

Spatial patterns of *Frankliniella occidentalis* (Pergrande) (Thysanoptera: Thripidae) populations in *Gladiolus communis* L

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ABSTRACT

Frankliniella occidentalis is the main pest affecting gladiolus flower in the southeast region of the state of Mexico. It is currently managed using blanket application of synthetic pesticides, without consideration of its spatial arrangement within the crop. The objective of this work is to analyze the spatial patterns of this insect using geostatistical techniques, over three phenological stages of growing in the main gladiolus-producing region in Mexico during the summer-fall cycle in 2013-2014. Semivariograms were obtained using models fitted with R program, and density maps were generated using kriging. Results showed aggregated populations of insects in all three phenological stages of the crop, independent of insect population density, during both years of the study. The insect's spatial patterns changed noticeably from one plot to another within the same municipality, as well as from one phenological stage to the next. The spherical and exponential model was generally the best fit, followed by the lineal model, showing that the aggregation centers begin in a specific location, then radiate continuously outward throughout the plot. The observed points of aggregation allow for specific, targeted application of control methods, particularly synthetic pesticides. The maps generated

allow the visualization of the changes in spatial patterns of aggregation of *F. occidentalis* during the different phenological stages of gladiolus cultivation.

KEYWORDS: aggregation, geostatistic, gladiolus, kriging.

INTRODUCTION

The gladiolus is the most economically valuable cut flower crop in Mexico; 3,983 ha are cultivated nationally each year, nearly a third of which is cultivated in Mexico State (1,429.5 ha; [1]).

Thrips (Insecta: Thysanoptera) are considered the main insect pest affecting the cultivation of gladiolus as well as other ornamental and horticultural crops across Mexico due to the damage they inflict on flower appearance. *Thrips simplex* and *Frankliniella occidentalis* both feed on gladiolus plants by scraping the epidermal tissues of the leaves and flowers, decreasing the esthetic quality of the inflorescence, as well as causing white patches in both leaves and flowers, which dry out prematurely [2-4]. When severely infested, floral buds desiccate and fail to open. On the other hand, *T. simplex* is considered to be the main pest species, since in addition to feeding on plant tissues it reproduces and completes its entire lifecycle on the gladiolus [5, 3]. However, *F. occidentalis* only uses the gladiolus for feeding (with no evidence of

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reproduction on the gladiolus) [6]; its polyphagous habit allows it to infest a wide variety of hosts, leading to continual influx of *F. occidentalis* to gladiolus crops from other plants cultivated in the region, such as roses, gerber daisies, chrysanthemums and strawberries. Because thrips' damage so greatly diminishes the value of the gladiolus flowers, the acceptable limit of insect density on this and other ornamental plants is close to zero [7]; for this reason, the control of both of these insects currently consists of blanket spraying a variety of synthetic insecticides, often at higher than recommended doses.

In order to generate efficient management strategies for this insect, it is necessary to study the spatial arrangement of the *F. occidentalis* populations, as well as their temporal and spatial dynamics. In this work, we used geostatistical techniques to determine the spatial distribution patterns of *F. occidentalis* populations in commercial gladiolus plots in southeastern Mexico State by constructing models that describe their spatial behavior and allow for their visualization at the plot level. The objective of this work is to obtain the spatial patterns of *F. occidentalis* populations in commercial gladiolus plots in the southeastern region of Mexico State.

MATERIALS AND METHODS

During the summer-fall growing cycles in 2013 and 2014, two commercial plots in the municipalities of Tenancingo (T1, T2), Villa Guerrero (VG1, VG2), and Ocuilan (O1, O2) with histories of damage by thrips were sampled. A variety of ornamentals and cut flowers are cultivated in open fields and under floating covers, and maize and strawberry are produced in these municipalities. The gladiolus plots sampled are surrounded by other crops including rose, chrysanthemum, gerber daisy, carnation, strawberry and maize, as well as other gladiolus plots.

Sampling was carried out during three phenological stages in the "roja borrega" gladiolus variety, first 40 days after planting (DAP; vegetative stage), 70 DAP (spathe stage), and 107 DAP (flowering stage). Within each plot, a 100 m x 100 m grid was established, and an insect trap was installed every 10 m, for a total of 121 traps per plot.

Traps for collecting thrips consisted of yellow No. 8 plastic cups (Amscan[®], México), 8.5 cm tall, 4 cm

in diameter at the base, and 7.5 cm in diameter at the rim, as suggested by [8, 9]. The inverted cup was suspended from a 1.5 m-tall wire base using plastic raffia, and the outside of the cup was coated with vegetable oil so that thrips would adhere to the surface. The traps were checked with a 20X lens to count and remove the captured thrips. Species-level identification was carried out at the entomology laboratory of the Institute of Biology at the National Autonomous University of Mexico. Trap locations were marked using a differential global positioning system (dGPS Model SPS351, Trimble[®], CA). Thrips density was analyzed separately for each capture date. Raw thrips population data were explored statistically prior to proceeding with geostatistical analyses.

For geostatistical analyses, we first generated an estimated semivariogram using the capture data for each sampling site and phenological stage. The experimental value of the semivariogram was calculated based on the formula proposed by [10]:

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i+h) - z(x_i)]^2 \text{ where: } \gamma^*(h)$$

is the experimental value of the semivariogram for the distance interval h , $N(h)$ is the number of pairs of sampling points separated by the distance interval h , $z(x_i)$ is the value of the variable of interest at the sampling point x_i , and $z(x_i+h)$ is the value of the variable of interest at the sampling point x_i+h . This type of semivariogram is called the experimental semivariogram and was fitted to a predefined theoretical semivariogram. The experimental semivariogram was obtained using the program R [11, 12] with the gstat package [13]. Seven different models were evaluated (spherical, Gaussian, exponential, linear, Matern, Bessel and pentaspherical) to determine which model best fit the experimental variogram of the density values of the insect and the model with the lowest error was selected [14].

The level of aggregation was evaluated using the quotient resulting from dividing the nugget value (C0) by the sill (C0+C), where <0.25, 0.25-0.75, and >0.75 indicate strong, moderate, and weak aggregation, respectively [15].

After selecting the model that presented the least error, we interpolated using kriging. Three kriging

models were evaluated (simple, ordinary, and universal) using the cross-validation technique. The kriging model that had the lowest precision error was chosen to carry out the interpolation based on mean error $ME = \frac{1}{n} \sum_{i=1}^n [z(x_i) - \bar{z}(x_i)]$, which should be near zero [16]. The root mean square error (RMSE) was also calculated

$$(RMSE) = \sqrt{\frac{1}{n} \sum_{i=1}^n [z(x_i) - \bar{z}(x_i)]^2};$$

a semivariogram model is considered adequate if, as a rule of thumb, the value of this statistic approaches zero [17, 18] and the mean standardized prediction

$$\text{error } (MSPE) = \frac{1}{n} \sum_{i=1}^n \frac{ME}{\sigma^2(x_i)},$$

is near zero [16]. The result of kriging was a spatial layer in Geotiff format, generated using the rgdal library for R. Finally, the map was edited using the program Surfer 15.0 (Surface Mapping System, Golden Software Inc. 809, 14th Street, Golden, CO, 804011866, USA) to visualize the spatial behavior of the thrips.

RESULTS AND DISCUSSION

Thrips were present during all phenological stages during both the 2013 and 2014 growing cycles. The most abundant species collected was *F. occidentalis*, followed by *Thrips simplex*, and all other species. *F. occidentalis* density and distribution patterns differed among municipalities and over time, both between years and among phenological stages within each year.

First, at the scale of municipality, Ocuilan had the highest thrips density in 2013 (Table 3), while Tenancingo (Table 1) had the highest density in 2014. Within seasons, *F. occidentalis* density was highest during the vegetative stage (40 DAP), then decreased by 107 DAP in Ocuilan in 2013, and in all plots evaluated in 2014. Exploratory statistics showed that overall, thrip density was normally distributed (Tables 1, 2 and 3).

At the scale of individual plots, in 2013 in the O1 and O2 plots, the highest insect abundance was found during the vegetative stage (40 DAP; Table 3), while for plots VG1, VG2, and T1, the highest density was during the spathe stage (70 DAP), and only in T2 the highest infestation was found in the flowering stage (107 DAP). In 2014, the highest thrips density occurred at the vegetative stage (40 DAP) in all of

the plots sampled, while the lowest density occurred during the spathe stage and flowering stages in Ocuilan and the spathe stage (70 DAP) in Villa Guerrero.

The fact that *F. occidentalis* was the predominant species in gladiolus plantations in the southeast region of Mexico State is indicative that gladiolus is an attractive host species for this insect. It is likely that the presence of other attractive crops in neighboring areas, including strawberry and chrysanthemum, favor the proliferation of this species, allowing it to displace the more specialized *T. simplex*, which elsewhere is considered the main pest of gladiolus even when found together with *F. occidentalis* [3].

Because the greatest damage caused by larvae and adults in this ornamental plant is cosmetic, the acceptable levels of thrips are close to zero, which contributes to the constant use of pesticides [19]. However, despite constant application of insecticides in the Tenancingo and Villa Guerrero plots the densities of *F. occidentalis* surpassed the permissible levels in 2014. As such, all of the thrips densities determined in this study caused esthetic damage to the gladiolus flowers, and the producers intensified the use of synthetic pesticides during the spathe and flowering stages to keep *F. occidentalis* populations from affecting the quality of flowers produced. This likely explains the lower thrips densities during the spathe stage in 2013 and 2014 and the flowering stage in 2014.

With respect to the spatial patterns of the insect populations, we were able to model the distribution of *F. occidentalis* over the full range of insect densities encountered during sampling. The high level of spatial dependence in the fitted models indicates that there is a spatial relationship among the observations from each sampling point of *F. occidentalis* (i.e. aggregate distribution). The aggregation found in the different phenological stages is indicative of a low dispersibility [20, 11] within the gladiolus plots.

The nugget effect was near zero, indicating that the sampling error was minimal and the sampling scale adequate [21]. Most of the models evaluated showed high spatial dependence, indicating a spatial relationship between the insect density values at each of the sampling points, except for the models

Table 1. Summary of density and parameters of models fitted to semivariograms obtained in gladiolus (*Frankliniella occidentalis*) plots in summer-autum of 2013-2014, in Tenancingo Mexico.

Plot	DAP ^a	Density (promedio)	Normality	Standar Devsiation (σ)	Model	Nugget	Sill	Range	Nugget/Sill	Level of space dependence	ME	RMSE	MSPE
2013													
1	40	0.26	1.38	1.18	Spherical	0.00	0.47	9.58	0.00	High	0.01	0.64	0.41
	70	0.82	0.61	1.12	Spherical	0.00	0.39	9.61	0.00	High	0.00	0.61	0.37
	107	0.69	0.49	0.87	Spherical	0.00	0.29	8.50	0.00	High	0.01	0.50	0.25
2	40	0.85	-0.02	0.91	Spherical	0.00	0.37	6.60	0.00	High	0.00	0.56	0.32
	70	0.54	1.48	0.83	Exponential	0.13	0.08	6.59	1.62	Low	0.00	0.46	0.21
	107	0.91	0.04	0.74	Exponential	0.19	0.08	6.64	2.37	Low	0.00	0.52	0.27
2014													
1	40	6.01	0.18	9.39	Pentaspheric	0.00	0.71	5.66	0.00	High	0.01	0.88	0.77
	70	2.83	1.61	2.48	Lineal	0.00	0.51	4.61	0.00	High	0.00	0.72	0.52
	107	1.24	-0.25	1.38	Spherical	0.00	0.17	8.65	0.00	High	0.01	0.39	0.15
2	40	5.98	-0.37	5.76	Exponential	0.00	0.68	4.27	0.00	High	0.00	0.81	0.66
	70	2.28	1.69	1.91	Pentaspheric	0.06	0.15	10.8	0.40	Medium	0.00	0.49	0.24
	107	1.87	-1.03	1.93	Lineal	0.09	0.23	9.64	0.39	Medium	0.00	0.58	0.33

^aDAP: Days after planting.

Table 2. Summary of density and parameters of models fitted to semivariograms obtained in gladiolus (*Frankliniella occidentalis*) plots in summer-autum of 2013-2014, in Villa Guerrero Mexico.

Plot	DAP ^a	Density (promedio)	Normality	Standar Devsiation (σ)	Model	Nugget	Sill	Range	Nugget/Sill %	Level of space dependence	ME	RMSE	MSPE
2013													
1	40	1.74	0.71	1.78	Spherical	0.05	0.76	10.7	0.06	High	0.01	0.82	0.67
	70	1.70	0.42	1.76	Lineal	0.17	0.16	13.1	1.06	Low	0.00	0.54	0.29
	107	1.81	0.18	2.38	Pentaspherical	0.00	0.39	8.37	0.00	High	0.00	0.57	0.33
2	40	0.88	1.57	2.77	Exponential	0.09	0.27	2.28	0.33	Medium	0.01	0.60	0.36
	70	0.51	0.91	1.96	Lineal	0.00	0.43	3.28	0.00	High	0.02	0.64	0.41
	107	0.92	1.19	2.71	Spherical	0.00	0.42	3.46	0.00	High	0.00	0.69	0.48

Table 2 continued..

2014													
Plot	DAP ^a	Density (promedio)	Normality	Standar Deviation (σ)	Model	Nugget	Sill	Range	Nugget/Sill	Level of space dependence	ME	RMSE	MSPE
1	40	4.60	1.15	5.88	Exponential	0.00	0.26	4.48	0.00	High	0.00	0.49	0.24
	70	1.35	2.21	2.25	Spherical	0.00	0.13	6.56	0.00	High	0.00	0.33	0.11
	107	1.85	0.11	2.26	Exponential	0.07	0.29	3.51	0.24	High	0.01	0.60	0.36
2	40	6.36	0.64	6.68	Gaussian	0.00	0.30	2.19	0.00	High	0.00	0.55	0.30
	70	1.50	0.62	1.40	Pentaspherical	0.09	0.04	12.5	2.25	Low	0.00	0.36	0.13
	107	2.12	-0.28	1.78	Spherical	0.00	0.29	3.08	0.00	High	0.00	0.54	0.29

^aDAP: Days after planting.

Table 3. Summary of density and parameters of models fitted to semivariograms obtained in gladiolus (*Frankliniella occidentalis*) plots in summer-autum of 2013-2014, in Ocuilán Mexico.

2013													
Plot	DAP ^a	Density (promedio)	Normality	Standar Deviation (σ)	Model	Nugget	Sill	Range	Nugget/Sill	Level of space dependence	ME	RMSE	MSPE
1	40	2.72	1.15	3.49	Exponential	0.08	0.34	4.13	0.24	High	0.00	0.67	0.45
	70	0.84	0.26	1.05	Lineal	0.19	0.05	9.47	4.35	Low	0.00	0.50	0.26
	107	0.87	0.18	1.35	Spherical	0.26	1.45	13.1	0.18	High	0.02	1.27	1.60
2	40	3.11	-0.15	2.65	Exponential	0.00	3.82	5.00	0.00	High	0.00	0.98	3.94
	70	1.64	1.93	1.57	Exponential	0.00	0.38	4.24	0.00	High	0.00	0.60	0.36
	107	2.31	-0.62	2.02	Spherical	0.09	0.29	16.0	0.31	Medium	0.00	0.62	0.39
2014													
1	40	1.10	1.49	0.97	Spherical	0.00	0.26	8.95	2.0	High	0.00	0.52	0.28
	70	1.04	0.03	1.05	Spherical	0.00	0.92	6.67	1.12	High	0.00	1.05	1.11
	107	1.04	0.03	1.05	Spherical	0.02	0.25	6.22	0.08	High	0.00	0.55	0.30
2	40	2.20	-0.91	2.27	Spherical	0.00	0.11	10.07	0.00	High	0.00	0.33	0.11
	70	0.17	0.23	0.13	Spherical	0.00	0.16	10.43	0.87	High	0.00	0.35	0.13
	107	0.21	-0.89	0.21	Spherical	0.00	0.32	10.84	0.00	High	0.00	0.56	0.31

^aDAP: Days after planting

for 70 DAP for the VG1 plot and 40 DAP in VG2 in 2013, 70 DAP in VG2 in 2014, 70 and 107 DAP in T2 in both years, and 70 DAP in O1 and 107 DAP in O2 in 2013. The mean error of prediction (ME), the root mean square error (RMSE), and mean standardized prediction error (MSPE) had values close to zero for the semivariograms obtained (Tables 1 to 3), validating the fitted models.

All of the variation in the insect distribution was explained by the spatial structure established by each of the respective semivariograms, giving the fitted models 98% credibility, according to [22]. Like *Anaphothrips obscurus* [6], *Thrips palmi* [23], *Th. simplex* en gladiolus [24] and *F. occidentalis* in *Physalis ixocarpa* [25], thrips here showed aggregate distributions in all sampling locations, both years, and all sampling dates (though the particular theoretical models that best fit the distributions differed).

In the Ocuilan plots in 2014, the insect populations showed similar patterns during the vegetative and flowering stages, fitting the spherical model (Table 3). In 2013, the majority of the semivariograms obtained in the cycle were fit to exponential models, except for distributions at 107 DAP of both plots, but changed during the spathe stage in both plots. However, though the two plots differed from each other, each plot's distribution pattern was similar at the vegetative stage, and then showed a distinct pattern during the spathe stage in O1 (exponential during the vegetative stage and lineal at spathe) and O2 (exponential in spathe, and spherical at flowering).

In Villa Guerrero, the semivariograms generated were fit to several different models, and in both years and plots the model that best fit the semivariogram differed among phenological stages. In 2013, the lineal model fits the spatial pattern presented by the insect population during the spathe stage in both plots. In 2014, each stage presented a distinct pattern (Table 1).

In Tenancingo, the spherical models fit the spatial pattern presented by the insect population during the vegetative stage in both plots in 2013, though the semivariograms of T1 plot fit a spherical model during all three phenological stages, but in T2 the change occurred between the vegetative and flowering stages. In 2014, the semivariograms generated were fit to several different models, and

in both plots the model that best fit the semivariogram differed among phenological stages (Table 1).

The stage of highest density of *F. occidentalis* fit to exponential and spherical model in Ocuilan and Tenancingo, while in Tenancingo different models were fit for the highest-density stage in both years of the study. While the highest semivariogram range values occurred when the insect populations were best fit by pentaspherical or spherical models, there was no evidence that range values were associated with population density. However, the fitted models showed that while in 2013 the highest range values from the fitted models occurred during the flowering stage, during 2014 they occurred during the spathe and vegetative stages.

The spatial patterns fit to the spherical model indicate that the insect aggregation occurs in certain specific areas within the plot with respect to the rest of the sampling points; rapid increase was observed close to the origin, but the degree of increase is diminished as distance increases (Fig. 1, 2, and 3). This means that *F. occidentalis* infestation spreads through gladiolus or other nearby host plants (rather than simply showing aggregation), suggesting environmental conditions, plant genotypes, microclimates, or niches that favor thrips infestation throughout the different phenological stages.

In biological terms, the exponential model indicates centers of aggregation of *F. occidentalis* with irregular or random boundaries. The spatial variability found in the distribution of *F. occidentalis* both in the physical space of the plot as well as during different sampling dates was similar to that reported by [25] in *Physalis ixocarpa*. The differences in the spatial dynamics of the insect from one stage to the next depends on the temperature, weed management, and presence of other phytophagous insects or predators, as well as the morphology expressed by each plant variety [26].

The maps generated allow the visualization of changes in spatial distribution of *F. occidentalis* among the different phenological stages during the two years evaluated, revealing changes over time both in the specific locations of pests within plots, as well as in the spatial patterns of aggregation.

In Ocuilan, the O1 plot had centers of aggregation in the central and northeast parts of the plot during all three phenological stages in 2013, while in O2

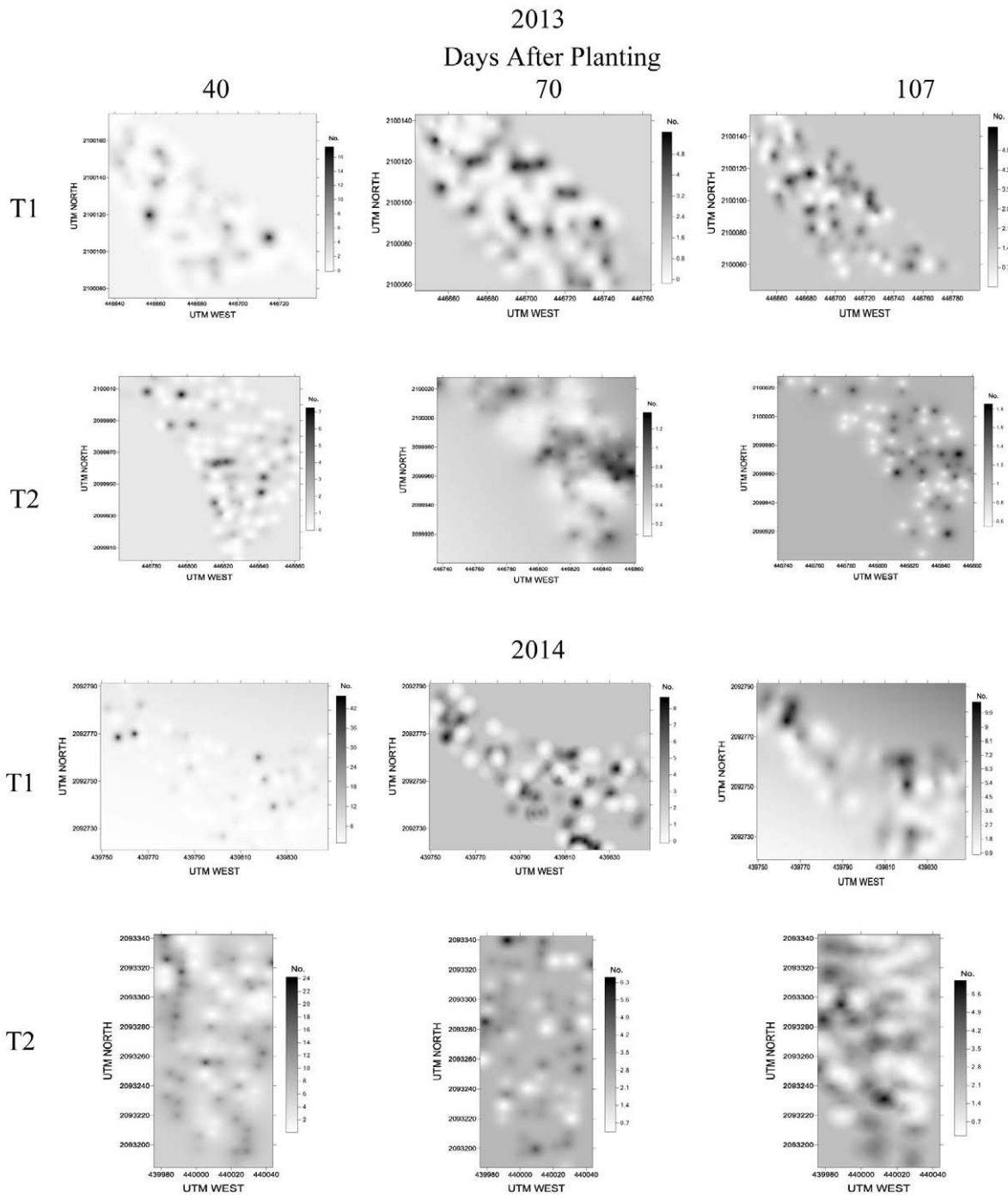


Fig. 1. Kriging interpolation of *Frankliniella occidentalis* in three sampling dates by plot, during 2013-2014, in Tenancingo (T), State of Mexico.

the centers of aggregation tended to occur in the central and north during the vegetative stage, but shifted to eastern and western direction during the spathe stage, and in flowering stages the aggregation

centers were located in the central and southeast regions. In 2014, the centers of aggregation in O1 were located in the northwestern part during vegetative stage, but during the spathe and flowering

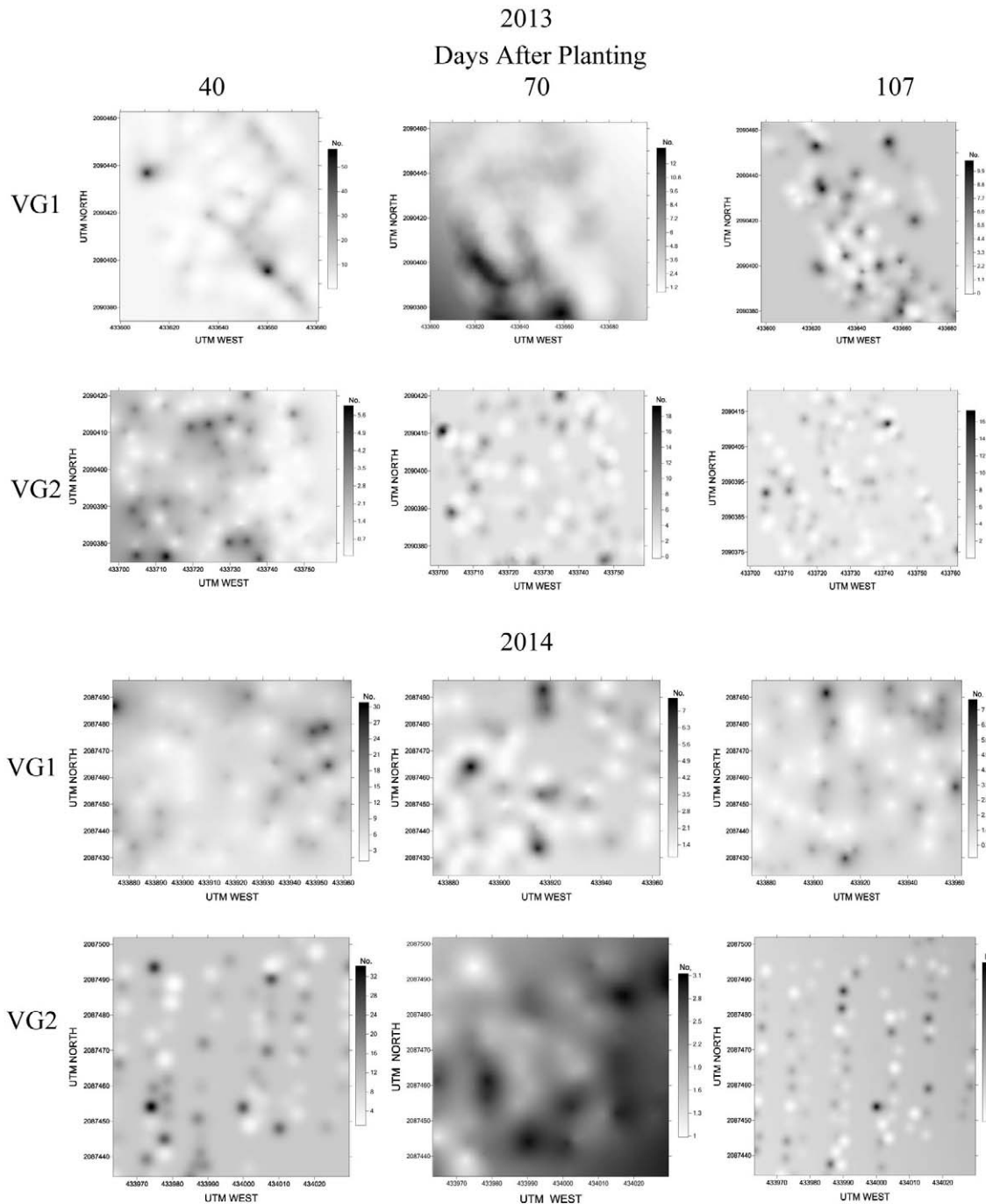


Fig. 2. Kriging interpolation of *Frankliniella occidentalis* in three sampling dates by plot, during 2013-2014, in Villa Guerrero (VG), State of Mexico.

stages, they were located along the northeast and southeast zone; while in O2 they were located in the central and west part of the plot, with a tendency toward the southeast during all three sampling dates (Fig. 3).

In Villa Guerrero, in 2013, the VG1 plot showed centers of aggregation distributed in an east-west orientation at the vegetative stages, and at the spathe stage they were located in the southeast part of the plot, changing toward the central part

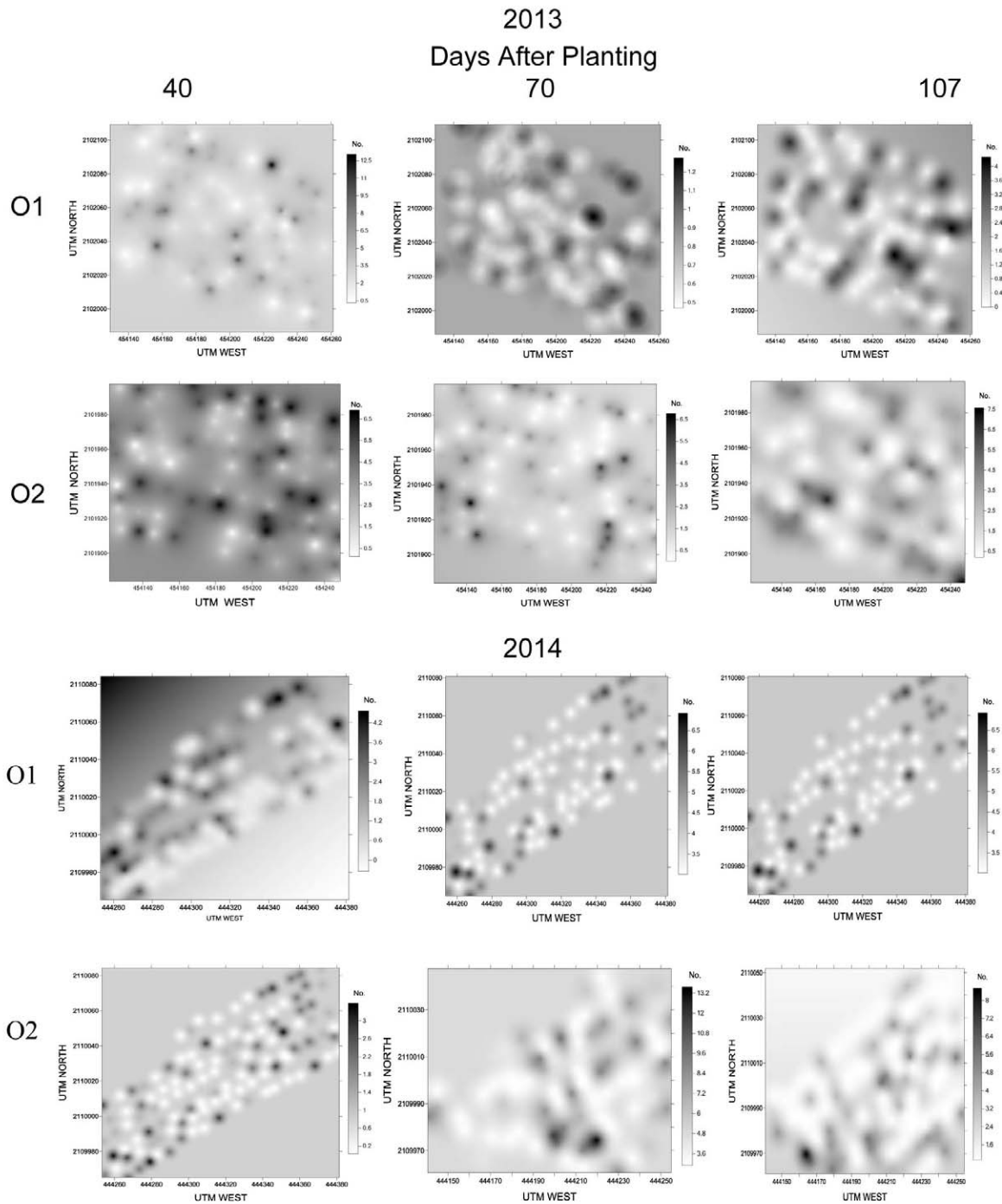


Fig. 3. Kriging interpolation of *Frankliniella occidentalis* in three sampling dates by plot, during 2013-2014, in Ocuilan (O), State of Mexico.

of the plot during the flowering stage, while in VG2, the centers of aggregation were located in the southwest and north of the plot at the vegetative stages, but at the spathe and flowering stages they were distributed in the north and east of the plot

(Fig. 2). In 2014, the centers of aggregation were located in the north and east of the plot in VG1 during vegetative and flowering stage, but in the spathe stage they were located in the northern and central parts of the plot; in VG2, the centers of

aggregation were expressed over the whole plot during the vegetative and flowering stages, but the insect population was strongly concentrated in the eastern part of the plot during the spathe stage.

In Tenancingo, the centers of aggregation were located in the central part of T1 plot during all three phenological stages in 2013, but infestation intensity varied among aggregation centers due to differences in average population density (Fig. 1, Table 1), while in T2 the aggregation centers were in the northern and eastern parts of the plot. In 2014, the centers of aggregation tended to be located in the northeast during the vegetative and flowering stages, shifting toward the southeast during the spathe stages in T1. In T2, the aggregations of the insect were in the northern part of the map during the spathe and vegetative stages, while during the flowering stage the aggregation of *F. occidentalis* was located in the north part of the plot (Fig. 1), and the overall population density of the insect decreased (Table 1).

The changes in the spatial pattern of the centers of aggregation of *F. occidentalis* indicate the variability and spatial dynamics presented by this pest within the gladiolus crop, similar to results reported by [24], but in plots with higher population density of *Th. simplex*. Notwithstanding, there was one instance in which the pest was distributed over most of the plot (spathe stage in VG2 in 2014 and vegetative stage in O2 in 2013), likely due to the limited control that producers have over infestation during these two phenological stages.

The distribution of the centers of infestation within the plot suggests that *F. occidentalis* originates from point sources, such as infested propagules [2] or seed, or other human activities [21]. This suggests inefficient treatment of seeds or cultivation of host plant species or genotypes that favor insect development. This kind of spatial behavior has been reported in *Th. simplex* in gladiolus crops in a climatically different region [24].

The visualization of centers of aggregation of these populations represents an important tool for monitoring and control for integrated crop management. The fact that the centers of aggregation of *F. occidentalis* are present at specific geographic points during each of the phenological stages, during both years, allows the establishment of point-specific management. Even so, [7] consider the management

of this insect pest difficult, particularly when the target crop is associated with other alternative plant hosts for *F. occidentalis*, which is polyphagous. It is therefore particularly important to evaluate the stability of centers of aggregation over time, as well as the effects of the presence of other hosts, such as chrysanthemum and strawberry, on the density and mobility of *F. occidentalis* populations.

Taking advantage of this pest's aggregation in specific points, by directing control actions in a precise way [27, 28], would yield economic, social, and environmental benefits [29] by allowing the application of pesticides to specific points, slowing the development of resistance in the insects, etc. This is the foundation of site-specific management [28]. Spatial studies like this one allow the visualization of variability among populations and identification of infested and infestation-free areas, providing precise, real time descriptions of the location of insects within plots [30].

CONCLUSION

Frankliniella occidentalis populations expressed aggregate type spatial patterns in the different phenological stages of the gladiolus, adjusting to different spatial models in the evaluated plots.

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflict of interest.

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