SEASONAL ABUNDANCE AND SPATIAL DISTRIBUTION OF THE LEAFMINER, *LIRIOMYZA TRIFOLII* (DIPTERA: AGROMYZIDAE), AND ITS PARASITOID, *OPIUS DISSITUS* (HYMENOPTERA: BRACONIDAE), ON BEAN IN SOUTHERN FLORIDA

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Abstract

Seasonal population densities of *Liriomyza trifolii* (Burgess) and its parasitoid *Opius dissitus* (Muesebeck) were studied at 3 snap bean (*Phaseolus vulgaris*) sites in south Florida from 2010 to 2011. *L. trifolii* population density presented a seasonal preference, and was significantly abundant during Dec 2010 (17.9 ± 1.5 adults per 5 leaves) and Jan 2011 (30.3 ± 2.7 adults per 5 leaves) when the temperature was relatively low (~ 3 °C). Its parasitoid, *O. dissitus* showed a pattern of population density similar to *L. trifolii*, and was abundant during December 2010 (4.5 ± 0.45 adults per 5 leaves) and January 2011 (5.4 ± 0.73 adults per 5 leaves). A direct density dependent relationship was found between *O. dissitus* parasitism and *L. trifolii*. Spatial distribution patterns of *L. trifolii* and *O. dissitus* were evaluated at these 3 bean sites. Both *L. trifolii* and *O. dissitus* showed an aggregated (clumped) distribution pattern when their densities were high during Dec 2010 to Jan 2011, but a regular (uniform) distribution pattern when their densities were low during Sep 2010 and Feb 2011.

Key Words: biological control, aggregative distribution

Resumen

La densidad de población estacional de *Liriomyza trifolii* (Burgess) y su parasitoide *Opius dissitus* (Muesebeck), fue estudiada en tres sitios de frijól verde (*Phaseolus vulgaris*) en el sur de la Florida desde el 2010 hasta el 2011. La densidad de población de *L. trifolii* presenta una preferencia estacional, y fue significativamente más abundante a partir de diciembre del 2010 (17.9 ± 1.5 adultos por cada 5 hojas) a enero del 2011 (30.3 ± 2.7 adultos por cada 5 hojas) cuando la temperatura es relativamente baja (~23 °C). El parasitoide, *O. dissitus* mostró un patrón de densidad de población similar a *L. trifolii,* y fue abundante en diciembre del 2010 (4.5 ± 0.45 adultos por cada 5 hojas) y enero del 2011 (5.4 ± 0.73 adultos por cada 5 hojas). Se encontró una relación directa dependiente de la densidad entre el parasitismo por *O. dissitus* y la densidad de *L. trifolii.* Se evaluaron los patrones de distribución espacial de *L. trifolii* y *O. dissitus* en estos tres sitios de frijol. *Liriomyza trifolii* y *O. dissitus* mostró un patrón de distribución agregado (agrupado), cuando la densidad de su población fue alta desde diciembre del 2010 hasta enero del 2011, pero mostró un patrón de distribución regular (uniforme), cuando la densidad de su población fue baja en septiembre del 2010 y febrero del 2011.

The leafminer, *Liriomyza trifolii* (Burgess), is a phytophagous fly feeding on a wide range of ornamental and vegetable plants and is one of the main pests of vegetable crops in south Florida (Seal et al. 2002). The species is distributed in all temperate and tropical regions of the world. The adult female injures plant tissues with its ovipositor and feeds on the exudates (Parrella 1987). Eggs are deposited into the leaf puncture and develop inside the leaves. The mining activity of larvae causes damage to the mesophyll layer of the leaf and the feeding rate increases rapidly as the larvae develop (Fagoonee & Toory 1984). The mature larvae exit the leafmine and drop to the ground to pupate in the soil.

Opius dissitus (Muesebeck) is a solitary larval-pupal cndoparasitoid of *L. trifolii*. The *O. dissitus* female deposits her egg directly inside the leafminer larva through the mine, and the host larva consumes the plant and develops until pu-

pation (Bordat et al. 1995a). *O. dissitus* develops inside the host pupa and finally emerges out of the pupa. Generally, only one parasitoid emerges from one pupa. *O. dissitus* has been reared from *L. trifolii* infested celery leaves, tomato leaves and weeds in Florida (Stegmaier 1972; Schuster & Wharton 1993; Schuster & Gilreath 1991). *O. dissitus* was found to be the most abundant parasitoid of *L. trifolii* on the bean crop in our preliminary study.

Effective monitoring of parasitoid and host densities is essential for making management decisions. Some of the reasons for the rapid increase in leafminer population densities include intensive insecticide applications leading to the development of resistance (Saito 2004) and reduction in natural enemy densities (Minckenberg & van Lenteren 1986). Other abiotic factors that may affect leaf miner population densities include temperature, light intensity and moisture (Shepard et al. 1998; Saito et al. 2008, Leibee 1986). For instance, high daily temperatures (≥30 °C) reduced leafminer, *L. huidobrensis* (Blanchard) adult density on cucumber (Abou-Fakhr-Hammad & Nemer 2000). For *O. dissitus*, Bordat et al. (1995b) reported that 20 °C was optimal for both the adult male and female, and the optimum temperature for female reproduction was 25 °C. Light conditions could also affect leafminer density levels, and the pupariation of emergent *L. trifolii* larva can be delayed for a short time by continuous lighting condition (Leibee 1986). In addition, Shepard et al. (1998) reported that moisture level might be another factor affecting leafminer density. They found that the infestation on potato by *L. huidobrensis* was more severe during the wet season.

Quantitative characterization of insect spatial distribution allows for a better understanding of insect ecological behavior and their interactions with parasitoids. Parasitoids' foraging efficiency is believed to be increased when the host is in an aggregative distribution pattern, which leads to a direct density dependent relationship and more effective biological control (Hassell & May 1974; Heads & Lawton 1983). In general, the spatial distribution pattern of an insect herbivore may be affected by several factors including the quality of foliage of the host plant for oviposition (Faeth 1991). In addition, leafminer larval density could affect female parasitoid oviposition behavior (Nelson & Roitberg 1995). In our study, the relationship between bean crop growth periods, and the population densities of the leafminer and its key parasitoid, *Opius dissitus*, and was investigated.

The specific objectives of this study were (1) to determine the seasonal abundance of *L. trifolii* and its parasitoid, *O. dissitus*, on snap bean; (2) to determine their spatial distribution patterns and (3) to determine the relationship between *L. trifolii* density and *O. dissitus* parasitism.

Materials and Methods

Study Sites

The study was conducted in Homestead, Dade County, Florida. In this area, bean (*Phaseolus vulgaris* L.) crops are grown commercially in open field conditions. There are 2 growing seasons per year, which taken together extend from Oct to Mar. In this study, 3 bean sites were prepared at the Tropical Research and Education Center (TREC), University of Florida. The field at each site was 50 m × 30 m, i.e., 1500 m^2. This field at each site was divided into 15 equal 100 m^2 plots with dimensions of 10 m × 10 m. These small plots were sampled in order to elucidate the distribution patterns of the leaf miner and its parasitoid during Sept. 2010-Feb. 2011. A series of 300 m^2 plots was created in which each was formed by combining three 100 m^2 plots in order to study the distribution patterns of the leaf miner and its parasitoid in larger area. Site 1 was planted with bean from Sep to Oct 2010, site 2 from Oct to Dec 2010, and site 3 from Dec 2010 to Feb 2011. The soil type of the study area is Krome gravelly loam, which consists of about 33% soil and 67% pebbles. The snap bean, *P. vulgaris* (supplied by Harris Moran seed Company, Modesto, California), was seeded directly in rows 91 cm apart with a 20-cm within row plant spacing. A pre-plant herbicide, halosulfuron methyl (Sandea®, Gowan Company LLC., Yuma, Arizona), was applied at 51.9 g/ha for controlling nutsedge, *Cyperus rotundus* L, and broad-leaf weeds. At planting, granular fertilizer (6: 12: 12 / N: P: K) was soil incorporated at 1345 kg/ha. Liquid fertilizer (4:0:8 /N:P:K) was applied at the rate of 0.56 kg N/ha/day in furrow by the side of the seed row during 3, 4 and 5 wk after planting. Plants were irrigated by sprinkler at one inch (2.54 cm)/day to maintain optional soil moisture. The fungicide chlorothalonil (Bravo®, Syngenta Crop Protection, Inc., Greensboro, North Carolina) was used at 2.81 L ha^{-1} during early bean growth stage to prevent fungal diseases. No insecticide was used at these study sites.

Seasonal Densities of *Liriomyza trifolii* and *Opius dissitus*

Each bean site was divided into 15 equal plots (10 m × 10 m). Sampling was initiated when bean plants had two primary leaves fully unfolded, and continued once per week until the beans were harvested. In the sampling, 5 bean leaves, 1 leaf per plant, were randomly collected in each plot (total 75 leaves per site). When the bean plants produced new leaves and the primary leaves dropped off, the mature bottom leaves were always collected as samples because of the feeding preference of *L. trifolii* for the older mature leaves (Facknath 2005).

The sampled leaves from each plot were placed separately into Petri dishes (10 cm diam). Each

Petri dish was labeled with the plot number and sampling date. All bean samples were transported to the laboratory and placed in a growth chamber at 25 °C, 70% RH and 14: 10 h L: D for further development of *L. trifolii* and *O. dissitus*. The samples in each Petri dish were checked every day for leafminer pupae. When pupae were found they were carefully separated from the leaves, and transferred into a new appropriately marked Petri dish (10 cm diam) to record their origin. The number of pupae from each plot was recorded. The pupae were placed in the same growth chamber for further development into adults. The numbers of emerged adults of *L. trifolii* and of its parasitoid, *O. dissitus*, from the pupae were recorded and assessed.

Statistical Analyses

The density of *L. trifolii* in each week was calculated based on the number of emerged pupae and adults from leaf samples per plot. The density of *O. dissitus* was calculated as the number of emerged adults from leafminer pupae per plot. The density of *L. trifolii* and *O. dissitus* was subjected to analysis of variance (ANOVA, PROC GLM, SAS Institute Inc. 2003) to determine differences in the various growth periods. Means were separated by Least Significance Difference (LSD) ($P < 0.05$).

Spatial Distribution of *Liriomyza trifolii* and *Opius dissitus*

This study was conducted in the same field as the seasonal abundance study. Plot design, sample collection and sample preparation were as discussed before. The spatial distribution of these 2 insect species within each of the 3 bean sites was determined based on data collected from 2 different sized plots: a) 15 plots each 100 m^2 ; and b) 5 plots each 300 m^2 . Spatial distribution patterns of *L. trifolii* and *O. dissitus* were evaluated by using Taylor's power law (Taylor 1961) and Iwao's patchiness regression (Iwao 1968). The Taylor's power law linear regression model is:

$$\log s^2 = b \log x + \log a$$

Where the slope b is the index of aggregation, a is the factor related to sample size and x indicates mean density. Iwao's patchiness regression was also used to access the variance to mean relation and to evaluate the distribution patterns. The linear regression model is:

$$x^* = \beta x + \alpha$$

Where x^* is the mean crowding (Lloyd 1967) expressed as $x^* = x + s^2/\bar{x} - 1$, slope b is the index of regression, and a is the sampling factor. In both of the models, when the slope (b and b) value is not significantly different from 1, it indicates a random distribution pattern; slope significantly >1 indicates an aggregated distribution pattern; and slope significantly <1 indicates a regular distribution pattern ($P < 0.05$). The goodness of fit of each data set to the linear regression model was evaluated by the r^2 value. The student t test was used to determine significant differences between the slopes in both of the models ($P < 0.05$).

Parasitism and Host Density

The relationship between *O. dissitus* parasitism proportion and leafminer density in each week was analyzed by transformed log x linear regression analysis (PROC GLM, SAS Institute Inc. 2003).

$$y = b \log x + a$$

The goodness of fit of the data set to the linear regression was evaluated by r^2 value. Parasitism efficiency was expressed as parasitism proportion in each sampling plot calculated as: y = number of emerged *O. dissitus*/number of the leafminer pupae. x is the mean density of leafminer pupae. Slope b values were used to determine the relationship between the parasitism proportion and host density ($P < 0.05$). When the slope b was significantly > 0, it indicated a direct density dependence; significantly < 0 indicated a reverse density dependence ($P < 0.05$). The regression analyses were carried out on the combined data from all three sites.

Results

Seasonal Density of *Liriomyza trifolii* and *Opius dissitus*

The density of *L. trifolii* (0.4 ~ 4.9 pupae per 5 leaves) and *O. dissitus* (0.0 ~ 1.9 adults per 5 leaves) in the bean field at site 1 was low, from 9 Sep to 28 Oct 2010 (Fig. 1). At this site, the densities of *L. trifolii* (4.9 ± 0.7 pupae per 5 leaves) and *O. dissitus* (1.9 ± 0.3 adults per 5 leaves) were significantly higher ($F = 12.88$, df = 7, 112, $P < 0.0001$; $F = 5.38$, df = 7, 112, $P < 0.0001$) in the middle of the bean growth period than at either the beginning or the end of the bean growth period; each being < 1.0 per 5 leaves.

At the bean site 2 (Fig. 2), the densities of the leafminer (2.2 ~ 3.3 pupae per 5 leaves) and the parasitoid (0.0 ~ 2.1 adults per 5 leaves) were low in early growth period during Oct 2010, but they increased rapidly during the 2nd half of Nov 2010 (16.2 ± 2.3 pupae per 5 leaves; 3.1 ± 0.5 parasitoids per 5 leaves). The densities of *L. trifolii* (17.9 ± 1.5 pupae per 5 leaves) and *O. dissitus* (4.5 ± 0.45 adults per 5 leaves) were both significantly

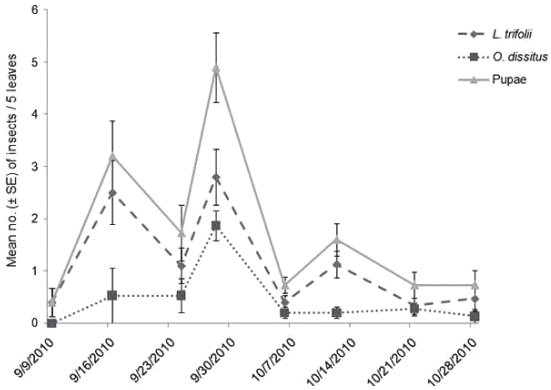

Fig. 1. Density (mean ± SE/5 leaves) of *Liriomyza trifolii* pupae, emerged *Liriomyza trifolii* and *Opius dissitus* at bean site 1 from 9 Sep through 28 Oct 2010.

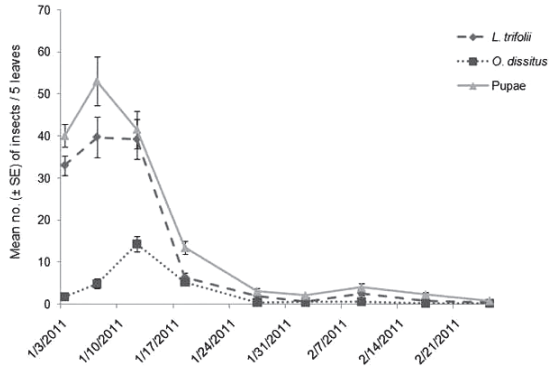

Fig. 3. Density (mean ± SE/5 leaves) of *Liriomyza trifolii* pupae, emerged *Liriomyza trifolii* and *Opius dissitus* at bean site 3 from 3 Jan 2010 through 21 Feb 2011.

higher (F = 51.99, df = 9, 140, P < 0.0001; F =21.7, df = 9, 140, P < 0.0001) during the late growth period [Dec 2010] than during earlier growth period at this site.

At the bean site 3 (Fig. 3), the densities of *L. trifolii* (53.1 ± 5.8 pupae per 5 leaves) and *O. dissitus* (14.4 ± 1.8 adults per 5 leaves) reached the highest density levels in early Jan 2011 and these were significantly higher (F = 61.1, df = 8, 126, P < 0.0001 for *L. trifolii*; F = 35.6, df = 8, 126, P < 0.0001 for *O. dissitus*) than the rest growth period. The density of *L. trifolii* and *O. dissitus* decreased toward the end of Jan 2011, and remained low until the end of the growth period (0.87 ~ 4.1 pupae per 5 leaves; 0.2 ~ 0.67 parasitoids per 5 leaves) in Feb 2011.

Overall, the seasonal abundance of *L. trifolii* (Fig. 4) was low in Sep and Oct 2010, and again in February 2011. The leafminer density level started to increase in the 2nd half of Nov 2010 and reached the highest average density level (30.3 ± 2.7 adults per 5 leaves) (F = 61.5, df = 5, 354, P < 0.0001) in Jan 2011. The parasitoid density level was the highest (5.4 ± 0.73 adults / 5 leaves) (F = 30.95, df = 5, 354, P < 0.0001) during the first half of Jan 2011;, and the density of *O. dissitus* was always high when leafminer population was abundant; and always low when the host density was low.

Spatial Distribution of *Liriomyza trifolii*

In Sep 2010, the distribution pattern of *L. trifolii* (Table 1) in 100 m^2 plots was aggregated based on Taylor's power law (b = 1.22, P = 0.006, r^2 = 0.49), but, based on Iwao's patchiness regression, this distribution was a regular (b = 0.60, P = 0.164, r^2 = 0.23). In 300 m^2 plots *L. trifolii* showed a regular distribution pattern based on both Taylor's power law (b = 0.98 P < 0.0001, r^2 = 0.72), and, also in Iwao's patchiness regression (b = 0.74, P =0.035, r^2 = 0.44).

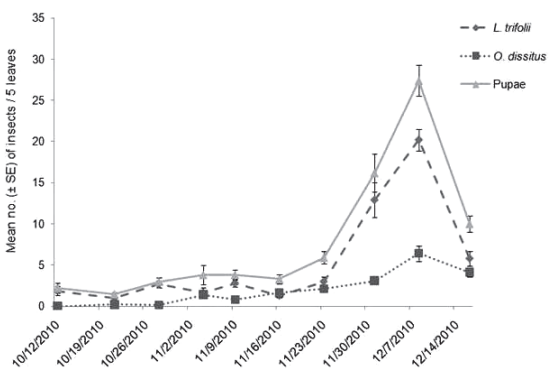

Fig. 2. Density (mean ± SE/5 leaves) of *Liriomyza trifolii* pupae, emerged *Liriomyza trifolii* and *Opius dissitus* at bean site 2 from 12 Oct through 14 Dec 20100.

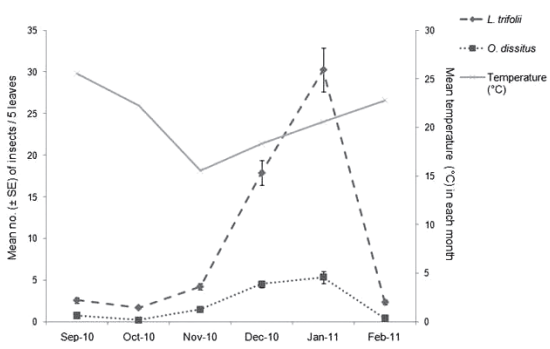

Fig. 4. Density (mean ± SE/5 leaves) of *Liriomyza trifolii* pupae, emerged *Liriomyza trifolii* and *Opius dissitus* from 10 Sep 2010 through 11 Feb 2011

TABLE 1. TAYLOR'S POWER LAW AND IWAO'S PATCHINESS REGRESSION PARAMETERS PERTAINING TO THE DISTRIBUTION OF *LIRIOMYZA TRIFOLII* AND *OPIUS DISSITUS* ON BEAN IN SEP 2010.

	Plot size (m^2)	Taylor's power law			Iwao's patchiness regression		
		r^2	a	b	r^2	a	b
L. trifolii	100	0.49	0.013	1.22_{AGG}	0.72	0.64	0.98_{REG}
	300	0.23	0.46	0.60_{REG}	0.44	2.06	0.74_{REG}
O. dissitus	100	0.56	0.027	1.37_{AGG}	0.45	-2.27	2.74_{AGG}
	300	0.023	0.40	-0.32_{REG}	0.0066	3.77	-0.38_{REG}

AGG, aggregated distribution, slop b is significantly > 1. REG, regular distribution, b is significantly < 1 ($P \leq 0.05$). The division number of 15 and 5 for plot sized at 100 m^2 and 300 m^2, respectively.

In Nov 2010, *L. trifolii* (Table 2) showed an aggregated distribution pattern in both sizes of plots; i.e., in 100 m^2 plots: (b = 1.20, P = 0.0038, r^2 = 0.38) and in 300 m^2 plot (b = 1.58, P = 0.008, r^2 = 0.52) based on Taylor's power law. Similar pattern of distribution was observed in both sizes of plots when data were analyzed by using Iwao's patchiness regression method (100 m^2: b =1.20, P < 0.0001, r^2 = 0.8) (300 m^2: b = 1.45, P = 0.001, r^2 = 0.67).

In Dec 2010, *L. trifolii* (Table 3) had an aggregated distribution pattern (b = 1.63, P = 0.0045, r^2 = 0.47) (b = 1.10, P < 0.0001, r^2 = 0.95) when plot size was 100 m^2 based on both methods of analysis. In 300 m^2 plots the *L. trifolii* population showed a regular distribution pattern (b = 0.98, P = 0.0352, r^2 = 0.13) based on Taylor's power law, but an aggregated distribution (b = 1.05, P = 0.0004, r^2 = 0.86) based on Iwao' patchiness regression.

In Jan 2011 *L. trifolii* presented an aggregated distribution pattern (b = 1.74, P = 0.0019, r^2 = 0.42) (b = 1.12, P < 0.0001, r^2 = 0.92) in 100 m^2 plot based on both methods of analysis (Table 4). A similar pattern of distribution was observed when plot size was 300 m^2 (b = 1.41, P = 0.0009, r^2 = 0.69) (b = 1.05, P < 0.0001, r^2 = 0.99), irrespective of method of analysis.

In Feb 2011 (Table 5) *L. trifolii,* in both 100 m^2 and 300 m^2 plots, showed a regular distribution pattern (b = 0.81, P = 0.038, r^2 = 0.23) (b = 0.98, P = 0.054, r^2 = 0.32) based on Taylor's power law, but an aggregated distribution pattern (b = 1.23, P = 0.0002, r^2 = 0.54) (b = 1.20, P = 0.0012, r^2 = 0.67) based on Iwao's patchiness regression.

Spatial Distribution of *Opius dissitus*

In Sep 2010 *O. dissitus* had an aggregated distribution pattern (Table 1) based on Taylor's power law and on Iwao's patchiness regression, i.e., (b = 1.37, P = 0.033, r^2 = 0.56) (b = 2.74, P = 0.069, r^2 = 0.45) when plot size was 100 m^2, and a regular distribution pattern (b = -0.32, P = 0.77, r^2 = 0.023) (b = -0.38, P = 0.88, r^2 = 0.0066) when plot size was 300 m^2.

In Nov 2010 (Table 2) in 100 m^2 plots *O. dissitus* had a regular distribution pattern (b = 0.97, P = 0.0004, r^2 = 0.53) based on Taylor's power law, but an aggregated distribution pattern (b = 1.11, P < 0.0001, r^2 = 0.70) based on Iwao's patchiness regression. However in 300 m^2 plots *O. dissitus* showed an aggregated distribution based on both methods (b = 1.10, P = 0.0013, r^2 = 0.66), and (b = 1.15, P = 0.0004, r^2 = 0.73).

In Dec 2010, *O. dissitus* (Table 3) presented an aggregated distribution pattern in 100 m^2 plot (b = 1.90, P = 0.0034, r^2 = 0.50) (b = 1.42, P < 0.0001, r^2 = 0.81) based on both methods of analysis. Distribution patter did not differ when plot size was increased to 300 m^2 (Taylor's power law: b = 1.51, P = 0.082, r^2 = 0.37; Iwao's patchiness regression: b = 1.19, P = 0.0013, r^2 = 0.79).

TABLE 2. TAYLOR'S POWER LAW AND IWAO'S PATCHINESS REGRESSION PARAMETERS PERTAINING TO THE DISTRIBUTION OF *LIRIOMYZA TRIFOLII* AND *OPIUS DISSITUS* ON BEAN IN NOV. 2010.

	Plot size (m^2)	Taylor's power law			Iwao's patchiness regression		
		r^2	a	b	r^2	a	b
L. trifolii	100	0.38	-0.052	1.20_{AGG}	0.8	-0.24	1.20_{AGG}
	300	0.52	-0.22	1.58_{AGG}	0.67	-1.02	1.45_{AGG}
O. dissitus	100	0.53	-0.084	0.97_{REG}	0.7	-0.19	1.11_{AGG}
	300	0.66	-0.007	1.10_{AGG}	0.73	-0.114	1.15_{AGG}

AGG, aggregated distribution, slop b is significantly > 1. REG, regular distribution, b is significantly < 1 ($P \leq 0.05$). The division number of 15 and 5 for plot sized at 100 m^2 and 300 m^2, respectively.

TABLE 3. TAYLOR'S POWER LAW AND IWAO'S PATCHINESS REGRESSION PARAMETERS PERTAINING TO THE DISTRIBUTION OF *LIRIOMYZA TRIFOLII* AND *OPIUS DISSITUS* ON BEAN IN DEC. 2010.

	Plot size (m^2)	Taylor's Power Law			Iwao's patchiness regression		
		r^2	a	b	r^2	a	b
L. trifolii							
	100	0.47	-0.63	1.63_{AGG}	0.95	-0.76	1.10_{AGG}
	300	0.13	0.16	0.98_{REG}	0.86	0.76	1.05_{AGG}
O. dissitus	100	0.5	-0.73	1.90_{AGG}	0.81	-0.16	1.42_{AGG}
	300	0.37	-0.25	1.51_{AGG}	0.79	-0.33	1.19_{AGG}

AGG, aggregated distribution, slop b is significantly > 1. REG, regular distribution, b is significantly < 1 ($P \leq 0.05$). The division number of 15 and 5 for plot sized at 100 m^2 and 300 m^2, respectively.

In Jan 2011, *O. dissitus* in 100 m^2 plots showed an aggregated distribution (b = 1.13, P = 0.005, r^2 = 0.38) (b = 1.09, P < 0.0001, r^2 = 0.88) based on both methods of analysis (Table 4). In 300 m^2 plots, *O. dissitus* presented an aggregated distribution (b = 1.10, P = 0.024, r^2 = 0.41) based on Taylor's power law, but a regular distribution (b = 0.99, P < 0.0001, r^2 = 0.89) based on Iwao's patchiness regression.

In Feb 2011 (Table 5), based on Taylor's power law, parasitoid *O. dissitus* showed a random distribution pattern (b = 1.00, P < 0.0001, r^2 = 0.72) in 100 m^2 plots and a regular distribution pattern (b = 0.87, P = 0.001, r^2 = 0.86) in 300 m^2 plots. Based on Iwao's patchiness regression, *O. dissitus* presented a regular distribution pattern (b = 0.63, P = 0.11, r^2 = 0.17) (b = 0.47, P = 0.189, r^2 = 0.23) in both of 100 m^2 and 300 m^2 size plots.

Opius dissitus Parasitism and *Liriomyza trifolii* Host Density

The data on the weekly number of leafminer pupae and emerged parasitoids were used to analyze the relationship between the parasitism and host density. A direct density dependent relationship between *L. trifolii* density and *O. dissitus* parasitism proportion was observed based on the combined results of three bean sites (b = 0.095, df = 1, 21, r^2 = 0.17, P = 0.049).

DISCUSSION

No specific population density pattern of *L. trifolii* and *O. dissitus* was found within any specific growth period of bean sites (Figs. 1, 2, and 3). However, the densities of *L. trifolii* and *O. dissitus* were high from mid-Nov 2010 to mid-Jan 2011, but low during other bean growing months. Therefore, the abundance of *L. trifolii* and *O. dissitus* display a seasonal preference for the bean crop.

Temperature is an important abiotic factor affecting agromyzid leafminers and parasitoid abundance. Abou-fakhr-Hammad (2000) reported that the population density of pea leafminer, *L. huidobrensis* was reduced by high daily average temperatures. Saito et al. (2008) found that the garden pea leafminer, *Chromatomyia horticola* (Goueau) (Diptera: Agromyzidae), was abundant during the cool season in Japan. Homestead is located within a subtropical area, and the leafminer *L. trifolii* was more abundant when the average monthly temperature was relatively low (< 20 °C). *O. dissitus* also showed seasonal density dependent pattern similar to that of *L. trifolii*. *O. dissitus* was abundant when the leafminer density was high, and sparse when leafminer density was sparse. The present findings on the density level of *L. trifolii* and its parasitoid *O. dissitus* agreed with those of Valladares and Salvo (2001), who stated that abundance of the parasitoids was positively correlated with leafminer host density.

TABLE 4. TAYLOR'S POWER LAW AND IWAO'S PATCHINESS REGRESSION PARAMETERS PERTAINING TO THE DISTRIBUTION OF *LIRIOMYZA TRIFOLII* AND *OPIUS DISSITUS* ON BEAN IN JAN 2011.

	Plot size (m^2)	Taylor's power law			Iwao's patchiness regression		
		a	b	r^2	a	b	r^2
L. trifolii	100	0.42	-0.80	1.74_{AGG}	0.54	-0.31	1.23_{AGG}
	300	0.69	-0.06	1.41_{AGG}	0.67	-0.33	1.20_{AGG}
O. dissitus	100	0.38	-0.013	1.13_{AGG}	0.88	0.69	1.09_{AGG}
	300	0.41	0.06	1.10_{AGG}	0.89	1.27	0.99_{REG}

AGG, aggregated distribution, slop b is significantly > 1. REG, regular distribution, b is significantly < 1 ($P \leq 0.05$). The division number of 15 and 5 for plot sized at 100 m^2 and 300 m^2, respectively.

TABLE 5. TAYLOR'S POWER LAW AND IWAO'S PATCHINESS REGRESSION PARAMETERS PERTAINING TO THE DISTRIBUTION OF *LIRIOMYZA TRIFOLII* AND *OPIUS DISSITUS* ON BEAN IN FEB 2011.

	Plot size (m^2)	Taylor's power law			Iwao's patchiness regression		
		r^2	a	b	r^2	a	b
L. trifolii	100	0.23	-0.11	0.81_{REG}	0.54	-0.31	1.23_{AGG}
	300	0.32	-0.11	0.98_{REG}	0.67	-0.33	1.20_{AGG}
O. dissitus	100	0.72	0.00	1.00_{RAD}	0.17	0.16	0.63_{REG}
	300	0.86	-0.13	0.87_{REG}	0.23	0.05	0.47_{REG}

RAN, random distribution, b is not significantly different from 1 ($P \leq 0.05$). AGG, aggregated distribution, slop b is significantly > 1. REG, regular distribution, b is significantly < 1 ($P \leq 0.05$). The division number of 15 and 5 for plot sized at 100 m^2 and 300 m^2, respectively.

The spatial distribution of *L. trifolii* tended to be aggregated when its density was high, from Nov 2010 to Jan 2011. Both Taylor's and Iwao's methods of analyses were in agreement in describing this distribution. But *L. trifolii* tended to have a relatively regular distribution pattern when its abundance was relatively low in Sep 2010 and Feb 2011. At this low population density in the present study both methods of analyses agreed in describing the distribution pattern of *L. trifolii*. In comparing the results on distribution of *L. trifolii* and *O. dissitus*, it is clear that distribution pattern of *O. dissitus* followed that of *L. trifolii*. It has been reported that the *L. trifolii* distribution pattern is affected by the plant leaf size, with smaller leaf size tending to cause an aggregated distribution pattern (Ayabe and Shibata 2008). In our study, the number of total leaves and total leaf area per bean plant increased with the progression of the plant growth, which did not increase the level of aggregation of *L. trifolii*. Therefore, the spatial distribution pattern of *L. trifolii* can be affected by its density, but not by the aggregate area of the host plant foliage. In addition, both *L. trifolii* and *O. dissitus* tended to have an aggregated distribution pattern under the cool temperature (November 2010 to January 2011), but a regular pattern when the temperature was higher (Sep through Oct 2010, and again in Feb 2011). Therefore, temperature can be another factor affecting *L. trifolii*. Whether temperature also directly determines the distribution pattern of *O. dissitus* cannot be concluded from these data, because the density of *L. trifolii* is the main determinant of the density and distribution pattern of *O. dissitus*.

The regression slope of the transformed equation showed parasitism of *O. dissitus* on *L. trifolii* to be density dependent. However, the density dependent relationship between host density and the parasitism proportion was weak in the present study. Nelson and Roitberg (1995) reported that leafminer parasitoid, *O. dimidiatus* tended to have a density-dependent behavior when host mine density increased. Some authors have indicated that a host aggregated distribution pattern would increase parasitoid foraging efficiency, and this may lead to a density dependent parasitism (Hassell & May 1974; Heads & Lawton 1983). Indeed, a significantly higher parasitism rate found when the leafminer population had an aggregated distribution pattern. Nevertheless the results also supported the theory that spatial aggregation pattern is not the only factor that drives increased biological control efficiency (Reeve and Murdoch 1985).

The density patterns of *L. trifolii and O. dissitus* presented a seasonal preference. The parasitoid, *O. dissitus* was found to be the most abundant parasitoid of *L. trifolii* throughout the whole commercial bean growing season from the fall 2010 into the winter of 2011. *L. trifolii* distribution was mostly aggregated in bean fields as indicated by both methods of analysis in 70% instances. *O. dissitus* has great potential as a biological control agent for control of *L. trifolii* in south Florida. Additional studies should investigate the effectiveness of *O. dissitus* as a biological control for *L. trifolii* in a wide range of conditions.

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