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Mapping of Spatial Behavior of *Scirtothrips perseae* (Insecta: Thysanoptera) in Avocado Orchards Using Geostatistical Techniques

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ABSTRACT

Currently, the implementation of efficient programs of integrated pest management are of vital importance, especially due to the fact that avocados produced in the study area are sold abroad. This favors the adoption of new technologies to reduce the application of agrochemicals and perform integrated pest management more effectively. The objective of the research was to determine the spatial distribution of thrips in commercial avocado orchards. To conduct the mapping of the spatial distribution, geostatistics was used, since it allows to know the location and mobility patterns of the pest, the present study was carried out in the municipality of Donato Guerra in 2019, Donato Guerra is located in the central zone of Mexico, and it is among the main avocado producers of the state. The distribution of the pest insect was incorporated for all the samples, these samples were taken every fifteen days for a year, obtaining 24 samplings in total. A semivariogram was determined for each sampling date, these semivariograms were adjusted to spherical models in most of the cases, the level of spatial dependence was determined to be high in all dates. The infested area was calculated for all the samplings and maps of pest were made through the kriging technique.

Keywords: Kriging, semivariograms, avocado, spatial distribution.

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INTRODUCTION

Avocado (*Persea americana* Mill.) ranks first in capital inflow from exports of agricultural products of Mexico (SE, 2019); the south-central zone of the country-particularly states like Mexico, Puebla and Morelos- have acquired in the last few years a great importance in production and commercialization of this crop, ranking second place in production at national level, (SIAP, 2019). By increasing the area under cultivation, phytosanitary problems increased as well, pest like thrips, whitefly, borers, scale insects, among others damaged not only the orchards but the commercial quality of the fruit. The insects commonly called thrips are found in the crop feeding on the small fruits (Salgado, 1993), their damage can be seen through the ridges and bumps protruding in the pericarp (González et al, 2000); these deformations become more visible as the fruit reaches maturity (Fisher & Davenport, 1989; González et al, 2000). Species like; larvae and adults of *Scirtothrips perseae*, cause damage on young foliage, creating distortion and dark scars on the underside of the leaf, along the leaf veins; something similar happens to the young fruit, which can become completely covered by a dark scar. Although, frequently more small scars can be observed, and occasionally elongated scars are observed as well, (Ascensión et al, 1999; Johansen, Mujica, & Ascensión, 1999; Hoddle, 2002), this symptom associated to thrips causes major damage, because it represents huge economical losses for avocado growers, due to the rejection of the product as exportation quality fruits.

A tool being used to monitor pests like thrips in avocado is geostatistics, because it provides a more accurate measure of behavior and spatial distribution in avocado orchards; these tools consider the bidimensional nature of the distribution of organisms through their exact spatial location, besides, this distribution may be represented through maps that are very useful in decision making (Isaaks & Srivastava, 1988; Rossi, Mulla, Journel, & Franz, 1992; Sciarretta, Trematerra, & Baumgartner, 2001; Blom & Fleischer, 2001; Ramírez, González, Ocete, & López, 2002). The objective of this research was to characterize the spatial distribution of *Scirtothrips perseae* in commercial avocado orchards that allow to know graphically the spatial distribution of the pest insect and its location in time and space.

MATERIALS AND METHODS

The study was carried out in 2019 from January to December, in Donato Guerra, State of Mexico; This site has appropriate characteristics for avocado production, such as an average altitude of 2,200 masl, an annual average temperature of 19.2 degrees Celsius, and an average rainfall of 1,000 mm. For this study, four plots were selected, one in each cardinal point of the municipality, each one with an area of four hectares, at the same time, weed control was carried out conventionally in each plot (agricultural machinery was used). Also, 200 trees were randomly selected, all of them without insecticides treatment, each tree was georeferenced using DGPS (Trimble Brand, PRO-XR model) to establish its geographic coordinates, the sampling was carried out twice a month, to obtain a total of 24 samplings throughout the year.

To count thrips, number eight yellow plastic cups (Plastifestival brand) covered with a commercial adhesive (spider-plus) were used as recommended by (Hernández, Ramos, De la Paz, & González, 1999). Sixteen glasses distributed in each tree were placed, 3,200 glasses in total for the entire experimental unit, four glasses were placed in each cardinal point of the tree, the count was done visually and manually, to later place the glass in the same place, where it was first placed. Later they were identified in the Entomology Laboratory of the Faculty of Agricultural Sciences of the Autonomous University of the State of Mexico. A statistical analysis was performed on the original data of the *Scirtothrips perseae* populations for each sampling in order to evaluate normality; for this, the asymmetry coefficient and the kurtosis test were performed. All the data was found to have a normal distribution.

The geostatistical analysis was carried out with the estimation of the semivariogram, which was done based on the acquired data from the samplings of thrips populations (Journel & Huijbregts, 1978; Isaaks & Srivastava, 1989).

The experimental semivariogram for each sampling in the experimental plots was performed using the program Variowin 2.2 (Software for Spatial Data Analysis in 2D. Spring Verlag, New York; USA).

Once the experimental semivariograms corresponding to each sampling date of the different stages were estimated, they were adjusted to a theoretical semivariogram. The level of spatial dependence was calculated in order to determine how strong the relationship between the obtained data and the theoretical model was. This value is obtained dividing the nugget effect by the sill, expressed in percentage: less than 25% is high; between 26 and 75% is moderate and over 76% is low (Cambardella et al*,* 1994; López et al, 2002). The corroboration of the adjusted models to the experimental semivariograms was carried out with the cross validation procedure (Isaaks and Srivastava, 1989), which eliminates a sample value. The geostatistical interpolation method called kriging, as well as, the model of the semivariogram being validated were used to estimate the value of the variable of interest at any given sampling point. The parameters of the model being validated are the nugget effect, the sill and the range, they are modified in a trial and error procedure until the cross validation statistics are obtained.

The statistics are the following: mean of the estimation errors (MEE), mean square error (ECM), dimensionless mean square error (ECMA); an additional statistic to validate the aptitude of the model consists in the variance of errors being less than the variance of the sample.

Once the semivariograms were obtained, mapping of density of thrips was carried out using the ordinary kriging technique (this method was used since the sample mean and sample variance had been determined). Kriging technique is an accurate estimate and its equations do not depend on the values measured, but on their positions and the semivariogram they do. This technique also allows the possibility of obtaining maps of the spatial distribution of the studied organisms, which, in turn, have wide usefulness (Samper & Carrera, 1996). Kriging was performed with the program Surfer

9.0, the estimations are represented through maps for each adult sampling date. The infested area was calculated with the obtained maps (Sánchez, Ramírez, González, & De León, 2011; Ramírez, Solares, Figueroa, & Sánchez, 2013).

RESULTS AND DISCUSSION

The presence of *Scirtothrips perseae* was registered in all 24 samplings carried out in the municipality of Donato Guerra; results show that for the first sampling in March the highest population density was found with 46.7 organisms per tree, on the other hand, November presented the lowest population density with only 2.11 organisms per tree. It is important to mention that the highest population densities were found when the phenological stage corresponded to flowering, as mentioned by Quiñones et al (2015) who argue that the highest population densities of thrips are due to the presence of flowers in the avocado tree, therefore, the damage reflected on the fruit is explained by the presence of the organisms when there were still in the flowering stage.

The semivariograms were adjusted mostly to spherical models, except the second sampling in July, which was adjusted to a Gaussian model (Table 1). In reference to the geostatistical analysis, the spatial dependence was high in all sampling dates, which is attributed to the existence of a high spatial ratio in each sampling point. Regarding the parameter nugget effect, its value was zero in all sampling dates, indicating a minimal sampling error, so the sampling scales were appropriate for this study. The simple ranges fluctuated between 25.19 in July and 58.9 in September (Table 1). The range values found, express that the validity of the adjusted models extents to reasonable distances to explain the phenomena aggregation of the insect population.

Table 1. Parameters (Pepita Effect, Plateau and Range) of the models fitted to the semivariograms of *Scirtothrips perseae* in Donato Guerra, State of Mexico.

Month	Model	Sample mean	Range	Sill	Nugget	Spatial dependence level
January 1	Spherical	4,57	45,60	17,06	0	High
January 2	Spherical	6,26	43,10	25,70	0	High
February 1	Spherical	15,00	44,39	139,50	0	High
February 2	Spherical	34,28	39,86	649,20	0	High
March 1	Spherical	46,70	38,62	728,87	0	High
March 2	Spherical	27,94	43,22	311,57	0	High
April 1	Spherical	5,44	45,32	17,40	0	High
April 2	Spherical	6,41	45,62	18,67	0	High
May1	Spherical	4,89	41,80	10,75	0	High
May2	Spherical	4,16	49,40	10,60	0	High
June 1	Spherical	3,49	44,12	9,41	0	High
June 2	Spherical	2,15	57,03	4,16	0	High
July 1	Spherical	6,39	53,47	27,77	0	High
July 2	Gaussian	10,15	25,19	114,05	0	High
August 1	Spherical	14,33	54,00	108,75	0	High
August 2	Spherical	11,18	52,20	85,44	0	High
September 1	Spherical	5,72	55,80	19,48	0	High
September 2	Spherical	4,71	58,90	11,92	0	High
October 1	Spherical	3,83	47,50	8,16	0	High

Table continued

Month	Model	Sample mean	Range	Sill	Nugget	Spatial dependence level
October 2	Spherical	4,54	55,10	9,31	0	High
November 1	Spherical	4,83	57,00	10,52	0	High
November 2	Spherical	2,11	41,80	3,18	0	High
December 1	Spherical	5,19	54,40	11,39	0	High
December 2	Spherical	7,76	45,00	11,58	0	High

Table 2. Values of the cross validation statistics of the semivariograms obtained in the samplings in the municipality of Donato Guerra: mean of the estimation errors (MEE), mean square error (ECM) and dimensionless mean square error (ECMA).

Month	Sampling	Sample mean	Sample variance	MEE	Error variance	ECM	ECMA
January	1	4,57	18,28	0,14 ns	11,65	0,13	1,11
January	2	6,26	28,91	0,11ns	19,03	0,10	1,10
February	1	15,00	145,62	0,10ns	101,29	0,11	1,13
February	2	34,28	668,43	0,09ns	388,07	0.08	1,09
March	1	46,70	749,54	0,13ns	451,04	0,11	1,06
March	2	27,94	410,85	0,10ns	214,98	0,13	1,12
April	1	5,44	19,98	0,12ns	10,52	0,14	1,10
April	2	6,41	21,90	0,07ns	16,77	0,07	1,08
May	1	4,89	24,78	0,11ns	20,53	0,09	1,11
May	2	4,16	10,99	0,08ns	8,13	0,06	1,13
June	1	3,49	9,69	0,10ns	7,48	0,11	1,11
June	2	2,15	4,48	0,12ns	2,71	0,12	1,09
July	1	6,39	23,47	0,09ns	18,51	0,10	1,06
July	2	10,15	278,51	0,14ns	176,31	0,13	1,08
August	1	14,33	130,90	0,10ns	111,90	0,08	1,14
August	2	11,18	109,14	0,13ns	96,42	0,14	1,10
September	1	5,72	22,76	0,08ns	15,06	0,11	1,12
September	2	4,71	12,31	0,07ns	9,59	0,12	1,06
October	1	3,83	8,55	0,11ns	6,22	0,08	1,33
October	2	4,54	10,26	0,14ns	7,05	0,13	1,11
November	1	4,83	11,61	0,12ns	8,59	0,07	1,14
November	2	2,11	3,72	0,09ns	1,96	0,11	1,10
December	1	5,19	11.92	0,10ns	8,37	0,06	1,08
December	2	7,76	2,32	0,08ns	1,50	0,13	1,32

To calculate the infested area, the density maps prepared by the kriging method were used. The infested area was calculated for each sampling date (Table 3), this studied area surpassed 50% in every sampling date, even in four sampling dates, it reached 99%; the lowest value found was 56%. The affected area is not directly linked to the population fluctuation, this means there can be high rates of infested area, but low population fluctuation. This calculation is used to know how the pest behaves in regards to its adaptation within the crop.

Table 3. Infested and non-infested area (%) obtained in the sample of *Scirtothrips persea* in the central zone of Mexico.

Month	Sample	% infested	% non-infested
January	1	84	16
January	2	99	1
February	1	81	19
February	2	82	18
March	1	93	7
March	2	91	9
April	1	86	16
April	2	64	36
May	1	94	6
May	2	86	14
June	1	80	20
June	2	71	29
July	1	56	44
July	2	62	38
August	1	77	23
August	2	70	30
September	1	85	15
September	2	67	33
October	1	65	35
October	2	68	32
November	1	97	3
November	2	99	1
December	1	99	1
December	2	99	1

Another key tool in the spatial analysis of pests is density mapping (Fig. 1), as mentioned before, in the present study, 24 samplings were taken, the infestation maps graphically show the pest behavior in the study zone, aggregation centers of the pest were observed, this confirms the models of the semivariograms that each sampling date was adjusted to.

Papers like the one of Maldonado et al (2016) show the spatial distribution of insects, in this case the semivariograms of the spatial distribution of thrips were adjusted to a spherical model which in biological terms implies that the insects were present in some points more than in others. This means that there were aggregation centers of the pest which was also found in the works of Jiménez et al (2013), who studied the spatial distribution of thrips in husk tomato crops. The Gaussian model found in July indicates that the pest has a continuous distribution within the plot which implies an expansion within it, (Alves et al, 2006).

The elaboration of density maps used in pest behavior studies as reported by Quiñones et al (2015) the spatial distribution and infestation maps of thrips in gladiolus crops, and Jiménez et al (2013) who did the same in husk tomato crops, found out that the insects were found in aggregation centers. Density maps may be very useful in an integrated management of thrips, since it makes possible the direct control measures towards the specific infestation points which can be located in the map, as reported by García (2004).

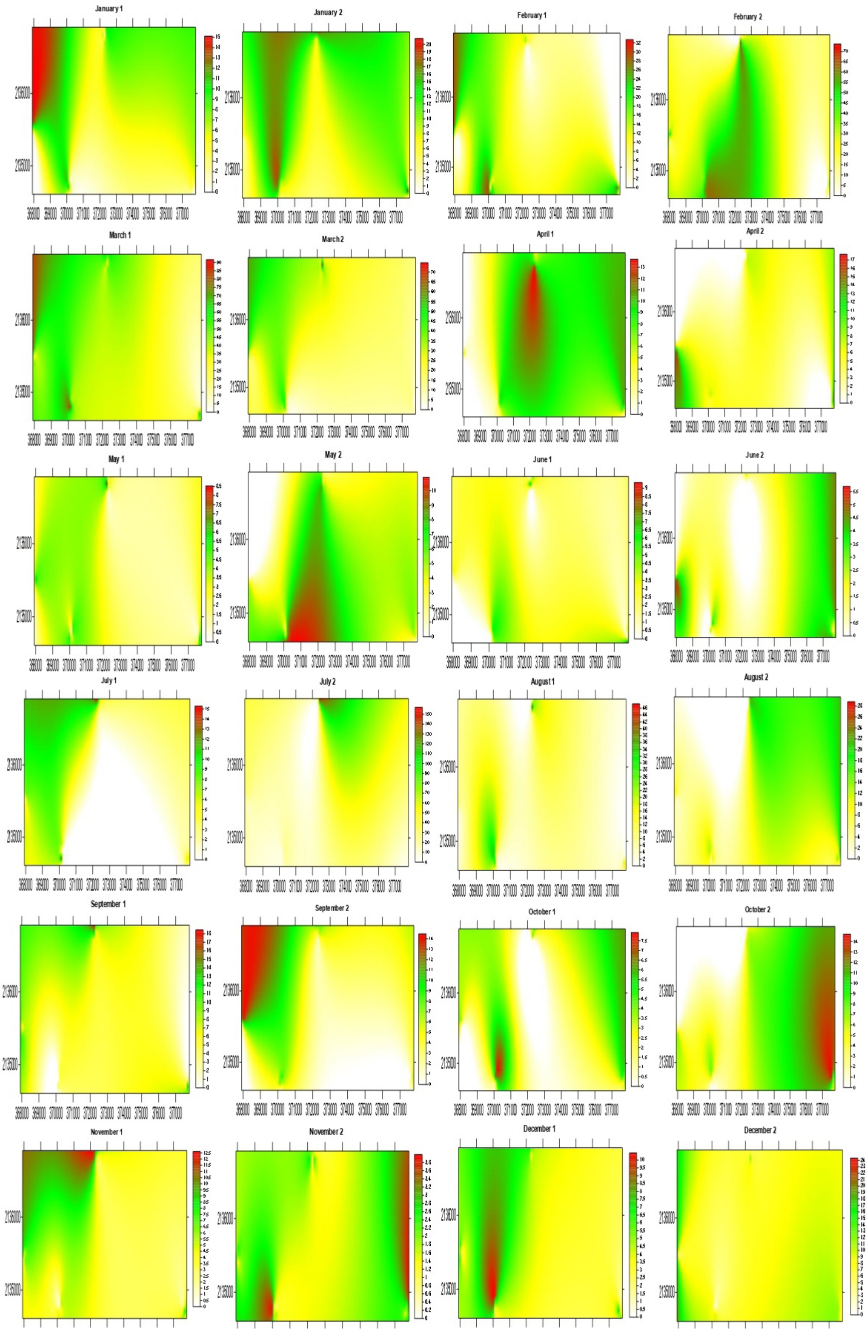

Figure 1. Density maps of *Scirtothrips perseae* populations obtained in the samplings.

The correct way to interpret the maps of each sampling is using the scale found next to the map, the color scale corresponding to a certain density within the crop can be found there. Even though, the maps seem to present the same color, it is necessary to visualize the scale because months like February and March presented the highest densities of *Scirtothrips perseae.* (Fig. 1), whereas, November and December presented the lowest densities but coloring looks the same than the rest of the months. Knowing how to interpret these maps aid within decision making that directly affect the control of this pest that causes considerable losses in the crop.

Fortnightly sampling provides an overview of the pest behavior throughout the year, so decision making can diminish the damage thrips cause to the avocado crop, which would lead to higher productions and therefore higher profits for avocado growers.

A difference was observed in the aggregation center maps obtained, compared with the ones obtained by Maldonado et al (2016) that showed a spatial behavior a little different from the thrips in general. In the second, the aggregation center was more delimited and the ones obtained in this study were more gradual and at certain points they resembled lines throughout the plot, biologically this difference can be due to the fact that in this study only *Scirtothrips perseae* was sampled and in the study mentioned above it included thrips in general.

The usage of geostadistics when studying pests behavior allows to know the fluctuation and position of the agents within the plot, which is a great aid since targeted control methods can be used; these methods can result in significant savings in the application of chemical products or alternative methods, as the control is directed to aggregation zones, which also translates in a lower environmental impact (Schotzko & O'keeffe, 1988; Bautista, Cordona, & Soto, 2013). One of the most common thrips control methods is an insecticide spinosad commercially known as Spintor, this product acts very effectively in the control of thrips. Knowing how the pest behaves spatially, targeted applications can be made on population niches, therefore, economical savings can be obtained. Another alternative is the usage of predators as reported by Ramírez et al (2018) who used *Orius insidiousus* obtaining a decrease in thrips populations, as well as, Acosta et al (2017) who used *Amblyseius swirskii* in the control of this plague.

For a better spatial analysis of pests and diseases in agricultural crops, it is important to determine the level of infestation in the area, this knowledge will allow us to determine the actions to control and prevent pests. In the present study, the infested area was determined for the 24 samplings (Table 3), infestation higher than 80% was found in most of the sampling carried out. Papers like Esquivel and Jasso (2015) also showed percentages of infestation in the studied plots; there is no relationship between the percentage of infestation and the density of infestation, levels of infestation found were high but the density was low which do not exceed the economic thresholds established for avocado. The months with the highest infestation were January in the second sampling, November in the second sampling as well as both of December samplings with a 99 percentage of infestation, in contrast the sampling in July reported the lowest infestation level with 56 of percentage. This data is in agreement with the highest and lowest densities of the pest population fluctuation within the area of study. It should be noted that the rate of infestation is not directly related with the population density of the pest, since we can have very high levels of infestation, but low densities that do not exceed the economic threshold of the pest.

The avocado growers in the study zone do not know the spatial behavior of *Scirtothrips perseae,* so the present work will allow growers and competent authorities to develop integrated management programs for this phytosanitary problem that are more efficient, timely and relevant, it will also make possible to establish more efficient strategies knowing the location and preferences of *Scirtothrips perseae.* The importance of studies like the current one lies in the fact that they determine ecological niches occupied and played by this kind of insect pest, which allows a better understanding of their behavior and in this manner, establish strategies that give better results.

More research on the spatial behavior of pest insects is required to conclude that the spatial distribution is the same, year after year, the spatial distribution of pest insects is limited or potentiated by; climate conditions, and biotic factors in orchards such as; weeds, and other crops. Thrips population densities are not related to aggregation centers since aggregation centers are conserved at different densities. The maps presented show when a greater population fluctuation of thrips was obtained. There are limitations to apply this type of research in Mexico since most farmers do not have the appropriate technologies. This research meets the objective of bringing these technologies closer to farmers so that they can determine the most appropriate management for their orchards. The flowering times of the avocado crop (February, March, April, August, September) showed the highest densities, it would be the right time to carry out some control over the pest insect.

CONCLUSIONS

In this study, *Scirtothrips perseae* presented an aggregated spatial behavior within the avocado production orchards in the State of Mexico. The application of geostatistical techniques allowed to know such behavior through population density maps.

Therefore, targeted control measures can be carried out in the aggregation centers of the pest, and thereby reduce economic and environmental costs.

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