

SPATIAL DISTRIBUTION AND MAPPING OF *JACOBIASCA LYBICA* (BERGEVIN AND ZANON) (HEMIPTERA: CICADELLIDAE) EGG POPULATIONS IN IRRIGATED SHERRY VINEYARDS

DISTRIBUCIÓN ESPACIAL Y MAPEO DE *JACOBIASCA LYBICA* (BERGEVIN Y ZANON) (HEMIPTERA: CICADELLIDAE) DE LAS POBLACIONES DE HUEVOS EN VIÑEDOS DE REGADÍO

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ABSTRACT

The green cicadellid *Jacobiasca lybica* (Bergevin and Zanon) (Hemiptera: Cicadellidae) has recently become in one of the most serious pests on vineyards in the Southern regions of the Iberian Peninsula. In order to characterize the spatial and temporal variability of the density of *J. lybica* eggs, we employed the spatial statistical techniques such as Geostatistics and Spatial Analysis by Distance Index (SADIE). The density and spatial distribution of *J. lybica* varied considerably among the years. Spherical and exponential functions provided the best fit for cross-validation. The spatial distribution of *J. lybica* eggs was aggregated (non-random spatial dependence) in all data. *J. lybica* density data showed moderate spatial dependence. The nugget and sill varied considerably. *J. lybica* density maps achieved by kriging were used to estimate the percentage of susceptible surface that should be treated with a site-specific insecticide treatment based on an estimated economic threshold for each date. The index I_a and J_a showed aggregate distribution. Following the completion and analysis of the maps of infestation more than one centre of aggregation of this insect pest was observed. The *J. lybica* infested areas varied considerably among dates. About 73 and 8% of the total area was infested with *J. lybica*. So, if an insecticide application was limited to the areas exceeding the economic threshold, the average reduction in insecticide cost achieved in vineyard could be around 42%. *J. lybica* has been shown to have relatively stable patches over time and space.

Key words: Geostatistics, kriging, site-specific pest management, semivariogram, patch stability, SADIE.

RESUMEN

El cicadelido verde *Jacobiasca lybica* (Bergevin y Zanon) (Hemiptera: Cicadellidae) recientemente se ha convertido en una de las más graves plagas en los viñedos del sur de las regiones de la Península Ibérica. Con el fin de caracterizar la variabilidad espacial y temporal de la densidad de huevos de *J. lybica*, se emplearon técnicas de la estadística espacial tales como la Geoestadística y Análisis Espacial por Índices de Distancia (SADIE). La densidad y distribución espacial de *J. lybica* variaba considerablemente entre los años.

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La distribución espacial de los huevos de *J. lybica* fue agregada (no aleatoria dependencia espacial) en todos los datos. *J. lybica* densidad de los datos mostraron dependencia espacial moderada. El efecto pepita varió considerablemente. *J. lybica* densidad de los mapas obtenidos por kriging los cuales fueron utilizados para estimar el porcentaje de la superficie susceptible de que deben ser tratados con un sitio específico tratamiento con insecticida sobre la base de un umbral económico estimado para cada fecha. Las áreas infestadas por *J. lybica* variaban considerablemente entre las fechas. Los índices I_a y J_a mostraron una distribución agregada. Tras la realización y análisis de los mapas de infestación se observó más de un centro de agregación de este insecto plaga. Cerca de 73 y 8% de la superficie total fue infestada por *J. lybica*. Por lo tanto, si la aplicación de un insecticida se limitaba a las zonas superiores a los umbrales económicos, el promedio de reducción de los costos en insecticidas realizados en viñedo podría situarse en torno a 42%. *J. lybica* ha demostrado tener manchones relativamente estables en el tiempo y el espacio.

Palabras clave: Geoestadística, krigeado, sitio específico de manejo de plagas, semivariograma, estabilidad espacio temporal, SADIE.

INTRODUCTION

Insect populations are typically spatially heterogeneous in their densities. This heterogeneity is often of considerable importance for the development of sampling procedures (Southwood, 1978), for understanding predator-prey relationships (Hassell and May, 1974), for understanding intraspecific competition (Iwao, 1970), and in the development of rational pest-management strategies (Hughes and McKinlay, 1988).

For these reasons, a great deal of effort has been invested in characterizing spatial patterns of insect densities. Most earlier studies have attempted to describe spatial patterns with the use of dispersion index such as s^2/\bar{x} (David and Moore, 1954), coefficients of Taylor's power law (Taylor, 1984), Morisita index (Morisita, 1959), Lloyd's patchiness index (Lloyd, 1967) and Iwao's patchiness regression coefficients (Iwao, 1972). These index focused on the frequency distribution of samples (mostly quantify the relationship of the sample variance to the mean) but ignored the insect explicit spatial location. This property produces certain undesirable effects: a) these index often fails to differentiate among different spatial patterns (Hurlbert, 1990), and b) their descriptions

of spatial pattern greatly depend on the size of sample units (Sawyer, 1989). Therefore, alternative methods that rely on the geographic location of samples must be used to study their spatial arrangement. Geostatistical techniques offer such alternative approach.

Geostatistics is a branch of spatial statistic that was originally developed for the mining industry in the 1950s and 1960s. The technique is now widely recognized as an important tool for the estimation of the abundance and distribution of natural resources (Rossi *et al.*, 1992). Unlike the traditional procedures commonly used in biological studies, in which mean-variance relationships are evaluated from observations assumed to be random and independent, spatial statistical procedures recognize that sample observations may be dependent, and nonrandom sampling strategies may be more useful (Schotzko and O'Keeffe, 1989). Consequently, spatial analysis measures the extent of dependence in the sample data by evaluating variance as a function of the distance and direction between observations. Recently there has been considerable interest in their application to study spatial distribution of insects (Schotzko and O'Keeffe, 1989; Liebhold *et al.*, 1993; Crist, 1998; Schotzko and

Quisenberry, 1999). Therefore, application of geostatistics techniques allows the production of maps as the first step for spatially explicit management Fleischer *et al.* (1999).

Among the new developments of the spatial statistical studies, a new methodology has recently appeared; it is called Spatial Analysis Distance Indexes (SADIE by its initials in English) that has been developed by Dr. Joe N. Perry of the Department of Entomology and Nematology the Rothamsted Experiment Station (UK). SADIE identifies the data model for two-dimension space, with associated index of aggregation and a test for the diversion of randomness based on an algorithm attraction, which features a biological model for dispersing individuals from a source in which each individual is assigned a territory dynamic (Perry, 1995; Perry *et al.*, 1996). This method makes use of data concerning each sampling and there is no restriction on the location of the sampling units.

J. lybica has recently become one of the most serious problems in vineyards in the Southern regions of the Iberian Peninsula, producing important economic injuries (Araújo, 1988; Quartau *et al.*, 1989; Quartau and Rebelo, 1992; Ocete *et al.*, 1999). In spite of the high incidence of its infestations, at present little is known about its spatial distribution and biology.

The objectives of this study were to: 1) characterise the spatial and temporal variability of *J. lybica* eggs in vineyards; 2) investigate the feasibility of developing accurate maps of *J. lybica* and 3) develop site-specific insecticide application maps for areas that exceeded an economic threshold.

MATERIAL AND METHODS

Study area and sampling

Field studies of *J. lybica* were conducted at Jerez de la Frontera (Cádiz, Spain). An area measuring 35 m wide by 55 m long was selected for the

intensive survey in 2005 and 2006. Rows were oriented south-north across the study area.

J. lybica egg density samples were collected on a 2- by 9-m grid pattern, resulting in a total of 126 sampling units. The position of each grid point was georeferenced using a Differential Global Positioning System (DGPS). At each node, the number of eggs of *J. lybica* was counted on ten leaves (López, 1997). Samplings (Table 1) was carried out monthly during the months of greatest insect activity, between June and October (Toledo, 1992). In year 2005 the experimental plot was treated with Malation to control *J. lybica* (7 of August).

An economic threshold (ET) was previously estimated at 1 egg plant⁻¹ (Toledo, 1992). So when *J. lybica* egg density exceeded the ET a control action was required.

Exploratory statistical analysis

Egg density from each date was treated as a study case and was analysed statistically. Data distribution was described using classical descriptors (mean, standard deviation and skewness). The descriptive statistics of eggs density suggested that they were not normally distributed (skewness between 1 and -2) (Table 2) and therefore log transformation, $\log_{10}(n+1)$, was used for geostatistical analysis.

Geostatistical analysis

The spatial variation of *J. lybica* eggs was described and quantified (Isaaks and Srivastava, 1989; Webster and Oliver, 1990). The variogram, a central tool of geostatistics, describes the structure and spatial scale of variation by measuring the degree of spatial correlation between sampling points. Geostatistical prediction or kriging enables a property to be predicted optimally at an unsampled location. Prediction of the property can be made for any points (punctual kriging) or over certain areas (block kriging), and estimates are unbiased and have minimum variance.

Semivariogram models were fitted to experimental semivariogram values to assess the spatial structure of variation in eggs plant⁻¹. Isotropy was assumed because experimental semivariograms were fitted in four directions (0, 45, 90 and 135°) over the field and directional differences were not seen. Thus, omnidirectional experimental semivariograms were computed for interval distances of 1 m as follows (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:

$\gamma^*(h)$ = experimental semivariogram value at distance interval h .

$N(h)$ = number of sample value pairs within the distance interval h .

$z(x_i)$, $z(x_i+h)$ = sample values at two sample points separated by a distance interval h .

Several semivariogram functions (Isaaks and Srivastava, 1989) were evaluated to identify the model that produced the best fit. The best fit models were used to perform ordinary point kriging on a regular grid of 1 m x 1 m.

In order to compare the nugget magnitude, values of spatial dependence were calculated after Robertson (1995) as $(1-\text{nugget/sill}) \times 100$, indicating spatial distribution as random if <26%, moderately if between 26%-75% or strong spatial dependence if >75% (Gonzalez-Andujar *et al.*, 2001).

A cross-validation procedure was performed to check model validity. The estimated model parameters were modified in a "trial-and-error" procedure until adequate cross-validation statistics were obtained (Isaaks and Srivastava, 1989). To cross-validate a semivariogram model, each sample value was deleted one by one from the data set and kriging, described

below, was used to estimate quantity of eggs at the location of the deleted sample using the remaining samples. Differences between estimated and experimental values of number of eggs were summarized using the following cross-validation statistics: mean estimation error (MEE), mean squared error (MSE), and standardized mean square error (SMSE) (Isaaks and Srivastava, 1989; Hevesi *et al.*, 1992). A model was considered to ensure unbiased estimates of number of eggs if the MEE was not significantly different than zero and was considered accurate if the MSE was, as a practical rule, less than the variance of sample values (Hevesi *et al.*, 1992). The SMSE indicated the consistency of the observed MSE with the calculated estimation uncertainty, expressed as the kriging estimation error variance, described below (Journel and Huijbregts, 1978; Isaaks and Srivastava, 1989). Model validity was satisfied if the SMSE was within the interval $1 \pm 2/(2/m)0.5$ (Hevesi *et al.*, 1992).

This geostatistical technique provides the best linear unbiased estimates (BLUE) of a particular variable at a point where it is unknown (Journel and Huijbregts, 1978). The geostatistical analysis was performed with the geostatistical package COKRIG6 (Hevesi, 1992, personal supply). As a final step, SURFER 9.0 was used to map kriged estimates.

Site-Specific insecticide application

The different *J. lybica* egg density maps achieved by kriging were used to estimate the percentage of insect-free surface and the percentage of surface susceptible to be treated with a site-specific insecticide treatment. Insecticide treatment was assumed to be needed for a *J. lybica* egg density exceeding 1 egg plant⁻¹ (Toledo, 1992).

Spatial and temporal stability

Short-term (within a year) and long-term (among the years) spatial stability was studied

using the bivariate Cramér-von Mises test (Syrjala, 1996). This test is an extension of the univariate Cramér-von Mises test used to contrast the difference between two cumulative distribution functions (Γ_1 and Γ_2) (Conover, 1980). The test is defined by four statistics,

$$\psi_c = \sum_{k=1}^K [\Gamma_1(x_{c,k}, y_{c,k}) - \Gamma_2(x_{c,k}, y_{c,k})]^2$$

where x and y represent the sampling location coordinates defined relative to corner c ($c=1, \dots, 4$).

$$\Psi = \frac{1}{4} \sum_{c=1}^4 \psi_c$$

Finally, the test statistics are defined as the average of the following statistics (Syrjala, 1996).

Spatial Analysis by Distance Index (SADIE)

Distribution

Spatial distribution was established using Spatial Analysis by Distance Index (SADIE). SADIE is a set of analytical techniques to detect and measure the degree of non randomness in the two-dimensional spatial patterns of populations (see Perry, 1995; Perry *et al.*, 1996 for a general introduction). The SADIE method provides an index of aggregation (I_a) for spatial data and a probability (P_a) that the data are not distributed randomly. Also, SADIE provides an index (I_m) of spatial association or dissociation between two data sets (Perry, 1998; Korie *et al.*, 2000) that permit analysis temporal stability.

To describe the spatial pattern of *J. lybica*'s eggs, two index were used, the main SADIE index I_a and one subsidiary index J_a (Perry 1995, 1998). The data show spatial aggregation if $I_a > 1$ and are considered different from random if the associate probability is $P_a < 0.025$. The associated index J_a discriminates between patterns where there is a major cluster, for which its value is greater than one, and two or

more clusters, for which its value is equal to or less than the unit.

Temporal stability

The association index I_m (Perry 1997, 1998; Korie *et al.*, 2000) was applied to assess the stability of spatial distribution between sampling periods. The index I_m allows a direct comparison between two sets of counts (in these cases successive weeks and years). The index presents association (spatial stability) if $I_m > 1$. The probability that two distributions are associated is considered significant if $P_m < 0.025$. A high level of association between eggs spatial distributions in successive samples would give an indication of their temporal stability.

RESULTS

Geostatistical analysis

Exploratory Statistical Analysis

Density and spatial distribution of *J. lybica* varied considerably with dates. The mean *J. lybica* egg density was 0, 51 and 1, 20 eggs plants⁻¹ in 2005 and 2006, respectively (Table 1).

Table 1. Statistical summary.

Year 2005			
Dates (Day- Month)	\bar{x}	SD	Skew
29-06	0,35	0,64	4,56
07-08	0,09	0,28	6,86
30-08	0,53	1,06	3,91
27-09	0,92	1,25	5,43
26-10	0,69	0,89	7,53
Year 2006			
Dates (Day- Month)	\bar{x}	SD	Skew
27-06	0,82	1,16	4,01
25-07	1,38	1,32	-3,51
30-08	1,56	1,37	-4,17
27-09	1,66	1,50	7,30
28-10	0,61	0,91	4,85

Spatial and temporal distribution

Anisotropic semivariograms did not show any differences in spatial dependence with the directions, therefore isotropic semivariograms were chosen. The semivariogram model parameters for 2005 and 2006 are listed in

Table 2. Spherical and exponential isotropic models provided the best fit because the cross-validation criteria were met in all study cases (Table 3).

Figure 1 and 2 present the shape of the semivariograms fitted.

Table 2. Parameters (nugget, sill and range) of the adjusted models to the semivariograms of the number of eggs of leafhopper.

Date	Model	Nugget	Sill	Range (m)	Spatial dependence (%)	Level of espace dependence
29-06-2005	Spherical	0,020	0,034	41,45	58,82	Moderate
07-08-2005	Spherical	0,008	0,023	28,64	34,78	Moderate
30-08-2005	Spherical	0,009	0,024	25,20	37,50	Moderate
27-09-2005	Spherical	0,008	0,028	18,20	28,57	Moderate
26-10-2005	Spherical	0,014	0,022	21,48	63,63	Moderate
27-06-2006	Exponential	0,024	0,052	70,00	46,16	Moderate
25-07-2006	Exponential	0,022	0,058	62,08	37,93	Moderate
30-08-2006	Exponential	0,019	0,063	58,88	30,15	Moderate
27-09-2006	Spherical	0,035	0,061	39,91	57,37	Moderate
28-10-2006	Spherical	0,021	0,039	37,80	53,84	Moderate

Table 3. Value of the statistical of the crossed validation: mean estimation error (MEE). mean squared error (MSE) and standardized mean square error (SMSE).

Date	Sample Size	Average Sampled	Variance Sampled	MEE	Variance of the errors	MSE	SMSE
29-06-2005	126	0,09	0,02	0,13 ^{ns}	0,01	0,02	1,10
07-08-2005	126	0,02	0,007	0,10 ^{ns}	0,002	0,003	1,03
30-08-2005	126	0,12	0,04	0,12 ^{ns}	0,01	0,02	1,07
27-09-2005	126	0,21	0,05	0,12 ^{ns}	0,04	0,04	1,12
26-10-2005	126	0,17	0,04	0,13 ^{ns}	0,03	0,03	1,19
27-06-2005	126	0,19	0,05	0,11 ^{ns}	0,01	0,03	1,10
25-07-2006	126	0,30	0,07	0,12 ^{ns}	0,02	0,05	1,13
30-08-2006	126	0,33	0,07	0,10 ^{ns}	0,02	0,06	1,11
27-09-2006	126	0,35	0,06	0,12 ^{ns}	0,01	0,05	1,08
28-10-2006	126	0,15	0,04	0,11 ^{ns}	0,01	0,02	1,12

$1 \pm 2(N)^{0.5} = 1 \pm 0,45$. ns: not differs significant to 5%

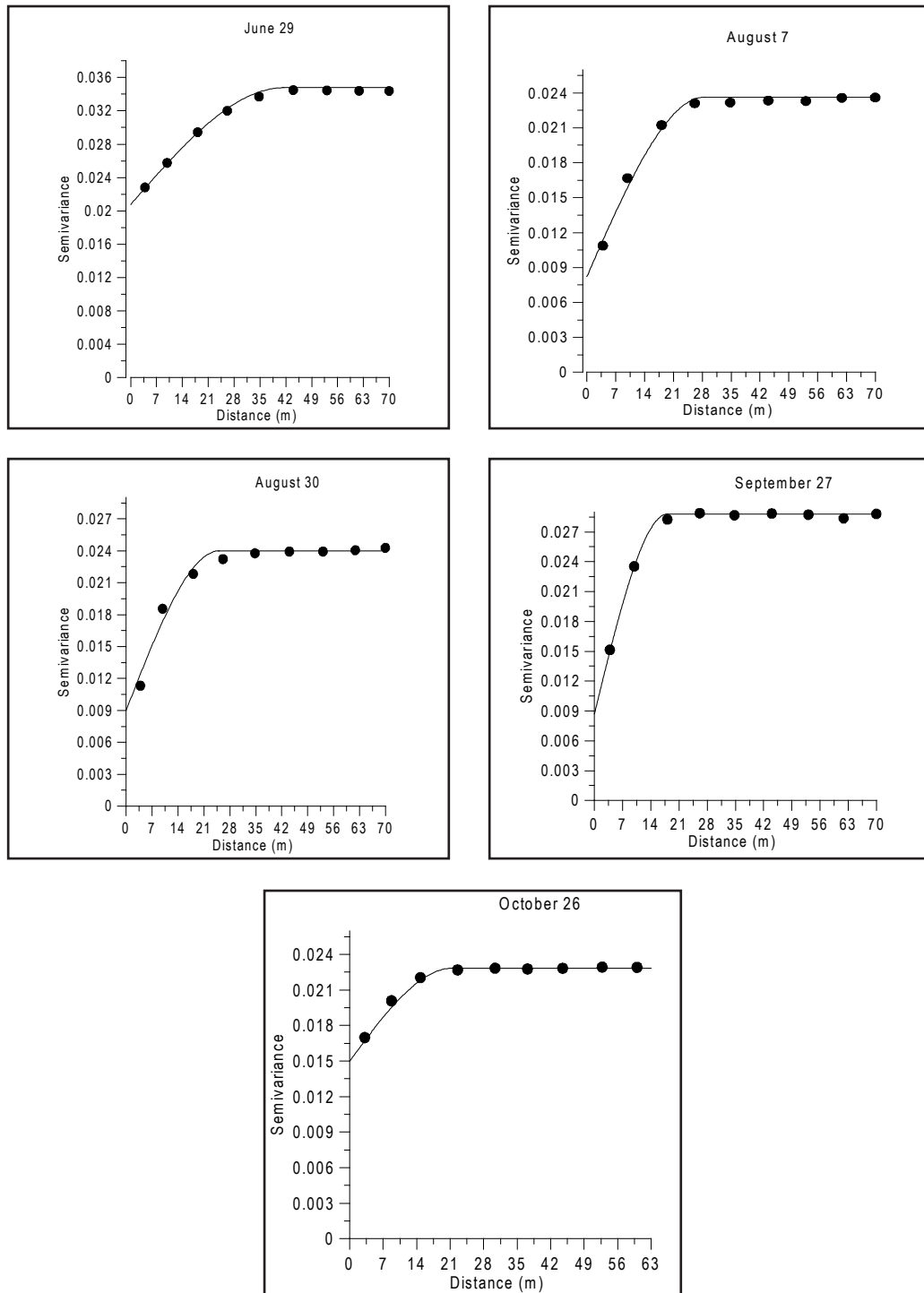


Figure 1. Experimental (circles) and fitted semivariograms of *J. lybica* egg density in 2005.

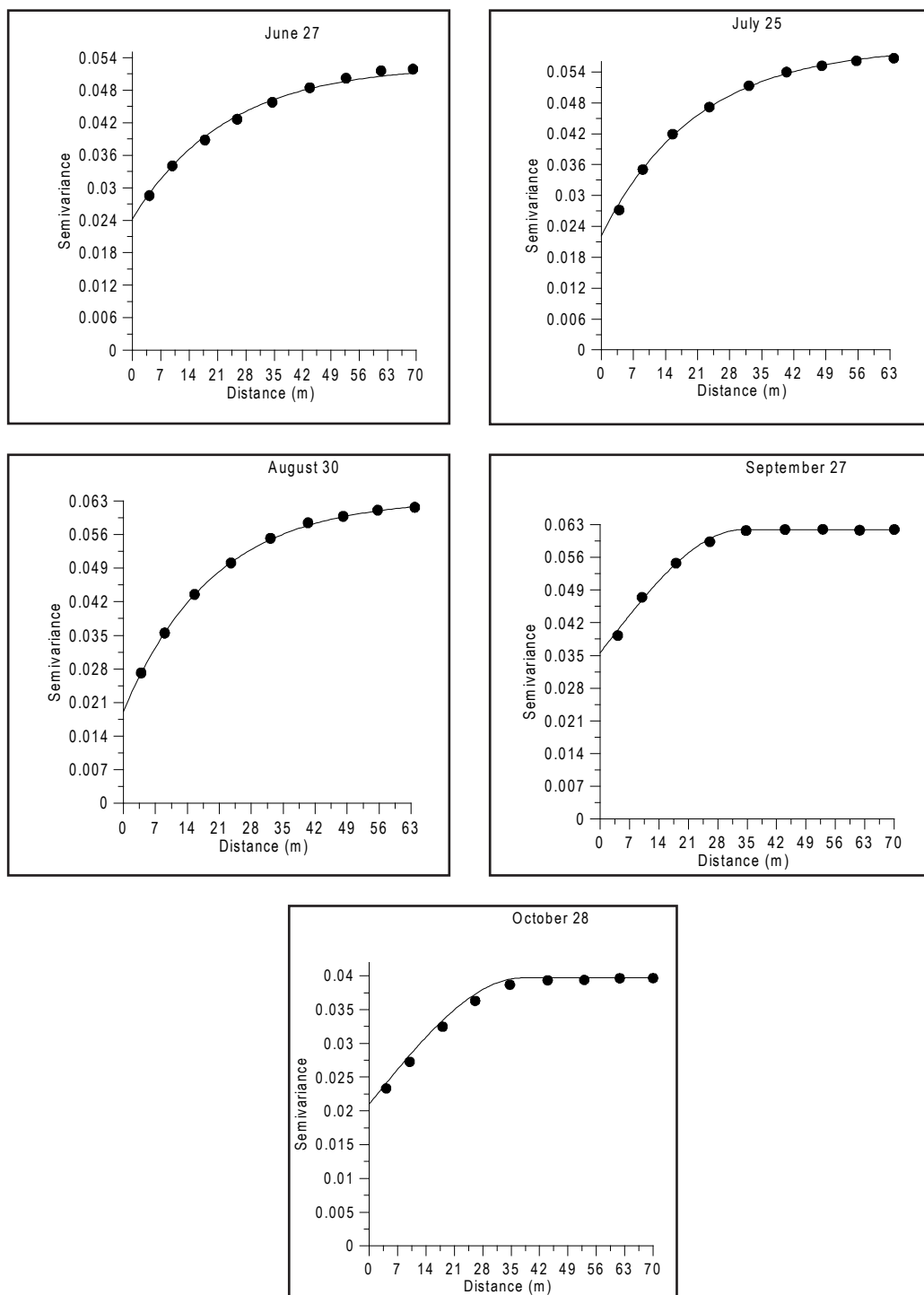


Figure 2. Experimental (circles) and fitted semivariograms of *J. lybica* egg density in 2006.

Mapping

The *J. lybica* egg density maps for each year are shown in Figure 3 and 4. A visual assessment reveals a distinct aggregation depending on dates.

Site-specific insecticide application

The use of the geostatistics allows the elaboration of maps. These resulting maps present clearly areas of variable densities and can lead accurately to the site-specific pest management (Fleischer *et al.*, 1997). The *J. lybica* infested areas varied considerably between dates. About 73 and 8% of the total area was infested (Table 4).

Table 4. Percentage of total area infested (*J. lybica* density ≥ 1 egg plants⁻¹).

Date	Total area infested (%)
29-06-2005	73,0
07-08-2005	8,7
30-08-2005	26,2
27-09-2005	48,4
26-10-2005	46,8
27-06-2006	54,8
25-07-2006	40,5
30-08-2006	36,5
27-09-2006	26,2
28-10-2006	57,9

The results of comparing the maps of density within and between years are specified in the Tables 5 and 6. Results indicate that within years there is some stability and between years the stability is lower, possibly by the action of the application of insecticides.

Table 5. Bivariate Crámer-von Mises comparison of egg maps within years.

Y e a r 2005	ψ_{2005}	Y e a r 2006	ψ_{2006}
29-06 vs. 07-08	1,18 ^s	27-06 vs. 25-07	1,58 ^s
07-08 vs. 30-08	1,77 ^s	25-07 vs 30-08	0,30 ^{ns}
30-08 vs. 27-09	0,12 ^{ns}	30-08 vs. 27-09	0,33 ^{ns}
27-09 vs. 26-10	0,19 ^{ns}	27-09 vs. 28-10	1,27 ^s

ns: not differs significant to 5%

Table 6. Bivariate Crámer-von Mises comparison of egg maps between years.

Date Compared	ψ
29-06-05 vs. 27-06-06	1,64 ^s
07-08-05 vs. 25-07-06	2,76 ^s
30-08-05 vs. 30-08-06	2,09 ^s
27-09-05 vs. 27-09-06	0,26 ^{ns}
26-10-05 vs. 28-10-06	0,16 ^{ns}

ns: not differs significant to 5%

Spatial Analysis by Distance Index (SADIE)

Spatial distribution

In all the cases, the sample variance exceeded the mean, indicating overdispersion (Table 8). By 7 of August 2005 there was a strong reduction (75%) in the egg population compared to the previous sample as a consequence of an insecticide application (Table 7). There was a higher egg density in 2006 than 2005 probably associated with the insecticide in 2005 (Table 7). In both

years, the population increased until reaching a peak by the end of September (Table 7). Similar population development has been reported by Toledo (1992).

Aggregation (I_a) was measured for each sample date. Table 8 indicates that in all the cases studied the values of I_a gave values significantly greater than unity ($P_a < 0.025$), indicating a high level of aggregation. Values of index J_a were not statistically different from one (Table 7) indicating evidence for more than one cluster, except in the dates with the lower average densities (29 June, 7 August and 30 August 2005) (Table 7), indicating the presence of one cluster (Table 8). The aggregation index I_a showed a periodic trend of increasing and decreasing in both years, suggesting the expansion and contraction of aggregation foci (Table 7).

The index I_a and J_a corroborate the existence of an aggregate distribution of green cicadellid

populations in most cases, over a center aggregation in the spatial distribution. However, when the average egg densities were low, the index J_a showed a single center aggregation. This indicates that this index J_a is not efficient when the average densities are very low.

Temporal stability

Im values for each pair-wise comparison between successive data sets are showed in Table 8. During 2005, indications of temporal association were found between 30 August and 27 September and between 27 September and 26 October, indicating a stable temporal distribution. The eggs densities in these two dates were higher than the other dates (Tables 7). The association index for 29 June and 7 August indicated that the arrangement of the counts were randomly placed with respect to one another probably as a consequence of the insecticide application.

Table 7. Sample variance and mean (eggs plant⁻¹). Value of the Index I_a and J_a and their respective probabilities P_a and Q_a .

Date	\bar{x}	S^2	I_a	P_a	J_a	Q_a
29-06-2005	0,35	0,41	1,58	0,017	1,47	0,022
07-08-2005	0,08	0,09	1,53	0,008	1,36	0,012
30-08-2005	0,53	1,12	1,16	0,006	1,39	0,024
27-09-2005	0,92	1,56	1,84	0,020	1,25	0,386
26-10-2005	0,69	0,79	1,77	0,010	1,23	0,411
27-06-2006	0,82	1,34	1,55	0,011	1,19	0,225
25-07-2006	1,38	1,74	1,67	0,007	1,14	0,316
30-08-2006	1,56	1,87	1,77	0,005	1,23	0,408
27-09-2006	1,66	2,25	1,93	0,002	1,27	0,571
28-10-2006	0,61	0,83	1,42	0,016	1,11	0,361

Values of $I_a > 1$ indicate aggregation

During 2006, we found temporal association only in two comparisons (25 July and 30 August, 30 August and 27 September) (Table 8). Such association was especially strong between 30

August and 27 September. Again, the dates with higher densities presented temporal association (Table 9). Thus, short-term temporal stability seems to be influenced by the high densities.

Table 8. Association index for association between spatial distribution of two sets counts. Index in bold indicate association are significant ($P_m < 0,025$).

Year 2005	
Dates Compared	I_m
29-06 &. 07-08	-1,02
07-08 &. 30-08	-0,87
30-08 &. 27-09	1,25
27-09 &. 26-10	1,61
Year 2006	
Dates Compared	I_m
29-06 &. 25-07	-0,58
25-07 &. 30-08	1,43
30-08 &. 27-09	2,17
27-09 &. 28-10	-1,06

Values of $I_m > 1$ indicate spatial association

Table 9. Association index for association between spatial distribution of two sets counts. Index in bold indicate association are significant ($P_m < 0,025$).

Dates compared	I_m
29-06-05 vs. 27-06-06	-0,92
07-08-05 vs. 25-07-06	-1,75
30-08-05 vs. 30-08-06	-1,08
27-09-05 vs. 27-09-06	1,37
26-10-05 vs. 28-10-06	2,44

DISCUSSION

As it was previously mentioned, traditional study methods of the spatial distribution of organisms present flaws and limitations. The size of the sample and the relationship between the average and the variance has caused problems when determining the spatial behaviour of plague insects (De los Santos *et al.*, 1982; Bohlen and Barret, 1990; Butts and Schaalje, 1994). The above information questions the fact of continuing to use these traditional methods in this sort of studies. Due to this problems and the availability of appropriate statistical packages, the interest

on the use of different branches of spatial statistics for the study of insect spatial distribution has been increased. Two methods of spatial statistics have shown to give efficient results, these are: geostatistics and SADIE; they have the advantage of characterizing the spatial distribution in a range of multiple scales and directions, making possible the production of density maps, besides, they are both independent from the relation between the average and the variance. With the results obtained with this study, the efficiency of both methods to determine the spatial pattern of the *J. lybica* egg populations is evident. Thanks to the application of these tools it was possible

to determine, without any margin of error, the aggregation of the populations of the insect egg; corroborated with the produced maps, we managed to establish the real percentage of infestation, and the existence of a certain spatial and temporal stability of the populations was determined. The prior information will allow us to handle the populations of *J. lybica* more appropriately, so that the supplies and the efforts in controlling this plague can be optimized.

Geostatistical analysis

Exploratory Statistical Analysis

The egg density in 2005 was strongly influenced by the insecticide application in the second date (Table 1). As expected, the population evolution increased until reaching a maximum by the end of September (Toledo, 1992).

Spatial and temporal distribution

The nugget value in 2005 varied considerably (Table 2). This variability might be due to the insecticide application in the second date influencing patchiness at smaller scales than 7 m or may simply be the result of sampling error (Heisel *et al.*, 1996). On the other hand, the year 2006 presented similar nugget values in all the considered dates (Table 2). The nugget variance expressed as a percentage of the total semivariance was used to define distinct classes of spatial dependence for the *J. lybica* egg density (Table 2). Medium nugget ratios (between 28 and 63%) were found in all the studied dates, which indicate a moderate spatial dependence and a high variability between sampling points (Table 2).

The sill presented a similar value in all dates in year 2005 ranging between 0,034 and 0,022. The sill values in 2006 were greater than in 2005 as consequence of not insecticide application (Table 2). The low sill values found are the result of a small mean density. The range varied from 41, 45 m to 18, 20 m.

Works with similar results have been reported by Rossi *et al.*, 1992; Liebhold *et al.*, 1993; Midgarden *et al.*, 1993; Speight *et al.*, 1998; Blom and Fleischer, 2001; Sciarretta *et al.*, 2001; Trematerra and Sciarretta, 2004 and Trematerra *et al.*, 2004.

Mapping

The *J. lybica* populations were highly aggregated in year 2005 giving rise not only to a higher semivariance (differences between observations were greater) but also a steeper slope (greater degree of correlation between observations) in the semivariogram of 2005 compared to 2002 (Fig. 1 and 2).

Site-specific insecticide application

The year 2005 presented a larger variation in the infested area as a consequence of the insecticide application. The total area infested was more stable in 2006 (Table 4). However, the average infestation was similar in both years, 40,62% in 2005 and 43,18% in 2006. Therefore, if a given insecticide was applied just to the infested areas (density ≥ 1 egg plant⁻¹), the average reduction in insecticide cost achieved could have been around 42%. Weisz *et al.* (1996) found a 49% infested area in his study on colorado potato beetle. There are few studies about site-specific pest control.

The usefulness of the infestation maps obtained with kriging for improving the decision-making process is strictly dependent on *J. lybica* patch dynamics. If egg patches are stable, kriging can be done periodically without overburdening the decision making process, whereas if they are not stable, maps will need to be drawn each year, a significant cost increase. However, if egg patches are considered as stable for a few years, direct spraying would account for a percentage insecticide application saving of the same magnitude as the uninfected portions of the field (Fleischer *et al.*, 1999).

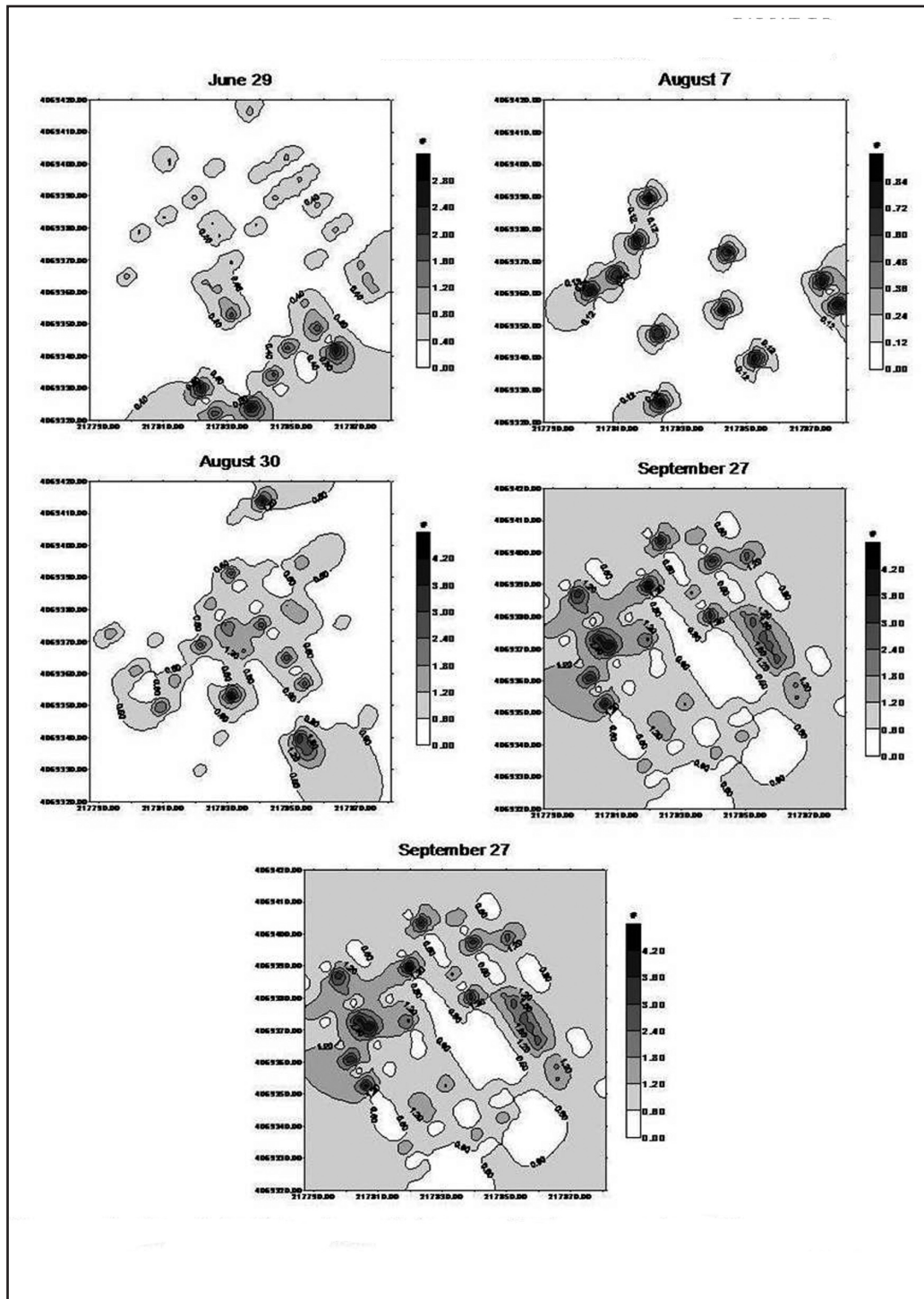


Figure 1. Countour plots of *Jacobiasca lybica* egg density (egg plant⁻¹) for year 2005.

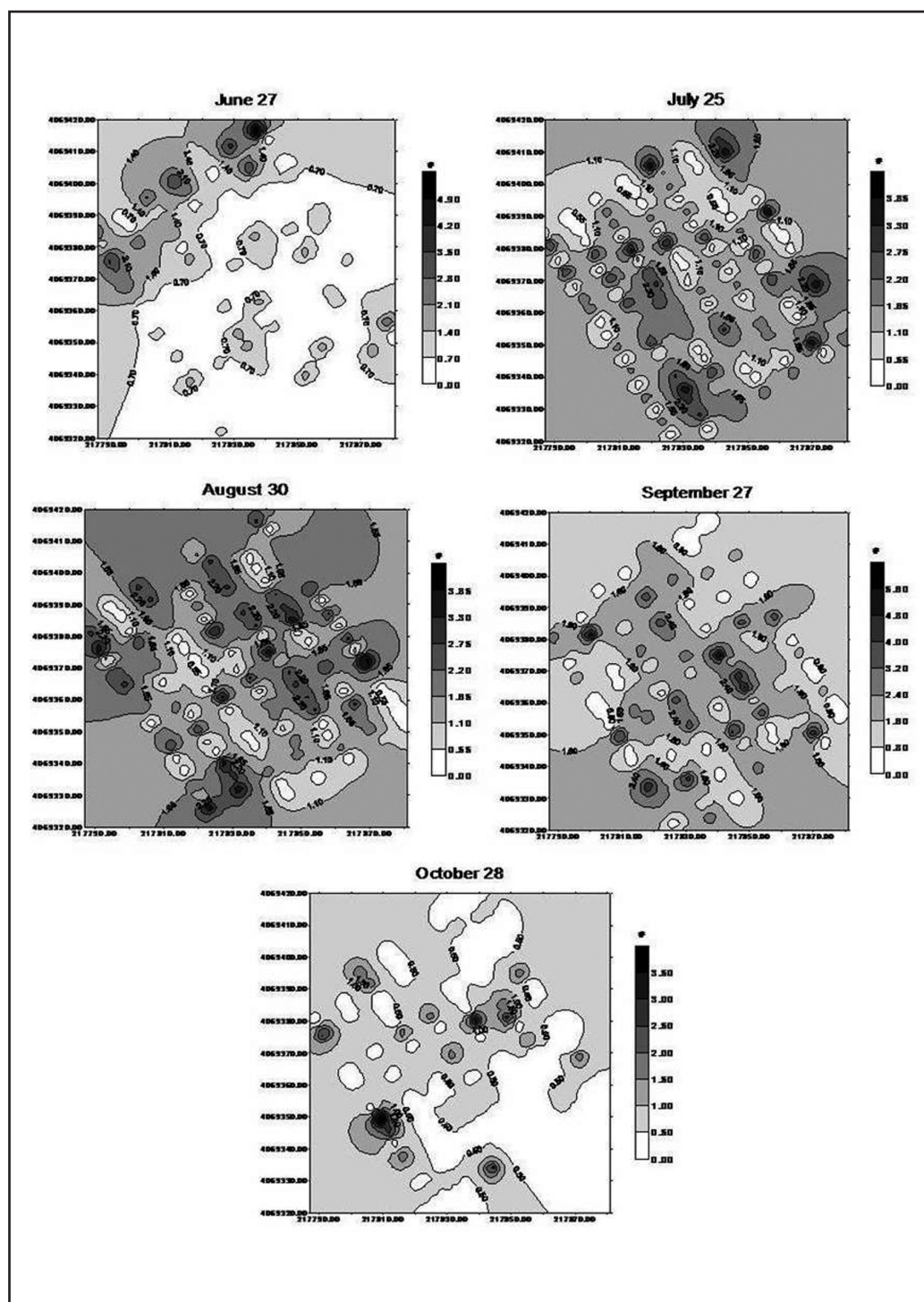


Figure 2. Countour plots of *Jacobiasca lybica* egg density (egg plant⁻¹) for year 2006.

The comparison among the different maps could provide us with information regarding the predictability of the egg infestation. Table 6 shows results obtained in the comparison within a year. In year 2005 we can observe no statistical differences in the two last comparisons (Table 5). The eggs densities in these two last dates were higher than other dates (Table 1). Insecticide application in the second date broke the spatial structure and consequently the spatial population stability. Year 2006 presented a similar behavior. Again, the dates with higher densities (Table 1) presented a no significant difference. Thus, short-term stability seems to be influenced by the high densities.

Table 6 shows the results of long-term stability (between years). There were not significative statistical differences in the last two dates, indicating space stability. Possibly, as a consequence of the existence of preferential areas due to the better physiological conditions of the vineyards that would attract the adults to deposit eggs. However, such long-term stability did not appear in the other dates probably as the result of insecticide application.

Spatial Analysis by Distance Index (SADIE)

Spatial distribution

The *J. lybica* density maps for each year are shown in Figures 3 and 4. A visual assessment reveals a distinct aggregation depending on dates. Multiple clusters of high density were observed in 2001 (Fig. 3). Distribution in multiple aggregation centers has been reported for other insects (Magro *et al.*, 1999; Ferguson *et al.*, 2000; Perry *et al.*, 2002).

On 7 August 2001, there was a strong decrease of the egg population as consequence of the insecticide application. However, some aggregation centers can be seen. It would seem that insect movement between the surrounding unsprayed areas and the treated crop may be occurred. After this date the population increased very quickly covering

practically the whole field (Fig. 3). Insecticide effect may be difficult to interpret or fail to detect the true effect if only small areas within a field are monitored or if a species exhibits either low number or spatial heterogeneity (Mead-Briggs, 1998). Our study indicates that the insecticide Malation disrupted the spatial structure of *J. lybica* and that the pattern of recovery can be related to dispersal ability (Holland *et al.*, 2000).

During 2002, we found strong aggregations as indicated by I_a indices (Table 7) with multiple density clusters (Fig. 4).

Some authors have detected edged effects in their studies (Perry, 1998; Winder *et al.*, 1999; Bohan *et al.*, 2000; Winder *et al.*, 2001; Xu and Madden, 2003). Such circumstance was not apparent in our results (Fig. 3 and 4).

The *J. lybica* infested areas varied considerably between dates and can lead accurately to the site-specific pest management (Fleischer *et al.*, 1997). Between 97% and 27% of the total area was free of *J. lybica* eggs (Fig. 3 and 4). Year 2005 presented the bigger variation in the infested area as consequence of the insecticide treatment.

What was detected with SADIE index can be observed with the maps developed with kriging of geostatistical analysis, an aggregated distribution and a several aggregation centers.

Temporal stability

Association between years was also tested. Indications of association were found in September and October (Table 9), suggesting a stable distribution pattern. In contrast, in June, July and August none association was apparent (Table 9) probably as consequence of insecticide application in early 2005.

Temporal stability has been detected for some insects (Ferguson *et al.*, 2000; Fernandez *et al.*, 2000; Thomas *et al.*, 2001). In our case, there was not clear pattern of temporal

stability. However, short and long-term spatial stability seems associated with high levels of populations.

If the location of egg population distribution is predictable and stable in space and time, the potential for reducing agrochemical inputs to farmland could be increased, through direct spraying on the leaf hopper population patches (Weisz *et al.*, 1996; Fleischer *et al.*, 1999). However, this study albeit based on a single field, indicates that the lack of a clear spatial stability both spatially and temporally, would make precision farming application difficult for *J. lybica* eggs. Further work is necessary to establish if insect aggregation can persist at the same location for long periods.

CONCLUSIONS

First, the space geostatistical methods and SADIE proved to be effective in establishing the spatial structure of populations of eggs *J. lybica*.

Second, the implementation of Geostatistics allowed us to model the spatial structure of *J. lybica* eggs with spherical models with nugget in the majority of cases.

Third, the results obtained with the techniques Geoestadísticas showed the existence of a spatial structure aggregate, and the level of dependency of the same, moderate.

Fourth, the analysis showed a pattern SADIE space added to the populations spread over several centers of aggregation.

Fifth, using kriging we were able to establish maps of the spatial distribution of the *J. lybica* eggs.

Sixth, in some cases was identified the existence of short and long spatial and temporal stability of populations of the insect eggs.

Seventh, the effect of insecticides in 2005 changed in a significant way the spatial structure of the populations of the insect eggs.

Eighth, the pest was not uniform, existing free areas of infestation by *J. lybica*.

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