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POPULATION DYNAMICS OF THE COTTON APHID, *APHIS GOSSYPPII* (HOMOPTERA: APHIDIDAE), ON STRAWBERRIES GROWN UNDER PROTECTED STRUCTURE

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ABSTRACT

A well developed management plan is in place for control of pests such as the twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), in field and greenhouse grown strawberry, *Fragaria ananassa* Duchesne; however, an integrated pest management approach to control the cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae), is not available. In order to initiate an effective program for the cotton aphid, the population dynamics of the aphid and the effectiveness of the pink spotted lady beetle, *Coleomegilla maculata* DeGeer (Coleoptera: Coccinellidae), to control aphids were studied on greenhouse strawberry. Results from this experiment established peaks of aphid infestation throughout the growing season and location of different cotton aphid life forms on the plant. The greatest positive response of the pink spotted lady beetle to cotton aphid occurred at high prey density. This characteristic indicates that the pink spotted lady beetle may be a good candidate for augmentative biological control of cotton aphid on strawberry in the greenhouse. This study provides a basis for developing a biological control of cotton aphid component for an integrated strawberry pest management program.

Key Words: *Aphis gossypii*, biological control, *Coleomegilla maculata*, *Fragaria*, greenhouse, integrated pest management, pests, pink spotted lady beetle, strawberry

RESUMEN

Existen programas de manejo establecidos para el control de la araña roja, *Tetranychus urticae* Koch (Acari: Tetranychidae) en el cultivo de la fresa, *Fragaria ananassa* Duchesne, producida en el campo e invernadero; sin embargo, un manejo integral para el control del pulgón del algodón, *Aphis gossypii* Glover (Homoptera: Aphididae), en el mismo cultivo, todavía no está disponible. A fin de establecer la efectividad de programas de control del pulgón del algodón, la dinámica poblacional del pulgón y la efectividad del predator, *Coleomegilla maculata* DeGeer (Coleoptera: Coccinellidae), fue estudiada en el invernadero. Resultados de este experimento demostraron los picos de infestación durante el desarrollo del cultivo y la localización de las diferentes formas del pulgón en la planta. El predator responde mejor cuando la población de pulgones es más densa. Esta característica da la indicación del potencial del predator como agente controlador de pulgón. Estos estudios proveen las bases de control biológico que han de implementarse en un programa sostenido del pulgón en el cultivo de la fresa.

Translation provided by the authors.

The strawberry, *Fragaria ananassa* Duchesne, is a high value crop commercially produced in California, Florida, Michigan, North Carolina, New York, Ohio, Oregon, Pennsylvania, Washington, and Wisconsin (Sorensen et al. 1997). Florida ranks second in harvested area, total yield, and production after California (USDA-FAD 2001-2002). The Florida strawberry industry produces during the months of November through March in the field and high-quality production during these months is the key to maintaining profitability. The Florida strawberry industry seeks to remain competitive during this small window of opportunity when market prices are high and

the volume from California is low (NASS-USDA 2003). One alternative to increase strawberry profitability is through greenhouse production. Growing strawberries under protective culture has become a viable alternative for strawberry producers worldwide because of the elimination of soil fumigation, the reduction of fungal and bacterial diseases, and the reduction of water usage. At present, the area of strawberries grown under protected cultivation in Florida is less than 1 ha (NASS-USDA 2003); however, this is expected to increase as growers look for new alternatives to enhance early production (Parran 2004).

Mites are the most important pest of field and greenhouse strawberries, with the twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), a potential pest wherever strawberries are produced (Oatman & McMurtry 1966; Howard et al. 1985; Price & Kring 1991). The twospotted spider mite has been successfully controlled in the field in some areas of Florida by the introduction of *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) onto the strawberry crop when about 5-10% of the strawberry leaflets have been infested with one or more mites (Van de Vrie & Price 1994). In the greenhouse, the use of *Neoseiulus californicus* McGregor to control twospotted spider mites has been very successful (unpublished data).

Although aphids are not a major problem on field strawberries (Mosser & Nesheim 2003), in greenhouse strawberries, the cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae), can be a serious problem (Leclant & Deguine 1994). This small, soft-bodied insect feeds on the underside of leaves sucking out plant sap. The cotton aphid varies in color and size (Watt & Hales 1996); spring populations can be darker and may be twice the size of "yellow dwarfs" generally present in the summer (Nevo & Coll 2001). High populations of aphids can reduce the vigor of the plant, making it susceptible to other pests. The honeydew that aphids excrete reduces fruit quality because of the development of a black sooty mold on the substrate. Moreover, this sooty mold reduces photosynthate production and otherwise reduces the quality of the plant causing considerable economic injury. Natural enemies are important in control and regulation of the cotton aphid. Any factor reducing parasitoids, predators or other biological control agent could result in economic damage to the crop (Kaplan & Eubanks 2002). Natural enemies effective against the cotton aphid include lady beetles *Coccinella septempunctata* L. and *Hippodamia convergens* Guérin-Ménéville, the green lacewing *Chrysoperla carnea* Stephens, and wasps *Lysiphlebus testaceipes* (Cress) and *Aphidius colemani* L. (Howard et al. 1985; Van Driesche & Bellows 1996; Kaplan & Eubanks 2002). The pink spotted lady beetle, *Coelomegilla maculata* DeGeer (Coleoptera: Coccinellidae), also is known to feed on the cotton aphid (Rondon et al. 2004); however, the role of the pink spotted lady beetle in the strawberry ecosystem is relatively unknown. This polyphagous predator is abundant in herbaceous crops such as maize *Zea mays* L., alfalfa *Medicago sativa* L., and potato *Solanum tuberosum* L. where the lady beetle feeds on various prey (Gordon 1985; Krafur & Obrycki 2000).

This 2-year study was initiated to monitor the population dynamics of natural late-fall and early-spring infestations of the cotton aphid on strawberries grown in a greenhouse and to evalu-

ate the effectiveness of pink spotted lady beetle third instars to control aphids.

MATERIALS AND METHODS

Strawberry Production

Strawberry plants were produced at the University of Florida (UF), Horticultural Sciences Department, Institute of Food and Agriculture Sciences in Gainesville, FL, following the protocol of Paranjpe et al. (2003). The following exceptions were made; after cutting the runners from mother plants, 'Sweet Charlie' strawberry plugs were grown in the greenhouse using a low mist fertigation system (water plus fertilizer). Four trays of 80 plugs per tray were set on a 1 Peat:1 Perlite mix media. Plugs were exposed to a 2-week chilling period (4.0-6.0°C) in the growth chamber before transplanting at 25.0 ± 2.0 and 10.0 ± 2.0°C day and night temperature, respectively, with a 9-h photoperiod. After the chilling period, plugs were transplanted to 2-liter plastic pots in soilless medium (2 Peat:1 Perlite mix). Forty rows of four pots per row were arranged on top of an 8-m long metal bench. Monitoring started when four fully developed leaves appeared. A weekly rotation of Quadris® 2.08F (azoxystrobin at 275 g active ingredient/ha) and Nova® 40W (myclobutanil at 142 g active ingredient/ha) sprays were made as necessary for preventing powdery mildew, the main disease in strawberry greenhouse production.

Aphid Sampling Methods

The seasonal population dynamics of the cotton aphid was monitored in strawberries grown in a greenhouse at the UF. Aphid populations were monitored twice weekly from January to May during 2002 and 2003. The average temperature in the greenhouse during this experiment was 22 and 16°C, day and night, respectively. The experimental design was a randomized complete block with four replications. Each block consisted of 20 plants from which five plants per replication were randomly selected. Six rows of strawberries separated each block. The total numbers of apterous and alate adults and nymphs were counted *in situ* from the developing bud and from the middle strawberry leaflet (sampling unit) of one plant with the aid of 5× and 14× lenses. The 5× lens was used to locate the aphids, and the 14× to separate life forms. Nymphs and "dwarf" forms were discriminated from the adults based on the short cauda plate present at the tip of the abdomen in the immature stages as compared with a long cauda present in the adult form (Blackman & Eastop 2000). No insecticide was used at any time during the investigation and the reduction of aphid population was caused by natural "overex-

ploitation” of the habitat (number of aphids/leaflet). The elimination of old strawberries leaflets was the only measure used as cultural control. *Aphis forbesi* (Weed), the strawberry root aphid, and other pests were physically removed from leaves and buds to avoid any effect on the study.

Caged Greenhouse Trial

An experiment was conducted to examine the effectiveness of the pink spotted lady beetle third instar as a predator of the cotton aphid. The pink spotted lady beetle was obtained from Entomos LLC (Gainesville, FL 32608), a local insect supplier during the first year of the experiment. The second year, the pink spotted lady beetle came from our own colony. Lady beetles were reared following proprietary Entomos protocol.

In a greenhouse, five clean strawberry plants (one plant per pot) were placed in a 1-m³ nylon covered cage. The five strawberry plants were infested with adult aphids on a marked leaf. Three cages of plants were infested with five aphids per plant (low infestation), three cages were infested with ten aphids per plant (medium infestation), and three cages were infested with 15 aphids per plant (high infestation). To diminish the possibility of the dispersal of the aphids, only three stems per plant were kept. Based on previous observations, three stems per plant allow the sustainability of a strawberry plant. After 1 week, the number of aphids on the labeled compound leaf per plant was counted. After counting was completed, one, three, or five third instars of the pink spotted lady beetle were released into the cages. The number of aphids consumed on the marked leaf was counted weekly for 4 weeks. The experiment was repeated three times on a split block design in time. Parasitized aphids and other pests were physically removed from the strawberry plants.

Data Analysis

The general linear model (GLM) procedure was used to construct analysis of variance (ANOVA) for mean number of nymphs, apterous, and alate adult aphids each year (SAS Institute 2000).

Means of the proportions of prey consumed by the pink spotted lady beetle third instar were compared and separated by the least significant difference (LSD) test ($P = 0.05$).

RESULTS

Population Dynamics of Aphids

In 2002, overall mean numbers of nymphs observed on leaves were greater than number of nymphs observed on emerging buds ($F = 26.34$; $df = 3, 12$; $P > 0.001$) (Table 1). Nymph densities on the bud were greatest on 15 March (16.75 ± 5.46) and then gradually decreased towards the end of the sampling period (Fig. 1A). Two peak populations were observed on leaves on 25 February (15.95 ± 4.33) and on 15 March (14.5 ± 3.81) (Fig. 1A). Overall numbers of apterous adults on the bud were greater than number of adults on the leaves ($F = 18.34$; $df = 3, 12$; $P > 0.001$) (Table 1). Adult density on the bud was greatest on 25 February (24.55 ± 5.32) and on 15 March (39.65 ± 7.23) and then density gradually decreased towards the end of the sampling period (Fig. 1B). Two peaks were observed on leaves on 25 February (19.50 ± 7.23) and on 15 March (17.55 ± 4.41) (Fig. 1B). Overall numbers of alate adults on the bud were greater than numbers of alate adults on leaves ($F = 14.34$; $df = 3, 12$; $P > 0.001$) (Table 1). On the bud, numbers of alate adults were greatest on 11 March (0.2 ± 0.1) (Fig. 1C). Two peaks were observed on 11 March (3.00 ± 1.18) and 8 and 15 April (0.5 ± 0.2 and 0.5 ± 0.1 , respectively) (Fig. 1C). Overall combined numbers of aphids (nymphs, adults and alate adults) on the bud were greater than combined number of aphids on the leaves ($F = 12.34$; $df = 3, 12$; $P > 0.001$) (Table 1). On the bud, combined numbers of aphids were highest on 15 February (24.65 ± 9.87) and on 15 March (56.40 ± 11.35) (Fig. 1D). Two peaks also were observed on leaves on 25 February (35.50 ± 9.85) and 15 March (32.15 ± 8.15) (Fig. 1D).

In 2003, overall mean numbers of nymphs observed on leaves were greater than number of aphids observed on the emerging bud ($F = 23.18$; $df = 3, 12$; $P > 0.068$). Nymph densities on the bud

TABLE 1. OVERALL MEAN NUMBER (\pm SE) OF NYMPHS, APTEROUS, AND ALATE ADULTS, AND COMBINED NUMBER OF COTTON APHIDS INFESTING STRAWBERRIES GROWN UNDER PROTECTED CULTIVATION, GAINESVILLE, FL.

Life form	2002		2003	
	Leaflet	Developing buds	Leaflet	Developing buds
Nymphs	5.09 \pm 1.43	3.94 \pm 1.25	4.30 \pm 1.35	3.07 \pm 1.27
Apterous adult	6.62 \pm 1.56	8.29 \pm 1.54	6.67 \pm 1.13	9.26 \pm 2.35
Alate adult	0.03 \pm 0.01	0.29 \pm 0.11	0.46 \pm 0.23	0.03 \pm 0.01
Combined (nymphs and apterous and alate adults)	11.90 \pm 3.11	12.26 \pm 2.80	11.23 \pm 2.89	12.36 \pm 3.63

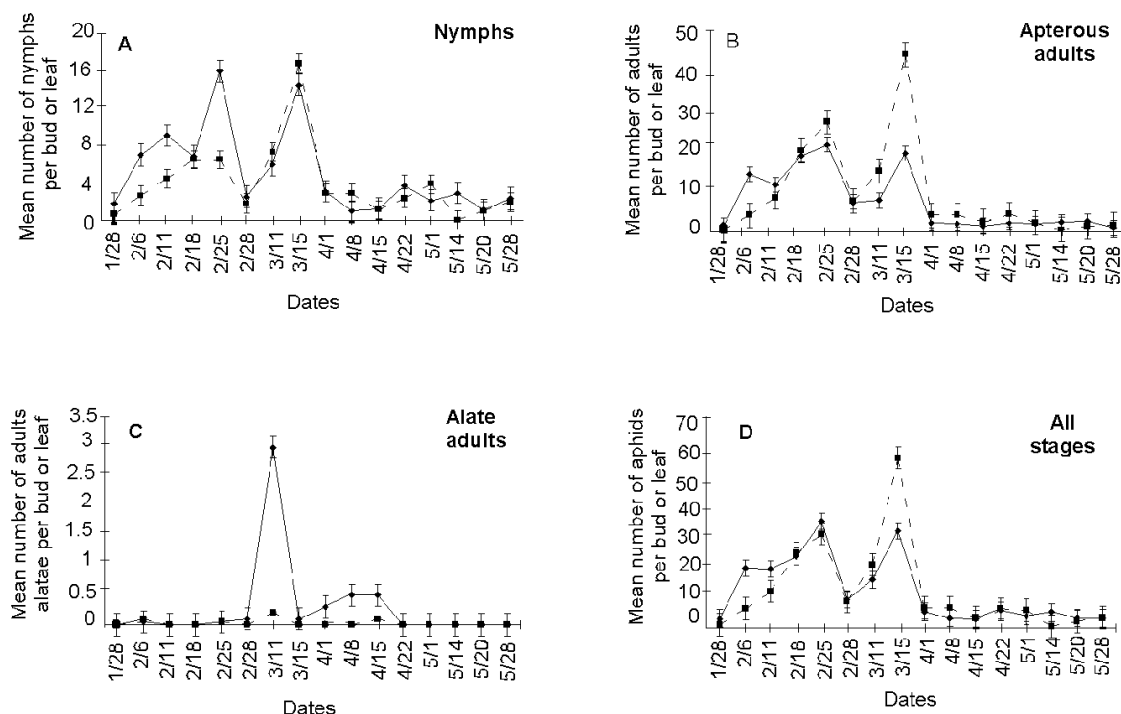


Fig. 1. Population dynamics of nymphs (A), apterous adults (B), alate adults (C), and total (D) of the cotton aphid on strawberries grown in a greenhouse during 2002 in Gainesville, FL. Legend: ---■--- bud —◆— leaf.

were greatest on 16 March (8.45 ± 1.46) and then gradually decreased towards the end of the sampling period (Fig. 2A). Two peaks were observed on leaves on 9 February (7.85 ± 2.31) and on 16 March (10.16 ± 3.2) (Fig. 2A). Overall numbers of apterous adults on the bud were greater than on the leaves ($F = 15.14$; $df = 3, 12$; $P > 0.069$). Adult densities on the bud were greatest on 15 February (24.18 ± 2.65) and on 1 March (24.96 ± 3.26) and then gradually decreased towards the end of the sampling period (Fig. 2B). One peak was observed on leaves 16 March (21.16 ± 3.86) (Fig. 2B). Overall numbers of alate adults on the leaves were greater than on buds ($F = 8.37$; $df = 3, 12$; $P > 0.071$). In the bud, numbers of alate adults were low throughout the experiment while in the leaves, it reached its highest on 9 March (3.68 ± 0.9) (Fig. 2C). Overall combined numbers of aphids on the bud were greater than on the leaves ($F = 9.15$; $df = 3, 12$; $P > 0.079$). On the bud, combined numbers of aphids were greatest on 15 February (33.16 ± 2.89) (Fig. 2D). One peak was observed on leaves on 16 March (37.16 ± 3.46) (Fig. 2D).

Response of the Pink Spotted Lady Beetle Third Instar to Different Aphid Densities

One week after five aphids were released per plant, there was an average of 59.9 ± 12.6 aphids per strawberry leaf. One third instar pink spotted

lady beetle reduced 53.8, 36.2, 27.2, and 20.6% of the aphid population after 1, 2, 3, and 4 weeks, respectively ($F = 13.57$; $df = 2, 5$; $P > 0.001$) (Fig. 3A). Three predators reduced 97, 28.6, 15, and 13.2% of the aphid population 1, 2, 3, and 4 weeks, respectively, after being released ($F = 11.14$; $df = 2, 5$; $P > 0.078$) (Fig. 3A). Five predators reduced 29, 5, 2.2, and 2.2% of the aphid population 1, 2, 3, and 4 weeks, respectively, after being released ($F = 3.47$; $df = 2, 5$; $P > 0.090$) (Fig. 3A).

One week after ten aphids were released per plant, there was an average of 77.7 ± 21.6 aphids per strawberry leaf. One third instar pink spotted lady beetle reduced 70.2, 11, 8 and 6.2% of the aphid population after 1, 2, 3, and 4 weeks, respectively ($F = 21.14$; $df = 2, 5$; $P > 0.001$) (Fig. 3B). Three predators reduced 87.6, 12.6, 11 and 8% of the aphid population 1, 2, 3, and 4 weeks, respectively, after being released ($F = 18.53$; $df = 2, 5$; $P > 0.001$) (Fig. 3B). Five predators reduced 75.2, 22.8, 8.6, and 4.2% of the aphid population 1, 2, 3, and 4 weeks, respectively, after being released ($F = 15.10$; $df = 2, 5$; $P > 0.004$) (Fig. 3B).

One week after 15 aphids were released per plant, there was an average of 167.3 ± 28.4 aphids per strawberry leaf. One third instar pink spotted lady beetle reduced 96.3, 46.2, 46.3 and 39.0% of the aphid population after 1, 2, 3, and 4 weeks, respectively ($F = 9.60$; $df = 2, 5$; $P > 0.001$) (Fig. 3C). Three predators reduced 98.2, 87.3, 35.4, and

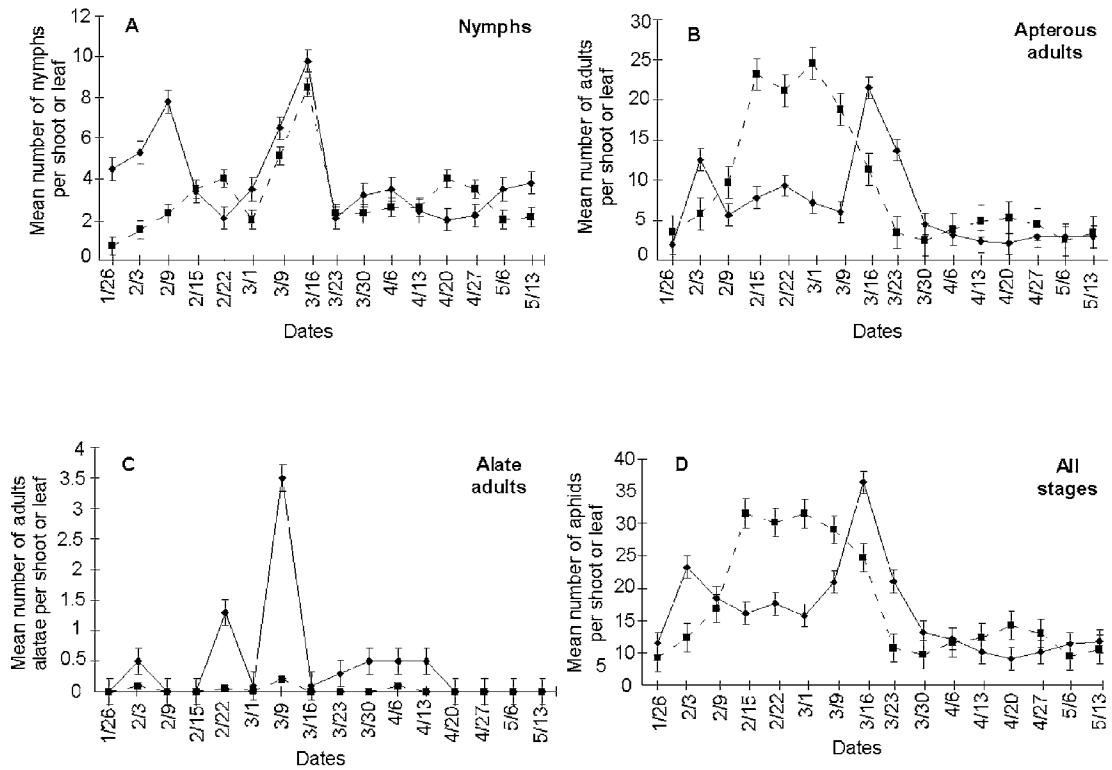


Fig. 2. Population dynamics of nymphs (A), apterous adults (B), alate adults (C), and total (D) of the cotton aphid on strawberries grown in a greenhouse during 2003 in Gainesville, FL. Legend: ---■--- bud —◆— leaf.

23.4% of the aphid population 1, 2, 3, and 4 weeks, respectively after being released ($F = 7.34$; $df = 2, 5$; $P > 0.001$) (Fig. 3C). Five predators reduced 98.2, 96.4, 57.3, and 22.4% of the aphid population 1, 2, 3, and 4 weeks, respectively, after being released ($F = 11.75$; $df = 2, 5$; $P > 0.011$) (Fig. 3C).

DISCUSSION

This study of the population dynamics of the cotton aphid on strawberries grown under protected cultivation established a basis for the development of future cotton aphid management. This study gave us an insight into when to expect possible pest outbreaks and the best time to apply control measures. However, multi-year data will be needed in order to establish a useful extension of this prediction. The seasonal peaks and distribution of different life forms (stages) of the pest within plants were successfully established.

In general, the cotton aphid was more abundant from mid-February to late-March, in a greenhouse located in Gainesville, FL. During those months, temperature in the greenhouse averaged 22 and 16°C, day and night, respectively, which is favorable for aphid development and reproduction (Leclant & Deguine 1994). Several studies already have been conducted regarding

the effect of the temperature on development, survivorship, and reproduction on different aphid species (Campbell et al. 1974; Aalbersberg 1987; Wang & Tsai 2000). Moreover, studies by Campbell et al. (1974) have indicated that peaks on aphid populations were positively correlated with moderate increases in temperatures.

Determining the location of the pest within the plant is important in order to establish the most effective control method. Different cotton aphid life forms predominated at different plant locations. In both years, nymphs were more frequently found on leaves than on the developing buds but apterous adults predominated on the buds. Alate adults were rare throughout the experiment and their presence in either developing buds or leaves was inconsistent in both years. The hypothesis as to why a specific life form prefers a specific site within the plant would be speculative at this point. Although in both years we found similar patterns, sugar content of the plant and specific nutritional requirements of each stage should have been taken.

The greatest positive response of the pink spotted lady beetle to cotton aphid occurred when the prey was most dense. This is a characteristic of an efficient predator and indicated that the pink spotted lady beetle might be a good candi-

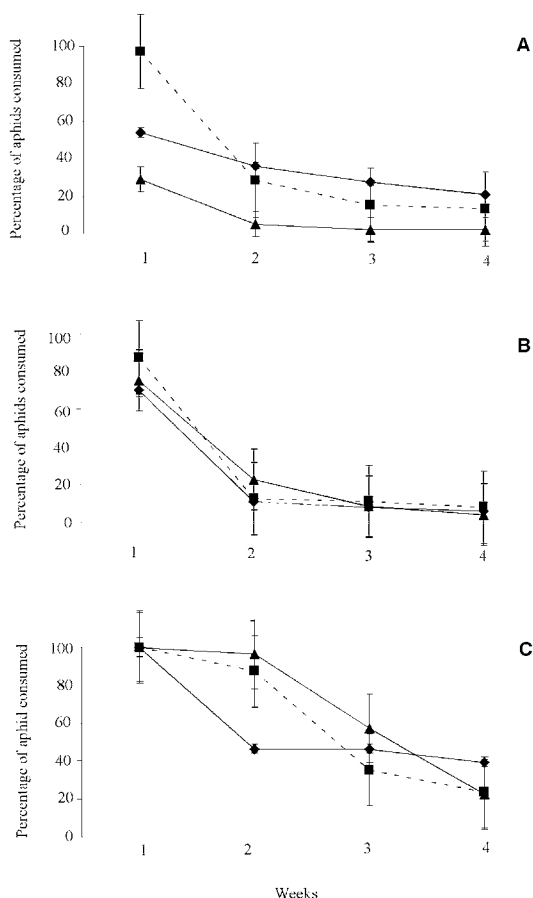


Fig. 3. Third instar pink spotted lady beetle response to low (A), medium (B), and high (C) densities of the cotton aphid. Legend: —◆— 1 predator; ---■--- 3 predators; —▲— 5 predators.

date for biological control of cotton aphid on strawberries. This is not the case for some other lady beetle species, in which their distribution did not always correspond with that of other aphid species (Park & Obyrcki 2004). Studies by Rondon et al. (2004) have determined the benefits of using lady beetles to control cotton aphids and twospotted spider mites. In a series of laboratory studies, they determined that approximately 80% of the prey offered was consumed by the pink spotted lady beetle only after 2 h of being exposed to the prey. The ability of lady beetles to seek aphids was evident during the cage greenhouse trial (personal observation).

These studies have increased the understanding of the relationship among the strawberry, its cotton aphid pest and an important biological control agent. They provide a basis for developing a biological control of cotton aphid component to a comprehensive integrated program of greenhouse strawberry pest management.

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