Population Fluctuation and Spatial Distribution of Trioza aguacate (Hemiptera: Triozidae) on Avocado (Lauraceae) in Michoacan, Mexico

Authors: González-Santarosa, María Graciela, Bautista-Martínez, Néstor, Romero-Nápoles, Jesús, Rebollar-Alviter, Ángel, Carrillo-Sánchez, José Luis, et al.

Source: Florida Entomologist, 97(4) : 1783-1793

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.097.0454

POPULATION FLUCTUATION AND SPATIAL DISTRIBUTION OF *TRIOZA AGUACATE* (HEMIPTERA: TRIOZIDAE) ON AVOCADO (LAURACEAE) IN MICHOACAN, MEXICO

María Graciela González-Santarosa[1], Néstor Bautista-Martínez[1*], Jesús Romero-Nápoles[1], Ángel Rebollar-Alviter[2], José Luis Carrillo-Sánchez[1] and Luis Martín Hernández-Fuentes[3]

[1]Colegio de Postgraduados, Campus Montecillo, Carretera México-Texcoco, Km 36.5, Montecillo, Texcoco, Estado de México, México, CP 56230

[2]Universidad Autónoma Chapingo, Centro Regional Universitario Centro Occidente, Periférico Paseo de la República Núm. 1000, Colonia Lomas del Valle, Morelia, Michoacán, México, CP 58170

[3]INIFAP, Campo Experimental Santiago Ixcuintla. Km 6 Entronque Carretera Internacional México-Nogales, Santiago Ixcuintla, Nayarit, México, Apartado Postal 100

*Corresponding author; E-mail: nestor@colpos.mx

Abstract

The psyllid *Trioza aguacate* Hollis & Martin (Hemiptera: Triozidae) causes deformation of leaves and young shoots of avocado. In recent years, population densities of this pest in avocado orchards have increased. The objectives of this study were to determine seasonal fluctuations of the populations of eggs, nymphs, and adults of *T. aguacate*, how these fluctuations are related to the incidence of avocado vegetative shoots, temperature and rainfall at 3 different altitudes in Michoacan, Mexico, i.e., 2,130 m, 1,860 m and 1,293 m. In addition, we attempted to determine the spatial distributions of nymphs and adults found on avocado vegetative shoots. We sampled the populations of adult and immature *T. aguacate* every 20 days from Jan 2012 to Jul 2013. To estimate population densities, 9 trees were selected in each orchard, and the trees were distributed in the form of a cross. From each replicate of trees, 4 shoots were randomly collected, and the eggs and nymphs were counted on them. Adults counts were obtained from yellow traps established at the 4 cardinal points in each tree. During the same period, young vegetative shoots, temperature and rainfall were recorded. The results showed that this psyllid was not present at all in the orchard located at the low altitude level of 1,293 m. The psyllid was present at the medium altitude site from Jan to Jun, and from Dec to Jun at the high altitude site. All of the development stages were most abundant from Mar to May, when avocado vegetative shoots were most abundant in both years. The abundance of eggs and nymphs showed a positive relationship with young vegetative shoots, a negative relationship with rainfall, and the eggs showed a positive relationship with temperature. The incidence of adults was strongly related with spring budding, but not significantly correlated with temperature. Both nymphs and adults had an aggregated spatial distribution.

Key Words: Triozidae, psyllids, aggregated indices, avocado pests

Resumen

El psílido *Trioza aguacate* Hollis & Martin (Hemiptera: Triozidae) causa deformación de hojas y brotes jóvenes de aguacate y en los últimos años ha incrementado su densidad de población en los huertos. El objetivo del estudio fue determinar la fluctuación poblacional de huevos, ninfas y adultos de *T. aguacate* y la relación que guarda su incidencia con la abundancia de brotes, la temperatura y la precipitación pluvial en diferentes altitudes en Michoacán, México, además de conocer su distribución espacial en los brotes. El trabajo se realizó con muestreos cada 20 días, de enero de 2012 a julio de 2013. Para estimar la densidad de población se seleccionaron nueve árboles en cada huerto, distribuidos en forma de cruz. De cada árbol se colectaron cuatro brotes al azar, donde se contabilizó el número de huevos y ninfas. Los adultos se contabilizaron en trampas amarillas colocadas en cada árbol en los cuatro puntos cardinales. Durante el mismo periodo, se registró la brotación vegetativa, temperatura y precipitación pluvial. Los resultados mostraron que el psílido no se presentó en el huerto con menor altitud (1,293 m), y que en los dos huertos donde estuvo presente, lo hizo en dos periodos (enero a junio de 2012, y enero a junio de 2013); la mayor incidencia de todos los estados de desarrollo se presentó de marzo a mayo, coincidiendo con la abundancia de brotes vegetativos, en ambos periodos. La abundancia de huevos y ninfas mostró una relación positiva con los brotes vegetativos jóvenes, una relación negativa con la precipitación, y los huevos mostraron una relación positiva con la temperatura. La incidencia de los adultos estuvo fuertemente relacionada con la brotación de primavera, pero no presento relación significativa con la temperatura. Tanto las ninfas como los adultos presentaron una distribución espacial en agregados.

Palabras Clave: Triozidae, psílido, índices de agregación, plagas de aguacate

It is estimated that the world avocado (*Persea americana* Mill.; Laurales: Lauraceae) production has increased in the last 4 decades, from 3,636,339 to 4,360,018 t in 2012. The main producing countries are Mexico (30.2%), Indonesia (6.7%), Dominican Republic (6.65%), USA (5.6%), Colombia (5.0%), Peru (4.9%), and Kenya (4.3%) (FAOSTAT 2014).

Mexico, the place of origin of avocado, has 151,022 cultivated ha from which 1,316,104 t of fruit are produced annually. Within Mexico, the state of Michoacan is the most important producer of this fruit with a total of 1,117,338 t, followed by Jalisco (40,846 t), Morelos (35,541 t), Nayarit (29,178 t), the State of Mexico (28,765t), Guerrero (14,783 t), and Puebla (12,015 t) (SIAP 2012).

Moreover, a wide variety of insects and mites are associated with different avocado plant structures in Mexico. Increased avocado monoculture, facilitated by deforestation of natural woods to establish the crop, has favored a high incidence of pest insects and mites (Wysoki et al. 2003). Among these pests, the psyllid *Trioza aguacate* Hollis & Martin (Hemiptera: Triozidae) was identified and recorded in 1997. This psyllid causes deformation of avocado leaves and young vegetative shoots (Hollis & Martin 1997). In the last few years, population densities of this pest have increased, but there is no information of its dynamics in the field. Therefore, the following objectives were proposed: a) to determine the population fluctuation of *T. aguacate* and the relationship between the incidence of *T. aguacate* and the abundance of vegetative shoots, temperature, and rainfall in 3 production zones at different altitudes in the state of Michoacan, and to determine the spatial distribution of this insect on avocado shoots.

Materials and Methods

Location of the Study Area

The study was carried out in 3 orchards located at different altitudes in the state of Michoacan from Jan 2012 to Jul 2013. The first orchard (San Lorenzo) is located at a high altitude (2,130 m) in the community of San Lorenzo, municipality of Uruapan (N 19° 31′ 25.45″ W 102° 05′ 12.58″). The second orchard (Los Gemelos) is located at a medium altitude level (1,860 m) in the ejido of El Tarascon, municipality of Salvador Escalante (N 19° 26′ 29.81″ W 101° 49′ 53.03″). The third orchard (La Fontana) is located at a low altitude (1,293 m) in the municipality of Ziracuaretiro (N 19° 23′ 59.41″ W 101° 55′ 28.20″). The orchards sampled were all growing 10-year-old ‘Hass’ avocados with a staggered formation at 10 m. distance from each other. Water supply at La Fontana came from a micro-sprinkler irrigation system; at Los Gemelos water was provided by rainfall and auxiliary irrigation; and at San Lorenzo water was supplied only by seasonal precipitation.

Abundance and Population Fluctuation of *T. aguacate*

To determine the abundance and population fluctuation of *T. aguacate* eggs and nymphs, each orchard was sampled every 20 days from Jan 2012 to Jul 2013. In each orchard 9 trees were selected at random in the form of a cross, and from each of these, 4 shoots were randomly collected, one from each cardinal point of the tree. The shoots were no more than 8 cm long and they came from the midsection of the canopy (approximately 1.6 m off the ground). The shoots were placed individually in previously labeled polyethylene bags, held in iceboxes, and then taken to the Entomology Laboratory of the Colegio de Postgraduados, where the numbers of eggs and nymphs at the terminal portion of the shoot were counted by a Leica Zoom 2000 stereomicroscope (Leica Microsystems, Buffalo New York, USA).

To determine the abundance and population fluctuation of *T. aguacate* adults, the same trees and time frames for sampling adults were used as for sampling nymphs. Four yellow sticky traps (7 × 14 cm) were placed in each tree at the 4 cardinal points and at a height of 1.60 m. The traps were covered with thin resin-based glue. Traps were replaced every 20 days. The numbers of adults caught in each trap were counted, and adults were sexed.

During the same period, the abundance of vegetative shoots was determined by randomly collecting 36 shoots in each of the sampled orchards, and the number of young vegetative shoots was counted after each sampling. To determine the mean temperature and rainfall every 20 days, relevant data were obtained from the agrometeorological station closest to each sampled orchard. These stations were operated by the Association of Avocado Producers, and Export Packers of Michoacán (APEAM).

To estimate the Poisson models, we used data on egg, nymph, and adult densities, and related them with young vegetative shoots, precipitation, and temperature in both avocado orchards. The data were processed with the SAS software (Statistical Analysis System, version 9.0 SAS Institute Inc., Cary, North Carolina).

Spatial Distribution

The spatial distribution of nymphs on shoots and adults in traps, the 2012 and 2013 sampling period date were used to calculate the Morisita Index and the Lloyd Index.

The index of Morisita (I_d) is expressed by following equation:

$$I_d = \frac{n(\Sigma_{i=1}^{n} x_i^2 - \Sigma_{i=1}^{n} x_i)}{n(\Sigma_{i=1}^{n} x_i)^2 - \Sigma_{i=1}^{n} x_i}$$

Where: n is the total number of sampling units, x_i is the number of individuals of the ith sampling unit, and is the total number of individuals per sampling. When $I_d = 1$, the distribution is random; when $I_d > 1$, the distribution is aggregated, and when $I_d < 1$, the distribution is uniform (Cadahia 1977).

The Lloyd aggregate mean (Lloyd 1967) was calculated using the following equation:

$$m^* = \bar{X} + \frac{s^2}{\bar{X}} - 1,$$

where m* is Lloyd's aggregate mean, $\bar{X}$ is the mean, and S^2 is the sample variance. If $m^* = \bar{X}$, the distribution is random; if $m^* > \bar{X}$, it is aggregated, and if $m^* < \bar{X}$, it is uniform. Considering that m* depends on the population density, it follows that an individual in a densely populated region receives greater pressure to modify its distribution pattern than an individual in a dispersed population. Lloyd's index, $L = m^*/\bar{X}$, was also calculated, which in turn depends on the relationship between Lloyd's aggregate mean and the sample mean. The interpretation of Lloyd's index is somewhat similar to that of Lloyd's aggregate mean; thus, when L > 1 then $m^* > \bar{X}$, and therefore, L > 1 represents an aggregated distribution pattern.

Results

Abundance of *Trioza aguacate*

From all the shoots samples collected in the 497 days of study at the high altitude site (San Lorenzo), 2,228 eggs and 2,078 nymphs were collected, while 379 adults were collected from the traps at this site. At the medium altitude site (Los Gemelos), from all of the shoots, 1,547 eggs and 2,163 nymphs were collected, and 742 adults were collected from the traps. At the low altitude site (La Fontana), no eggs and no nymphs were detected in any of the shoots sampled, nor were any adults caught in the traps.

At the high altitude site, the highest mean density of *T. aguacate* was in Apr 2012, with 3.94 (SE = 0.574) nymphs per shoot and 2.7 (SE= 0.69) adults per trap. In 2013, the maximum mean densities were 14.1 (SE = 3.43) nymphs per shoot in May, and Mar 1.8 (SE = 0.40) adults per trap .

At the medium altitude site, the maximum mean density was 22.5 (SE = 3.8) nymphs per shoot in Apr, and 11.1 (SE= 1.84) adults per trap in May during the 2012. In the 2013 period, the maximum mean densities were 9.2 (SE = 2.6) nymphs per shoot in Apr, and 1.6 (SE = 0.49) adults per trap in Jan.

With regard to the male: female ratio, the males were found to be more abundant than the females. At the high altitude site, the male: female ratio was 1.6:1 in the 2012 and the 1.3:1 in the 2013 period. In the medium level, the ratio was 2:1 in the 2012 period and the 1.5:1 in 2013.

Population Fluctuation of *T. aguacate*

During the study period (Jan 2012 to Jul 2013), in the orchard located at the medium altitude site (Los Gemelos) and the high altitude site (San Lorenzo), the population fluctuation curves showed 2 well defined periods. The psyllid was present at the at the medium altitude site from Jan to Jun 2012, and from Dec 2012 to Jun 2013 at the high altitude site.

At the low altitude site (La Fontana), the psyllid was not detected in the shoots or in the traps in either period. On this site the higher temper-

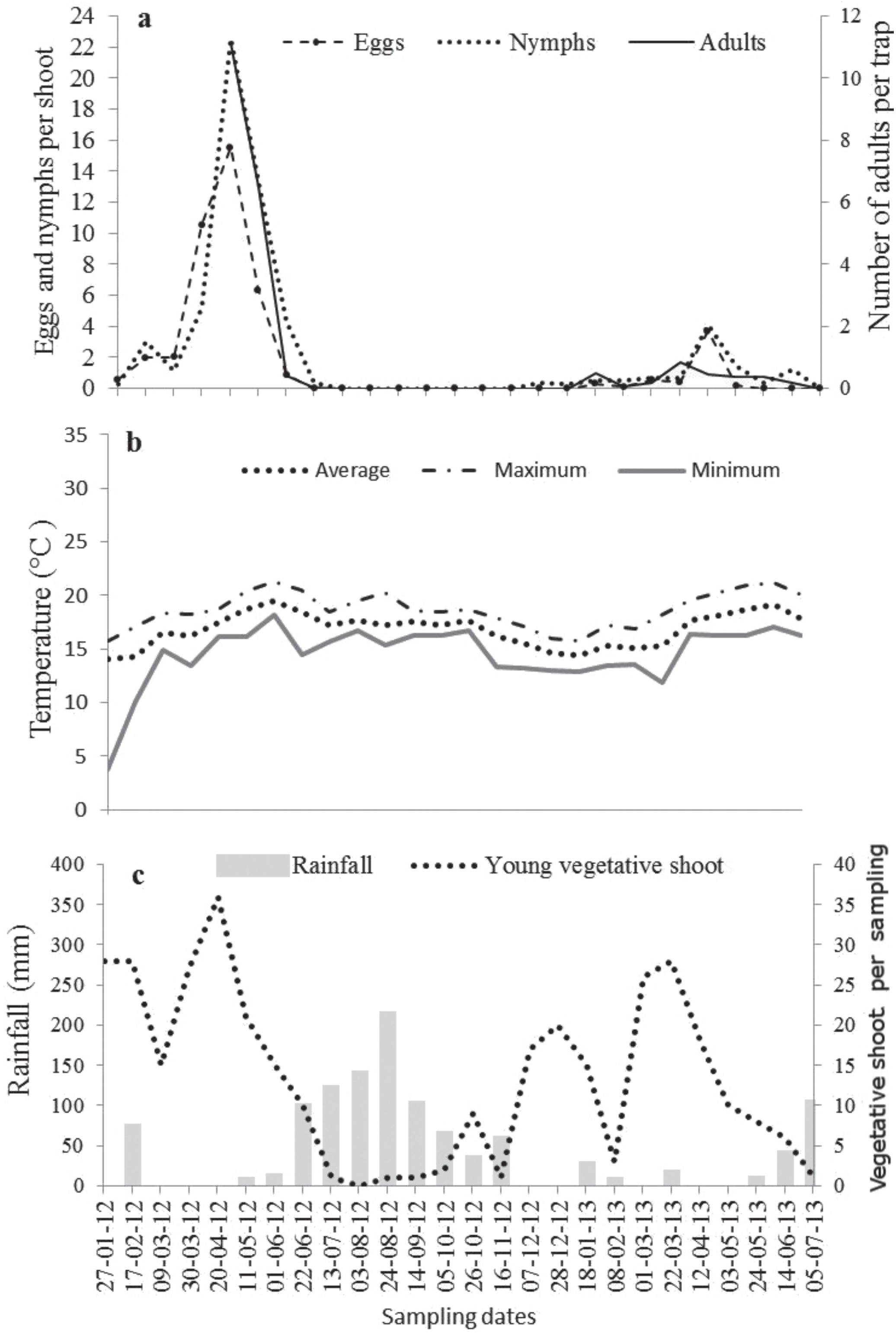

Fig. 1. Population fluctuation of *Trioza aguacate*, meteorological data, and vegetative shoots of avocado, 2012-2013, in the Los Gemelos orchard, located at the medium altitude level (1,860 m); a) Egg, nymph, and adult fluctuation; b) Average, maximum, and minimum temperatures; c) Young vegetative shoots fluctuation and rainfall.

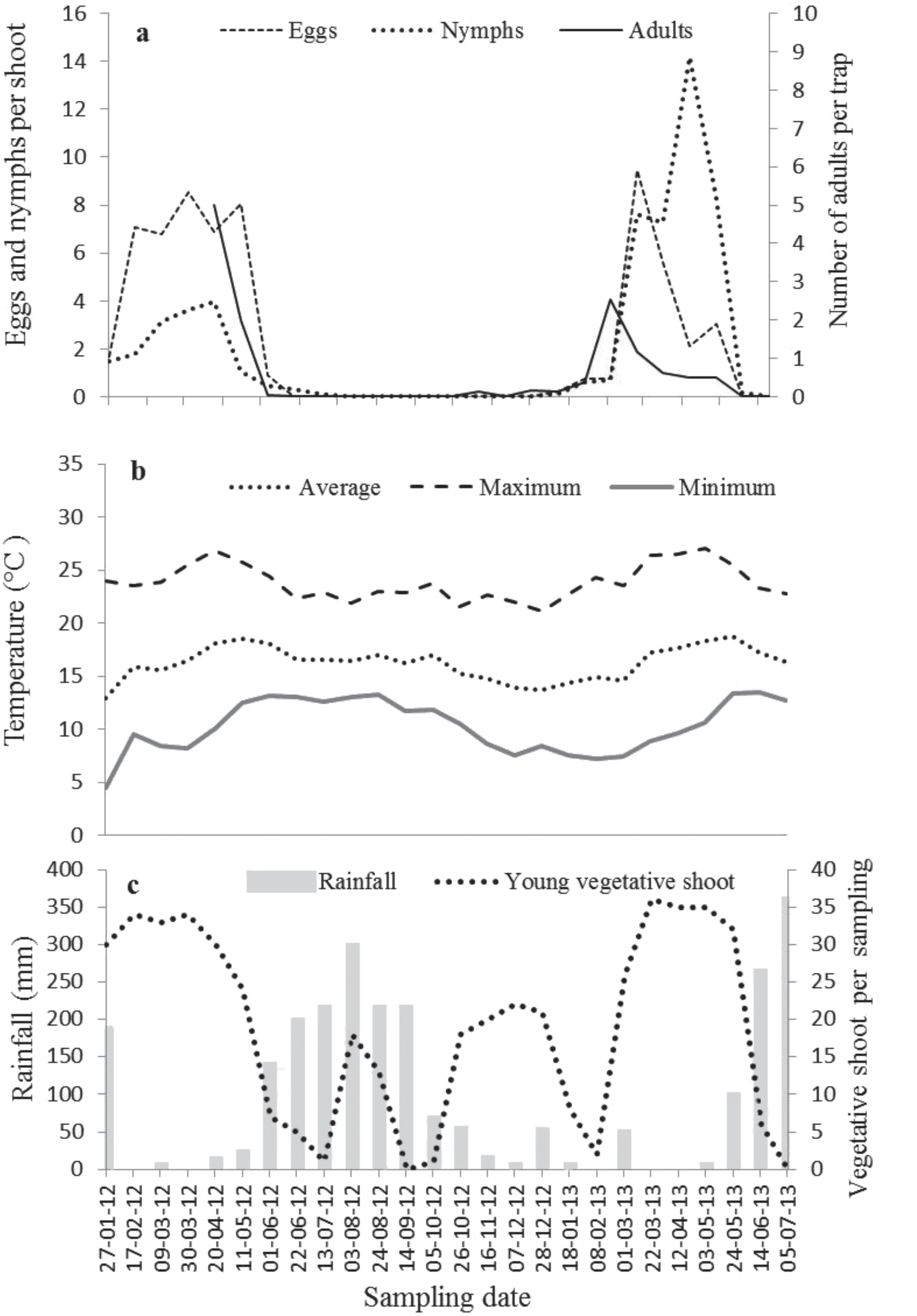

Fig. 2. Population fluctuation of *Trioza aguacate*, meteorological data, and vegetative shoots in avocado, 2012-2013, in the San Lorenzo orchard, located at the high altitude level (2,130 m); a) Egg, nymph, and adult fluctuation; b) Average, maximum, and minimum temperatures; c) Young vegetative shoots fluctuation and rainfall.

atures occurred in Feb (26.2 °C), Mar (28.3 °C), Apr (29.3 °C), May (29 °C), Jun (30.1 °C) and Jul (29.9 °C); the rainfall occurred from early Jun to mid-Oct and vegetative shoots occurred in Apr, Oct, Feb and May.

At the medium altitude site, the first adult psyllids were observed at the beginning of Dec 2012, showing a slight peak in egg and nymph density in the middle of Feb. The maximum population peak were reached in Apr, then the population dwindled in Jun, and became completely absent from Jul to Nov. These trends in abundance were similar in both periods; although the overall population density in the 2013 period was lower than in 2012 (Fig. 1).

At the high altitude site, during the 2012 period, the psyllid was observed since Jan. The eggs showed 3 maximum population peaks, i.e., in Feb, Apr, and May. Nymphs and adults reached their maxima in Apr. The populations decreased in Jun and was totally absent from Jul to Dec. In the 2013 period, the first adults were detected at the beginning of Jan, and reached the maximum population peak by mid-Feb, while the corresponding egg and nymphal peaks came in Mar and Apr, respectively (Fig. 2).

The results of the parameter estimation of the Poisson model are shown in Table 1, where we can see the estimators of the model for each of the parameters and the intercept, standard error, and the probability (*Pr*) values associated with the observed value of the Chi-square test statistic, in the 2 altitude levels where the psyllid was present.

The Poisson models derived from the above table for the medium altitude level (1,860 m) were: $\lambda_{\text{(Eggs)}} = e^{-5.9723 + 0.0886\ S - 0.3506\ R + 0.3464\ T}$ and $\lambda_{\text{(Nymphs}} = e^{-0.3815 + 0.0635\ S - 039308R}{}_{)}$. For the orchard in the high altitude level (2,130 m), the obtained Poisson models were: $\lambda_{\text{(Eggs)}} = e^{-3.3489 + 0.0852\ S - 0.0862\ R + 0.4857\ T}$ and $\lambda_{\text{(Nymphs)}}\, e^{-1.7457 + 0.085\ S - 0.862\ R + 0.1780\ T}$. In these equations λ represents the development stage of *T. aguacate*, S represents the young vegetative shoots, R is the mean rainfall every 20 days, and T is the mean temperature.

The previously described models explain a positive relationship between egg and nymph density and the number of young vegetative shoots, and a negative relationship with rainfall. Also the models indicated that the eggs showed a positive relationship with temperature at both altitude levels. The nymphs showed a positive relationship with temperature only at the high altitude level, while in the medium altitude level, the relationship was non-significant. In the case of adults, the relationships with the parameters of young vegetative shoots, rainfall, and temperature were non-significant in the model (Table 1) in both orchards.

TABLE 1. PARAMETERS ESTIMATED WITH THE POISSON MODEL, CONSIDERING THE NUMBER OF EGGS, NYMPHS, AND ADULT *TRIOZA AGUACATE* IN AVOCADO ORCHARDS AT TWO ALTITUDE LEVELS IN MICHOACAN, MEXICO.

		Medium altitude level (1,860 m)			High altitude level (2,130 m)		
Stage of development	Parameter	Estimator	Standard error	Pr > ChiSq	Estimator	Standard error	Pr > ChiSq
Eggs	Intercept	-5.9723	1.3385	<.0001	-3.2370	1.2462	0.0094
	Vegetative shoots	0.0886	0.0118	<.0001	0.0281	0.0134	0.0357
	Rainfall	-0.3506	0.1349	0.0093	-1.2397	0.4948	0.0122
	Temperature	0.3464	0.0711	<.0001	0.2709	0.0859	0.0016
Nymphs	Intercept	-0.3815	1.0853	0.7252	-4.6990	1.2510	0.0002
	Vegetative shoots	0.0635	0.0111	<.0001	0.0181	0.0096	0.0500
	Rainfall	-0.3938	0.1127	0.0005	-0.0922	0.0358	0.0100
	Temperature	0.0610	0.0597	0.3074	0.3592	0.0788	<.0001
Adults	Intercept	-14.9928	4.8702	0.0021	0.7221	4.6405	0.8763
	Vegetative shoots	0.1425	0.0285	<.0001	0.0560	0.0457	0.2210
	Rainfall	-0.7300	0.8642	0.3983	-1.1122	1.2363	0.3683
	Temperature	0.7063	0.2486	0.0045	-0.1135	0.3322	0.7326

TABLE 2. AGGREGATION INDICES CALCULATED WITH THE MEAN NUMBER OF *TRIOZA AGUACATE* NYMPHS AND ADULTS PER SAMPLING AT THE MEDIUM ALTITUDE AVOCADO ORCHARD AT SALVADOR ESCALANTE, MICHOACAN, MEXICO.

	Nymphs			Nymphs		
Sampling	Morisita index	Lloyd index	Spatial distribution	Morisita index	Lloyd index	Spatial distribution
2012 period						
27/01/12	1.25	1.25	Aggregated	NS	NS	NS
07/02/12	1.85	1.95	Aggregated	NS	NS	NS
09/03/12	2.71	2.88	Aggregated	NS	NS	NS
30/03/12	1.3	1.33	Aggregated	NS	NS	NS
20/04/12	1.25	1.29	Aggregated	1.16	1.18	Aggregated
11/05/12	1.66	1.74	Aggregated	2.15	2.9	Aggregated
01/06/12	1.55	1.62	Aggregated	1.63	1.66	Aggregated
22/06/12	4.64	4.75	Aggregated	0	0.44	Regular
2013 period						
07/12/12	2.54	2.6	Aggregated	SP	SP	SP
28/12/12	3.0	2.5	Aggregated	SP	SP	SP
18/01/13	2.89	3.0	Aggregated	3.0	3.16	Aggregated
08/02/13	1.85	1.9	Aggregated	0	0.44	Regular
01/03/13	1.53	1.57	Aggregated	1.2	1.19	Aggregated
22/03/13	3.9	4.13	Aggregated	1.1	1.09	Aggregated
12/04/13	2.27	2.42	Aggregated	1.47	1.5	Aggregated
03/05/13	1.95	2.05	Aggregated	1.18	1.19	Aggregated
24/05/13	1.73	1.76	Aggregated1	3.58	3.68	Aggregated
14/06/13	2.56	2.71	Aggregated	SP	SP	SP

SP = without psyllid presence; NS = not sampled

TABLE 3. AGGREGATION INDICES CALCULATED WITH THE MEAN NUMBER OF *TRIOZA AGUACATE* NYMPHS AND ADULTS PER SAMPLING AT THE HIGH ALTITUDE AVOCADO ORCHARD AT SAN LORENZO, URUAPAN, MICHOACAN, MEXICO.

	Nymphs			Nymphs		
Sampling	Morisita index	Lloyd index	Spatial distribution	Morisita index	Lloyd index	Spatial distribution
2012 period						
27/01/12	1.42	1.46	Aggregated	NS	NS	NS
07/02/12	1.33	1.36	Aggregated	NS	NS	NS
09/03/12	1.42	1.47	Aggregated	NS	NS	NS
30/03/12	1.16	1.18	Aggregated	NS	NS	NS
20/04/12	1.28	1.32	Aggregated	1.33	1.36	Aggregated
11/05/12	1.5	1.55	Aggregated	2.46	2.61	Aggregated
01/06/12	2.18	2.87	Aggregated	0	0.44	Regular
22/06/12	1.1	1.09	Aggregated	SP	SP	SP
13/07/12	3.6	3.34	Aggregated	SP	SP	SP
2013 period						
28/12/12	SP	SP	SP	1.2	1.19	Aggregated
18/01/13	0.9	0.91	Regular	3.6	3.34	Aggregated
08/02/13	2.1	2.19	Aggregated	1.68	1.71	Aggregated
01/03/13	2.7	2.87	Aggregated	1.15	1.16	Aggregated
22/03/13	1.2	1.22	Aggregated	1.06	1.06	Aggregated
12/04/13	1.8	1.88	Aggregated	1.25	1.27	Aggregated
03/05/13	2.1	2.25	Aggregated	1.12	1.13	Aggregated
24/05/13	1.7	1.78	Aggregated	2.76	2.88	Aggregated
14/06/13	4.2	4.0	Aggregated	SP	SP	SP

SP=without psyllid presence; NS = not sampled

Spatial Distribution

At the medium altitude site, the Morisita and Lloyd aggregation indices indicated that the spatial distributions in the vegetative shoots of *T. aguacate* nymph population were aggregated during the sampling periods (Table 2). Also the spatial distribution of the adults sampled by trap was aggregated, with the exception of the last sampling in 2012 and the sampling done in Feb 2013, when the index values were less than one. This latter value indicates a regular or uniform spatial distribution, which occurred, perhaps, because the population density was too low and the probability of finding an individual at the same point was low (Table 2).

At the high altitude site, in both periods (2012 and 2013), the calculated aggregation indices for the nymph population were greater than 1 in nymphs, thus indicating an aggregated spatial pattern. The adults showed the same distribution patterns as the nymphs based on aggregation indices. Thus both the nymph and adult populations had aggregated spatial distribution patterns in most samplings, with the exceptions of the last one of 2012 and the first sampling of 2013, in which the spatial distribution pattern was uniform (Table 3).

Discussion

At the high altitude site the abundances of the *T. aguacate* eggs, nymphs, and adults were slightly less in the 2012, than in the 2013 (0.82% fewer psyllids in 2012). At the medium altitude site, the abundances of eggs, nymphs, and adults were 17.62% higher in 2012 than in 2013. This could be because at the beginning of Jan, this orchard was sprayed with imidacloprid insecticide for thrips control, which coincided with the first appearance of *T. aguacate* adults, and which probably hindered oviposition. Thus the *T. aguacate* population density was artificially reduced.

Regarding population fluctuations, *T. aguacate* was present only from Jan to Jun at the high altitude site and from Dec to Jun at the medium altitude site. At these sites, there was a significant population decrease, and drastic disappearance of *T. aguacate* from Jul to Nov or Dec, depending on the altitude level. Probably this was due to the negative effect that rainfall has on population density . It is worth mentioning that in both orchards where *T. aguacate* was present, there were numerous avocado shoots from Mar to Apr, since at the high altitude site (San Lorenzo orchard) adequate soil moisture was provided by the rains that are normally present in the Valles Altos (highlands), while at the medium altitude site (Los Gemelos orchard), where rainfall in spring is deficient, soil moisture was provided by auxiliary irrigation.

At the 2 altitudes where the psyllid was present, there were strong correlations with vegetative avocado shoots, thus indicating that the abundance of eggs and nymphs greatly depends on the presence of young vegetative shoots. This brings about a notable increase of the population of the insect, since with the increase of new foliage in the tree, the conditions for adults to lay their eggs and the availability of young leaf tissue needed to feed nymphs are favored. This phenomenon is similar to that reported by Barbosa et al. (2004), who indicated that the eggs and nymphs of *Tuthillia cognata* Hodkinson, Brown & Burckhardt (Hemiptera: Psylloidea) in different development stages are located on the younger leaves of the upper third of the camu-camu plant, *Myrciaria dubia* (Kunth) McVaugh (Mytales: Myrtaceae) and Tsai et al. (2002), meanwhile, related the high population levels of the Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) to the availability of young shoots.

The highest densities of *T. aguacate* were observed (for all development stages) before the beginning of the rainy season, when rainfall was scarce (0-5.2 mm). This was verified with the moderate to high negative relationship between population densities of all development stages and rainfall at both altitudes. It was observed that when rainfall increased, the densities of all development stages of *T. aguacate* tend to decrease. These results coincide with the behavior of other psyllids, as reported by Pinedo et al. (2001) and Delgado & Couturier (2004), who pointed out that the greatest infestations of *Tuthillia cognata* occurred during the dry season, and populations decreased in the rainy season. Likewise, Dalberto et al. (2004) stated that the rainy season caused a decrease in the populations of the psyllid *Triozoida limbata* (Enderlein) (Hemiptera: Triozidae) in *Inga edulis* Mart. (Fabales: Fabaceae) trees in the Amazon in Brazil.

With regard to temperature, the model showed a positive relationship with eggs ($\alpha = 0.3464$, $P = < .0001$) at both altitude levels, and with nymphs ($\alpha = 0.3464$, $P = <.0001$) only at the high altitude level; and non-significant with nymphs ($\alpha = 0.2709$, $P = 0.0016$) at the medium altitude level. Adult density was non-significant ($\alpha = -0.1135$, $P = 0.7326$) at the high altitude level, however, there was a negative tendency at this stage of development. In the low altitude level (1,293 m), the psyllid was not present. In this area, the maximum temperatures were 28.6, 29.6, and 30.1 °C in Mar, Apr, and May, respectively. It is probable that high temperatures restrict the development of the psyllid, since it is in these months when the insect is present in the other 2 studied altitude levels. This behavior is also shown by *D. citri*, which at temperatures above 28 °C, decreases egg and nymph survival and affects female longevity and decreases egg production (Liu & Tsai, 2000). In the case of *Heteropsylla cubana*, temperatures from 32 to 33 °C, considerably increase the first nymph instars (Geiger & Gutierrez, 2000).

With regard to the spatial distribution of the psyllid, we found that nymphs and adults showed an aggregated distribution pattern during most of the samplings in both periods and at both altitude. Based on these results, the population generally tends to aggregate following the time of greatest shoot growth, and mainly in the egg and nymph development stages. This aggregated distribution is also shown by the different development stages of the psyllid *T. cognata* in camu-camu (Pérez & Iannacone 2009) and of the citrus psyllid *D. citri* in *Murraya paniculata* (L.) Jack (Sapindales: Rutaceae) in southern Florida (Tsai et al. 2002) and in la Habana, Cuba (Miranda et al. 2011). Nevertheless, in the last adult samplings from the traps in the 2012 period, at both altitudes, the aggregation index values were less than one, showing a uniform distribution pattern. This indicates that the probability of finding an individual in the same space as another decreases, which is probably due to the low population density present at the beginning of each period, when the first individuals appear and at the end of each period when the density declines due to the lack of vegetative shoots and the presence of rainfall.

In summary, this study showed that *T. aguacate* in Michoacan Mexico was present only from Jan to Jun at the high altitude site and from Dec to Jun at the medium altitude site, coinciding with the presence of spring avocado vegetative flower shoots and little or no rainfall. *Trioza aguacate* was not present at the low altitude level despite the presence of avocado vegetative shoots. All the development stages of *T. aguacate* showed negative relations with rainfall. According to the computed aggregation indices, nymphal and adult populations had aggregated spatial distributions on the avocado shoots.

ACKNOWLEDGMENTS

We thank B.Sc. Hector Guillen León, B.Sc. Jose Luis Caballero, B.Sc. Enrique Figueroa Juarez, Mr. Idelfonso Ponce Rubio and Mr. Alejandro Guerrero Vazquez, who are in charge and their owner of the orchards sampled. The first author acknowledges financial support for graduate studies with a scholarship from CONACYT.

REFERENCES CITED

BARBOSA, M. L. L., ACIOLI , A. N. S., OLIVEIRA , A. N., SILVA, N. M., AND CANTO, S. L. O. 2004. Ocorrência de *Tuthillia cognata* Hodkinson, Brown & Burckhardt, 1986 (Hemiptera: Homoptera, Psyllidae) em plantios experimentais de camu-camu *Myrciaria dubia* (H.B.K.) Mc Vaugh tem Manaus (Amazonas, Brasil). Acta Amazónica 34: 115-119.

CADAHIA, D. 1977. Repartición espacial de las poblaciones en entomología aplicada. Bol. Servicio de Defensa Contra Plagas 3: 219-233.

DALBERTO, F. M. S., MENEZES, JR. A., SIMOES, H. C., BENITO, N. P., AND PITWAK, J. 2004. Population dynamic of guava psyllid *Triozoida limbata* (Hemiptera: Psyllidae) in Londrina Paraná, Brazil. Ciências Agrárias, Londrina 25(2): 87-92.

DELGADO, C., AND COUTURIER, G. 2004. Manejo de insectos plagas en la Amazonía: su aplicación en camu camu. IIAP- Iquitos/ IRD-Francia, Lima, Perú. 147 pp.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAOSTAT). 2013. Producción mundial de aguacate. Disponible en: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E .

GEIGER, C. A., AND GUTIERREZ, A. P. 2000. Ecology of *Heteropsylla cubana* (Homoptera: Psyllidae): Psyllid damage, tree phenology, thermal relations, and parasitism in the field. Environ. Entomol. 29(1): 76-86.

HOLLIS, D., AND MARTIN, J. H. 1997. Jumping plantlice (Hemiptera: Psylloidea) attacking avocado pear trees, *Persea americana*, in the New World, with a review of Lauraceae-feeding among psylloids. Bull. Entomol. Res. 87: 471-480.

LIU, Y. H., AND TSAI, J. H. 2000. Effects of temperature on biology and life table parameters of the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Homoptera: Psyllidae). Ann. Applied Biology 137: 201-206.

LLOYD, M. 1967. Mean crowding. J. Animal Ecol. 36: 1-30.

MIRANDA, I., BAÑOS H., PEREZ , Y., AND DE LOS ANGELES, M. 2011. Patrón espacial y parámetros de crecimiento de *Diaphorina citri* Kuwayama y su parasitoidede *Tamarixia radiata* Waterston sobre *Muraya paniculata* Linn. Rev. Prot. Vegetal 26(2): 100-104.

PINEDO, M., RIVA, R., RENGIFO, E., DELGADO, C., VILLACRÉS, J., GONZÁLES, A., INGA, H., LOPEZ, A., FARROÑAY, R., VEGA, R., AND LINARES, C. 2001. Sistema de Producción de camu camu en Restinga. Programa de Ecosistemas Terrestres. Instituto de Investigaciones de la Amazonia peruana Proyecto Bioexport camu camu, Perú. 136 pp.

PÉREZ, D., AND IANNACONE, J. 2009. Fluctuación y distribución espacio-temporal de *Tuthillia cognata* (Hemiptera, Psyllidae) y de *Ocyptamus persimilis* (Diptera, Syrphidae) en el cultivo de camu-camu *Myrciaria dubia* (Myrtaceae) en Ucayali, Perú. Rev. Brasileira Entomol. 53(4): 635-642.

SAS SOFTWARE. 2002. Version 9.0. SAS Institute, Cary, NC.

SERVICIO DE INFORMACIÓN AGROALIMENTARIA Y PESQUERA (SIAP). 2012. Producción agrícola nacional y estatal de aguacate. http://www.siap.gob.mx/index . .php?option=com_wrapper&view=wrapper&Itemid=351).

TSAI, J. H., WANG, J. J., AND LIU, Y. H. 2002. Seasonal abundance of the Asian citrus psyllid, *Diaphorina citri* (Homoptera: Psyllidae) in Southern Florida. Florida Entomol. 85(3): 446-451.

WYSOKI, M., VAN DEN BERG, M. A., ISH-AM, G., GAZIT, S., PEÑA, J. E., AND WAITE, G. K. 2002. Pests and pollinators of avocado, pp. 223-293 *In* J. E Peña; J. L Sharp and M. Wysoki [eds.], Tropical Fruits Pests and Pollinators: Biology, Economic Importance, Natural Enemies and Control. CAB International, Wallingford, UK.