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Modelization of the spatial distribution of corn head smut (*Sporisorium reilianum* Langdon and Fullerton) in Mexico

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Abstract

Sporisorium reilianum has caused significant economical damages in Mexico, in temperate and relatively dry areas, where maize is cultivated. The knowledge about the spatial distribution of this pathogen is basic to elaborate integrated management programs, and precise and efficient the development of sampling methods and control techniques. Unfortunately, in Mexico there are no studies on spatial behavior of this disease. For this reason, this study was developed to model *S. reilianum* spatial distribution by the year 2008; and also, to establish its spatial behavior with geostatistics techniques. The sampling method established 100 points for each of 30 locations of 27 municipalities in the State of Mexico. In each point, 500 plants were counted and those presenting symptoms of the disease were recorded. A geostatistical analysis was done in order to estimate the experimental semivariograms. It was adjusted to theoretical models (spherical, exponential or gaussian) with the program Variowin 2.2; later, it was evaluated through the crossed validation with the geostatistical interpolation method or kriging. Finally, aggregation maps of the disease were elaborated. The disease was found in 30 sampled locations; all of them presented an aggregated spatial pattern of the disease. Twenty one locations were adjusted to the spherical model, five to the exponential model and two to the Gaussian model. Aggregation maps were established in all models. It was observed that *S. reilianum* was not uniform in the assess areas. Results showed the spatial distribution of *S. reilianum* and real infestation in field using geostatistical techniques.

Additional key words: geostatistics; kriging; *Zea mays*.

Resumen

Modelización de la distribución espacial del carbón de la espiga del maíz (*Sporisorium reilianum* Langdon y Fullerton) en México

Sporisorium reilianum causa daños económicos y ecológicos importantes en zonas con clima fresco y relativamente seco donde se cultiva maíz en México. El conocimiento de la distribución espacial de la enfermedad es indispensable para la elaboración de programas de manejo integrado, para el desarrollo preciso y eficiente de métodos de muestreo y de tácticas de control, pero se carece de estudios sobre su comportamiento espacial en México. Se realizó el presente trabajo para modelizar la distribución espacial de *S. reilianum* en el año 2008 y para establecer su comportamiento espacial con técnicas goeoestadísticas. Se muestrearon 100 puntos por localidad, en 30 localidades de 27 municipios del Estado de México. En cada punto se contabilizaron 500 plantas, registrando las que presentaban síntomas de la enfermedad. Se realizó el análisis geoestadístico para estimar el semivariograma experimental y éste se ajustó a un modelo teórico (esférico, exponencial o gaussiano) con el programa Variowin 2.2, y después se sometió a la validación cruzada con el método de interpolación geoestadística o krigeado y se elaboraron mapas de agregación de la enfermedad. La enfermedad se presentó en las 30 localidades muestreadas; todas ellas presentaron un comportamiento espacial agregado de la enfermedad, 21 se ajustaron al modelo esférico, 5 al modelo exponencial y 2 al modelo Gaussiano. En todos los modelos se establecieron mapas de agregación y se observó que *S. reilianum* no se distribuye uniformemente. Se logró establecer la distribución espacial de *S. reilianum* y su infestación real en campo con el uso de técnicas geoestadísticas.

Palabras clave adicionales: geoestadística; krigeado; *Zea mays*.

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Abbreviations used: CESAVEM (Comite Estatal de Sanidad Vegetal del Estado de México); MEE (mean estimation error); MSE (mean squared error); SMSE (standardized mean squared error).

Introduction

Head smut (*Sporisorium reilianum (*Kuhn) Langdon and Fullerton [=*Sphacelotheca reiliana)* (Kühn) Clint] *S. reilianum* causes important, economical and biological damages in cool dry areas where maize (*Zea mays* L.) is cultivated (De León, 2008). Its fungus infection is favored by soil temperature between 21 and 28°C and relative humidity between 15% and 25% (Pataky, 1999). The fungal spores remain viable in soil up to 10 years (SARH, 1992).

In Mexico, the disease incidence varies from 0.1 to 40% (SARH, 1992). Furthermore, incidences of 80% have been detected in others parts of the world (Pataky, 1999).

Since 2003, the Plant Health Committee of the State of Mexico (CESAVEM) detected the disease at elevations higher than 2,200 meters above sea level with a yield reduction up to 15% in susceptible hybrids and varieties (CESAVEM, 2005). Recently, the disease has infected native cultivars threatening the genetic diversity of maize in Mexico, which is considered the primary center of origin. Similarly, teosintle (*Zea mays* subsp. mexicana), the closest relative of maize, is affected by corn head smut.

An adequate control is linked to the spatial distribution knowledge of the disease as those that affect the root (Campbell and Benson, 1994). Even at present, there is a lack of information about its distribution in plots or regions that could provide epidemiological tools with a scientific support in a sustainable way. The knowledge of the spatial distribution of the disease is essential for the elaboration of integral management programs, as they may allow efficient and precise development of sampling methods, control tactics and risk assessment (Taylor, 1961; Boiteu *et al*., 1979; Ruesink, 1980; Taylor, 1984). Geostatistic allows characterizing the spatial distribution in a range of scales and multiple directions. It is a part of the average and sample variance. Geostatistics methods provide a more direct measure of the spatial dependence as they take into consideration the bi-dimensional nature of the organism distribution. Also, they permit to create useful maps (Isaaks and Srivastava, 1988; Oliver and Webster, 1991; Rossi *et al*., 1992; Speight *et al*., 1998; Blom and Fleischer, 2001; Sciarretta *et al*., 2001) which generate gradients of disease intensity (Nava-Díaz, 2009). One of the goals of precision agriculture is to focus the control measurement in specific zones infested by pests or diseases. With geostatistics it is possible to establish spatial distribution and infection maps, obtaining economical and environmental a savings when treating the maize seed with fungicides, in specific areas, where the disease is presented. The geostatistical spatial modeling was done with the almond leaf scorch disease (*Xylella fastidiosa*) (Groves *et al*., 2005) and with the lettuce drop (*Sclerotinia minor* and *Sclerotinia sclerotiorum*) in California (Hao and Subbarao, 2005); with the *Pratylenchus crenatus* in carrot (Hay and Pethybridge, 2005) in Tasmania; with the leaf spot (*Mycosphaerella fragariae*) on strawberry (Turechek and Madden, 1999) in Ohio, and with the association of the viruses *Beet necrotic yellow vein virus* and *Beet soil borne mosaic virus* in sugar beet (Workneh *et al*., 2003).

There are no previous results on *S. reilianum* spatial distribution. Consequently, in order to generate data management, it is important to generate related information with a set of programs and computer applications. sualized through maps. Also, it will be helpful for the integrated management of maize health. These elements should facilitate the use of technology in the area of agriculture precision and in economic benefits of the growers. In this context, in the present study the objectives were: a) to model the spatial distributions of *S. reilianum*, and b) to know the spatial behavior of corn head smut through geostatistics methods in the State of Mexico, Mexico.

Material and methods

The sampling was done when maize plants were at the 50% of stage R3 (Ritchie and Hanway, 1982). One hundred plots were taken per locations and the geographical point was registered with dGPS (Model SPS351, Trimble, USA). Each plot was divided into five quadrants or sampling points. In each point, 100 plants were counted consecutively in the same row, recording those with symptoms of the disease. Distinct symptoms of head smut appear when tassels and ears of infected plants were replaced by smut sori.

The disease incidence was estimated in a sampling during the 2008 agriculture cycle, collected in 27 municipalities of the State of Mexico.

The geostatistical analysis consisted in: 1) semivariogram estimation, 2) semivariogram parameters estimation, and 3) spatial distribution estimation using points through kriging. The estimation of the semivariogram was done with data collected in the site of disease sampling. The semivariogram experimental value was calculated according to the following formula (Journel and Huijbregts, 1978; Isaaks and Srivastava, 1989):

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

where: $\gamma^*(h)$ is the experimental value for the interval of distance h; $N(h)$ is the number of pairs of sampling points separated by intervals of distance h; $z(x_i)$ is the value of the variable of interest in the sampling point x_i, and $z(x_i + h)$ is the value of the variable of interest in the sampling point $x_i + h$. Any mathematical function can be used to model a semivariogram as long as it is positive and defined (Armstrong and Jabin, 1981). In practice, one of the functions is chosen as a model; therefore the required conditions can be accomplished (Isaaks and Srivastava, 1989). A standard procedure is the visual selection of a function that seems to be adjusted to the semivariogram experimental values and subsequently to a validation is done (Englund and Sparks, 1988).

The validation of the adjusted models to the experimental semivariogram was done through crossed validation (Isaaks and Srivastava, 1989). In the same way, a simple value is eliminated and the method of geostatistical interpolation, kriging, is used along with the semivariogram model to validate, in order to estimate the value of the variable of interest in such sampling point from the remaining sample values. This procedure is frequently used in all the sampling points. The differences among the experimental and estimated values are summarized in statistical parameters of crossed validation (Isaaks and Srivastava, 1989; Hevesi *et al.*, 1992). The parameters to be validated are: the nugget effect, sill and range which have been modified in testing an error until obtaining the following statisticals of crossed validation:

a) Mean estimation error (MEE):

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

where $z^*(x_i)$ is the estimated value of the variable of interest in the point x_i, $z(x_i)$ is the measured value of the variable of interest in the x_i point and n is the number of sampling point used in the interpolation. MEE has not been significantly distant from 0 (t test), in the case, it will indicate that the semivariogram model allows the calculation of not slanted estimated values.

b) Mean squared error (MSE):

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^{n} [z^*(x_i) - z(x_i)]^2$$

A semivariogram model is considered adequate if the statistical value is close to zero (Hevesi *et al.*, 1992).

c) Standardized mean squared error (SMSE):

$$\text{SMSE} = \frac{1}{n} \sum_{i=1}^{n} \frac{[z^*(x_i) - z(x_i)]}{\sigma k}$$

where σ_k is the standard deviation of the expected error in the estimation with kriging. The validity of the model is correct if SMSE is included between the values 1 ± 2 $(2/N)^{0.5}$.

d) To validate the adjustment of the model another statistical was used which consists in that the variance value of errors has to be minor than the sample variance.

The spatial dependence level was calculated in order to determine how strong the relationship between the data collected in the sampling is. This value was obtained when dividing the nugget effect between the sills, expressed in percentage: less than 25% is high; between 26 and 75% is moderate and higher than 76% low (Cambardella *et al.*, 1994; López-Granados *et al.,* 2002).

After validating the semivariogram models, the kriging method was used to estimate the unbiased values to points that were not sampled, for the density maps elaboration of the disease. The incidence estimations of corn head smut in the studied locations were done with the program VarioWin 2.2 (Univ. of Lausanne, Switzerland). Besides, maps which indicated the spatial behavior of *S. reilianum* in the State of Mexico were elaborated, and the real infested area with this fungus was estimated with the program Surfer 9.0 (Golden Sufer, Colorado, USA).

Results

Corn head smut was detected in all locations sampled in 2008, *i.e.,* 30 locations of 27 counties of the State of Mexico; the disease incidence fluctuated from 0.2 to 3.4%. The highest incidence in the plot was observed in San Jose Ixtapa, Temascalcingo County. The infested area with this disease was 914.8 ha (Table 1).

The crossed validation statistical analysis showed that the semivariograms obtained were adjusted to a model with spherical spatial structure in 21 counties (Fig. 1). Five counties were adjusted to the exponential model (Fig. 2), and two counties were adjusted to the Gaussian model (Fig. 3) showing a spatial structure which is aggregated to the corn head smut in all locations. There was no nugget effect in all the adjustments. For every semivariograms of the model obtained, a nugget effect equal to zero was determined, which means that 100% of the distribution variation of the disease is explained by the established spatial structure in the respective semivariograms. The zero value in the

Table 1. Corn head smut incidence, affected area and infested estimated surface by county and location in 2008

No.	County	Location	Area (ha)	Incidence (%)	% infested
1	Acambay	San Antonio Detiña	8.50	0.2	78
2	Almoloya de Juarez	Santa Juana	23.20	0.2-2.2	93
3	Amanalco	San Juan	4.60	0.2	28
4	Atlacomulco	Tic Tic	52.30	0.2-0.8	42
5	Calimaya	Calimaya	151.00	0.2-0.4	32
6	Chalco	San Martin Cuautlalpan	16.70	0.6-1.7	10
7	Chapa de Mota	La Esperanza	12.70	1.0	62
8	Cocotitlan	San Andres	52.50	0.2-1.6	88
9	Donato Guerra	San Jose Tiloxtoc	0.82	0.8	93
10	Huehuetoca	Santa Maria	17.50	0.6	17
11	Ixtapan del Oro	El Salto y Mesas	6.19	0.2-0.8	84
12	Jilotepec	San Pablo Huantepec	19.80	0.2	82
13	Metepec	Metepec	15.00	0.2	81
14	Otzoloapan	El Calvario	0.45	0.8	37
15	Rayon	Rayon	8.50	0.2-1.2	39
16	San Mateo Atenco	Guadalupe	151.50	0.8-3.4	79
17	Santo Tomas	El Jocoyol	0.45	0.8	13
18	Soyaniquilpan	San Jose Deguedo	8.50	0.2-1.2	97
19	Temascalcingo	San Jose Ixtapa	151.50	0.8-3.4	21
20	Temascaltepec	La Finca	14.93	0.2-0.6	76
21	Temoaya	Taborda	13.50	0.4-0.8	15
22	Tenancingo	San Jose El Cuartel	26.43	0.2	13
23	Tenango del Valle	Tenango	13.70	0.2	89
24	Tlalmanalco	Tlalmanalco	34.00	0.2-0.6	27
25	Toluca	Cerrillo	21.70	0.2	28
26	Valle de Bravo	Santa Teresa T.	8.90	0.2-1.0	81
		Santa Magdalena T.	9.93	0.2-1.8	83
27	Xonacatlan	Ejido Xonacatlan	60.00	0.2-2.0	89
Total			914.80		

nugget means that the sampling error was minimal and the sampling scale was the adequate (Rossi *et al*., 1992).

The sill values varied between 0.000060 and 0.087000 in the spherical model; from 0.003038 to 0.024554 in the exponential model and from 0.000336 to 0.000240 in the Gaussian model. The range values fluctuated between 157.30 to 1730.80 m in the spherical model; from 644.75 to 1083.09 m for the exponential model and from 2035.44 to 2230.19 m in the Gaussian model (Table 2), which probably caused different kinds of aggregation in the different locations analyzed. The values obtained inside the appropriated rank of the statistical crossed (Table 3) allowed validating the adjusted models. The spatial dependence level found in all cases was high. The adjusted semivariogram model established for each location is shown in the Figure 1.

Aggregation maps of corn head smut and gradients of the disease were designed in all models for its visualization (Fig. 2). The divergence among maps is due to the differences presented in the corn head smut locations in each county. The distribution of *S. reilianum* population in maize was studied in specific zones for locations with incidences higher than 1.4%. Also aggregations with irregular shapes were obtained and two aggregations in a continuous way for the locations of Guadalupe, San Mateo Atenco and San Antonio Detiña, in Acambay. A relationship between incidences of the disease and high number of aggregation centers was not observed, similar as in the counties with minor incidence of the disease which presented more free areas. The highest aggregation centers could be observed at various stages of the map, where the highest rates tended to be located in the center area of the map in most of all counties (Fig. 4).

S. reilianum infested areas were between 10.0 and 97.0%, in the locations Chalco and Soyaniquilpan respectively, to the total sampled area (Table 1). The highest, estimated infested areas, was in Soyaniquilpan (97%),

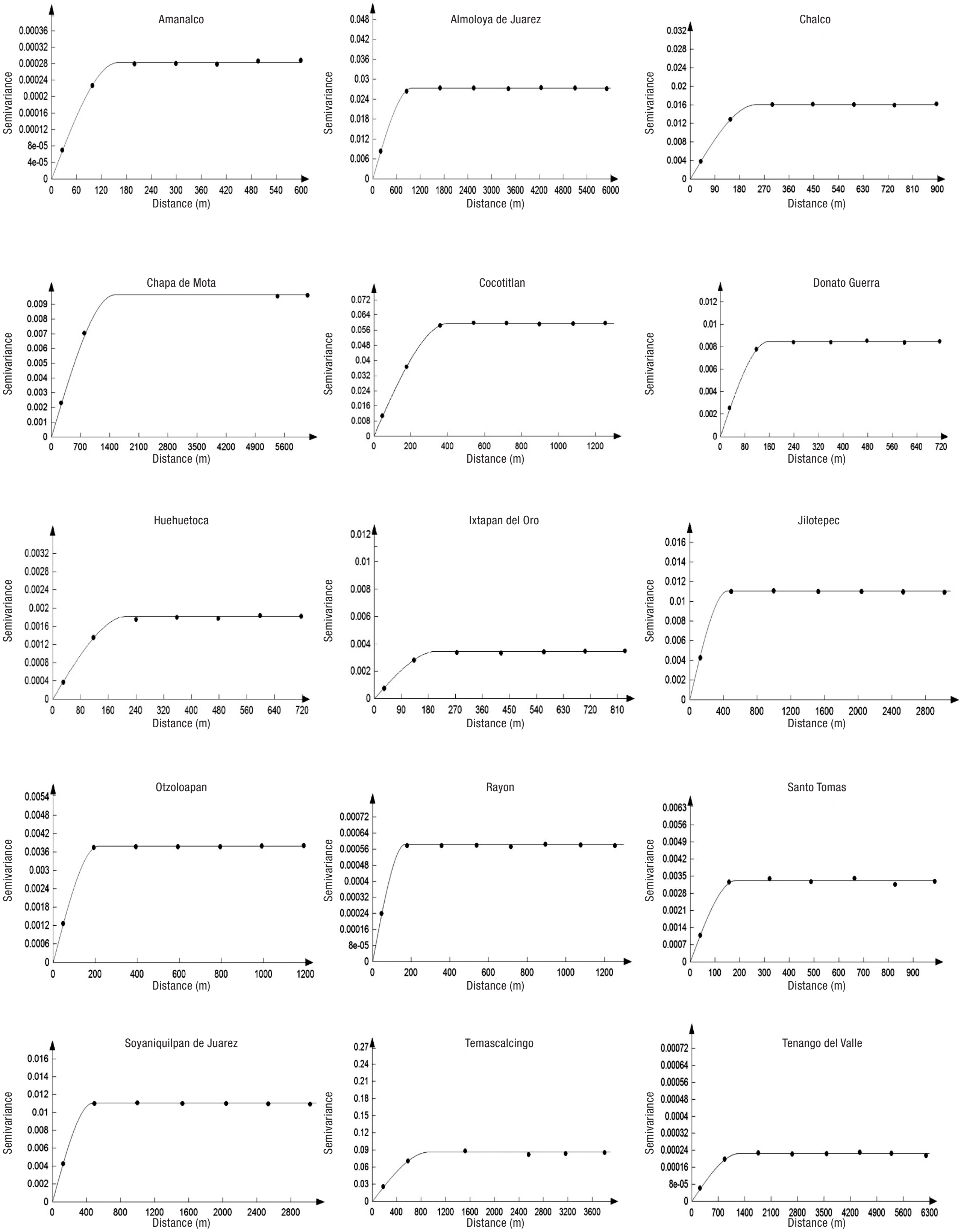

Figure 1. Semivariograms by locations adjusted to the spherical model in 2008.

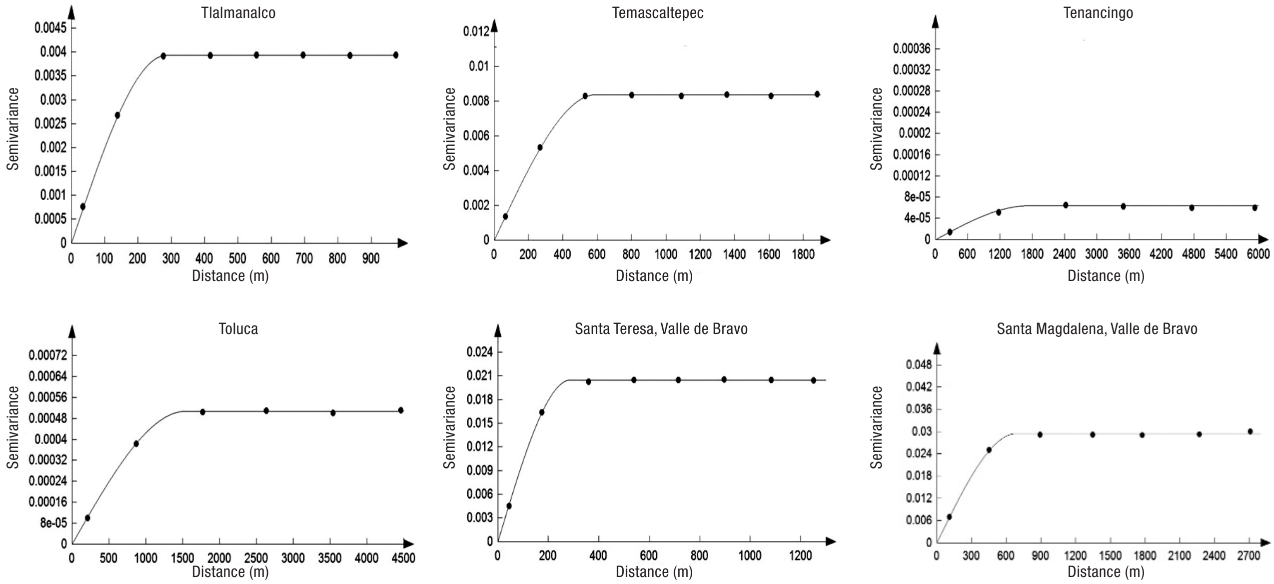

Figure 1 (cont.). Semivariograms by locations adjusted to the spherical model in 2008.

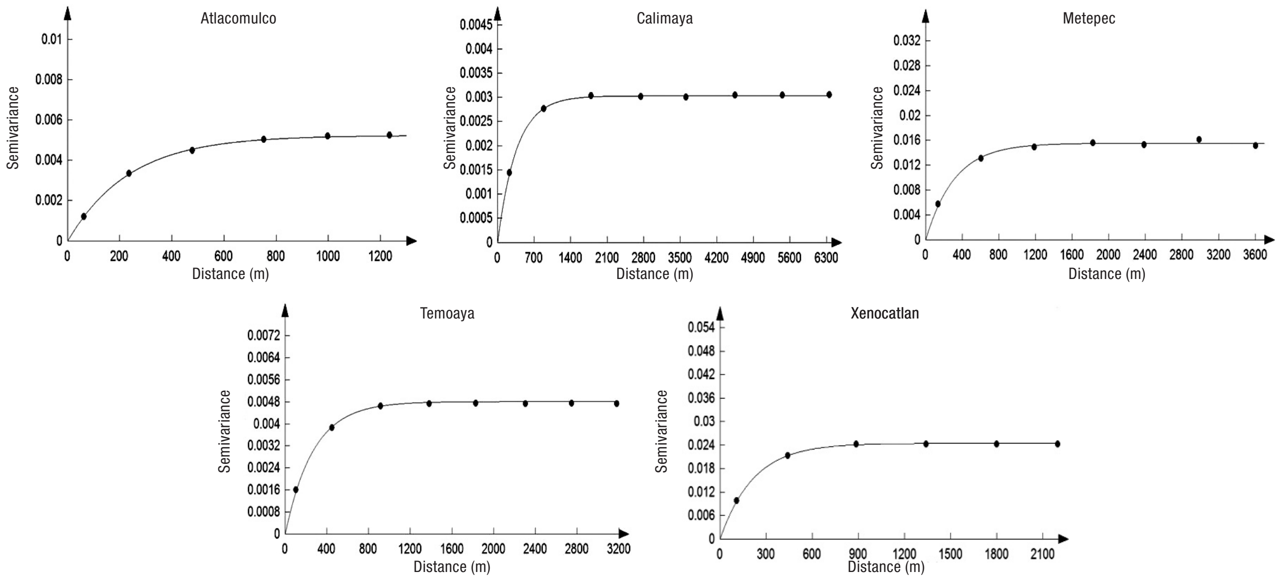

Figure 2. Semivariograms by locations adjusted to the expoential model in 2008.

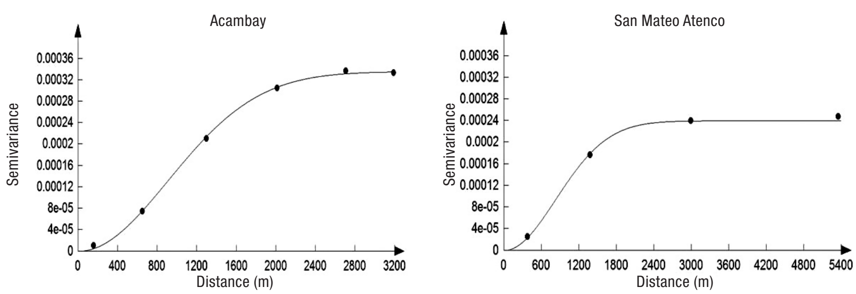

Figure 3. Semivariograms by locations adjusted to the Gaussian model in 2008.

Table 2. Parameters (nugget, sill and range) in the adjusted models of corn head smut semivariograms by county in 2008

No.	County	Model	Nugget	Sill	Range	Nugget/ Sill (%)	Level of space dependence
1	Acambay	Gaussian	0	0.000336	2,230.19	0.00	High
2	Almoloya de Juarez	Spherical	0	0.027461	987.60	0.00	High
3	Amanalco	Spherical	0	0.000283	159.24	0.00	High
4	Atlacomulco	Exponential	0	0.005261	702.99	0.00	High
5	Calimaya	Exponential	0	0.003038	1,083.09	0.00	High
6	Chalco	Spherical	0	0.016246	243.00	0.00	High
7	Chapa de Mota	Spherical	0	0.009669	1,526.23	0.00	High
8	Cocotitlan	Spherical	0	0.059632	403.00	0.00	High
9	Donato Guerra	Spherical	0	0.008492	157.29	0.00	High
10	Huehuetoca	Spherical	0	0.001830	215.44	0.00	High
11	Ixtapan del Oro	Spherical	0	0.003476	210.64	0.00	High
12	Jilotepec	Spherical	0	0.011178	453.11	0.00	High
13	Metepec	Exponential	0	0.015600	942.02	0.00	High
14	Otzoloapan	Spherical	0	0.003803	215.08	0.00	High
15	Rayon	Spherical	0	0.000586	169.99	0.00	High
16	San Mateo Atenco	Gaussian	0	0.000240	2,035.44	0.00	High
17	Santo Tomas	Spherical	0	0.003333	182.75	0.00	High
18	Soyaniquilpan	Spherical	0	0.011076	474.50	0.00	High
19	Temascalcingo	Spherical	0	0.087000	933.01	0.00	High
20	Temascaltepec	Spherical	0	0.086770	591.91	0.00	High
21	Temoaya	Exponential	0	0.004824	812.26	0.00	High
22	Tenancingo	Spherical	0	0.000060	1,730.80	0.00	High
23	Tenango del Valle	Gaussian	0	0.000266	1,269.66	0.00	High
24	Tlalmanalco	Spherical	0	0.003938	284.20	0.00	High
25	Toluca	Spherical	0	0.000508	1,540.35	0.00	High
26	Valle de Bravo	Spherical	0	0.020538	287.99	0.00	High
		Spherical	0	0.029584	689.26	0.00	High
27	Xonacatlan	Exponential	0	0.024554	644.74	0.00	High

Donato Guerra (93%) and Almoloya de Juarez (93%). This allowed us to identify the free diseased areas and infested ones.

Discussion

The high level of spatial dependence observed in this study showed an aggregated distribution of corn head smut for all the assessed counties in the State of Mexico. The differences in disease incidences and the amount of land with the presence of the disease originated three types of aggregation. The validation of the semivariograms in each county corroborated the aggregated distribution of the disease at a region level which allowed us to be certain that the method used and the sampling scale were appropriate. The geostatistical analysis was adequate for the study of the spatial distribution of the disease.

The different levels of incidence of the disease were associated to the spatial distribution which was adjusted to the spherical model, and which indicated that in each location there are zones where *S. reilianum* (Tables 1 and 3) is more evident, than in the rest of the sampled points, and suggests either the presence of environmental conditions or susceptible corn genotypes which favored the expression of the disease under this spatial distribution. This possible association between the levels of incidence of the disease with the spherical distribution would allow to previously knowing the disease aggregation. This could facilitate selecting the monitoring actions and would direct the control measurements to specific points.

The incidences of the disease from 0.2 to 1.8% were associated with the exponential spatial distribution. The counties with an adjustment of the semivariogram to the exponential model show an irregular or random distribution of corn head smut limits within the study

Table 3. Table 3. Value of the statistical of the crossed validation in the aggregation model of corn head smut by county in 2008: mean estimation error (MEE), mean squared error (MSE) and standardized mean squared error (SMSE)

No.	County	Sample size	Sample average	Variance sample	MEE	Variance of the errors	MSE	SMSE
1	Acambay	100	0.002	0.0040	0.13^{ns}	0.00031	0.03	1.05
2	Almoloya de Juarez	100	0.030	0.04990	0.09^{ns}	0.03201	0.09	1.11
3	Amanalco	100	0.002	0.00040	0.10^{ns}	0.00029	0.11	1.07
4	Atlacomulco	100	0.016	0.01014	0.11^{ns}	0.00872	0.14	1.10
5	Calimaya	100	0.016	0.00454	0.08^{ns}	0.00285	0.02	1.04
6	Chalco	100	0.024	0.02542	0.10^{ns}	0.01752	0.07	1.09
7	Chapa de Mota	100	0.010	0.00990	0.13^{ns}	0.00729	0.10	1.02
8	Cocotitlan	100	0.073	0.07581	0.11^{ns}	0.05221	0.12	1.13
9	Donato Guerra	100	0.016	0.01254	0.07^{ns}	0.00771	0.09	1.03
10	Huehuetoca	100	0.006	0.00356	0.11^{ns}	0.00203	0.03	1.05
11	Ixtapan del Oro	100	0.032	0.01112	0.14^{ns}	0.00801	0.05	1.10
12	Jilotepec	100	0.012	0.00116	0.09^{ns}	0.00052	0.10	1.12
13	Metepec	100	0.032	0.03418	0.10^{ns}	0.02164	0.06	1.09
14	Otzoloapan	100	0.012	0.00546	0.08^{ns}	0.00318	0.02	1.14
15	Rayon	100	0.004	0.00078	0.13^{ns}	0.00055	0.11	1.06
16	San Mateo Atenco	100	0.002	0.00040	0.11^{ns}	0.00027	0.04	1.03
17	Santo Tomas	100	0.008	0.00634	0.07^{ns}	0.00576	0.14	1.07
18	Soyaniquilpan	100	0.018	0.01608	0.12^{ns}	0.00921	0.08	1.10
19	Temascalcingo	100	0.161	0.26738	0.09^{ns}	0.15281	0.12	1.13
20	Temascaltepec	100	0.022	0.01112	0.14^{ns}	0.00393	0.06	1.04
21	Temoaya	100	0.012	0.00786	0.10^{ns}	0.00612	0.05	1.07
22	Tenancingo	100	0.002	0.00040	0.09^{ns}	0.00025	0.10	1.11
23	Tenango del Valle	100	0.004	0.00078	0.08^{ns}	0.00061	0.09	1.09
24	Tlalmanalco	100	0.011	0.00468	0.13^{ns}	0.00361	0.06	1.09
25	Toluca	100	0.004	0.00078	0.05^{ns}	0.00064	0.09	1.10
26	Valle de Bravo	100	0.052	0.02530	0.10^{ns}	0.01328	0.11	10.7
		100	0.062	0.05096	0.07^{ns}	0.03711	0.05	1.05
27	Xonacatlan	100	0.460	0.05588	0.09^{ns}	0.03622	0.09	1.12

$1 \pm 2\ (2/N)^{0.5} = 1 \pm 0.45$. ns: do not differ significantly ($p = 0.05$).

area. This means that the existence of a possible factor which could originate it, the improved varieties and commercial hybrids are the most susceptible to the disease, therefore it is possible that the presence of such genotypes could be either irregular within the location or it could be originated for a higher abundance of native varieties, which are less susceptible to the disease (CESAVEM, 2005).

The Gaussian model adjustment in the locations of Soyaniquilpan de Juarez and San Mateo Atenco with an incidence of 0.2% of corn head smut, indicates that the disease was expressed continuously respecting to the simple points (Table 3). These results suggest the presence of genotypes and environmental factors which favor the disease expression so the disease aggregation can be continuously present.

The geostatistic spatial model of *S. reilianum* in corn obtained in this study, agrees with that obtained by Groves *et al*. (2005) in the almond leaf scorch disease (*Xylella fastidiosa*) and with the lettuce drop (*Sclerotinia minor* and *Sclerotinia sclerotiorum*) by Hao and Subbarao (2005) in California. Equally, the model of the damages caused by *Pratylenchus crenatus* in carrots was achieved (Hay and Pethybridge, 2005) in Tasmania. Leaf spot caused by *Mycosphaerella fragariae* (Turechek and Madden, 1999) in Ohio, and the association of the *Beet necrotic yellow vein virus* and *Beet soilborne mosaic virus* in beet plantations (Workneh *et al*., 2003). Similarly, Larkin *et al*. (1995) modeled the epidemic caused by *Phytophthora capsici* in chili plantations to determine the spatial patterns of the disease, the content of water in soil and its relation with the progress of the disease at plot level.

The usage of geostatistical techniques allows the elaboration of maps which may assist on the accurate pest and disease management (Fleischer *et al*., 1997).

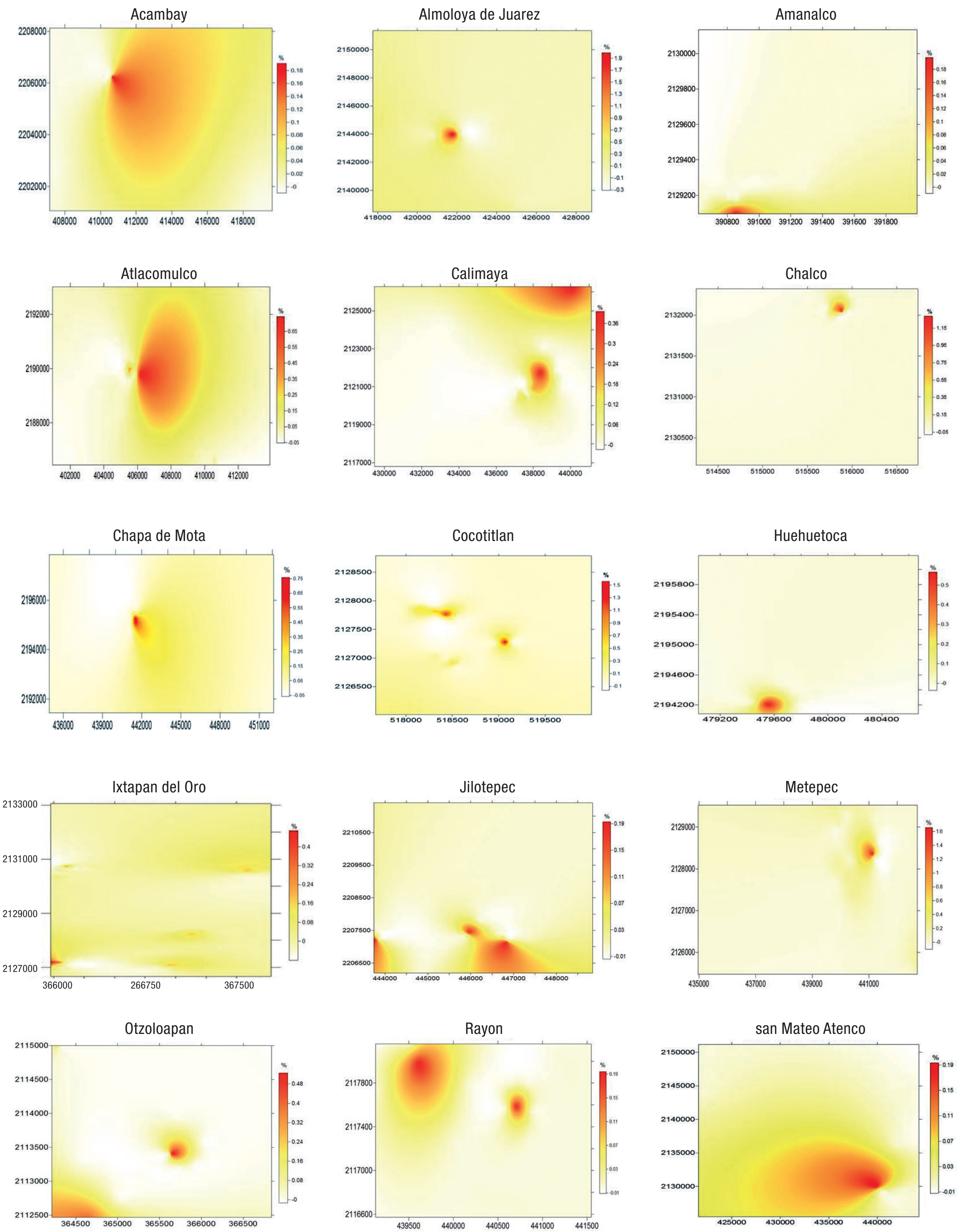

Figure 4. Corn head smut density maps obtained in 2008; % indicates disease incidence.

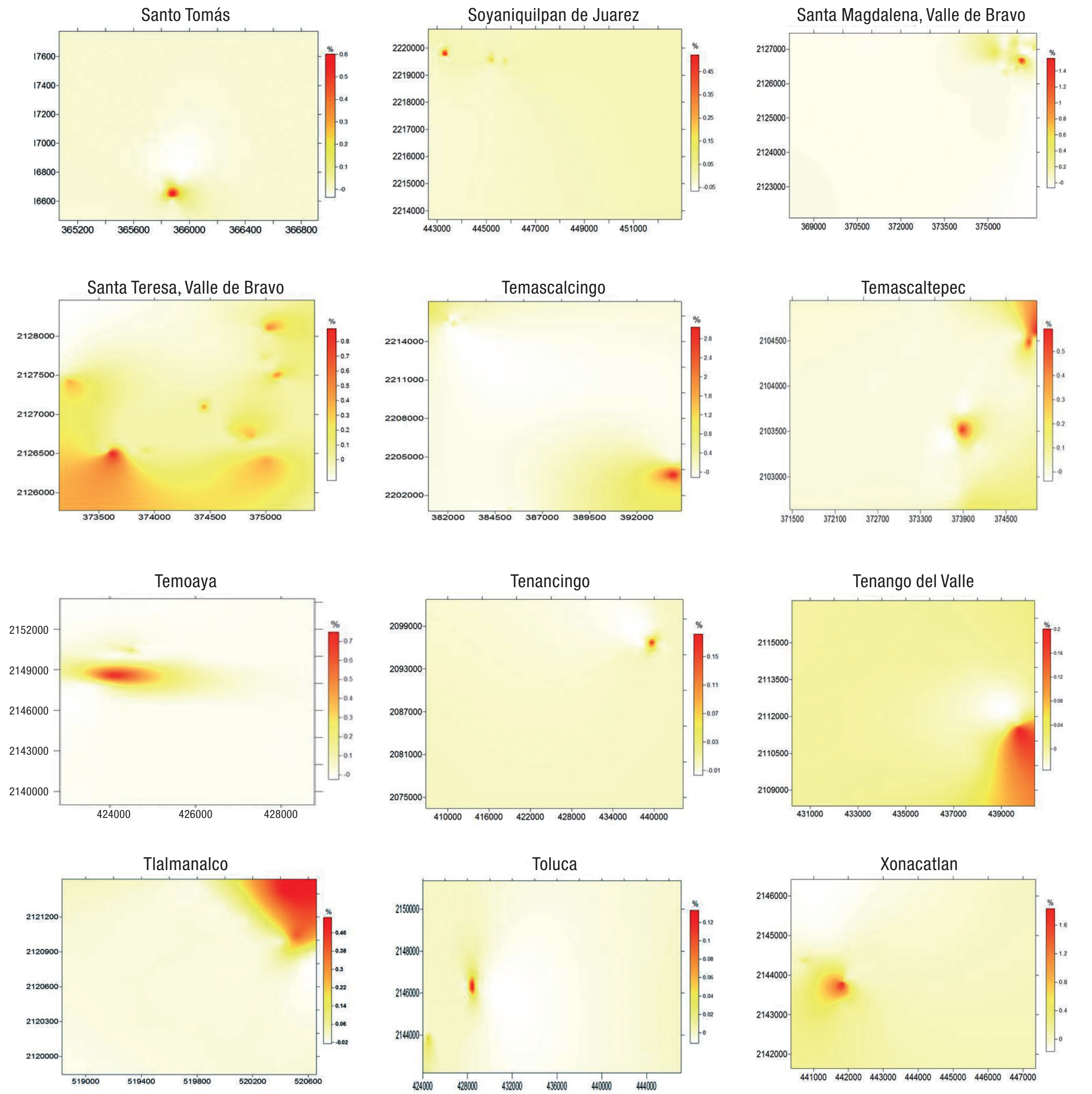

Figure 4 (cont.). Corn head smut density maps obtained in 2008; % indicates disease incidence.

This management has the potential to reduce the utilization of pesticides and to slow down the development of resistance due to the creation of temporary dynamic housings (Fleischer *et al*., 1999). The use of pest and disease distribution maps to lead control measurements in heavily infested areas was done in a beginning by Weisz *et al*. (1996), who emphasizes that pest management provides a tool to lower cost by reducing the use of insecticides.

The maps obtained in this study showed that *S. reilianum* was not distributed in 100% of the studied area; it means that, the distribution was not uniform. These results fit with the ones of Roumagnac *et al*. (2004) who obtained maps of *Xanthomonas axonopodis* pv. *allii* in onion with a non uniform distribution of the disease, Gavassoni *et al*. (2001) obtained irregular maps of *Heterodera glycines* distribution in soybean, meanwhile the non-uniform distribution of *Colletotrichum* *kahawae* in coffee was obtained by Mouen Bedimo *et al*. (2007). It was observed that the highest percentage of the estimated area without infestation was associated with the spherical model apart from of the obtained incidence level, except in Temoaya, where it was adjusted to the exponential model. On the contrary, the highest percentages of the estimated infested area were associated to the exponential and spherical models. It was not found a relation between the higher rates of infestation on field with the higher percentages of the estimated infested areas.

Fleischer *et al*. (1999) indicates that a damaging organism shows variable densities in the total area infested, and that such infestation rarely reaches 100%; which allows to direct the methods of control in the infested areas and especially in those where the population exceeds the economic threshold as long as this level can be known. The results suggest implementing several actions to control the disease and direct the sampling activities in locations where corn head smut was found. With the obtained maps of *S. reilianum* aggregations is possible to establish control strategies applied to specific corn head smut infested areas. The use of corn seed treated with fungicides and the elimination of infected plants should justify the usage of precision agricultural techniques to control the damages caused by *S. reilianum*.

This work about the spatial distribution of *S. reilianum* in maize, which was obtained with the use of geostatistical tools is, the first report worldwide on the pathogen management towards precision agriculture.

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