Article

Spatial modeling of *Oligonychus perseae* (Tuttle, Baker and Abbatiello) using geostatistical techniques

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Abstract

Within the pests that affect the avocado crop we find *Oligonychus perseae* or better known as crystalline spider. This mite produces affectations in the epidermis of the leaves discoloring the injured areas, in severe attacks they cause defoliation and low production, all this as a result of the extraction of the cellular content of the tissues. In the State of Mexico, there are about 10 000 hectares planted with avocado, with an average production of 15. 602 t ha^{-1}. The spatial distribution of *O*. *perseae* in four municipalities producing avocado var. Hass through the application of geostatistical analysis and ordinary krigeado. The results show that the crystalline spider populations are presented in an aggregate way, adjusting mostly spherical models. The area infested with the mite exceeded 73% of the municipality in all samples and the maximum number of individuals found was 1 445 organisms per tree. The most affected municipalities were Coatepec Harinas and Donato Guerra.

Keywords: avocado, crystal spider, krigeado.

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Introduction

Oligonychus perseae or crystalline spider is a mite native to Mexico, discovered in 1975 and described in 1976 by Tuttle, and so far its presence has been reported in the United States of America, Costa Rica, Israel, Spain and Portugal (EPPO, 2003, 2006; Alcázar *et al*., 2005; Ferreira *et al*., 2006). The crystalline mite is found in avocado crops throughout the year and the susceptibility to infestation varies significantly according to the variety (Kerguelen and Hoddle, 2000). The mite, which can be found in avocado trees throughout the year, requires temperatures between 10 and 25 °C, with the season becoming dry when their populations increase (Gallegos, 1983).

Nymphs and adults generate damage from the sap suction that they perform on the underside of the leaflets, where they form silky nests in a circular fashion. The characteristic damages consist of brown to black spots on the underside of the leaves (Hoddle, 2000). Severe damage thresholds have been detected when there are around 100 mites per leaf, which causes defoliation and therefore, sunspot on the fruits (Kerguelen and Hoddle, 2000).

The most efficient chemical control method (95% reduction) consists of 80% sulfur applied by direct spraying on trees, but it affects the beneficial entomofauna present in the avocado tree. The biological control for this mite has been carried out with predators of the Phytoseiidae family (Maoz *et al*., 2011).

Therefore, precision agriculture is emerging as a new control alternative, since the application aimed at specific areas can avoid effects on beneficial fauna and minimize contamination of production orchards; for this purpose, it was intended to model the spatial distribution of *Oligonychus persea*, through the use of geostatistics to represent it through population density maps and illustrate its presence in the municipalities.

Materials and methods

The study was conducted in four municipalities of the State of Mexico (Coatepec Harinas, Temascaltepec, Donato Guerra and Tenancingo de Degollado) where avocado production stands out among other crops. The municipality of Coatepec Harinas is located at 18.936 latitude and -99.76866 longitude with a height between 1 600 and 3 900 meters above sea level. Donato Guerra is located at 19.3083 north latitude and -100.142 longitude with an average altitude of 2 200 meters above sea level.

Temascaltepec is located south of the State at an average height of 1 720 meters above sea level at 19.0444 north latitude and -100.045 west longitude while Tenancingo de Degollado has its location at 18.9667 north latitude and -99.6 longitude with an average altitude of 2020 meters above sea level. The study area consisted of two hundred trees distributed and marked throughout the municipalities evaluated using the quadrant method.

Sampled trees were selected in plantations 10 years old. Fortnightly counts of the mobile crystalline spider stadiums were made. 60 leaves of the low, middle and high stratum of the tree were selected taking as reference the cardinal points of the tree. Each tree was georeferenced with a Garmin eTrex

Vista HCx2007 navigator. This according to the essays made by Gonzalez (2012). To make the observations a magnifying glass of 20 x was used, the sampling was performed from January 3 to June 18, 2017.

Geostatistical analysis

The experimental semivariograms were estimated using the data collected, the semivariogram was calculated using the following formula: (Journel and Huijbregts, 1978; Isaaks and Srivastava, 1989). Where: γ^* (h) is the experimental value of the semivariogram for the distance interval h; N (h) is the number of pairs of sample points separated by the distance interval h; z (xi) is the value of the variable of interest at the sampling point xi, and z (xi + h) is the value of the variable of interest at the sampling point xi + h.

Any mathematical function can be used for a semivariogram model as long as it is positive and defined (Armstrong and Jabin, 1981). The Variowin 2.2 program (Software for the analysis of spatial data in 2D. Spring Verlag, New York; USA) was used to perform the experimental semivariogram corresponding to each sampling.

The theoretical models commonly used to adjust the experimental semivariograms are the spherical, the exponential, the Gaussian, the logarithmic, the pure nugget, the hole effect and the monomic according to Samper and Carrera (1996); Trematerra and Sciarretta (2004). The parameters of the model to be validated (C0, nugget effect, C, plateau and a, range or scope) are modified until obtaining adequate cross-validation statistics. The cross-validation values are:

Average estimation errors: $\text{MEE}=\frac{1}{n}\sum_{i=1}^{n}[z^*(x_i)-z(x_i)]$

Where: $z^*(x_i)$ is the estimated value of the variable of interest at point x_i; z (x_i) is the measured value of the variable of interest at point x_i and n is the number of sample points used in interpolation. The MEE should not be significantly different from 0 (t test), in which case, it would indicate that the semivariogram model allows the calculation of unbiased estimators.

Mean square error: $\text{ECM}=\frac{1}{n}\sum_{i=1}^{n}[z^*(x_i)-z(x_i)]^2$

A semivariogram model is considered adequate if, as a practical rule, the value of the statistic is close to zero (Hevesi *et al*., 1992).

Mean dimensionless quadratic error: $\text{ECMA}=\frac{1}{n}\sum_{i=1}^{n}\frac{[z^*(x_i)-z(x_i)]}{\sigma k}$

Where: σk is the standard deviation of the expected error in the estimate with the krigeado. The validity of the model is satisfied if ECMA is between the values 1 ±2 (2/N) 0.5.

Level of spatial dependence

It was calculated in order to determine the strength of the relationship between the sampling data. This value is obtained by dividing the effect of nugget between the lower edge, expressed as a percentage: less than 25% is considered high, between 26 and 75% moderate and greater than 76% is considered low (Cambardella *et al*., 1994; López *et al*., 2002).

Mapping

The maps were prepared by interpolation of values through ordinary krigeado, this process allows the unbiased estimation of values associated to points that were not sampled all this based on what was established by Samper and Carrera (1996) through the use of the program Surfer 9 (Surface Mapping System, Golden Software Inc. 809, 14th Street. Golden, Colorado 80401-1866. USA). And finally, the infested area of the estimates that are represented in the form of maps for each municipality was established, with the use of the GIMP version 2.8 and IMAGE J program.

Results and discussion

During the structural analysis of the data, the variogram was the process that best characterized spatial continuity. The variograms were constructed to later adjust them to theoretical models. The results show that the majority of semivariograms were adjusted to spherical models in the four municipalities evaluated (Table 1). The semivariograms were subjected to the cross-validation process, their values reflect the appropriate ranges to continue the process. This procedure has been carried out in several studies to corroborate that the model to which the distribution of other pests was adjusted is suitable, an example of this is the work of Jiménez *et al*. (2013); Rivera *et al*. (2017); Acosta *et al.* (2017).

The value of the nugget effect in the 12 samples of the four municipalities had a value equal to zero, which implies that the sampling scale applied for the mite was correct and that there is a minimum sampling error in the observations made for the 48 samples. This means that 100% of the variation of the *O*. *perseae* distribution is explained by the spatial structure established in the semivariograms corresponding to each sampling, a situation that is consistent with that reported by Rossi *et al*. (1992). The spatial dependence was determined high for all cases (Table 1).

Table 1. Parameters of the theoretical models adjusted to the semivariograms of *Oligonychus perseae* (Tuttle, Baker and Abbatiello) by sampling date in four municipalities of the State of Mexico.

Date	Model				Rank (m)				Spatial dependence
	Coatepec Harinas	Donato Guerra	Temascaltepec	Tenancingo	Coatepec Harinas	Donato Guerra	Temascaltepec	Tenancingo	
3 Jan	Spherical	Spherical	Spherical	Spherical	18	13	14	19	High
18 Jan	Spherical	Spherical	Spherical	Spherical	16.5	19.5	20.5	21.5	High
3 Feb	Gaussian	Spherical	Spherical	Gaussian	19	16	15	14	High
18 Feb	Spherical	Spherical	Spherical	Spherical	21	18	17	17	High

Date	Model				Rank (m)				Spatial dependence
	Coatepec Harinas	Donato Guerra	Temascaltepec	Tenancingo	Coatepec Harinas	Donato Guerra	Temascaltepec	Tenancingo	
3 Mar	Spherical	Spherical	Gaussian	Spherical	11	17	14	14	High
18 Mar	Spherical	Gaussian	Spherical	Spherical	17.1	14.1	13.1	16.1	High
3 Apr	Spherical	Spherical	Spherical	Spherical	18.2	16.2	22.2	13.2	High
18 Apr	Spherical	Spherical	Spherical	Spherical	16.5	20.5	12.5	12.5	High
3 May	Gaussian	Spherical	Spherical	Gaussian	19.2	16.2	23.2	19.2	High
18 May	Spherical	Spherical	Spherical	Spherical	16.4	13.4	20.4	12.4	High
3 Jun	Spherical	Spherical	Spherical	Spherical	17.9	14.9	13.9	11.9	High
18 Jun	Spherical	Spherical	Gaussian	Gaussian	21	18	17	9.8	High

The range value is indicative of the maximum distance to which there is a relationship between the data and can be corroborated in the distribution maps. The values of the range for semivariograms of the municipality of Coatepec Harinas ranged from 11 to 21 m, while those corresponding to Temacaltepec showed ranges between 12.5 to 23.2 m, for Tenancingo, the value of the range showed a variation between 9.8 and 21.5 m differentiating Donato Guerra presented values ranging from 13 to 20.5 m (Table 1).

The maximum number of mites found in Coatepec Flours was 1 250 mites per tree during sampling in May, while for Temacaltepec it was 1 257 spiders per tree. For the municipalities of Tenancingo and Donato Guerra, 1 445 and 1 244 spiders per tree were found. The lowest incidence occurred in June, due to the presence of constant and abundant rains in the four production areas, while the decrease in temperature had interference in the months of January and February, beginning a rebound in March with more than 350 mites per tree.

As for the plateau, the values varied in the four study municipalities, Coatepec Harinas from 12.5 to 609.7, Donato Guerra ranged from 27.9 to 401, Temacaltepec showed values from 21.17 to 609.78 and Tenancingo de Degollado from 28.4 to 637; the above explains the types of aggregation present in the four municipalities. The incidence of the pest was managed by means of distribution maps, which will allow its graphic visualization and the spatial location of the aggregation centers.

In the distribution maps the red color is indicative of the largest number of individuals of *O. perseae* while the white color reflects the absence of mites. This technique has been used in other pests as thrips in the avocado crop in the State of Michoacán (Solares *et al*., 2012), thrips in the gladiolus crop in the State of Mexico (Quiñonez *et al*., 2015), Esquivel and Jasso (2014) with his study on the spatial distribution of soldierworms in the State of Mexico, Ramírez and Porcayo (2008) with the distribution of nymphs of *Jacobiasca lybica* in vineyards of Andalusia, Spain, among others.

In the different maps we can observe that the populations of *O. perseae* are presented in an aggregate way within the municipalities evaluated, this situation was also observed in the avocado leaves, since in the same nest we could find eggs, nymphs and adults, which corroborates the aggregation of crystal spider populations. These same results were observed by Silva *et al*. (2016) in the study of the population of *Vatiga* spp., which reports that this pest is presented in aggregate form in cassava cultivation. Maldonado *et al*. (2017) reports that avocado thrips populations in the State of Mexico are also presented in aggregate form within the commercial orchards evaluated during 2015.

As can be seen in Figure 1, in samples 1, 4, 7, 9, 10, 11 and 12 the location of the pest was found in the northern part of the municipality, while in samples 2, 3 and 6 the distribution was found in the center of the municipalities while sampling 5 showed the greatest number of mites in the east of the municipality and sampling 8 showed more mites in the Southeast of the municipality.

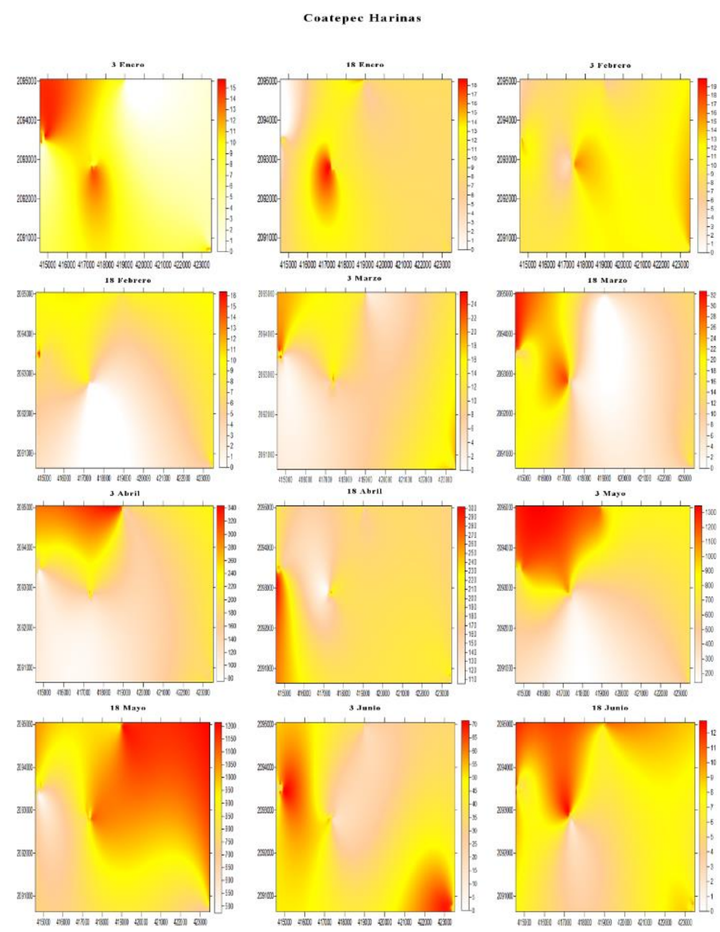

Figure 1. Density maps of the populations of *Oligonychus perseae* (Tuttle, Baker and Abbatiello) obtained in the sampling in the municipality of Coatepec Harinas, Mexico, semester 2017-A.

In Donato Guerra, the samples showed widespread infestation in the majority of the samples, with only samples 1, 8, 10 and 12 being the ones with the highest infestation towards the limits of the municipality (Figure 2).

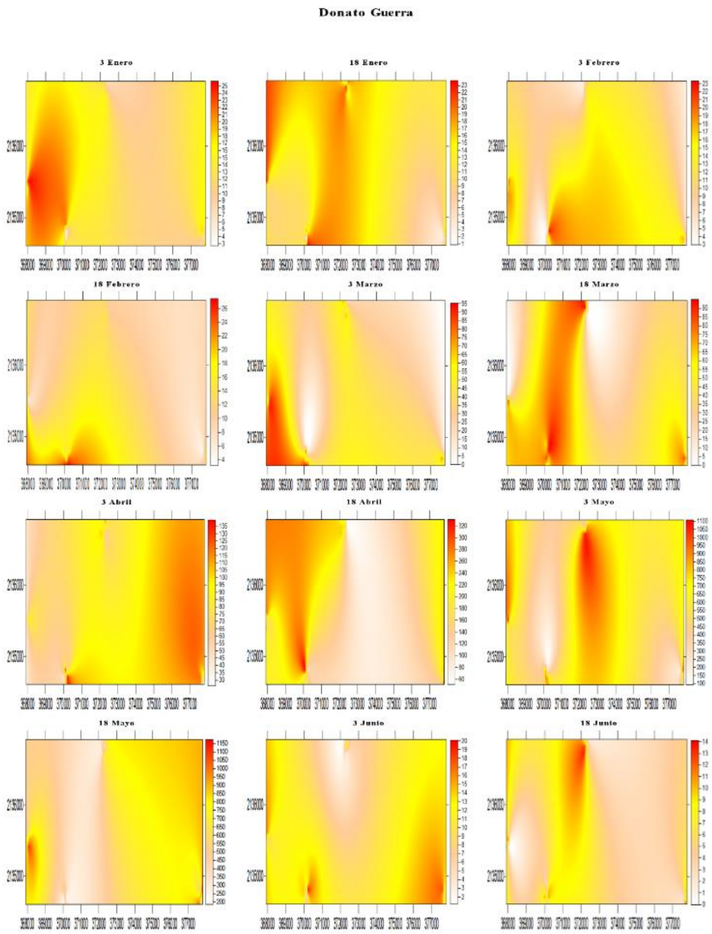

Figure 2. Density maps of the populations of *Oligonychus perseae* (Tuttle, Baker and Abbatiello) obtained in the sampling in the municipality of Donato Guerra, Mexico semester, 2017-A.

In the municipality of Temacaltepec (Figure 3), the plague showed a preference for the southern part of the municipality in samples 1, 3, 4, 6, 8, 10, 11, 12, while in the rest of the samples it was oriented more towards the Northeast (2, 5, 7), in sampling 9 we find a generalized infestation in the municipality.

The presence of spherical models in most semivariograms reflects that within the municipalities there are areas where there is a higher incidence of *O. perseae* allowing to locate the aggregation centers with more individuals in specific places as shown by the figures corresponding to the sampling of each municipality, which indicates that the distribution of this mite starts from a main focus and expands to the periphery, this behavior shows a similarity with the spatial distribution of *Brevipalpus phoenicis* in Valencia orange plantations in Colombia by Solano *et al*. (2008).

According to Isaaks and Srivastava (1989) cited by Moral (2004), a variable such as the density of insects on a plot is likely to be distributed very erratically over short distances, so that the most appropriate theoretical models for variograms should be spherical or exponential.

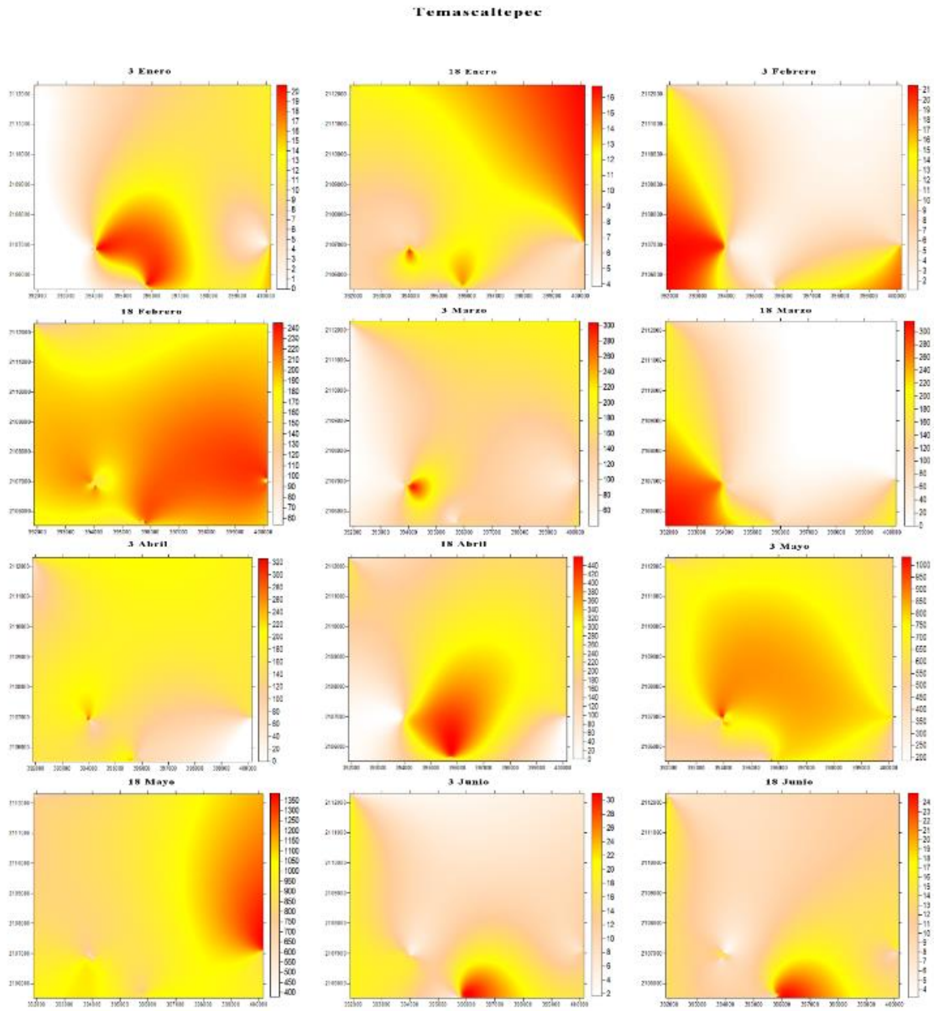

Figure 3. Density maps of the populations of *Oligonychus perseae* (Tuttle, Baker and Abbatiello) obtained in the sampling in the municipality of Temacaltepec, Mexico, semester 2017-A.

Regarding Tenancingo de Degollado, we could find a widespread infestation in samples 4, 6, 7 and 11 while in samples 1, 5 and 10 the plague was found west of the municipality. Samples 2, 8, 12 showed a presence of the plague towards the south and in the remaining samplings the plague appeared in the east of the municipality (Figure 4).

Thanks to the graphic representation of the presence of crystalline spider in avocado, it was possible to calculate the area infested by this mite in the four municipalities studied. For Coatepec Harinas the minimum infestation percentage was found in sampling 5; 91% of the infested area while most of the samples had 100% infestation. In Temacaltepec, the minimum infestation was observed in sampling 6; 73% followed by sampling 1, 7, 8 with more than 80% and the remaining samples with an infestation of 100%.

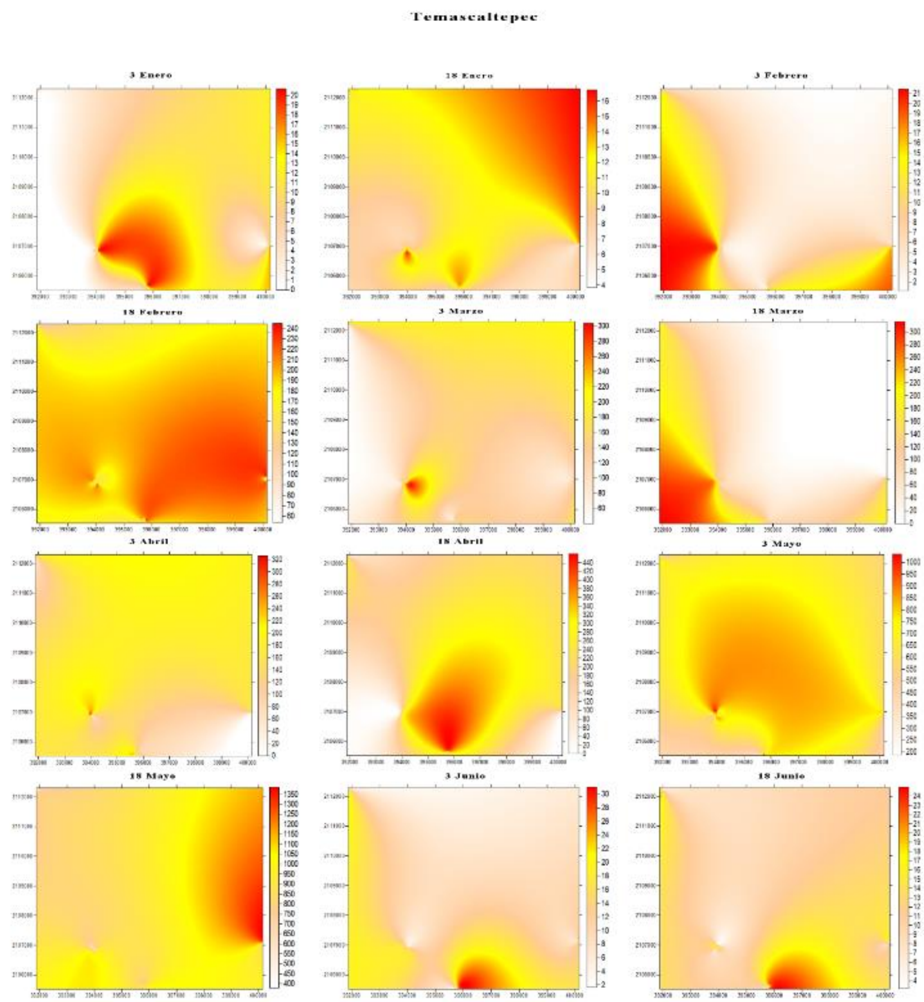

Figure 4. Density maps of populations of *Oligonychus perseae* (Tuttle, Baker and Abbatiello) obtained in the sampling in the municipality of Tenancingo de Degollado, Mexico, semester 2017-A.

Tenancingo de Degollado had the lowest infestation in sampling 12 with 78% of the area of the infested municipality followed by sampling 9, 7, 1, and 11 with up to 96% infested, all other samples had a 100% infestation. Donato Guerra presented the smallest infested area in sampling 6; 93% and 100% in the other samples except for sample 12 (Table 2). These incidents are mainly due to environmental conditions as reported by Salinas and Resendiz (1995) who conclude that the optimum relative humidity for the life cycle of *Oligonychus perseae* is 60% at a temperature of 25 °C for a biological cycle of between 24 days for males and 31 days for females.

As for the effects on foliage, it was observed that they do not generate significant damage despite the number of mites per tree found in the middle and low strata since they seek to migrate to the highest stratum of the tree in order to look for conditions for their survival, this behavior is explained since the lower part of the tree keeps more humidity, while the upper part of the tree presents a greater aeration, and therefore increases the temperatures therefore a lower relative humidity. Although it has been shown that high levels of infestation can reduce photosynthesis by more than 50%, its effect on performance has not yet been demonstrated (Maoz *et al*., 2011) or observed during work development.

Table 2. Infested area of *Oligonychus perseae* (Tuttle, Baker and Abbatiello), by sampling date in four municipalities of the State of Mexico, semester 2017-A.

	(%) Infested surface			
Num. sampling	Coatepec Harinas	Donato Guerra	Temascaltepec	Tenancingo de Degollado
1	100	100	80	99
2	100	100	100	100
3	100	100	100	100
4	100	100	100	100
5	91	95	100	100
6	92	93	73	100
7	100	100	94	98
8	100	100	90	100
9	100	100	100	87
10	100	100	100	100
11	100	100	100	96
12	97	96	100	78

Conclusions

The aggregate spatial distribution of *O. perseae* in the avocado crop was corroborated with the maps made with the krigeado. The development of crystalline spider incidence and distribution maps facilitates the detection of areas with a high level of infestation in avocado producing municipalities in the State of Mexico, to apply timely and effective management. The use of geostatistical techniques makes it possible to strengthen phytosanitary management programs within economically important crops such as avocado.

The application of biological control is recommended with the release of phytoseids and entomopathogenic fungi, as is done in countries such as Spain, where the crystalline spider is a serious problem that affects the avocado. During this work, training was carried out for cooperating producers to show the usefulness of the application of geostatistical techniques in the detection and monitoring of pests that affect crops. It is recommended to continue the study to thoroughly analyze the behavior of the mite in the municipalities evaluated for a further time to be able to make an appropriate management plan for each population and thus issue the pertinent recommendations for this pest.

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