morisita's index ($I\delta$), all samples showed values higher than one, reaffirming the aggregation of this species. Other confirmations of aggregate distribution were observed when assessing other indices. Assessment of the exponential K (Kmom), demonstrated that four of the five samples presented values between 0 and 2, only the sampling performed on 05/08/2012

Table 2. Chi-square test to fit the Poisson and negative binomial distributions of caterpillar data (< 1 cm).

Fall armyworm						
Dates	Poisson			Negative binomial		
	X^2	Df	P	X^2	Df	P
4/18/12	6.01 *	2	0.0496	5.84 ^{ns}	2	0.0539
4/24/12	18.93 **	3	0.0003	7.63 ^{ns}	3	0.1776
5/4/12	104.12 **	5	0.0000	87.48 **	6	0.0000
5/8/12	5.15 ^{ns}	3	0.1613	0.58 ^{ns}	3	0.9019
5/17/12	7.63 **	1	0.0057	2.43 ^{ns}	1	0.1191
5/30/12	IDF	IDF	IDF	IDF	IDF	IDF

X^2 – statistics of the chi-square test; df – number of the degree of freedom of the chi-square test; p – probability level of the chi-square test; ns - non-significant at 5 % level; * – significant at 5% level; ** – significant at 1% level; IDF – insufficient degree of freedom.

Table 3. Means, variances and indices of dispersion for the occurrence of caterpillars (> 1 cm).

Indices	4/18/12	4/24/12	5/4/12	5/8/12	5/17/12	5/30/12
fall armyworm						
m	-	0.0500	0.8400	0.6700	0.8900	0.4100
s^2	-	0.0884	2.2570	0.8496	1.5130	0.7090
$I = s^2/m$	-	1.7677	2.6869	1.2681	1.7000	1.7292
$I\delta$	-	20.0000	3.0120	1.4021	1.7875	2.8049
$X^2 I\delta$	-	175.00	266.00	125.54	168.30	171.20
K mom	-	0.0651	0.4980	2.4995	1.2714	0.5622
Cx	-	0.1919	0.0203	0.0041	0.0080	0.0182

m = sample mean; s^2 = variance; I = variance/mean ratio; $I\delta$ = Morisita's index; $X^2 I\delta$ = chi-square test for departure from randomness of the Morisita's index; k mom = *k* calculated by the method of moments; Cx = Green's coefficient.

showed a value higher than 2; according to Southwood (1978) cited by Costa (2009), K (mom) values between 2 and 8 indicate moderate aggregation. Most samples showed highly aggregate distribution, also shown by the Green's index (Cx), where values are higher than zero and smaller than one, indicating maximum contagion; according to Green (1966) cited by Melo et al. (2006), this index ranges from 0 (for random distributions) to 1 (for maximum positive contagion), and the negative values indicate uniform distribution.

In a study carried out in cotton crop, Fernandes et al. (2002) verified that *S. frugiperda* larvae present aggregate spatial distribution regardless of size; nevertheless, the same authors found that, in some samples, although maintaining an aggregate distribution model, caterpillars presented a slight trend to reduce the strong initial aggregation as they developed,

Table 4. Chi-square test to fit the Poisson and negative binomial distributions of caterpillar data (> 1 cm).

fall armyworm						
Dates	Poisson			Negative binomial		
	X^2	Df	P	X^2	Df	P
4/18/12	IDF	IDF	IDF	IDF	IDF	IDF
4/24/12	IDF	IDF	IDF	IDF	IDF	IDF
5/4/12	0.84 ^{ns}	3	0.1146	12.39 *	4	0.0147
5/8/12	0.67 ^{ns}	2	0.1598	1.30 ^{ns}	2	0.5215
5/17/12	0.89 **	3	0.0036	2.53 ^{ns}	3	0.4693
5/30/12	0.41 **	1	0.0013	2.70 ^{ns}	2	0.2595

X^2 – statistics of the chi-square test; df – number of the degree of freedom of the chi-square test; p – probability level of the chi-square test; ns – non-significant at 5 % level; * – significant at 5% level; ** – significant at 1% level; IDF – insufficient degree of freedom.

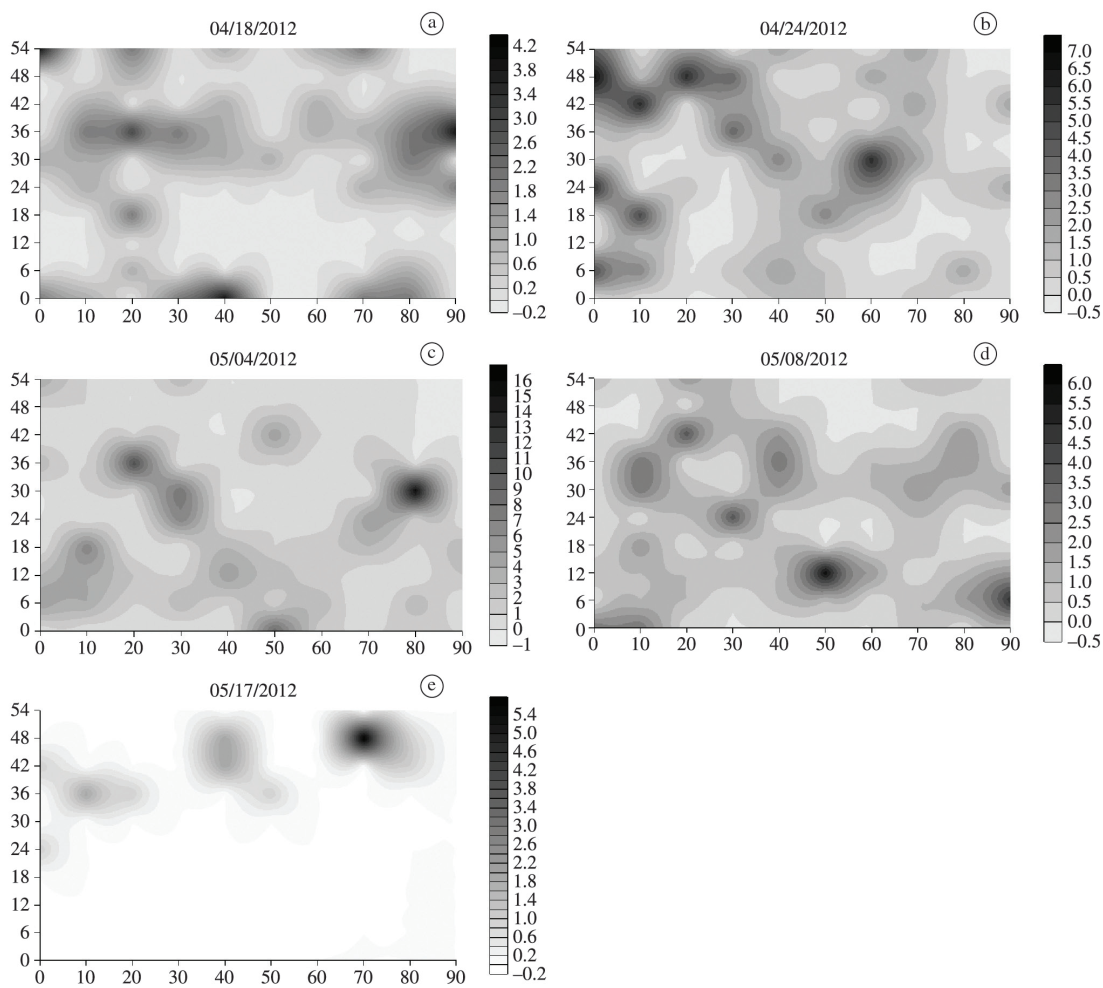

Figure 1. Map of linear interpolation of *Spodoptera frugiperda* larvae < 1 cm in length at days: a (04/18); b (04/24); c (05/04); d (05/08); and e (05/17). The values of x and y correspond to the distances of the plots (6 × 10 meters), increased intensity of darkening corresponds to higher density of caterpillars.

moving away from each other. This finding was not observed in this study, where caterpillars smaller and larger than 1 cm showed aggregate behavior in maize culture.

Conflicting results were found by Melo et al. (2006) working with the spatial distribution of maize plants infested with fall armyworm; they verified a random distribution pattern influenced by increased infestation. This difference may be related to the methodology used, especially to the presence/absence sampling form.

Results contrary to those found in the present study were also obtained by Farias et al. (2001b) who, using Taylor's law, verified values equal to 0.79 and non-significant t-test, indicating random behavior; according to the authors, this result is justified by the high mortality rate in the first instar caused by the action of parasitoids and predators and the frequent cannibalism at that stage of development. For caterpillars > 1 cm, it was not possible to perform the fit test to negative binomial and Poisson because caterpillars larger than 1 cm did not occur in the first samples (04/18 and 04/24/2012). Of the four samples, in the negative binomial test with sufficient number of classes, only the sampling performed on 05/04/2012 did not fit the aggregate distribution model (Table 4).

In a spatial distribution survey conducted in cotton crop, medium (between 1.5 and 2.5 cm) and large (longer than 2.5 cm) caterpillars presented moderate aggregate distribution, tending to random pattern (Fernandes et al., 2002). A similar result was verified by Melo et al. (2006) working with the spatial distribution of maize plants infested with fall armyworm; they verified that the Morisita's index calculated for large larvae in most of the samples, indicated that the individuals presented random arrangement.

The values of the chi-square tests indicate aggregate distribution of caterpillars > 1 cm, which can be justified by the last samples. However, the data showed no clarity as to the best aggregation model, reasonably fitting the negative binomial distribution, with some dates fitting the Poisson distribution (two dates pointed to randomness and two to negation). Similar results were reported by Farias et al. (2001a) working with the spatial distribution of fall armyworm in maize crop, who verified that small larvae fitted aggregate distribution; however, for large larvae, the negative binomial distribution does not properly describe their dispersion, but in general, according

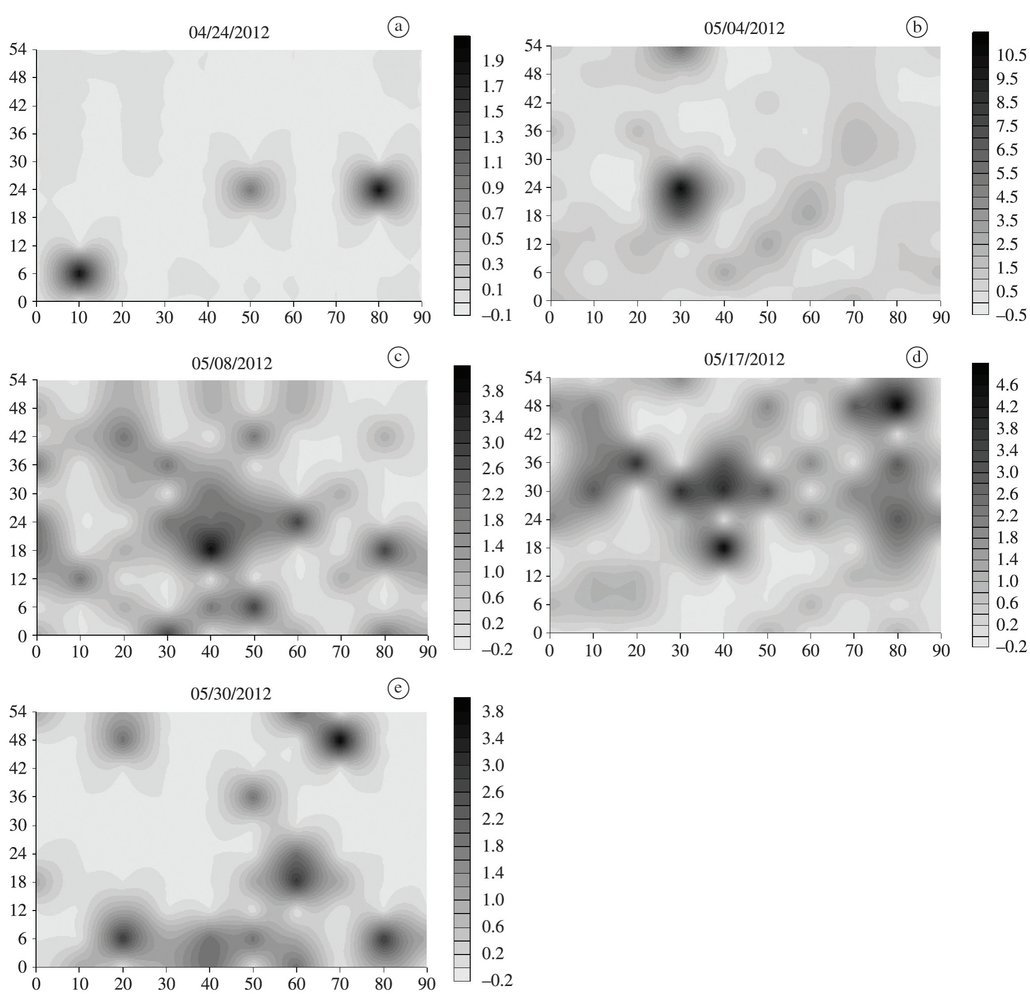

Figure 2. Map of linear interpolation of *Spodoptera frugiperda* larvae > 1 cm in length at days: a (04/18); b (04/24); c (05/04); d (05/08); and e (05/17). The values of x and y correspond to the distances of the plots (6 × 10 meters), increased intensity of darkening corresponds to higher density of caterpillars.

to the authors, counting of small, large and total larvae fit the negative binomial distribution better than the Poisson test; good fit was observed for large larvae when the positive binomial test was applied.

In the study of interpolation maps of the distribution of fall armyworm caterpillars < 1 cm, greater occurrence was observed from the borders into the center of the culture (Figure 1a). There was a distribution trend from the aggregation points and near or from the border into the culture center (Figures 1a to 1e).

Through these interpolation maps, it is possible to observe that fall armyworm larvae were distributed throughout almost the entire study area, but there were points of aggregation of larvae < 1 cm, which can be seen on the dark shades, confirming the aggregation found in previous analyses. Interpolation between the aggregation points has also occurred, that is, distribution occurred from the aggregation points (infestations) to other areas, which can be seen on the dark shades that follow the direction of the largest aggregation. Regarding the fall armyworm larvae > 1 cm, it is possible to notice that they are distributed throughout the experimental area, with low infestation in the first two readings, observed on the few points with dark shades, increasing as of the third reading. Interpolation between the aggregation points can also be observed (Figures 2a to 2e).

The results observed with the analyses of dispersion and interpolation maps both for caterpillars < 1 cm and larger may contribute to the development of management plans for this pest in maize cultivation in the wasteland of southern of Pernambuco state.

4 Conclusions

Both small and large fall armyworm larvae present aggregate pattern of distribution. The negative binomial distribution is the most appropriate model to represent the distribution pattern of small caterpillars (< 1 cm) in the field. Large caterpillars tend to spread from the points of aggregation to the other areas, while small ones occur in greatest abundance from the border into the center of cultures.

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