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Research Article

Spatial distribution pattern of *Spodoptera exigua* (Lepidoptera: Noctuidae) on sugar beet and advantage of site-specific spraying in the pest management

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Abstract
Spodoptera exigua (Hübner) is a destructive insect pest of sugar beet globally. In this study, we utilized some geostatistical techniques to locate sample points and determine spatial distribution pattern of the pest. Pheromone traps were used to predict accurate time of oviposition and visual sampling was used to determine larval density. In order to predict the population density at non-sampled locations, Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) techniques were used. The densities of different developmental stages of *S. exigua* were estimated weekly during August and September, 2016. The degree dependence values of *S. exigua* eggs in majority of dataset were larger than 76%, indicating their clumped distribution and strong spatial autocorrelation. Broadcast spraying was used when the density of the larvae in tracts overpassed the economic threshold. Also, we applied site-specific spraying to grid cells when larval densities were above the economic threshold. In most cases, larval mortality was not significantly different between broadcast spraying and site-specific spraying methods. Comparing two interpolation methods indicated that the data calculated for density of larvae and eggs of *S. exigua* were fitted better with OK model than IDW one. The findings of this research would be useful to develop sampling programs and to control *S. exigua* in Iran.
Key words: Inverse distance weighting, ordinary kriging, site-specific pest management, *Spodoptera exigua*.

بررسی الگوی توزیع فضایی *Spodoptera exigua* (Lepidoptera: Noctuidae) روی چغندر قند و مزیت سمپاشی مکان ویژه در مدیریت آفت

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چکیده
کرم برگخوار چغندر قند *Spodoptera exigua* (Hübner) یکی از آفات مخرب چغندرقند در جهان می‌باشد. در این پژوهش، از روش‌های زمین آمار برای تعیین نقاط نمونه‌برداری و تعیین الگوهای توزیع فضایی این آفت استفاده شد. از فرمون جنسی حشره برای پیش‌بینی زمان دقیق تخم‌گذاری و از روش نمونه برداری مشاهده‌ای برای تعیین تراکم لاروهای *S. exigua* استفاده شد. برای تخمین تراکم جمیعت حشره در مکان‌های نمونه برداری نشده، از روش وزن دهی معکوس فاصله و کریجینگ عادی استفاده شد. تراکم مراحل مختلف رشدی کرم برگخوار چغندرقند بصورت هفتگی در ماه‌های مرداد و شهریور سال ۱۳۹۵ برآورد شد. درجه وابستگی مربوط به تخم‌های کرم برگخوار چغندرقند در اغلب تاریخ های نمونه برداری، بیشتر از ۷۶ درصد بود که بیانگر الگوی توزیع تجمعی و همبستگی قوی فضایی آنها بود. سمپاشی سراسری زمانی‌که تراکم لاروهای آفت در شبکه‌ها بیشتر از آستانه اقتصادی بود، مورد استفاده قرار گرفت. همچنین از روش سم پاشی مکان ویژه، زمانی‌که تراکم لاروهای آفت در شبکه های نمونه‌برداری متجاوز از آستانه اقتصادی بود، استفاده شد. در بیشتر موارد، مرگ و میر لاروها در سم پاشی سراسری و مکان ویژه اختلاف معنی داری نداشتند. مقایسه دو مدل درون‌یابی نشان

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داد، داده‌های محاسبه شده برای تعیین تراکم لاروها و تخم‌های کرم برگخوار چغندرقند با استفاده از مدل کریجینگ عادی در مقایسه با مدل وزن دهی معکوس فاصله برازش بهتری داشتند. نتایج این مطالعه در بهبود برنامه‌های نمونه برداری به منظور مدیریت کرم برگخوار چغندرقند در ایران مفید خواهد بود.

واژه‌های کلیدی: وزن دهی معکوس فاصله، کریجینگ عادی، مدیریت مکان ویژه، *Spodoptera exigua*

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Introduction

Sugar beet (*Beta vulgaris* L., Chenopodiaceae) is a strategic and industrial plant in the world including Iran. The beet armyworm, *Spodoptera exigua* (Hübner) is a devastating pest of sugar beet in some countries of Asia, America and Europe (Zheng *et al.*, 2011). This cosmopolitan insect infests more than 90 host plants (Greenberg *et al.*, 2001). *Spodoptera exigua* can cause economic damage by feeding of different larval instars on foliage and fruit of various host plants (Zalom & Jones, 1994).

Determining the spatial distribution of herbivorous insect pests is essential to establish an efficient sampling program (Southwood & Henderson, 2000) and provide more accurate estimation of the yield loss (Hughes & McKinlay, 1988). By forestalling density of an insect’s population at non-sampled areas (Liebhold *et al.*, 1991), we will able to find its ecological relationships with various biotic and abiotic (environmental) factors (Hassell & May, 1974; Iwao, 1970).

Geostatistical methods could be helpful to analyze distribution pattern of the insects and the values associated with spatiotemporal phenomena (Isaaks & Srivastava, 1989). In these methods, knowledge of the value and the location of samples can be utilized in order to sum up the association among points (Liebhold *et al.*, 1991). The principle of the variograms structure to investigate the insects distribution has been well documented (Schotzko & Smith, 1991).

Chemical control by using broad-spectrum insecticides (especially organophosphates, carbamates, and pyrethroids) has been a common method of *S. exigua* management in Iran. However, widespread application of these insecticides can negatively influence on the environment and living beings (Burris *et al.*, 1994; Mascarenhas *et al.*, 1996). So, reducing insecticide use is an essential strategy to minimize environmental pollution and pests resistance and eventually to achieve the success of integrated management programs (Midgarden *et al.*, 1997; Wright & Verkerk, 1995). To attain this goal, site-specific integrated pest management could be utilized (Park *et al.*, 2007). This technique can create unsprayed refuges by minimizing the use of insecticide to specific regions of the farm. So, this method would be useful in decreasing insects’ resistance to insecticides and conserving their natural enemies. (Midgarden *et al.*, 1997; Park & Krell, 2005).

The aim of the current study is to evaluate *S. exigua* distribution pattern using geostatistical methods and determine the effect of sit-specific spraying on its population density.

Materials and methods

Experimental farm

The experiment was done in August and September 2016 at a research farm located in Pars-Abad Moghan (Ardabil province, Iran: 39˚ 35′ 37″N, 47˚50′ 8″ E). Three hectares of irrigated farms were chosen, divided into three tracts (S, B and C), and planted with sugar beet (cultivar Rosier). Each tract (1 hectare) contained three plots (B1= 3500 m^2, B2= 3500 m^2, and B3= 3000 m^2) that were assigned to broadcast spraying. Tract C was left as an untreated (control), and tract S included S1= 3500 m^2, S2= 3500 m^2 and S3= 3000 m^2 was considered as a site-specific spraying. The control and treatments were separated with an untreated zone (1 m wide) as a border. The examined tracts were separated to grids (11 m^2). The information of each grid location was determined and kept in a GPS receiver (Karimzadeh *et al.*, 2011).

Sampling program

Sampling program was conducted during August and September 2016. Sampling began when flight peak of *S. exigua* population occurred. The pest's population was monitored based on daily captures of male insects by sex pheromone traps. After determining the flight peak, distance-walk technique was used to estimate population density of the eggs and larvae (Weisz *et al.*, 1996). In this technique, after taking two walks (each 5.5 m long), the number of observed insects (eggs and larvae) on the top and under portions of the leaves were recorded (Figure 1). Every tract S, B and C had 84 sample points, resulting in a total of 252 sample points (Figure 2). The sample size (N) was calculated by a preliminary sampling as $N = (ts/dm)^2$, where t is t-student, s and m are standard deviation and average of primary sampling data, respectively, and d is desired fixed proportion of the m (Pedigo & Buntin, 1994). We selected 42 cells randomly and then the eggs and larvae of beet armyworm were counted and allocated to the center of that grid.

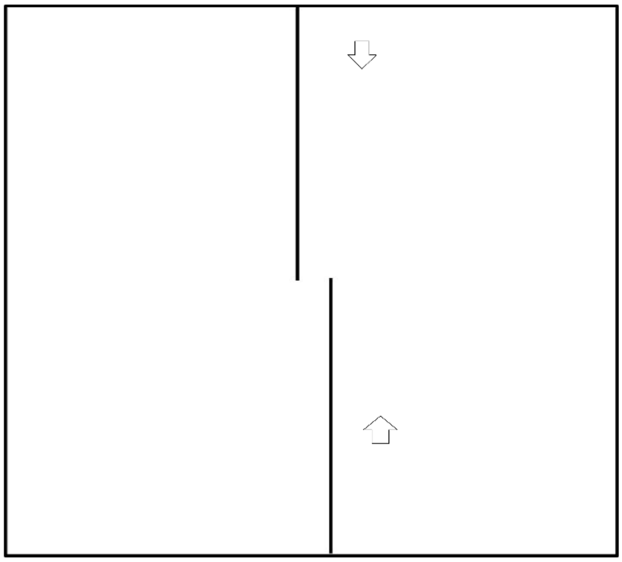

Fig. 1. Two walks (5.5 m) derived within a grid

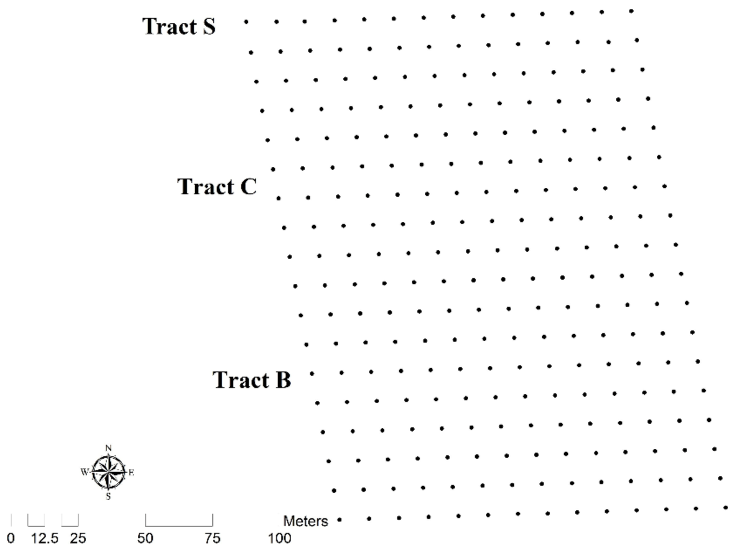

Fig. 2. Tracts and sample points utilized for spatial distribution test.

Spatial analysis

Geostatistical analysis is a common technique specifying the distribution type of *S. exigua*. To conduct this technique, we used Geostatistical Analyst extension of ArcGIS 9.3 ESRI (Environmental Systems Research Institute, Redland, CA, USA). The analysis includes three main stages: 1. Analysis of exploratory spatial data 2. Analysis of structure and estimating values at nonsampled areas or interpolation of surface, and 3. Exploratory Spatial Data Analysis (ESDA) tools that were used for assessment of geostatistical data and research of outliers and trends (Bressan *et al.*, 2010).

Data structural analysis

In the second step, spatial correlation of samples was quantified by semi-variogram that also can determine spatial distribution patterns (e.g. clumped, regular and random) (Johnston *et al.*,, 2001). Semi-variances of binary samples were utilized against the separation distance (h) among sample pairs to create a variogram (Johnston *et al.*,, 2001):

$$\hat{y}(h) = \frac{1}{2N(h)} \sum_{i=1}^{(N(h)} [Z(\mathrm{Xi}) - \mathrm{Z}(Xi + h)]$$

In this equation, $\hat{y}(h)$ = tested semi-variance at h, $N(h)$ = the count of sample pairs separated by h, Z(xi) and Z(xi + h) = sample values at two sample zones. The components of theoretical model (sill, partial sill, range and nugget) were used to investigate the spatial autocorrelation. Difference between sill and nugget was considered as partial sill. We measured the spatial autocorrelation via low semi-variance at small distances and increase with distance. To measure spatial dependence, degree of dependence (DD) parameter was used as DD = (CC_0+C) 100, where C and C_0 are partial sill and nugget, respectively. The DD value ≤ 25% is considered weak spatial dependence, 26-75% is moderate, and ≥76% is strong (Grego *et al.,* 2006). To make dependable variograms, plots close to each other were analyzed as a continuing zone and the borders separated them were not considered. Spatial autocorrelation measured by variogram was used to estimate variable values in unrecorded areas by kriging method. The last stage of analysis was to evaluate population density of the insect in unrecorded regions and drawing risk maps by kriging technique. The principles of cross-validation to estimate the accuracy of predictions and choose the model providing the best prediction were applied. Theoretical models were fitted to the empirical variograms. To evaluate how well the model fits the points, residual sum of squares (RSS) and R^2 were utilized. Models with the least RSS and highest R^2 values were selected. Another interpolation method is Inverse Distance Weighted (IDW) that is currently the most commonly used method for interpolation of the models and surface maps of the site using ArcGIS. The maps characterize the density of the beet armyworm population in examined field. This technique shows more correlations of nearer points to each other than farther ones. The IDW technique supposed that the correlation rate among nearer points is proportionate to the distance among them (Kravchenko & Bullock, 1999).

Application of insecticide

The insecticide hexaflumuron 10% EC was mixed with cypermethrin 40% EC and used (at a concentration of 700 ml/ha) for both broadcast and site-specific spraying methods. These insecticides were purchased from Iranian Chemical Production Company, Tehran. The broadcast spraying was conducted in dedicated plots when the population density of *S. exigua* larvae (different instars) overpassed the economic threshold (ET) (3 larvae on each sugar beet plant; unpublished data). In the site-specific method (SSM), spraying was applied merely in grids, where population of the beet armyworm overpassed the ET. Only one spraying was done against larval stages in August 2016 and another spraying was done in September 2016. Both spraying methods were done by a motorized knapsack atomizer sprayer (Toosfadak factories group, Mashhad, Iran). The advantage of the SSM is reduced pesticide application since sprayings are focused merely to zones where population density of the insect is high (Fleischer *et al.*, 1999).

Population density of *S. exigua* larvae and eggs were recorded 1, 3 and 7 days after spraying in August and September 2016. The formula of Sun-Shepard was applied for measuring percentage of mortality of *S. exigua* larvae (Muller & Schwinn, 1992) as follows:

$$\%M = Pt \pm Pc/100 + Pc Pt = (1 - Pt_a Pt_b)\ 100 \quad = 1 - Pc_b Pc_a 100$$

Where Pt is mortality (%), and Pc is alteration in sprayed and unsprayed plots. The Pt_b and Pt_a are *S. exigua* density in sprayed plots before and after spraying, respectively. The Pc_b and Pc_a are the density of this insect in control plots before and after spraying, respectively. The normality of data was checked by Kolmogorov-Smirnov test, and one-way ANOVA was used to analyze percentage of mortalities (SAS Institute Inc., 2003).

Determination of plant elements and chlorophyll

To evaluate the impact of micro- and macro-elements and chlorophyll content in the leaves of sugar beet on oviposition (number of eggs laid) and larval density of *S. exigua*, the amounts of these elements were determined. Nitrogen (N) content of sugar beet leaves was characterized by digesting the samples in sulfuric acid (H_2SO4 95-98%) and hydrogen peroxide (30%). In the next step, sodium hydroxide and potassium persulfate were used, followed by determination of nitrogen content by the method of Kjeldahl (1883). Chlorophyll content of the leaves in each sample point was recorded by chlorophyll meter (SPAD502 Plus, USA).

The sugar beet leaves were separately oven-dried and then powdered using an electric grinder. The quantity of 250 mg of dried samples was digested in sulfuric acid (5 mL) at 330°C for 120 min. After the addition of hydrogen peroxide (5 drops), they were kept for 1 h in a digester (Gupta, 2006). After filtration by Whatman filter paper No. 44, we reached the digested solutions to 50 mL by adding distilled water. The amounts of phosphorus (P) and potassium (K) were measured using an auto-analyzer (QuikChem, Series 8000, Lachat Instruments Inc., USA) and spectrophotometer (Perkin-Elmer 5100 PC), respectively. Zinc (Zn) content of sugar beet leaves was calculated by the Atomic Absorption Spectrometer (Video 11, Thermo Jarrel Ash Corporation, Franklin, USA) (Gupta, 2006).

The correlation of population density of *S. exigua* larvae with tested macro- and micro-elements and chlorophyll contents of sugar beet leaves was evaluated by Pearson correlation coefficient using Minitab ver. 16.0.

Results

Spatial analysis

Exponential and Gaussian models were best fitted with all dataset. Values of nugget were larger than zero in majority of dataset, showing that spatial autocorrelation was lower than the least distance between samples. The range of density dependence (DD) parameters of the eggs was from 20.66 to 125.31 %. As DD values of the eggs in majority of dataset were larger than 76%, it can be suggested that *S. exigua* eggs were clumped and had strong spatial autocorrelation (Table 1).

Table 1. Variogram components of *Spodoptera exigua* eggs and larvae in August and September 2016

Date of sampling	Tract	Model	Nugget	Partial sill	DD value%	Range
8 August	B	Ex	0.53	1.66	75.70	23.56
8 August	C	Ex	0.62	0.81	56.60	33.06
8 August	S	Sp	0.01	2.47	99.30	21.61
16 September	B	Ga	0.00	247.90	100.00	20.66
16 September	C	Ex	165.70	31.53	15.98	125.31
16 September	S	Sp	0.00	94.10	100.00	21.66

DD= Degree of dependence, Ex = Exponential model, Sp = Spherical model, Ga= Gausian model

The range of nugget values in majority of dataset was larger than zero. The DD values of the larvae in 11 sampling dates were between 26 and 75% (moderate spatial dependence), and in 9 sampling dates were larger than 76% strong spatial dependence (Table 2).

Table 2. Variogram components of *Spodoptera exigua* larvae in August and September 2016

Date of sampling	Tract	Model	Nugget	Partial sill	DD value (%)	Range
8 August	B	Ga	0.88	0.58	39.70	21.60
8 August	C	Ga	0.40	0.46	53.40	28.05
8 August	S	Ex	0.00	1.66	100.00	24.09
10 August	B	Ex	0.00	0.16	100.00	28.30
10 August	C	Ex	0.00	13.5	100.00	26.60
10 August	S	Ga	0.23	0.11	32.30	21.60
12 August	B	Sp	1.88	1.31	41.06	160.90
12 August	C	Ga	0.56	0.18	24.30	49.90
12 August	S	Ga	0.03	1.87	98.40	20.60
16 August	B	Ex	0.12	1.42	92.20	21.60
16 August	C	Sp	0.89	4.69	84.05	21.60
16 August	S	Ex	1.67	2.06	55.20	21.60
16 September	B	Sp	7.10	11.40	61.60	21.60
16 September	C	Ex	28.10	23.30	45.30	102.20
16 September	S	Ex	40.80	6.13	13.06	144.50
18 September	B	Ga	0.10	0.05	33.30	35.40
18 September	C	Ex	0.78	1.16	59.70	147.20
18 September	S	Ex	0.47	0.03	6.00	21.60
20 September	B	Ex	0.71	0.17	19.31	87.50
20 September	C	Ga	19.40	19.90	50.60	159.40
20 September	S	Ex	0.001	0.78	99.82	20.60
24 September	B	Ex	0.50	2.18	81.30	61.80
24 September	C	Ex	20.50	9.22	31.02	65.50
24 September	S	Ga	0.00	2.69	100.00	21.60

DD= Degree of dependence, Ex = Exponential model, Sp = Spherical model, Ga= Gausian model

Values of semi-variogram applied to interpolation by kriging technique indicated some of the risk maps made to imagine larval spatial distribution one day before spraying and one day after spraying in both August and September 2016 (Figures 3 and 4).

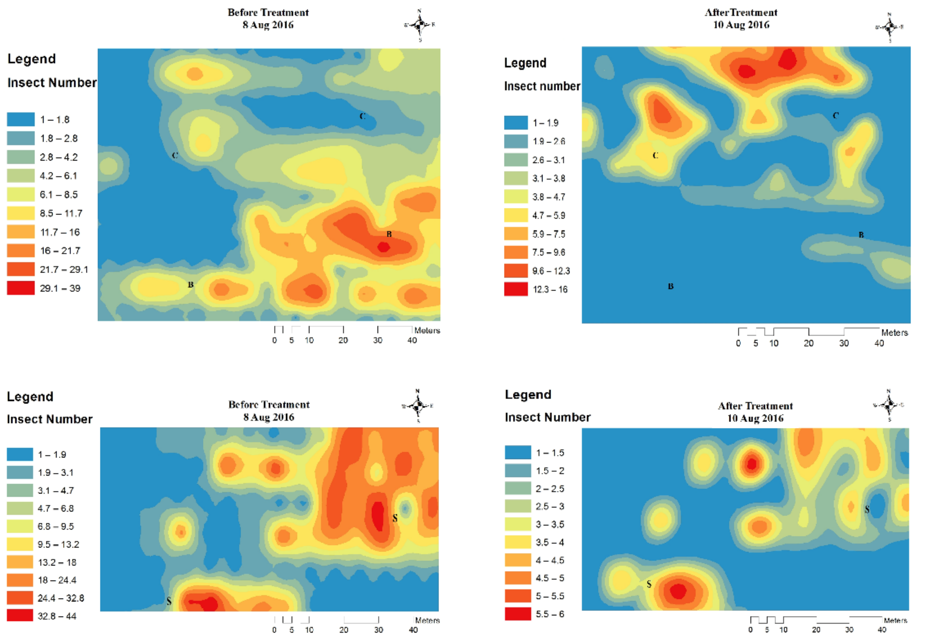

Fig. 3. Distribution maps of *Spodoptera exigua* larvae 1 day before and 1 day after treatment in August 2016.

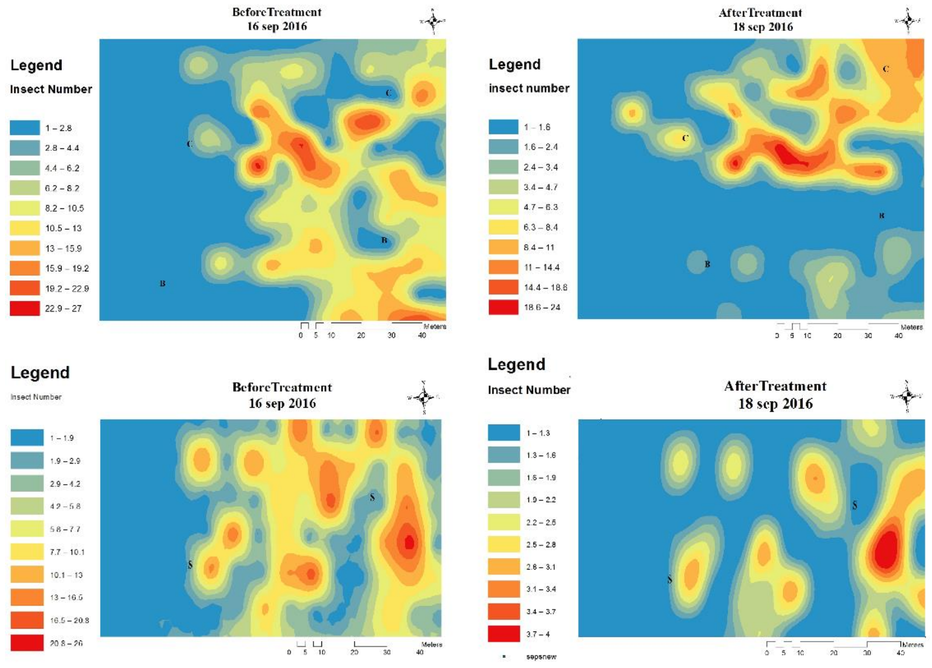

Fig. 4. Distribution maps of *Spodoptera exigua* larvae 1 day before and 1 day after treatment in September 2016.

Insecticide treatment

Mean density of *S. exigua* larvae in tract B was higher than ET, and therefore, they were broadcast-sprayed. Other tracts were left as a control, and tract S was used as a site-specific application.

Impact on *Spodoptera exigua* larval population

The range of population mortality was from 51.3 to 81.2% in broadcast and site-specific sprayed tracts 1, 3 and 7 days after treatments in August and September 2016. The highest mortality of larvae was obtained 1 day after treatment in broadcast spraying for both August and September 2016 (F= 4.36; df= 5,18; P<0.05), whereas the lowest mortality was in site–specific spraying 7 days after treatment in August and September 2016 (F=3.26; df= 5,18; P<0.05). Larval mortality caused by hexaflumuron + cypermethrin, in most cases, was not significantly different between broadcast and site-specific spraying methods (Table 3).

Table 3. Mean (±SE) percentage mortality of *Spodoptera exigua* larvae in August and September 2016

Sampling month	Treatment	24 h after treatment	72 h after treatment	7 days after treatment
August	Broadcast spraying	81.22 ± 2.08 a	76.35 ± 1.44 ab	71.21 ± 1.22 ab
	Site-specific spraying	74.86 ± 73 ab	66.17 ± 5.92 b	63.84 ± 3.84 b
September	Broadcast spraying	75.63 ± 3.04 a	69.81 ± 5.23 ab	57.96 ± 7.2 ab
	Site-specific spraying	70.19 ± 2.08 ab	69.31 ± 2.3 ab	51.33 ± 7.29 b

The means with the same letter in each sampling month are not significantly different (Tukey, P<0.05).

Comparison of two interpolation methods

The data calculated for density of larvae and eggs of *S. exigua* were fitted better with kriging model than IDW one (Table 4).

Table 4. Statistical summary for population density of *S. exigua* eggs in August and September 2016.

Month	Life stage	Model	RMSE	ME	R^2
August	Larvae	Kriging	9.06	0.008	0.53
August	Larvae	IDW	8.23	0.139	0.200
September	Larvae	Kriging	8.28	0.122	0.92
September	Larvae	IDW	8.23	0.130	0.200
August	Eggs	Kriging	11.08	0.057	0.53
August	Eggs	IDW	11.40	-0.08	0.010
September	Eggs	Kriging	15.40	0.10	0.88
September	Eggs	IDW	11.46	-0.084	0.032

IDW = inverse distance weighting

Correlation analysis

There were significant positive correlations between chlorophyll content and nitrogen concentration with population density of *S. exigua* larvae. A negative correlation was found between P, Zn, and K contents of tested leaves with density of *S. exigua* larvae (Table 5).

Table 5. Correlation coefficients (r) of population density of *Spodoptera exigua* larvae with macro- and micro-elements and chlorophyll contents of sugar beet leaves

Plant element	Density of larvae	
	r	p
Chlorophyll	0.94	0.00
Nitrogen	0.92	0.00
Phosphorus	-0.88	0.00
Potassium	-0.89	0.00
Zinc	-0.79	0.00

Discussion

Spatial distribution pattern contains patterns and frequency distribution; both give the information on how populations were arranged within and among the units. Understanding the insects' distribution in a region, the improvement of sampling techniques and mapping of the species will be highly useful to develop efficient control measures (Duarte *et al.,* 2015). The findings of this study indicated that DD values of *S. exigua* eggs in majority of dataset were larger than 76%, indicating their clumped distribution. Clumped distribution and spatial autocorrelation showed that SSM was possible for this stage. The spatial distribution of eggs in *S. exigua* is intrinsic and mostly related to the oviposition activity of adults. However, several characteristics of host plants like color, size, shape, texture, toughness, and the amounts of nutrients may affect the host selection by phytophagous insects (Bentz *et al.,* 1995). Herbivore insects must obtain enough amounts of energy by feeding on a favorable host plant. Nitrogen content is a fundamental elements required for development of phytophagous insects. The herbivores that feed from a high-nitrogen plant often have higher survival, faster development, greater growth (Fischer & Fiedler, 2000; Kaneshiro & Johnson, 1996; Prestidge, 1982; Wier & Boethel, 1995), and bigger body size (Jauset *et al.,* 2000; Kaneshiro & Johnson, 1996; Minkenberg & Ottenheim, 1990) than those feed from low-nitrogen plant.

The DD values of *S. exigua* larvae in some dataset were larger than 76%, showing clumped distribution of the larvae. A possible explanation for this result might be attributed to nutritional value of the plant, which influences on the insects' population density. As the spatial distribution of *S. exigua* larvae was clumped, using the SSM to control larvae could be economically better than whole-field spraying. In our experimentation, the SSM reduced amount of pesticide used in both August and September 2016 whereas still attaining an acceptable rate of control compared with whole-field management. So, in this technique the cost of management and possible exposure of workers to insecticides would be decreased (Weisz *et al.,* 1996). The SSM has not only a good potential to increase control efficiency, but also it can reduce the amount of insecticide application because the spraying is focused merely to regions where *S. exigua* density reached the ET. Research conducted by Karimzadeh *et al.* (2011) indicated that, compared with whole-field management, the SSM reduced the amount of insecticide used to control *Eurygaster integriceps* Put. (Hemiptera: Scutelleridae) by 40–50%.

The correlation analysis between population density of *S. exigua* larvae and leaf nutrient contents of sugar beet showed positive correlations between the insect density with leaf nitrogen and chlorophyll contents. A possible explanation for this might be related to this fact that nitrogen content increases the digestive efficiency of herbivorous insects (Manuwoto, 1984). The higher host plant leaf digestibility shows that the amounts of secondary compounds are low, resulting in more invasive of insect pests (Haukioja & Neuvonen, 1985; Schultz & Baldwin, 1982). Nutritional quality of a plant is a major index of its susceptibility/resistance to herbivorous insects (Ngai & Jefferies, 2004). Increases in nitrogen content of a host plant can improve its food quality and therefore increases the preference and performance of phytophagous insects (Prado *et al.,* 2010). In addition, plants with high nitrogen become more vulnerable to potential pests than those with low nitrogen (Bernays, 1983).

In this study, correlations between density of *S. exigua* larvae and leaf P, K, and Zn contents were negative. The P can decrease the suitability of sugar beet plants by changing secondary metabolites (such as phenolic and terpenes) and accumulation of phenolic materials like tannin and lignin, which have antifeedant effects on herbivorous insects (Facknath & Lalljee, 2005). Phenolics interfere with insect's digestion process, block enzyme activity, influence cells division, and finally cause slow growth in herbivorous insects. Another elements (e.g. K) increase plant efficiency to resist the insect pests by activating enzymes and increasing hardness of the cell wall. The element Zn can protect plants from insects' infestation by increasing the amount of toxic alkaloids in plant tissues (Paech & Tracey, 1955).

Mean percentage mortality of *S. exigua* larvae in August and September 2016 in both spraying methods showed no significant differences. However, in our experiment, SSM reduced the rate of insecticides used by 40-50% as compared to broadcast spraying. The SSM can lead to *S. exigua* resistance management by focusing insecticide application to specific locations, where population density of larvae is above ET. This management technique can also preserve refuges to protect natural enemies (Tabashnik, 1989; Roush & Daly, 1990). As the spatial distribution pattern of *S. exigua* was clumped, in some of dataset, so application of the SSM would be cheaper than whole-spraying method. Although higher sampling costs of SSM in the short time, environmental advantages of this method such as reduced harmful effects to humans, non-target organisms and ecosystem make it more acceptable (Park & Tollefson, 2006).

Geostatistical techniques are new technologies for mapping the insects' distribution in farm and at a regional level. Through relatively simple procedures, these techniques can be used to obtain maps with insect location and abundance to apply a specific management strategy, depending on the insect presence in a specific site. Sampling maps can be helpful in monitoring insect pests and determining their distribution within the farm. The use of these technologies can lead to reduce the doses and application rates of pesticides (Duarte *et al.*, 2015). The findings of current study can produce useful information regarding spatial distribution of *S. exigua* and advantages of SSM for its management. Since climatic factors (temperature, light, humidity, and various environmental stresses) are not controlled at farm, further experiments are required to study the spatial distribution pattern of *S. exigua* on sugar beet plants for at least two growth seasons.

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