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Population Density and Spatial Distribution Patterns of *Tetranychus urticae* (Acari, Tetranychidae) and its Predator *Stethorus gilvifrons* (Coleoptera: Coccinellidae) on Different Agricultural Crops

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ABSTRACT

Population density and spatial distribution pattern of *Tetranychus urticae* Koch and its predator *Stethorus gilvifrons* Mulsant on different agricultural crops including cucumber (var. Superdaminus) and five bean varieties including *Phaseulus vulgaris* var. Talash, *P. lunatus* var. Sadaf, *P. calcaratus* var. Goli, *P. calcaratus* var. Sun-ray and *Vigna sinensis* var. Parastoo were determined in the Tehran area, Iran, during 2005. The mean population density of the adults and total life stages of *T. urticae* on cucumber (150.71 mites per leaf) was significantly more than bean crops. Among bean varieties, the higher and lower density of the pest population was observed on Sun-ray (59.37 mites per leaf) and Parastoo (4.73 mites per leaf), respectively. Spatial distribution pattern of *T. urticae* was determined on different crops using Morisita's index and Taylor's power law regression method and spatial distribution of *S. gilvifrons* was measured using variance to mean ratio. The slope of Taylor's regression for *T. urticae* was 1.60, 1.89, 2.05 and 1.35 on Talash, Goli, Sadaf and Sun-ray, respectively. Morisita's index for *T. urticae* was significantly greater than one for all crops ($I_{\delta}>1$). The variance to mean ratio for *S. gilvifrons* was calculated 1.64, 1.90 1.32 and 11.54, on Talash, Sun-ray, Parastoo and cucumber, respectively. The results indicated that the spatial distribution pattern of *T. urticae* was aggregated and this pattern for *S. gilvifrons* in most cases was aggregated and in a few cases was random. Linear regression between density of *T. urticae* (independent variable) and density of *S. gilvifrons* (dependent variable) was used for determining the reaction of *S. gilvifrons* to the population density of *T. urticae*. The reaction of *S. gilvifrons* to density of *T. urticae* on Sun-ray variety was density independent and on other crops was density dependent. It could be concluded that different crops can influence the population density of *T. urticae* and spatial distribution pattern of *S. gilvifrons*. Spatial distribution parameters can be used to promote sampling programs and exact estimation of the population density of an organism.

Key words: *Tetranychus urticae*, *Stethorus gilvifrons*, population density, spatial distribution, bean varieties, cucumber.

INTRODUCTION

The two-spotted spider mite, *Tetranychus urticae* Koch is considered to be the most polyphagous species of the tetranychid spider mites (Ragkou *et al*., 2004). It is a major pest of vegetables and ornamentals in greenhouses and several agricultural outdoor crops (Granham, 1985; Rott & Ponsonby, 2000). This species is adapted to various environmental conditions and is distributed worldwide. Spider mites cause leaf cells to turn whitish or yellowish and produce leaf falls by sucking out the contents from the leaf cells (Shih & Wang, 1996; Ragkou *et al*., 2004). There are several important predators of *T. urticae*. The genus *Stethorus* Weise (Coleoptera: Coccinellidae) would be one of the best mite predators for biological control of spider mites in agricultural crops in most Mediterranean countries, and some parts of Europe and Asia (Chazeau, 1983; Charles *et al*., 1985; Bailey & Caon, 1986; Felland & Hull, 1996; Ofek *et al.,* 1997). In Iran, *Stethorus gilvifrons* Mulsant is one of the most common predators of two-spotted spider mites, especially around Tehran province. Conservation and augmentation of phytoseiids mites and *Stethorus* spp. have provided successful biological control of spider mites in various perennial crop systems in the world (Helle & Sabelis, 1985; Nyrop *et al.,* 1998), suggesting that a similar approach could be implemented in bean and cucumber crop systems.

Estimating the population density of arthropods relative to economic thresholds is the cornerstone of basic research on agricultural ecosystems and the principal tool for building and implementing pest management programs (Kogan & Herzog, 1980). This requires a reliable sampling program conducted at specific times using a suitable sampling technique with a given sampling unit and sample size all based on the spatial distribution characteristics of the pest population (Pedigo & Buntin, 1994).

Quantitative knowledge of temporal and spatial distribution patterns of arthropod pests and their natural enemies is essential for understanding interactions and is a prerequisite for the development of reliable sampling plans for estimating and monitoring abundance of pests and natural enemies (Onzo *et al*., 2005). This information leads to the development of a scouting and pest management program that more accurately estimates total injury (Hughesh & McKinlay, 1988) and makes timely decisions to implement management tactics to prevent crop loss (Haughes, 1996; Shih & Wang, 1996). Toward this goal, ecological and behavioral investigations (Faleiro *et al.,* 2002) of pest and predator populations can determine population growth rates (Jarosik *et al.,* 2003) and describe the spatial distributions and probability distributions of both populations (Southwood & Henderson, 2000). In order to develop sustainable biological control strategies, it is also necessary to understand how habitat structure influences the ability of natural enemies to locate and eliminate sparsely distributed prey patches (Stavrinides & Skirvin, 2003).

In order to control of *T. urticae*, chemical treatments are often applied when farmers first detect mites without attention to the pest economic threshold. This approach is costly to growers because they may be treating selections for resistance development needlessly and may eliminate important biological control agents on these crops. A sampling program and spatial distribution pattern of *T. urticae* play important role in determining a reliable economic threshold.

Despite the economic importance of two-spotted spider mites on different bean species and cucumber, little research has focused on the development of efficient population sampling programs based on spatial distribution coefficients of this mite and its predator, *Stethorus gilvifrons* Mulsant. To fill this gap, we carried out an investigation to develop a reliable sampling program, describing differences in spatial distribution and levels of abundance over time of *T. urticae* and *S. gilvifrons* on different bean varieties and cucumber grown in Tehran area, Iran. The goal of this study is to investigate the population density and spatial distribution patterns of *T. urticae* and its predator *S. gilvifrons* and interaction between them on cucumber and different bean varieties. The results of this research can be used to establish IPM strategies based on monitoring methods that aid in the timing of control tactics that conserve and/or enhance the impact of biological control agents two-spotted spider mites.

MATERIAL AND METHODS

Experimental design

Field studies were carried out at experimental field at Faculty of Agriculture, Tarbiat Modares University from July to November 2005. Five bean varieties including: common bean *Phaseolus vulgaris* L. var. Talash; lima bean *P. lunatus* L. var. Sadaf; Aduki beans *P. calcaratus* Roxb var. Goli; *P. calcaratus* var. Sun-ray; cowpea *Vigna sinensis* L. var. Parastoo; and and cucumber *Cucumis sativus* L. var. Superdaminus were planted in a randomized complete block design in field (52.5×27 m) with four blocks and six plots per block. The plots measured 4×8 m.

Sampling program

Sampling unit

The sampling technique often dictates the form of the sampling unit (Pedigo & Buntin, 1994). Different life stages of *T. urticae* and *S. gilvifrons* usually colonize on the under-surface of leaves, thus one leaf of each crop was selected as a sampling unit. Once a week from 7th August until 5th November 2005, leaves were randomly collected mid-morning in the field to provide an unbiased picture of the population mean (Pedigo & Buntin, 1994). The population density of each life stage of *T. urticae* and *S. gilvifrons* was estimated by counting the number per leaf using a stereomicroscope in the laboratory and by the direct scanning of leaves for each species and life stage in the field.

Relative variation and sample size

The precision of sampling was estimated by calculating the Relative Variation (*RV*) using the following equation:

$$RV = \left(\frac{SE}{m}\right)(100) \qquad (1)$$

where *SE* is the standard error and *m* is the mean density of primary sampling data.

Sample size (*N*) formula was as follow:

$$N = \left(\frac{t \times s}{d \times m}\right)^2 \qquad (2)$$

where *t*, *s*, *d* and *m* are the *t*-student of table, standard deviation, the range of accuracy and mean density of primary sampling data, respectively (Pedigo & Buntin, 1994).

Reaction of *S. gilvifrons* to the population density of *T. urticae*

A linear regression analysis of the mean density of *S. gilvifrons* (dependent variable) versus mean density of *T. urticae* (independent variable) was used to describe the interaction between these two species on different crops. If the linear regression between two variables is not significant ($b=0$), the predator's reaction to its prey density is density independent. If the regression is significant where $b<0$, the predator's reaction is inversely density dependent but if $b>0$, this predator's reaction is density dependent.

Spatial distribution of *T. urticae* and *S. gilvifrons*

Spatial distribution for *T. urticae* was characterized using Taylor's power law (Taylor, 1961) and Morisita's index (Morisita, 1962), whereas the variance to mean ratio wasd calculated for *S. gilvifrons* on different crops. The Taylor's power law relates the variance (S^2) to the sample mean (m) as follows:

$$S^2 = am^b \qquad (3)$$

where a is a scaling factor related to sample size and b measures the species aggregation. If b=1, <1 or >1, the distribution is described as random, regular or aggregated, respectively (Taylor, 1961). By using a log transformation, we can estimate the coefficients with linear regression by:

$$\text{Log}(S^2) = \text{Log}(a) + b\,\text{Log}(m) \qquad (4)$$

where a and b are the parameters of the model, which were estimated by a log-log transformation that caused the equation to be linear (Martinez-Ferrer *et al*., 2006). For proving statistical goodness of fit (b =1), t was calculated (t_c) according to:

$$t_c = \frac{(b-1)}{SE_b} \qquad (5)$$

where t_c was compared with t table (t_t) (df = n-2 and a = 5%). If $t_c > t_t$ the distribution is aggregated (Pedigo & Buntin, 1994).

Morisita's index ($I_ä$)**:** According to Morisita's index, diversity of numbers of individuals per quadrat could be used as a measure of spatial pattern and was calculated by the following equation:

$$I_\delta = \frac{n\sum x_i(x_i-1)}{N(N-1)x_i} \qquad (6)$$

where n is the number of quadrates sampled, xi is the number of individuals in the ith quadrate, $I_ä$ is the Morisita's index, N is the total number of individuals in n quadrates. If $I_ä > 1$, $I_ä < 1$ or $I_ä = 1$, then the spatial distribution is aggregated, regular or random, respectively. To determine if the sampled population significantly differs from random, the following large sample test of significance was used (Hucheson & Lyons, 1989).

$$Z = \frac{(I_\delta - 1)}{\left(\frac{2}{nm^2}\right)^{1/2}} \qquad (7)$$

Comparing values of Z with tabulated values for a normal distribution and reject the hypothesis that the sampled population is dispersed randomly if $|Z|>Z(\alpha/2)$ (Pedigo & Buntin, 1994).

Index of dispersion:

The variance (S^2) to mean (m) ratio is used to describe the distribution of a population as follows:

$S^2/m > 1$ Aggregated

$S^2/m = 1$ Random

$S^2/m < 1$ Regular

Departure from a random distribution can be tested by calculating the index of dispersion, I_D, where n is the number of samples:

$$I_D = (n-1)S^2/m \qquad (8)$$

The Z coefficient was calculated for testing the goodness-of-fit:

$$Z = \sqrt{2I_D} - \sqrt{(2v-1)} \qquad (9)$$

where $v=(n-1)$. If the spatial distribution would be random, but if $z>1.96$ or $z<-1.96$ it would be aggregated or regular, respectively (Pedigo & Buntin, 1994).

Statistical analysis

The data of population densities of examined species on different agricultural crops were checked for homogeneity for variance before analysis (ANOVA). Mean comparison between the treatments were carried out using least significant difference (LSD) (P<0.05). Different methods including linear regression were used to determine spatial pattern of *T. urticae* and *S. gilvifrons.* This linear regression was also used for determining the kind of interaction between predator and its prey.

RESULTS

Sampling program

One leaf per plant of each crop was selected as a sample unit due to activity place of *T. urticae* and *S. gilvifrons*. The reliable sample size with maximum relative variation of 20% (d=0.2) was 40 and 30 leaves for bean varieties and cucumber, respectively.

Population density of *T. urticae* and *S. gilvifrons*

Mean population densities of different stages of the mite on five bean varieties and one variety of cucumber on each date are shown in Tables 1 and 2. There were significant differences between population densities of adult stages of *T. urticae* on different crops (F =158.81 ; df =2754 ; P < 0.05). Across all sampling dates, the maximum and minimum peak population densities of egg, larva, nymph, adult and overall stages of mites were observed on Sun-ray (59.37 mites per leaf) and Parastoo (4.73 mites per leaf), respectively. The population density of *T. urticae* on cucumber (150.71 mites per leaf) was significantly higher than bean varieties (F = 141.21 ; df =2754 ; P < 0.05). The population density of *S. gilvifrons* peaked at 4 beetles per Sun-ray leaf during the warm months from July to September.

Reaction of *S. gilvifrons* to the population density of *T. urticae*

The results of linear regression between mean density of *T. urticae* and mean density of *S. gilvifrons* are shown in Table 3. The reaction of *S. gilvifrons* to population density of *T. urticae* was density dependent (P<0.05, b>0). on all the crops except Sun-ray variety which was density independent (P>0.05, b=0).

Table 1. Mean (±SE) population density of adults of *T. urticae* (per leaf) on different crops in 2005

	Cucumber	Beans				
Date	Superdaminus	Sun-ray	Parastoo	Sadaf	Goli	Talash
07 Aug.	36.57±6.33 a	1.68±1.86 cd	4.60±1.09 cd	8.82±1.35 bc	15.40±2.30 b	5.25±0.82 cd
22 Aug.	60.10±7.24 a	17.35±2.14 b	0.03±0.025 c	1.78±0.28 c	0.15±0.068 c	1.10±0.18 c
26 Aug.	32.60±5.08 a	10.35±1.09 b	0.03±0.025 c	1.35±0.32 c	0.05±0.034 c	0.88±0.21 c
01 Sep.	19.36±2.16a	8.30±1.15 b	0.02±0.025 d	0.70±0.19 cd	0.05±0.034 d	2.02±0.40 c
08 Sep.	14.00±3.09 a	2.80±0.32 b	0.02±0.025 c	0.70±0.19 d	0.45±0.21 bc	1.17±0.23 bc
17 Sep.	8.93±1.88 a	1.87±0.54 b	0.10±0.078 b	0.45±0.12 bc	0.25±0.08 b	0.42±0.13 b
24 Sep.	10.83±1.66 a	2.05±0.45 b	0.55±0.16 bc	0.45±0.15 b	0.77±0.21 bc	0.35±0.13 c
06 Oct.	12.26±1.98 a	4.90±0.72 d	0.20±0.09 c	0.40±0.12 c	0.77±0.18 c	0.57±0.16 c
13 Oct.	13.66±2.51 a	2.12±0.32 b	0.47±0.19 b	0.07±0.04 b	0.17±0.10 b	0.62±0.18 b
22 Oct.	2.20±0.77 a	0.42±0.25 b	0.12±0.073 b	0.07±0.042 b	0.12±0.08 b	0.25±0.10 b
29 Oct.	1.90±0.70 a	1.25±0.74 ab	0.65±0.21 b	0.32±0.02 b	0.20±0.03 b	0.32±0.11 b
05 Nov.	0.16±0.11 cd	5.54±0.38 a	0.025±0.02 d	0.50±0.17 bc	0.075±0.05 c	0.80±0.22 b

The means followed by different letters in the same row are significantly different (P<0.05; LSD).

Table 2. Mean (±SE) population density of overall life stages of *T. urticae* (per leaf) on different crops in 2005.

	Cucumber	Beans				
Date	Superdaminus	Sun-ray	Parastoo	Sadaf	Goli	Talash
07 Aug.	239.5±25.90 a	74.40±30.87 cd	20.02±4.12 d	74.40±20.73cd	140.32±30.95b	105.5±15.3 bc
22 Aug.	430.2±57.54 a	160.30±18.33 b	0.03±0.02 c	7.90±1.31 c	0.65±0.15 c	13.08±2.36 c
26 Aug.	411.4±47.60 a	159.13±22.35b	0.43±0.23 c	5.35±1.10 c	1.00±0.41 c	7.50±1.60 c
01 Sep.	173.2±18.67 a	99.80±1.27 b	0.13±0.06 c	4.68±1.20 c	2.38±1.04 c	19.45±5.36 c
08 Sep.	98.6±18.93 a	34.17±5.60 b	0.20±0.01 c	7.63±1.77 c	2.13±0.90 c	12.18±2.41 c
17 Sep.	87.00±8.25 a	7.53±1.38 b	1.78±1.17 b	6.93±0.86 b	6.73±1.26 b	7.68±2.00 b
24 Sep.	91.30±8.32 a	19.25±5.40 b	6.90±1.81c	7.13±3.05 c	10.88±3.91 bc	3.58±1.07 c
06 Oct.	120.80±26.16 a	72.90±11.90 b	2.98±1.90 c	5.43±1.87 c	20.90±5.43 c	7.75±1.94 c
13 Oct.	108.50±14.84 a	63.30±12.05 b	10.70±4.40 c	4.60±1.36 c	8.13±2.30 c	17.70±3.92 c
22 Oct.	25.80±9.58 a	7.65±3.95 b	3.58±0.86 b	7.60±1.31 b	6.75±2.01 b	5.85±1.32 b
29 Oct.	19.10±6.49 a	11.25±5.39 ab	9.13±3.45 ab	2.70±0.65 b	15.40±10.53 ab	8.43±1.94 ab
05 Nov.	3.10±1.17 ab	2.78±1.37 ab	0.95±0.38 b	5.28±1.03 a	1.78±0.63b	5.30±1.17 a

The means followed by different letters in the same row are significantly different (P<0.05; LSD).

Table 3. Regression analysis between population density of *T. urticae* and *S. gilvifrons* on different crops in 2005.

Crop	a	b	SE_b	$P_{reg.}$	r^2
Talash	0.027	0.0030	0.00019	0.000	0.963
Goli	-0.002	0.0003	0.00001	0.000	0.974
Sadaf	-0.003	0.0013	0.00015	0.000	0.896
Parastoo (cowpea)	-0.003	0.0032	0.00112	0.016	0.459
Sun-ray	0.011	0.0006	0.00028	0.051	0.329
Superdaminus (cucumber)	-0.018	0.0003	0.00011	0.020	0.440

a=Intercept, b=Slope, SE_b=Standard error of slope, P_{reg}=P-value of regression

Spatial distribution of *T. urticae* and *S. gilvifrons*

Taylor's power law indicated an aggregated distribution pattern (b >1) for the mite, *T. urticae* on all bean varieties but not the cowpea variety, Parastoo: 1.60, 1.89, 2.05, 1.35 and –1.64 for Talash, Goli, Sadaf, Sun-ray and Parastoo, respectively (Table 4).

The estimated Morisita's indices ($I_{ä}$) were almost all >1 which indicated an aggregated pattern for all crops. However, the values of $I_{ä}$ decreased and reached 1 for the Sun-ray on 5 November (Table 5).

The spatial distribution of the predatory beetle, *S. gilvifrons* using the variance to mean ratio showed that bean varieties of Talash and Sun-ray, cow pea variety Parastoo and cucumber variety Superdaminus had values of 1.64, 1.90, 1.32 and 11.54, respectively (Table 6). Therefore spatial distribution pattern of the predator was also aggregated on these crops. But on two other bean varieties, Goli and Sadaf, the respective ratios were 0.99 and 0.98, indicating a random pattern.

DISCUSSION

Several methods are available for sampling spider mites in row crops such as individual plant unit observation, imprint on paper, machine brushing onto a plate, beat cloth, paper, or funnel techniques. The most precise method is direct counting of all stages of mites on plant leaflets using the aid of a stereomicroscope (Kogan & Herzog, 1980). With attention to the life stage of *T. urticae* and *S. gilvifrons*, plant leaves were selected as sampling units and counts made of individuals per sampling unit. via stereomicroscope and visual counts techniques, respectively. Shih & Wang (1996) used the stereomicroscope in order to count the number of each stage of *T. urticae* on the carambola leaves. The population density of *T. urticae* and *Stethorus punctillum* Weise were determined on raspberry leaves using stereomicroscope whereas counts of *S. punctillum* adults were recorded on Pherocon sticky boards (Roy *et. al.,* 2005).

On most sampling dates, the highest population density of adults (F =158.89; df =2754; P < 0.05) and overall life stages (F =141.2; df =2754; P < 0.05) of the mite was significantly higher on cucumber in comparison with the bean varieties. Cucumber may be more suitable for mite activity and sustain higher population densities than the bean and cowpea varieties due to the presence of dense trichomes and the larger leaf size of cucumber. The absence of trichomes and waxy leaves in Parastoo may be the reason Parastoo sustained the lowest population density of *T. urticae* of the five bean varieties. The higher population density of *T. urticae* on the leaves of the other bean varieties including Sadaf, Goli, Talash and Sun-ray in comparison with Parastoo, was attributed to the presence of dense hooked trichomes on the leaves that caused suitable environment for mite activity and reproduction. This was in agreement with Ahmadi *et al.* (2005) description of the spatial distribution pattern of *T. urticae* on four bean varieties.

Values for Taylor's power law and Morisita's index found that mites had an aggregated spatial distribution due to the limited mobility of *T. urticae* females. This behavior has been described for *T. urticae* on other crop systems (Kennedy & Smitley, 1985). As populations become more spatially aggregated, it requires a larger sample size to obtain density estimates at an acceptable level of precision (Nachman, 1985). Shih & Wang (1996) evaluated the spatial distribution of *T. urticae* in a carambola orchard by several methods. They observed that by using of Taylor's power law and Iwao's patchiness regression analysis, spatial distribution of *T. urticae* population was aggregated within and among the patches. Ahmadi *et al*. (2005) reported that the spatial distribution pattern of *T. urticae* on four bean varieties using variance to mean ratio and Taylor's power law was aggregated and on Parastoo variety using Taylor's power law was random. Martinez-Ferrer *et al*. (2006) determined that the dispersion patterns generated by Taylor's power law indicated an aggregated pattern ($b > 1.21$) of *T. urticae* on both leaves and fruits of clementines in Spain. The contagious distribution and the high degree of patchiness created by the aggregative behavior of *T. urticae* minimizes the attack rate from the predators and enhances the advantages of a complex life type, a fitness of survival and reproductive strategy of *T. urticae*. The spatial distribution pattern is influenced by the behavior of *T. urticae* including the collective egg deposition of parental females, the complex life type, the incremental tendency of dispersal and activity behavior which are an age-dependant function of *T. urticae*.

The spatial distribution pattern of predatory beetle *S. gilvifrons* using a variance to mean ratio was random on Sadaf and Goli and was aggregated on cucumber and the other three bean varieties, suggesting that different plant varieties can influence spatial distribution of the predator. This behavior of *S. gilvifrons* is a positive response to the aggregative behavior of *T. urticae* for enhancing the predation efficiency. These results showed that due to similarity of spatial distribution pattern of *T. urticae* and *S. gilvifrons* (aggregated pattern) on some plant varieties, it could be a useful agent for biological control of the mite on these plants. Chen-Wenlong (1994) studied the spatial distribution pattern and sampling technique for the predatory beetle *S. chengi* Sasajii in citrus orchards and observed an aggregated spatial distribution pattern for this predator and its host, *Panonychus citri* Koch using similar methods to estimate the spatial distribution.

The results of linear regression between population density of *T. urticae* and population density of *S. gilvifrons* indicated that the reaction of *S. gilvifrons* to population density of *T. urticae* on Sun-ray variety was density independent ($b=0$, $P>0.05$) but was density dependent ($b=0$, $P<0.05$) on the other crops.

This research demonstrated that the different plant varieties had distinct effect on population density of *T. urticae* and spatial distribution pattern of its predator, *S. gilvifrons*. During the growing season, the population density of the mite on different crops was significantly different. The highest population density of the pest was obtained on cucumber and among bean varieties the highest and lowest density was on the Sun-ray and Parastoo, respectively. The reaction of *S. gilvifrons* to population density of *T. urticae* on many experimented crops was density dependent. Therefore, *S. gilvifrons* can be used as a suitable biological agent in integrated pest management of *T. urticae* on all these crops except the Sun-ray variety. The coefficients obtained from spatial distribution models can be used in developing the sampling program of *T. urticae* on each crop. To improve the management of *T. urticae* on agricultural crops, a precise sampling program is needed. This plan is crucial to further develop and implement integrated pest management (IPM) strategies on these crops.

Table 4. Spatial distribution parameters (Taylor's method) of *T. urticae* on different crops in 2005.

Crop	a	b	SE_b	t_t	t_c	P_{reg}
Talash	0.74	1.60	0.13	2.23	4.58	0.000
Goli	0.71	1.89	0.14	2.23	6.01	0.000
Sadaf	0.29	2.05	0.26	2.23	3.94	0.000
Parastoo (cowpea)	0.88	-1.64	0.14	2.23	18.83	0.000
Sun-ray	1.27	1.35	0.12	2.23	2.73	0.000
Superdaminus (cucumber)	-	NS	0.51	-	-	0.474

a=Intercept, b=Slope, SE_b=Standard error of slope, t_t=t-table, t_c=t-calculated, P_{reg}=P-value of regression, NS=non-significant

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Table 5. Parameters of Morisita's index and *Z* calculated of *T. urticae* on different crops in 2005.

Date	Superdaminus		Sun-ray		Parastoo		Sadaf		Goli		Talash	
	I_δ	*Z*	I_δ	*Z*	I_δ	*Z*	I_δ	*Z*	I_δ	*Z*	I_δ	*Z*
07 Aug.	1.3	275	1.9	810	2.6	145.4	4.0	100.3	2.8	120	1.8	410.0
22 Aug.	2.8	129.2	1.5	384.6	0.0	0.0	1.9	48	1.8	7.63	2.2	70.6
26 Aug.	1.5	708.3	1.8	542	10.9	35.9	2.5	37	6.9	119.4	2.6	57.6
01 Sep.	1.3	235.7	1.7	331.8	4.0	6.7	3.4	51.06	8.2	718	3.9	265.4
08 Sep.	2.0	350	2.0	156.9	8.3	6.9	2.9	99	7.7	67.4	2.4	80.5
17 Sep.	1.2	86.2	2.2	41.4	17.88	140.7	2.4	44	2.3	37.6	3.5	86.9
24 Sep.	1.2	71.9	3.9	266.3	3.6	80	8.0	237.4	5.9	249	4.3	53.2
06 Oct.	2.3	645.2	2.0	340	16.9	211.2	5.5	109.5	3.5	250	3.3	82.8
13 Oct.	1.5	196.2	2.4	400	7.5	327	4.2	81	4.0	150	2.9	155
22 Oct.	4.9	397	1.1	4.5	3.0	33.0	2.0	36.2	4.3	101.2	2.8	48.1
29 Oct.	4.3	221.3	9.9	468.4	6.4	225	2.9	24.0	19.2	1820	2.9	75.4
05 Nov.	6.3	63.3	1.0	129.3	6.5	23.7	2.3	31.4	5.5	293.3	2.7	41.7

Table 6. Spatial distribution parameters (variance to mean ratio) of *S. gilvifrons* on different crops in 2005.

Crop	S^2/m	I_D	*Z*	Spatial distribution
Talash	1.64	788.009	8.76	Aggregated
Goli	0.996	477.583	-0.024	Random
Sadaf	1.90	911.856	11.77	Aggregated
Prastoo	0.988	473.635	-0.152	Random
Sun-ray	1.32	634.03	4.68	Aggregated
Superdaminus	11.54	414.404	2.01	Aggregated

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