ASSESSMENT OF COST AND PERFORMANCE OF *ERETMOCERUS EREMICUS* (HYMENOPTERA: APHELINIDAE) FOR WHITEFLY (HOMOPTERA: ALEYRODIDAE) CONTROL IN COMMERCIAL POINSETTIA CROPS

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ABSTRACT

Releases of *Eretmocerus eremicus* Rose and Zolnerowich (Hymenoptera: Aphelinidae) at release rates of 3.0-7.5 females per plant per week successfully suppressed whitefly populations on commercial poinsettia (*Euphorbia pulcherrima* Willd. ex Koltz.) crops in fall of 1996 at four Massachusetts commercial producers. At two sites, the whitefly populations consisted exclusively of greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), and at the other two sites exclusively of silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring. Parasitoids were received from commercial suppliers and monitored weekly to determine the sex ratio of newly emerged adults, as well as the rate of adult emergence. Commercially produced pupae were 48.1% (± 2.2 SE) female and had 58.1% (± 3.6 SE) emergence under greenhouse conditions. Plants from the four biological control greenhouses in this trial at the time of sale of the crop had an average of 0.55 (± 0.28 SE) nymphs per leaf. Chemically-protected poinsettias offered for sale at eight local retail outlets had an average of 0.16 (± 0.09 SE) nymphs per leaf. Final whitefly densities in both biological control and insecticide-treated greenhouses were acceptable to consumers. An average of 6.8 insecticide applications was applied to suppress whiteflies in chemical control greenhouses in this trial, compared to 1.7 in the biological control greenhouses. Use of biological control was 27 fold more expensive, costing $2.14 per plant compared to $0.08 for chemical control. Cost of biological control was inflated by three factors: (1) an incorrectly high estimate by one grower of number of plants per greenhouse, (2) an unusually long production period (23 weeks) for one grower, and (3) miscommunication with the insectary concerning manner of filling orders to compensate for reduced percentage of emergence of adult parasitoids from ordered parasitized nymphs. Control of these cost-inflating factors would allow some reduction in the cost of the use of this parasitoid, but not to levels competitive with current pesticides. This study is the first to demonstrate the ability of *E. eremicus* releases to suppress *T. vaporariorum* populations in commercial poinsettia crops and parasitism of *T. vaporariorum* by *E. eremicus* was 7.5-fold higher (ave. 24.8% parasitism of fourth instar nymphs in pooled seasonal samples) than that observed in *B. argentifolii* (ave. 3.3%).

Key Words: *Eretmocerus eremicus, Bemisia argentifolii*, *Trialeurodes vaporariorum* poinsettia, biological control, augmentative release, evaluation, cost, greenhouses

RESUMEN

Liberaciones de *Eretmocerus eremicus* Rose y Zolerowich (Hymenoptera: Aphelinidae) a razón de 3.0-7.5 hembras por planta por semana lograron un control efectivo de mosquita blanca en cuatro cultivos comerciales de nochebuena (*Euphorbia pulche-*

rrima Willd. ex Koltz.) de Massachusetts durante el otoño de 1996. En dos sitios, las poblaciones de mosquita blanca consistieron exclusivamente de la mosquita blanca de invernadero, *Trialeurodes vaporariorum* (Westwood), mientras que en los otros dos sitios las poblaciones fueron exclusivamente de mosquita blanca de la hoja plateada, *Bemisia argentifolii* Bellows and Perring. Los parasitoides fueron obtenidos de proveedores comerciales y monitoreados semanalmente para determinar la proporción de machos y hembras adultos recién emergidos, así como la tasa de emergencia de adultos. Las pupas producidas comercialmente fueron 48.1% (± 2.2 SE) hembras y tuvieron una tasa de emergencia de 58.1% (± 3.6 SE) bajo condiciones de invernadero. Al momento de su venta, plantas provenientes de los cuatro invernaderos de control biológico usados en este estudio tuvieron un promedio de 0.55 (± 0.28 SE) ninfas por hoja. En comparación, plantas protegidas con insecticidas tuvieron un promedio de 0.16 (± 0.09 SE) ninfas por hoja al momento de su venta en ocho locales comerciales. Las densidades finales de mosquita blanca encontradas tanto en los invernaderos de control biológico como en aquellos donde se emplearon insecticidas fueron aceptables a los consumidores. En promedio, 6.8 aplicaciones de insecticida fueron hechas para controlar a la mosquita blanca en los invernaderos de control químico usados en este estudio, comparado con 1.7 aplicaciones en los invernaderos de control biológico. El costo del control biológico fue 27 veces más caro que el del control químico ($2.14 vs. $0.08 por planta). El costo del control biológico resultó elevado debido a tres factores: (1) el cálculo erróneo (demasiado alto) por parte de un productor con respecto al número de plantas por invernadero, (2) un período demasiado largo de producción (23 semanas) en el caso de un productor, y (3) falta de comunicación con personal del insectario respecto a la manera de compensar el porcentaje reducido de emergencia de adultos parasitoides logrado por las ninfas parasitadas ordenadas. El costo del uso de parasitoides podría reducirse al corregir los errores mencionados, pero no lo suficiente para ser competitivo con el uso de insecticidas. Este estudio es el primero en demostrar la eficacia del parasitoide *E. eremicus* en el control de *T. vaporariorum* en cultivos comerciales de nochebuena. El estudio demostró que el parasitismo de *T. vaporariorum* por *E. eremicus* fué 7.5 veces más alto que el obtenido con *B. argentifolii* (parasitismo de 24.8% vs. 3.3% de ninfas de cuarto instar).

Silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, (= the "B" strain of *Bemisia tabaci* [Gennadius]) and greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), (both Homoptera: Aleyrodidae) are important pests of poinsettia (*Euphorbia pulcherrima* Willd. ex Koltz.) in the United States (Helgesen & Tauber 1974, Byrne et al. 1990, Bellows et al. 1994). The parasitoids most extensively used for whitefly biological control in protected floricultural crops have been *Encarsia formosa* Gahan and *Eretmocerus eremicus* Rose and Zolnerowich (formerly given as *Eretmocerus* sp. nr. *californicus*) (both Hymenoptera: Aphelinidae) (Drost et al. 1996; Hoddle & Van Driesche 1996; Rose & Zolnerowich 1997; Hoddle et al. 1996, 1997ab, 1998abc; Hoddle & Van Driesche in press).

Previous trials in small, experimental greenhouses (holding 90 plants) suggested that a *Bemisia*-adapted strain of *E. formosa* (referred to as the Beltsville strain, Heinz & Parrella 1994) and *E. eremicus* had the potential to provide effective silverleaf whitefly control in poinsettia crops if released at rates of 1-3 females per plant per week (Hoddle et al. 1997ab, 1998a). Trials in commercial greenhouse poinsettia crops in 1995 in Massachusetts compared the efficacy of *E. eremicus* and the Beltsville strain of *E. formosa* at a release rate of 3 females per plant per week for each species. In both summer stock plants and fall Christmas crop plants, *E. eremicus* suppressed silverleaf whitefly better than the Beltsville strain of *E. formosa* (Hoddle and Van Driesche, 1999). Poinsettias from these 1995 trials were sufficiently free of whiteflies to

be acceptable to growers for use of cuttings from the summer crop (Hoddle & Van Driesche, 1999) and sale to retailers in the Christmas poinsettia market in the fall (Hoddle and Van Driesche, in press).

Here we report further results from commercial trials conducted in fall 1996 in Massachusetts in which four commercial poinsettia growers employed *E. eremicus* for control of whiteflies. The purpose of the trial was to assess the robustness of *E. eremicus* releases as a means of suppressing whiteflies in commercial poinsettia crops when applied to a wider variety of commercial conditions and when releases were made by growers. At each of four commercial greenhouse ranges, we measured the level of whitefly suppression achieved by releases *of E. eremicus* compared to whitefly populations treated chemically. At one study site, we made a further comparison to a caged whitefly population not subject to either biological or chemical control. The costs of biological control and chemical control were compared at all four locations.

Materials and Methods

Study Sites and Experimental Design

The study was conducted at four commercial greenhouse growers. Two growers were from the Connecticut River Valley in the western part of Massachusetts (Fairview Farms, Whately; Westover Greenhouses, Chicopee) and two were from eastern Massachusetts (Loosigian Farms, Methuen; Konjoian Greenhouses, Andover). The trial was conducted on the Christmas poinsettia crop between 3 July and 13 December 1996, with cropping periods varying from 17 to 23 weeks among sites. At each of the four locations, weekly observations were made in two greenhouses, one managed with biological control and one with insecticides. In the biological control greenhouses, our intent was to make weekly releases of 3 female *E. eremicus* per plant. In the chemical control greenhouses, the growers managed pests with pesticides. At 3 sites (Loosigian, Konjoian, and Westover), growers ordered parasitoids directly from commercial insectaries and made releases themselves. At one site (Fairview), we ordered and received parasitoids instead of the grower so we could assess the quality of weekly shipments in terms of number of parasitoid pupae shipped (compared to number ordered) and sex ratio of emerging adult parasitoids. At this site, we made releases and retrieved parasitoid exuviae weekly from release cups in greenhouses to determine the percentage emergence under greenhouse conditions. Greenhouse dimensions, names of poinsettia cultivars grown, numbers of plants and potting arrangements per greenhouse are given in Table 1. ("Plants" refers to independently rooted poinsettias; pots may contain one or several plants.)

To formally demonstrate, at least at one site, that whitefly populations on poinsettia increase sharply if left uncontrolled, a control cage was installed in the biological control greenhouse at Fairview Farms that received neither *E. eremicus* nor conventional insecticides for whitefly management. The control cage (153 cm long by 92 cm wide and 117 cm tall) was constructed of PVC pipe and covered with fine polyester screening (95 micron dia openings) capable of excluding entrance of whiteflies and parasitoids. The control cage contained 5 pots (20.3 cm), each with 3 poinsettia plants (total, 15 plants per cage). To initialize the caged whitefly population, we inspected all leaves on 100 plants from the greenhouse and chose plants that bore the number of whitefly nymphs and pupae needed to match the density of the whitefly population in the whole greenhouse as determined by a count of whiteflies on the potted cuttings at the start of the trial (see *Initial whitefly density*). Because initial whitefly densities at this site were very low, we augmented the silverleaf whitefly population in the biolog-

TABLE 1. GREENHOUSE TYPE, SIZE, PLANT NUMBER, POT NUMBER, AND POINSETTIA CULTIVARS IN TRIAL.

Site and treatment	Type	Dimensions	# Plants in greenhouse[1]	# Pots in greenhouse	Cultivars and potting dates[2]
Fairview biological control	plastic hoop	5m × 30m	1500 8/15/96 1021 12/6/96 902 12/12/96	500 (21.6 cm); three plants each	Freedom, 7 August
Fairview chemical	plastic hoop	5m × 30m	2448 for entire trial	612 (25.4 cm); four plants each	Freedom, 7 August
Konjoian biological control	glass	10m × 42m	2550 8/20/96 3193 9/17/96 2818 11/25/96 1633 12/3/96 345 2/10/96	625 (20.3 cm); three plants each; 1120 (15.2 cm); one plant each; 22 nine-plant hangers	Peter star, Freedom, V-14, Supjibi, 20 August
Konjoian chemical	glass	10m × 42m	3500 for entire trial	800 (10.2 cm); 500 (14 cm); 2200 (15.2 cm); all one plant each	Peter star, Freedom, V-14, Supjibi, 20 August
Loosigian biological control	plastic hoop	7m × 48m	1243 for entire trial	1243 (16.5 cm); one plant each	Red Sails, 13 August
Loosigian chemical	plastic hoop	7m × 48m	1200 for entire trial	1200 (16.5 cm); one plant each	Red Sails, 13 August
Westover biological control	glass	6m × 32m	2014 7/3/96 1331 12/4/96	160 (20.3 cm); three plants each; 256 ((30.5 cm); four plants each; 102 (38.1 cm); five plants each	Supjibi, Maren, Monet, V-17, V-14, Cortez Freedom, Peter Star, 3 July
Westover chemical	glass	15m × 61m	7800 for entire trial	2100 (17.8 cm); two plants each; 1200 (20.3 cm); three plants each	Supjibi, Maren, Monet, V-17, V-14, Cortez, Freedom, Peter Star, 3 July

[1]Earliest date gives initial number of plants. Pots were spaced initially at final densities. Subsequent dates reflect changes in number as crop was harvested.

[2]Sources of cuttings varied by variety and grower: Westover Greenhouse propagated V-14 and V-17 varieties from stock plants and purchased others as rooted cuttings; Fairview Farms purchased all plants as rooted cuttings; Loosigian Farms purchased unrooted cuttings; Konjoian Greenhouses propagated all varieties from stock plants.

ical control greenhouse using silverleaf whitefly-infested plants produced by using adult whiteflies from our laboratory colony of this species (see *Whitefly augmentation*). The numbers of whiteflies in the control cage were also augmented at the same rate so that they had the same starting density as the biological control greenhouse.

While control cages were not installed at the other three trial sites, we have shown in previous trials that silverleaf whitefly on poinsettia typically increases to high densities if not controlled (Hoddle & Van Driesche 1996; Hoddle et al. 1997ab, 1998a). No cage controls were included at sites that proved to be infested with greenhouse, rather than silverleaf, whitefly. Consequently control data showing unrestricted growth for that species in the absence of chemical or biological control were not collected in this trial. However, such growth has been observed in other trials (Helgesen & Tauber 1974, Rumei 1982).

During the trial we collected data on (1) the weekly numbers released, percentage emergence and sex ratio of *E. eremicus*, (2) the weekly whitefly densities in each greenhouse, (3) the species of whitefly present at each grower, (4) insecticide usage during crop production by each grower, and (5) the quality of plants at harvest (in terms of whitefly infestation).

Crop Management

Source of cuttings, potting dates, spacing, plant removals. Three of four greenhouses potted cuttings between 7 and 20 August. One location (Westover Greenhouses) potted on 3 July in order to produce large ("tree") poinsettias. Table 1 provides details on greenhouse type, size, numbers of plants, pot sizes, and cultivars.

Pesticide use. At three sites, the biological control greenhouse was treated only with fungicides and plant growth regulators. At one site, Konjoian Greenhouses, insecticides were sprayed on 23-30% of the plants in the biological control greenhouse. The infestation on these plants occurred because whitefly-infested plants from another greenhouse on the property were placed directly beneath the intake vent of the biological control greenhouse early in the cropping cycle, leading to a heavy, localized infestation on benches near the air intake fans. Plants sprayed with insecticides were excluded from sampling for the remainder of the trial.

Chemical and biological control greenhouses at all sites were treated with plant growth regulators and fungicides. Names and application dates of insecticides used to control foliar insects in chemical control greenhouses (and a portion of one biological control greenhouse) are presented in Table 2.

Parasitoid releases. Biological control greenhouses at all four sites received weekly releases of *E. eremicus* for whitefly control. The intended weekly release rate was 3 female parasitoids per plant. When plants were removed from biological control greenhouses for sale, numbers of parasitoids released per greenhouse were reduced accordingly. To avoid conflicts with parasitoids, yellow sticky cards (which are highly attractive to *E. eremicus*, Sanderson, unpub. data), used by growers to monitor whiteflies and fungus gnats, were not placed in any of the biological control greenhouses.

Whitefly Species Composition, Initial Density Estimate, and Augmentation

Whitefly species. Both *B. argentifolii* and *T. vaporariorum* infest poinsettia in Massachusetts. To determine the whitefly species present in each test greenhouse, ten heavily infested leaves were collected at each location in middle of the trial (mid-October). In the laboratory, all fourth instar nymphs, pupae and pupal cases were examined under a dissecting microscope and identified to species. Voucher specimens of

TABLE 2. APPLICATIONS OF INSECTICIDES MADE IN TRIAL FOR WHITEFLY CONTROL.

Grower	Greenhouse type	No. insecticide applications	Insecticides applied and application dates	Whitefly species present in greenhouse	Common chemical name
Fairview	biocontrol	0	None	*B. argentifolii*	
Fairview	chemical	1	Marathon 1%G (1% a.i.) (12 Sept.)	*B. argentifolii*	imidacloprid
Konjoian	biocontrol	7	Thiodan 50WP (50% a.i.) (on 12 benches) (19 Sept., 23 & 29 Oct.)[1]	*T. vaporariorum*	endosulfan
			Marathon 1%G (1% a.i.) (19 Sept., 6 Oct.)[2]		imidacloprid
			Orthene PT 1300 DS (3% a.i.) (on 12 benches) (23 & 29 Oct.)[1]		acephate
			Fulex Dithio (14% a.i.) (17 & 23 Nov.)		sulfotep
Konjoian	chemical	8	Thiodan 50WP (50% a.i.) (21 Aug. & 12 Sept., 29 Oct., 10 Nov.)	*T. vaporariorum*	endosulfan
			Avid 0.15EC (1.9% a.i.) (21 Aug., 10 Nov.)		abamectin
			PT 1300 (3% a.i.) (12 Sept., 29 Oct.)		acephate
			Vydate L (20% a.i.) (24 Sept., 1 Oct.)		oxymyl
			Fulex Dithio (14% a.i.) (16 & 23 Nov.)		sulfotep
Loosigian	biocontrol	0	None	*T. vaporariorum*	

[1]Thiodan and Orthene were applied to 30% of the plants in the biological control greenhouse.
[2]Marathon was applied to 23% of the plants in the biological control greenhouse.

TABLE 2. (CONTINUED) APPLICATIONS OF INSECTICIDES MADE IN TRIAL FOR WHITEFLY CONTROL.

Grower	Greenhouse type	No. insecticide applications	Insecticides applied and application dates	Whitefly species present in greenhouse	Common chemical name
Loosigian	chemical	8	Marathon 1%G (1% a.i.) (12 Sept.)	*T. vaporariorum*	imidacloprid
			Fulex Dithio (14% a.i.) (25 Sept., 17 & 21 Oct., 11 Nov.)		sulfotep
			Fulex Nicotine (14% a.i.) (20 Nov.)		nicotine
			Fulex Thiodan (14% a.i.) (2 & 13 Dec.)		endosulfan
Westover	biocontrol	0	None	*B. argentifolii*	
Westover	chemical	10	Azatin EC (3% a.i.) (9 & 16 Aug.)	*B. argentifolii*	azadirachtin
			Tame 2.4EC (33.6% a.i.) (9 & 16 Aug.)		fenpropathrin
			Attain PT 1800 TR (0.5% a.i.) (11 Sept., 3 Oct.)		bifenthrin
			Preclude TR (4.8% a.i.) (17 & 26 Sept.)		fenoxycarb
			Marathon 1%G (1% a.i.) (4 Oct.)		imidacloprid
			Talstar (7.9% a.i.) (28 Oct., 1, 8 & 14 Nov.)		bifenthrin
			Enstar II (65.1% a.i.) (28 Oct., 1, 8 & 14 Nov)		s-kinoprene

[1]Thiodan and Orthene were applied to 30% of the plants in the biological control greenhouse.
[2]Marathon was applied to 23% of the plants in the biological control greenhouse.

whiteflies were not retained as no opportunity exists for taxonomic confusion in our case. *Trialeurodes vaporariorum* is distinct in the context of greenhouse crops from all other whiteflies, and all *Bemisia* whiteflies in poinsettia greenhouse crops in North America are strain B of *B. tabaci* (= *B. argentifolii*), as the A strain was known only from outdoor crops and even there has disappeared over the last decade in North America, being replaced completely by the B strain.

Initial whitefly density. In order to determine if initial whitefly population densities in greenhouses designated as biological control greenhouses were within an acceptable range for management using parasitoids (considered by us to be 1.0 or fewer live nymphs, pupae and adults combined per cutting, for *B. argentifolii*, based on levels seen in our earlier trials, Hoddle et al. 1996, Hoddle and Van Driesche in press), population densities were estimated on cuttings at the time of potting. At each location, all nymphs, pupae, and adults on all leaves of 50 potted cuttings in the biological control greenhouse were counted within 1-2 days of the potting date (see Table 1), and numbers of leaves per cutting were recorded.

Whitefly augmentation. Because no whiteflies were seen on cuttings (n = 100) examined from the biological control greenhouse at one site (Fairview Farms), the whitefly population there had to be augmented by introducing whitefly-infested plants from our laboratory. Our intention was to add a number of immature whiteflies sufficient to bring the per plant density at this site up to the average value of the three other sites. To infest plants, we chose six uninfested poinsettia plants and used ventilated, clip-on leaf cages (2.5 cm dia) to enclose 4-5 pairs of whitefly adults over leaves for 2 days to produce eggs. We then counted the eggs produced and removed excess numbers. Infested plants each had three infested leaves; each infested leaf (after egg removal) bore an average of 105 *B. argentifolii* eggs (± 8.6 SE, n = 10 leaves counted). Infested plants were placed in the biological control greenhouse at Fairview Farms on 19 August. Initially, all infested leaf patches remained protected from attack by parasitoids within clip cages. One clip cage on each plant was removed on each of 19, 23, and 29 August, allowing for a gradual introduction of the whiteflies into the crop. A total of 1890 eggs (6 plants × 3 patches × 105 eggs per patch) were added to this greenhouse, which contained 1500 plants. We assumed 79% survival to the settled crawler stage (based on cohort survival data in Hoddle et al. 1998a), giving a projected augmented nymphal density of 1.0 nymph per plant, meeting our objective of a density comparable to the average density of the other three biological control greenhouses in the trial (1.05 nymphs per plant).

Parasitoid Sources, Application Methods, and Release Rates

The *E. eremicus* we used were purchased from commercial suppliers and shipped as parasitized *T. vaporariorum* fourth instar nymphs packed in sawdust, except for the material used at Fairview Farms. Sawdust was omitted from shipments send to our laboratory for use at this site in order to allow us to retrieve parasitized whiteflies for estimation of parasitoid number per unit weight, sex ratio, and percentage emergence. Over the course of the trial, parasitoids were obtained from two suppliers. From the start of the trial until 4 October, parasitoids were supplied by Beneficial Insectary, Inc. (14751 Oak Run Rd., Oak Run, CA 96069). This colony was discontinued mid-way through the trial, but the same population of *E. eremicus* was available from Koppert Biological Systems, Inc. in the Netherlands, and parasitoids from this source were used to complete the trial. Koppert's production of this species was initiated with the same material that had been used by Beneficial Insectaries (O. Minkenberg, pers. comm.), so the genetic composition of the parasitoids used in the trial was consistent throughout. Specimens from material sold by Koppert, Inc. as *E. californicus* (previ-

ous name for *E. eremicus*) were submitted for taxonomic confirmation to Michael Rose (specialist on the genera *Eretmocerus* and *Encarsia*, formerly of Texas A & M University) and were confirmed to be *E. eremicus*. Voucher specimens have been deposited in the insect collection of the University of California, Riverside campus**.**

Parasitoid pupae were shipped directly to three of the four participating growers because it was intended that processes used in the trial be as close to commercial as possible. Therefore, at three locations growers received parasitoid shipments and placed shipped material in release containers in greenhouses. These growers received parasitized fourth instar *T. vaporariorum* nymphs mixed with sawdust. This mixture was placed in styrofoam release cups (6 cm tall, 5.5 cm wide at bottom, 8.5 cm wide at top) that had the bottoms cut out and replaced with organdy (mesh 0.95 microns) to allow for drainage. Cups were attached 10 cm above the canopy to wooden stakes (50 cm long) placed in the potting media. In each biological control greenhouse, there were 15 release cups distributed evenly throughout the crop. Each week, growers emptied sawdust and any unemerged parasitoids from the previous week's release into pots of plants on benches where cups were located and then added the new material to the same cups. Watering was done so as to avoid wetting parasitoid pupae in release cups (either drip irrigation was used or workers were advised not to wet sawdust in release cups when hand watering).

To estimate numbers of parasitoids released, parasitoids for use at Fairview Farms were sent to our laboratory for subsampling before release. To estimate the number of parasitoids released, we measured the number of pupae per unit weight of material sent by the supplier, the weight of the shipment, the sex ratio of emerging adults, and the percentage of pupae from which parasitoids successfully emerged under greenhouse conditions.

Estimating number of E. eremicus pupae received from suppliers. Each week before taking parasitoid pupae to Fairview Farms to be released, we counted the number of live parasitoid pupae in each of ten 20 mg subsamples under a stereomicroscope at 25×. The average number of pupae per 20 mg was multiplied by 50 (to get the number per gram) and then by the weight (in g) of all pupae received to determine the total number of pupae actually shipped by the supplier in particular orders. The percentage deviation between this value and the number ordered was noted.

Estimating E. eremicus sex ratio. Each week, 200-300 parasitoid pupae from the shipment sent to our laboratory were placed in a petri dish in a growth chamber at 22°C and long day light regime (16:8 L:D) and held for emergence. One week after receipt, samples were frozen, and 15 groups of 10 adult parasitoids were examined at 50× with a stereomicroscope and their sex determined. Sexes were recognized based on the clubbed antennae of the female (Rose & Zolnerowich 1997).

Estimating E. eremicus emergence rate. Each week before adding new parasitoid pupae to release cups in the biological control greenhouse at Fairview Farm, whitefly nymphs with parasitoid exit holes and remaining dead nymphs in cups from the previous week were retrieved and returned to the laboratory, frozen, and used to estimate the parasitoid emergence rate. From the material returned to the laboratory from each week of the trial, 15 samples of 10 parasitoid "pupae" (comprised of whitefly nymphs containing dead parasitoid pupae and whitefly nymphal integuments with parasitoid emergence holes) were examined at 25× under a stereomicroscope, and classified as dead or emerged based on the presence of parasitoid emergence holes. The percent emergence was calculated as the number of whitefly nymphs with parasitoid emergence holes divided by the total number examined (nymphs containing dead parasitoid pupae plus whitefly nymphal integuments bearing parasitoid emergence holes).

Calculating release rates of E. eremicus. For one site (Fairview Farms) we used the above information on number of parasitoid pupae per unit weight, together with sex ratio and percent emergence, to adjust the number of parasitoid pupae actually released to achieve the intended release rate. At the other three sites, growers received shipments directly and made their own releases, and quality control checks were not made. At these sites, we estimated the number of parasitoid pupae that would be needed to achieve our intended release rate (3 females per plant per wk) by assuming a 50% female sex ratio and a 60% emergence rate. The sex ratio value was based on advice from the supplier and the emergence rate was based on quality control checks we made in greenhouse trials in 1995. Based on these assumptions, 10 parasitoid pupae per plant per week were ordered for each participating grower, with exact numbers being calculated from numbers of plants in each biological control greenhouse. Subsequent to the trial, we calculated the actual release rate achieved by reference to quality control data collected from samples taken for the Fairview Farms site.

Whitefly Population Sampling

Densities of whitefly life stages (adult whiteflies, live and dead nymphs and pupae) were estimated weekly throughout the cropping season by examining leaves on arbitrarily selected plants. At Westover Greenhouses, Konjoian Greenhouses, and Loosigian Farms, two arbitrarily selected mature leaves from each of the upper and lower halves of the plant from each of 30 arbitrarily selected plants (120 leaves total) in each greenhouse were inspected for whiteflies on each sample date.

Numbers of leaves examined in the biological control greenhouse at Fairview Farms differed from that of the other three sites because this greenhouse was also part of a separate, concurrent experiment with a more intense level of sampling. At Fairview Farms in the biological control greenhouse, three leaves (1 from the bottom third of the plant, 1 middle, and 1 top) on 90 plants (270 leaves total) were inspected. In the control cage in the biological control greenhouse at Fairview Farms, three leaves on each of eight plants were inspected in a similar manner, weekly. At Fairview Farms, the chemical control greenhouse was sampled for a shorter period than the biological control greenhouse. Three arbitrarily chosen leaves from each of 20 plants (60 leaves total) were inspected weekly, from 29 August to 13 November only. For figures in which whitefly densities are plotted on log scales, 0.001 was added to all counts to avoid zero values.

Measurement of Parasitoid-Caused Mortality

Whitefly nymphs killed by parasitoids through host feeding were included in counts of dead nymphs or pupae made to estimate densities (see above). Deaths from host feeding could not be distinguished from physiological death. Successful parasitism was scored by noting numbers of visibly parasitized fourth instar whitefly nymphs seen weekly on leaves on which whitefly stages were counted. Because parasitism was rare, weekly samples were not analyzed separately by date because of low sample sizes. Instead, season-long rates of parasitism were computed for each of the four biological control greenhouses by summing the number of visibly parasitized fourth instar whitefly nymphs across all sample dates. Parasitism was computed as the total number (A) of parasitized fourth instar whitefly nymphs summed across all dates within one location, divided by this same value (A) plus the summed value in the same samples of all whitefly pupae (B), (% parasitism = 100[A/ A +B]). Younger whitefly stages (various nymphs) were not included in the estimation of parasitism,

as these stages were too young for any parasitism they might have had to have become visible in samples. Parasitism rates were compared statistically between the combined samples of the two biological control greenhouses with *T. vaporariorum* and those of the two with *B. argentifolii.*

Whitefly Densities on Plants at Harvest

To compare the quality of plants in the trial to that of plants offered for sale in Massachusetts, we determined the densities of live nymphs, pupae, and adults on plants from the biological control and chemical control greenhouses and on poinsettia plants at 8 retail outlets in Massachusetts in December 1996. Numbers of whiteflies on plants at retail outlets were measured using a standardized market survey sampling protocol used previously in Massachusetts, in which six leaves (2 bottom, 2 middle and 2 top) on 15 arbitrarily selected plants were examined for live whitefly nymphs, pupae, or adults (Hoddle et al. 1997ab, 1998a).

Cost Analysis

To compare the costs of biological and chemical control, we computed the costs of parasitoids versus pesticides used for whitefly control in the biological control and chemical control greenhouses at each trial site. To compute the cost of chemical pest control, grower spray records were examined and all applications of materials to suppress whiteflies were noted. Using 1995 catalog prices for insecticides and label application rates and methods, we computed amounts and cost of insecticide applied in each application. Seasonal expenditures for pesticides were then summed and divided by the number of plants in each greenhouse to obtain a seasonal insecticide cost per plant. To compute the cost of parasitoids we used the 1996 commercial price of $11 per thousand pupae and an application rate of 10 pupae per plant (equal to 3 females per plant, based on an assumed 50/50 sex ratio and 60% emergence rate). Costs of labor for application were not considered for either chemicals or parasitoids (after Hoddle & Van Driesche 1996).

Statistical Analyses

Average seasonal values of parasitoid emergence rate, sex ratio, and release rate at Fairview Farms were compared to assumed or intended values with Student's t test. Densities of whitefly nymphs were compared between chemical and biological control greenhouses (and in one location, to whitefly nymphal densities in a control cage) using nested ANOVAs. A Chi Square test was used to compare rates of parasitism of greenhouse whitefly and silverleaf whitefly nymphs. This comparison was performed on data after pooling across all sample dates for the pair of locations with each whitefly species. A nested ANOVA was used to compare whitefly nymphal densities on leaves from the biological control and chemical control greenhouses to whitefly densities on leaves of plants offered for sale at retail outlets.

RESULTS

Crop Management and Pesticide Use

In the chemical control greenhouses, from 1 to 10 insecticide applications were made per greenhouse for whitefly control (avg. 6.8 ± 1.8 SE, Table 2), with an ave. of

8 applications against *T. vaporariorum* at two sites and 5.5 applications against *B. argentifolii* at the remaining two locations. In biological control greenhouses, three growers used no insecticides and one made 7 applications to a portion (about 30%) of the greenhouse (Table 2) to suppress whiteflies drawn in through the air intake vents.

Whitefly Species Composition, Initial Density, and Augmentation

Whitefly species. Of 216 nymphs and 404 pupal exuviae collected 17 October at Loosigian Farms and of 798 nymphs and 242 pupal exuviae collected on the same date at Konjoian Greenhouse, all were *T. vaporariorum*. In contrast, at Fairview Farms and Westover Greenhouse, all fourth instar nymphs and pupae seen in samples during the trial were *B. argentifolii*.

Initial whitefly density on potted cuttings. Mean numbers of live nymphs plus pupae per leaf (± SE) found in the initial count on poinsettia cuttings in the biological control greenhouses varied from 0.0 to 1.6 (Fairview Farms [0.0 initially, 1.0 after augmentation], Konjoian Greenhouses [1.6 ± 0.7], Loosigian Farms [1.4 ± 0.4], and Westover Greenhouse [0.14 ± 0.14]). Chemical control greenhouses at each site were filled with cuttings from the same sources as the biological control greenhouses.

Silverleaf whitefly levels at two sites (Fairview Farms and Westover Greenhouses) were considered suitable for use of biological control, based on previous trials in commercial greenhouses in Massachusetts (Hoddle & Van Driesche, in press). Potential for biological control of the greenhouse whitefly populations at Loosigian Farms and Konjoian Greenhouses could not be evaluated because no previous trials on biological control of this species on poinsettia had been run in Massachusetts.

Parasitoid Sex Ratio, Emergence, and Release Rates Achieved

Parasitoid sex ratio. The percentage of parasitoid pupae producing female parasitoids varied from 39 to 58% for 1500 insects examined from September to November (Fig. 1). The seasonal average, 48.1% (± 2.2 SE), did not differ statistically in a Student's t test from the assumed value (50%) used in calculating numbers of pupae for releases (t = -0.85, df = 9, $P > 0.05$)

Parasitoid emergence rate in greenhouse. The emergence rate in week one of the trial at the monitored site (Fairview Farms) was very low (16%) for unknown reasons. (Maximum daytime greenhouse temperatures were very high [36-43°C], but so were temperatures in several succeeding weeks in which emergence rates were higher.) In weeks 2-17, emergence rates varied from 37 to 75% (Fig. 2). The average emergence for weeks 2-17 was 60.7% (± 2.6 SE). This value did not differ statistically in a Student's t test from the assumed value (60%) used in calculating the release rate (t = 0.27, df = 15, $P > 0.05$).

Number of parasitoid pupae shipped by supplier versus number ordered. Important discrepancies occurred between numbers of parasitoids ordered and numbers received. At Fairview Farms, we calculated the number of parasitized nymphs to be placed in the greenhouse weekly ourselves and corrected for this discrepancy. At the other three locations, the supplier sent higher numbers of parasitized nymphs than ordered. Counts in our laboratory of numbers of parasitized nymphs averaged 264.6 (± 17.3 SE) per 20 mg (range 144-388). For ten shipments, numbers of pupae received from Koppert Biological Inc. were 201% of the number ordered (i.e., double), ranging from 127 to 365% of the desired number. The main identifiable reason for this excess was compensation by the supplier for non-emergence of, in their view, 30% of the shipped parasitoids. Subsequent to this trial we learned that Koppert views emergence of its product to average 70% and as a matter of policy, fills orders at 142% of the number requested to compensate.

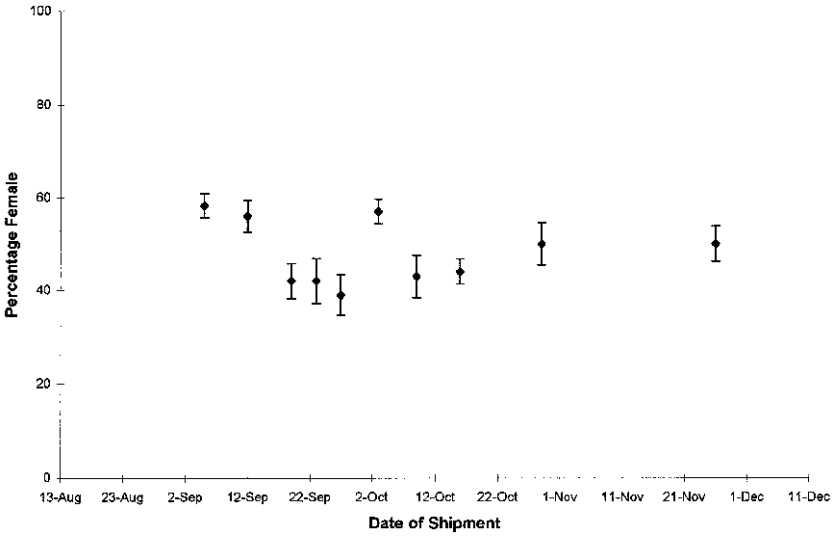

Fig. 1. Mean (± SE) percentage female of adult *Eretmocerus eremicus* emerging in the laboratory from material received weekly from insectaries supplying parasitoids for release in trial.

Actual parasitoid release rates. Release rates achieved at study sites varied because actual numbers shipped differed from numbers ordered (see above) and because, for particular dates, actual sex ratios or percent emergence differed from assumed values. At Fairview Farms, the average number of adult female parasitoids actually emerging into the crop per plant per week from parasitized nymphs was 2.92 (± 0.2 SE, range 0.60-4.15) (Table 3, Fig. 3). This rate did not differ statistically in a Student's t test from the intended release rate of 3.0 females per plant per week (t = -0.51, df = 1, $P > 0.05$).

Release rates at other greenhouses in the trial were estimated by using data on sex ratio and percentage emergence derived from the parasitoids shipped to us for use at Fairview Farms, and our estimate of the degree to which the supplier shipped more parasitized nymphs than ordered (which were calculated based on the ratio of number received to the number ordered for Fairview Farms). The supplier's over supply of parasitized nymphs to compensate for less than 100% emergence directly affected the release rate. Consequently, actual release rates (female parasitoid adults per plant per week) were 6.67 (± 0.87 SE) at Konjoian's Greenhouse, 4.47 (± 0.48 SE) at Loosigian Farms, and 4.72 (± 0.67 SE) at Westover Greenhouses.

Whitefly Population Monitoring

Fairview Farms. At Fairview Farms, only *B. argentifolii* was present. Whitefly density in the control cage increased steadily over the course of the trial, reaching 19.0 (± 4.6 SE) live nymphs per leaf by wk 18 (11 Dec.) (Fig. 4). Peak whitefly nymphal density in the control cage was 90 fold greater than that on uncaged plants in the biological control greenhouse, which did not exceed 0.2 (± 0.1 SE) nymphs per leaf (Fig. 5a).

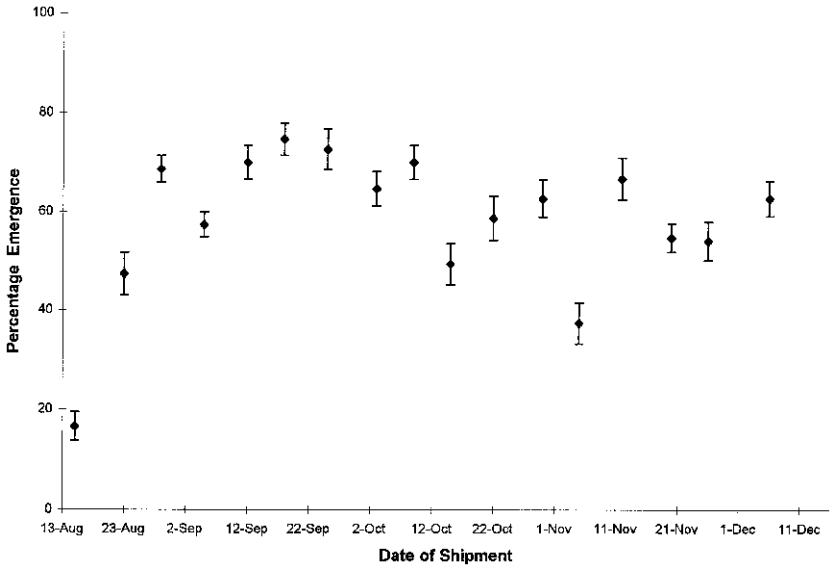

Fig. 2. Mean percentage (± SE) emergence of *Eretmocerus eremicus* after one week in the biological control greenhouse at Fairview Farms in Whately, MA.

Density of whitefly nymphs on uncaged plants in the biological control greenhouse was similar to that observed in the chemical control greenhouse, in which plants were treated with imidacloprid. Numbers of live pupae and adults were consistently below 0.04 per leaf (Fig 5 b, c).

Westover Greenhouses. At Westover Greenhouses, the grower produced a long season crop of extra large poinsettia plants that included poinsettia "trees" started 3 July (6 weeks earlier than the normal mid-August starting date for smaller poinsettias). The crop was infested exclusively with *B. argentifolii* and management problems in the chemical control greenhouse occurred, leading to a whitefly outbreak that reached 86.3 (± 20.8 SE) live nymphs per leaf on 3 October. Repeated applications of pesticides (Table 2) reduced this population to 0.47 (± 0.15 SE) nymphs per leaf by time of harvest (Fig. 6a).

In the biological control greenhouse, parasitoid releases consistently maintained whitefly densities below 1 live nymph per leaf until 21 November, with numbers then increasing to 1.31 (± 0.26 SE) by the time of harvest (Fig. 6a). Densities of live whitefly nymphs in the biological control greenhouse were consistently lower than those in the chemical control greenhouse between 31 July and 13 November. Numbers of live pupae and adults per leaf in the biological control greenhouse were consistently lower than those observed in the chemical control greenhouse until 30 October (Figs. 6 b, c).

Konjoian Greenhouses. At Konjoian Greenhouses, poinsettias were infested only with *T. vaporariorum*. Numbers of live nymphs per leaf in the portion of the biological control greenhouse not treated with insecticides exceeded 2 live nymphs per leaf on one sample occasion (2.8 nymphs on 1 October), but were at acceptable densities (1.03 ± 0.34 SE) at the time of sale (Fig. 7a).

TABLE 3. QUALITY CONTROL INFORMATION USED IN ESTIMATING ACTUAL RELEASE RATE *OF ERETMOCERUS EREMICUS* AT FAIRVIEW FARMS BIOLOGICAL CONTROL GREENHOUSE.

Release date	% female ($\bar{X}$ ± SE)	% emergence ($\bar{X}$ ± SE)	No. parasitized nymphs/20 mg[2] ($\bar{X}$ ± SE)	No. parasitized nymphs ordered	No. parasitized nymphs received[3]	Ratio oversupplied	No. plants in greenhouse	Estimated release rate (females per plant per week) ($\bar{X}$ ± SE)
16 Aug.	48 ± 1[1]	17 ± 3	144	14,895	11,232	0.75	1485	0
23 Aug.	48 ± 1[1]	47 ± 4	225	14,895	21,262	1.43	1485	0.80 ± 0.14
30 Aug.	48 ± 1[1]	69 ± 3	185	14,895	15,078	1.01	1485	2.28 ± 0.22
6 Sept.	58 ± 3	57 ± 3	219	14,895	16,717	1.12	1485	3.95 ± 0.22
12 Sept.	56 ± 3	70 ± 3	200	14,895	15,100	1.01	1485	3.22 ± 0.24
19 Sept.	42 ± 4	75 ± 3	293	14,895	27,982	1.88	1485	2.89 ± 0.30
26 Sept.	57 ± 3	73 ± 4	176	14,895	17,688	1.19	1485	2.92 ± 0.34
4 Oct.	43 ± 5	65 ± 4	351 ± 16	14,895	55,650	3.73	1485	4.17 ± 0.31
10 Oct.	44 ± 3	70 ± 3	354 ± 18	14,895	28,276	1.90	1485	2.79 ± 0.33
17 Oct.	42 ± 5	49 ± 4	275 ± 13	14,895	32,175	2.16	1485	3.09 ± 0.24
24 Oct.	50 ± 5	59 ± 5	373 ± 8	14,895	31,752	2.13	1485	2.08 ± 0.30
31 Oct.	48 ± 1[1]	63 ± 4	273 ± 14	14,895	25,389	1.71	1485	2.94 ± 0.35
7 Nov.	48 ± 1[1]	37 ± 4	234 ± 12	14,895	18,954	1.27	1485	3.04 ± 0.20
14 Nov.	48 ± 1[1]	67 ± 4	269 ± 12	14,895	20,427	1.37	1485	1.81 ± 0.21
21 Nov.	48 ± 1[1]	55 ± 3	388 ± 16	14,895	33,026	2.22	1485	3.23 ± 0.22

[1]For indicated weeks, data on % of pupae that yielded females were not collected. To compute the estimate of the release rate, we used the seasonal average for proportion female.
[2]For weeks 1-7, counts of pupae per 20 mg were supplied by the producer, with information on standard errors. For weeks 8-18, counts were made in our laboratory.
[3]Pupae received were estimated as total weight of pupae received times number of pupae counted in 10 subsamples of 20 mg each, times 50 (see materials and methods for details).
[4]Pupae shipped in sawdust this week, so quality control data were not obtained.
[5]Supplier changed as of 2 October.

TABLE 3. (CONTINUED) QUALITY CONTROL INFORMATION USED IN ESTIMATING ACTUAL RELEASE RATE *OF ERETMOCERUS EREMICUS* AT FAIRVIEW FARMS BIOLOGICAL CONTROL GREENHOUSE.

Release date	% female ($\bar{X}$ ± SE)	% emergence ($\bar{X}$ ± SE)	No. parasitized nymphs/20 mg[2] ($\bar{X}$ ± SE)	No. parasitized nymphs ordered	No. parasitized nymphs received[3]	Ratio oversupplied	No. plants in greenhouse	Estimated release rate (females per plant per week) ($\bar{X}$ ± SE)
27 Nov.	50 ± 4	54 ± 4	282 ± 7	14,895	29,134	1.96	1485	2.76 ± 0.26
5 Dec.	48 ± 1[1]	63 ± 04	259 ± 14	14,895	24,815	1.67	1021	2.57 ± 0.19
12 Dec.	No data[4]	No data[4]	No data[4]	14,895	No data		902	No data[4]

[1]For indicated weeks, data on % of pupae that yielded females were not collected. To compute the estimate of the release rate, we used the seasonal average for proportion female.
[2]For weeks 1-7, counts of pupae per 20 mg were supplied by the producer, with information on standard errors. For weeks 8-18, counts were made in our laboratory.
[3]Pupae received were estimated as total weight of pupae received times number of pupae counted in 10 subsamples of 20 mg each, times 50 (see materials and methods for details).
[4]Pupae shipped in sawdust this week, so quality control data were not obtained.
[5]Supplier changed as of 2 October.

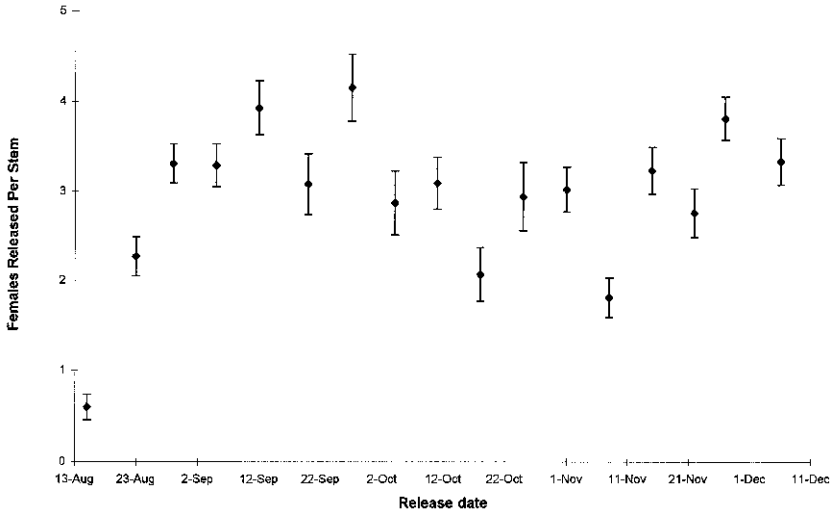

Fig. 3. Estimated mean (± SE) number of female *Eretmocerus eremicus* released per plant in the biological control greenhouse at Fairview Farms. (See Table 3 for calculations).

In the chemical control greenhouse, whitefly nymphal densities were similar to those in the biological control greenhouse until 12 November. After 12 November, nymphal densities remained lower in the chemical control greenhouse than in the biological control greenhouse through the end of the trial. Nymphal density was significantly lower in the chemical control greenhouse than in the biological control greenhouse on the last sample date before harvest (df = 1, F = 6.91, $P = 0.009$) (Fig. 7a). Pupal and adult counts in the biological control greenhouse (Fig. 7b, c) were lower than nymphal counts, but generally higher than counts of these stages in the chemical control greenhouse. Eight pesticide applications (Table 2) were made in the chemical control greenhouse, which reduced whitefly densities to 0.13 (± 0.05 SE) live nymphs per leaf at the time of sale (Fig. 7a).

Loosigian Farms. At Loosigian Farms, all whiteflies were *T. vaporariorum*. Numbers of live nymphs on the poinsettia crop in the biological control greenhouse exceeded 2 nymphs per leaf once, reaching 2.13 (± 1.02 SE) on 10 September (Fig. 8a). Densities of live nymphs on plants in the chemical control greenhouse reached 23.0 (± 7.6 SE) per leaf on 17 September, and eight pesticide applications (see Table 2) reduced numbers to 2.68 (± 1.0 SE), compared with 0.05 (± 0.03 SE) in the biological control greenhouse (Fig. 8a), at time of harvest. Nymphal densities in the biological control greenhouse were consistently lower than those in the chemical control greenhouse from 17 September through the end of the trial. At harvest, density of nymphs per leaf was significantly lower in the biological control greenhouse than in the chemical control greenhouse (df = 1, F = 12.08, $P = 0.0006$).

Numbers of live pupae and adults per leaf in the biological control greenhouse peaked at 0.08 (± 0.05 SE) on 19 November and 0.11 (± 0.05 SE) on 30 August, respectively (Figs. 8b, c). In contrast, in the chemical control greenhouse, numbers of live pupae reached 4.6 (± 1.50 SE) (on 12 November) and of adult whiteflies, 0.96 (± 0.22 SE) (on 15 October) (Figs. 8b, c).

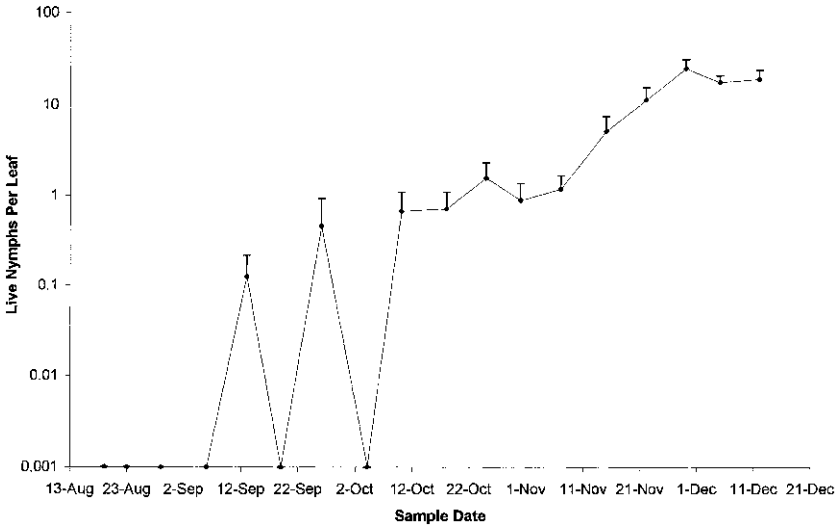

Fig. 4. Mean densities per leaf (± SE) of live *Bemisia argentifolii* nymphs in control cage at the biological control greenhouse at Fairview Farms.

Parasitoid-Caused Mortality

Numbers of dead nymphs on plants seen in whitefly density counts varied between locations and treatments. At Fairview Farms, chemical control was highly effective in suppressing whiteflies and dead nymphs were rarely detected. More dead nymphs were observed in the biological control greenhouse at this site, but numbers remained below 0.25 dead nymphs + pupae per leaf throughout the trial (Fig, 5d).

At Westover Greenhouses, where chemical control of whiteflies was ineffective until near the end of the trial, counts of dead whitefly nymphs in the chemical control greenhouse were high, exceeding 20 dead nymphs + pupae per leaf on some dates. In contrast, at this site in the biological control greenhouse, whitefly densities remained low and as a consequence, so did numbers of dead nymphs + pupae (Fig. 6d).

At Konjoian Greenhouses, numbers of live whitefly nymphs in the chemical and biological control greenhouses were similar on most sample dates (Fig. 7a), but numbers of dead nymphs + pupae were greater in the biological control greenhouse (Fig. 7d).

At Loosigian Farms, where densities of live nymphs in the chemical control greenhouse nearly always exceeded densities in the biological control greenhouse, so did densities of dead nymphs + pupae (Fig. 8d).

Parasitism, while rare in all four biological control greenhouses, was significantly higher ($\chi^2 = 22.27$, corrected for continuity; df = 1; $P < 0.005$) in the two greenhouses with *T. vaporariorum* populations (31.3% of 32 whitefly stages at Loosigian Farms and 18.4% of 228 whitefly stages at Konjoian Greenhouses) than at those locations with *B. argentifolii* (6.7% of 150 whitefly stages at Westover Greenhouses and no parasitism observed, of 50 whitefly stages at Fairview Farms).

End-of-Crop Whitefly Densities

At sale, plants produced in biological control greenhouses in this trial had 0.55 (± 0.28 SE) nymphs per leaf compared to 0.98 (± 0.36 SE) for the chemical control

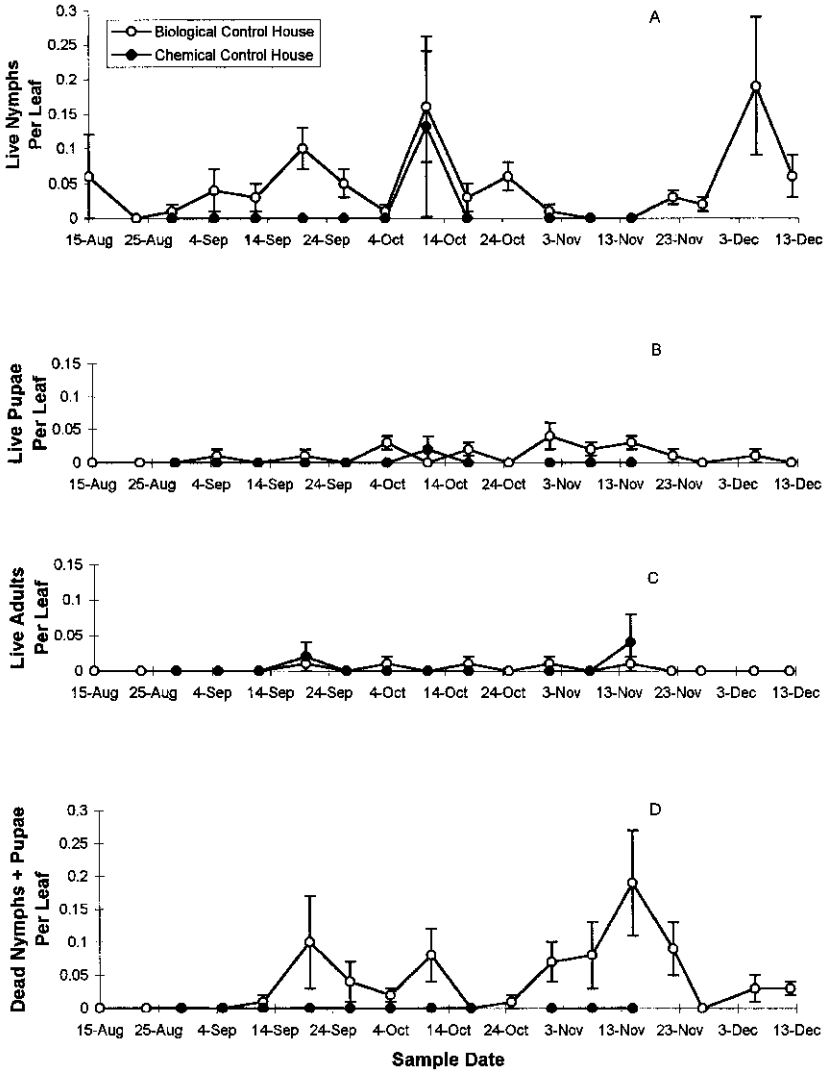

Fig. 5. Mean densities per leaf (± SE) at Fairview Farms greenhouses (in biological control and chemical control greenhouses) of *B. argentifolii* live nymphs (A), pupae (B), adults (C), and dead nymphs plus dead pupae (D).

houses at the test locations and 0.16 (± 0.09 SE) on poinsettias offered for sale at eight Massachusetts garden centers or shopping malls. A significant difference among these three treatments was detected using a nested ANOVA (df = 2, F = 10.63, P = 0.0001). Tukey's Studentized Range test indicated that nymphal densities in the biological control greenhouses did not differ from those in either the chemical control greenhouses in the test or the plants from retail outlets. However,

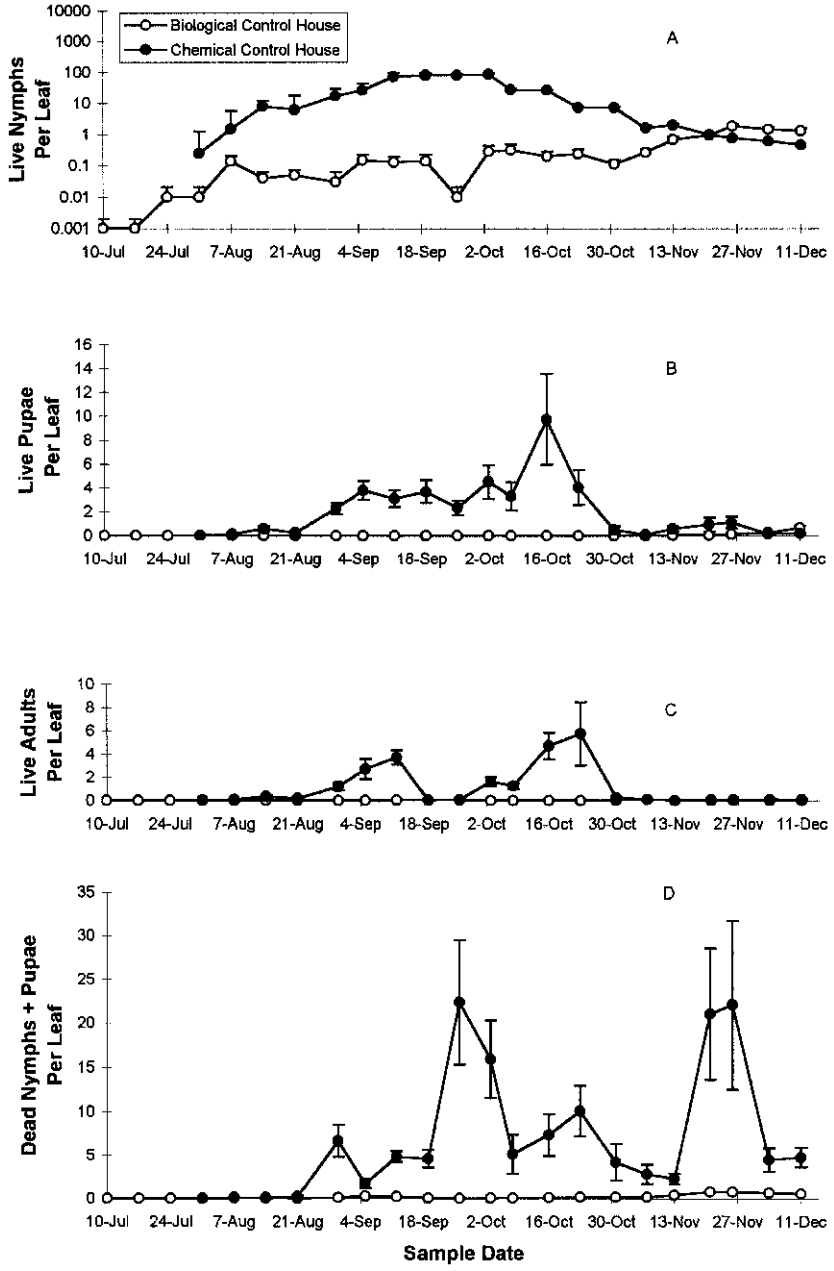

Fig. 6. Mean densities per leaf (± SE) at Westover Greenhouses (in biological control and chemical control greenhouses) of *B argentifolii* live nymphs (A), pupae (B), adults (C), and dead nymphs plus dead pupae (D).

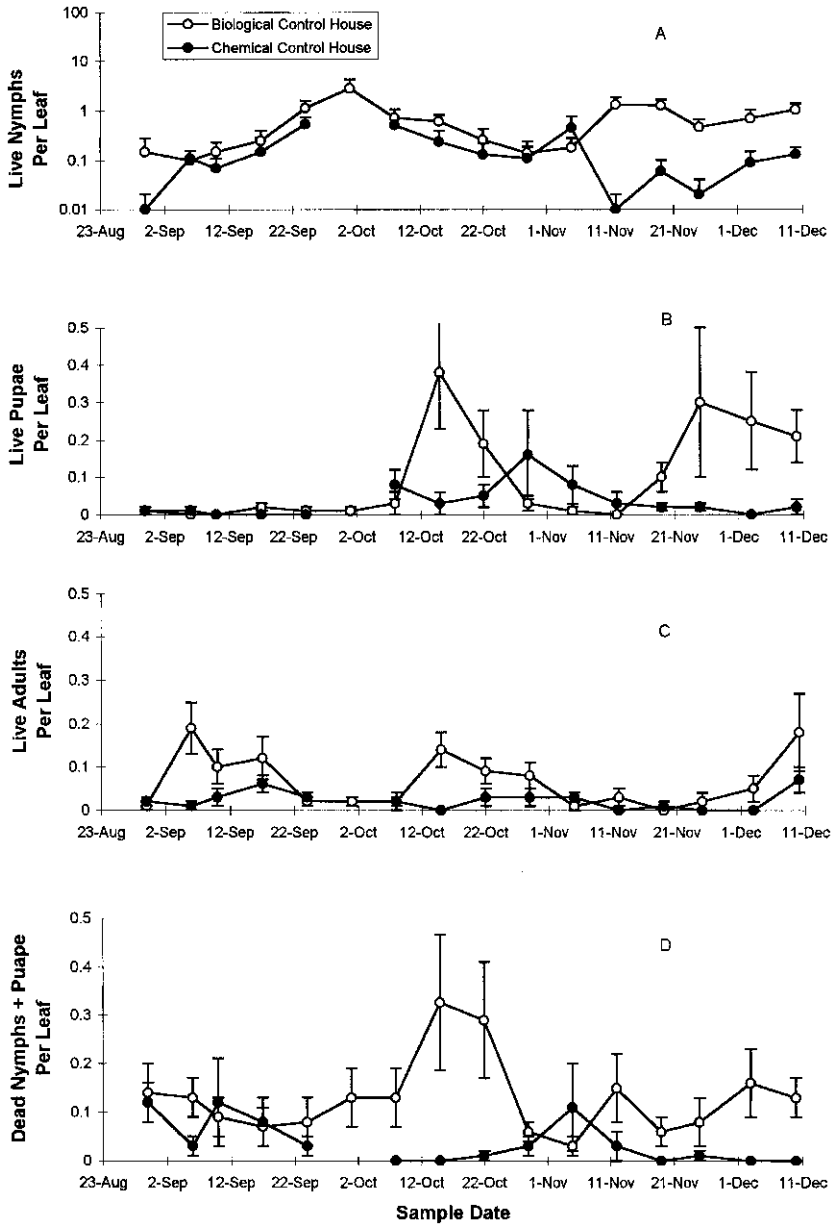

Fig. 7. Mean densities per leaf (± SE) at Konjoian Greenhouses (in biological control and chemical control greenhouses) of *T. vaporariorum* live nymphs (A), pupae (B), adults (C), and dead nymphs plus dead pupae (D). Data missing for chemical control greenhouse on 1 October due to pesticide application on sample date.

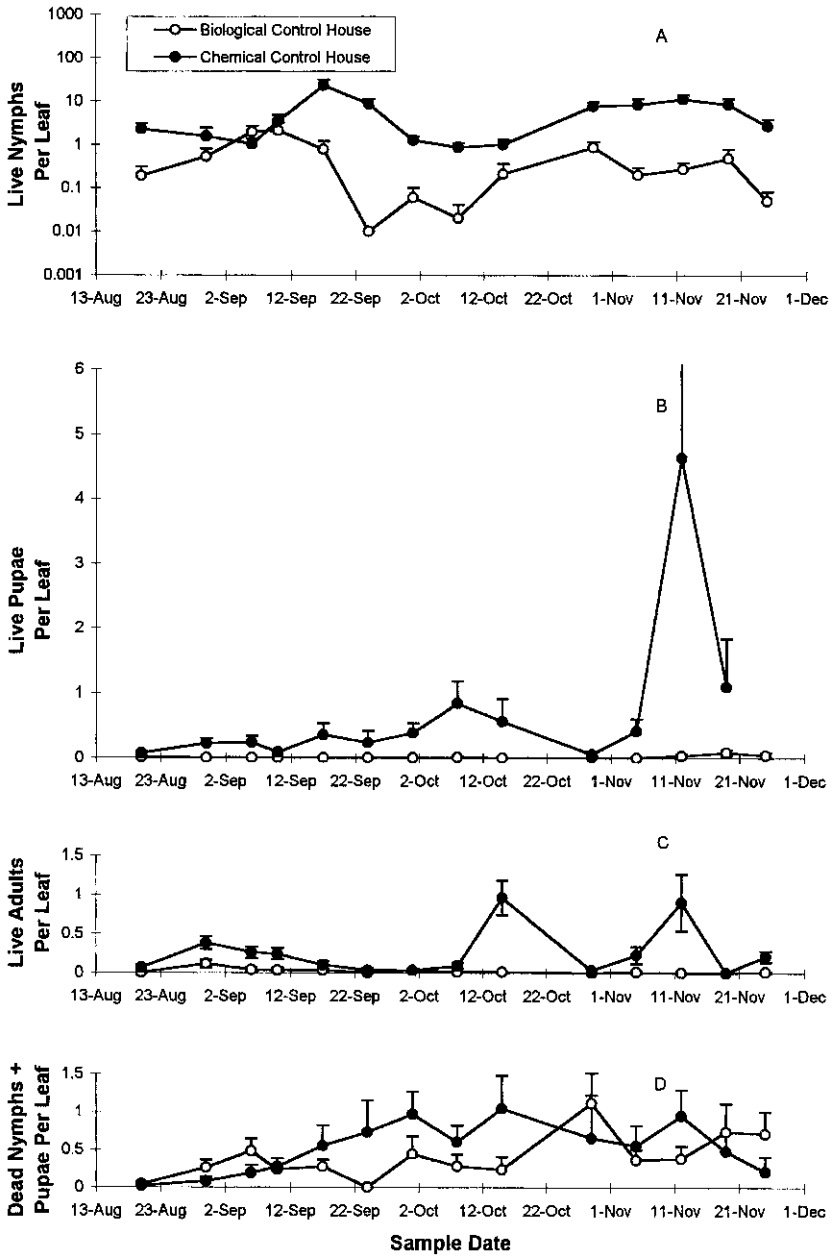

Fig. 8. Mean densities per leaf (± SE) at Loosigian Farms (in biological control and chemical control greenhouses) of *T. vaporariorum* live nymphs (A), pupae (B), adults (C), and dead nymphs plus dead pupae (D).

the chemical control greenhouses had higher nymphal densities than poinsettias from retail outlets.

Cost Analysis

Costs for whitefly control in chemical control greenhouses averaged $0.08 per plant (± $0.04 SE, range $0.02-0.15). Costs in biological control greenhouses averaged $2.14 (± $0. 15 SE, range $1.81-2.40) per plant. The average number of pesticide applications made for whitefly control was reduced 75% across all biological control greenhouses (ave. 1.7 applications) compared to usage in the chemical control greenhouses (ave. 6.8 applications). However, all insecticide use against whiteflies in biological control greenhouses occurred in one location, with no use of insecticides for whiteflies in the other three locations.

DISCUSSION

This trial assessed the efficacy of whitefly biological control in commercial poinsettia crops when management of *E. eremicus* releases was done solely by growers. *Eretmocerus eremicus* releases at rates used in this trial were effective at maintaining whitefly nymphal densities below 2 live nymphs or pupae per leaf at time of sale. At these levels, marketing of poinsettias in Massachusetts is not adversely affected by whiteflies, indicating that nymphal + pupal densities <2 do not exceed economic injury levels. This trial both extends the number of cases in which *E. eremicus* has been shown to suppress *B. argentifolii* on poinsettia and is the first to demonstrate the ability of *E. eremicus* to suppress *T. vaporariorum* on this crop.

The intended release rate in the biological control greenhouses was 3 female parasitoids per plant per week. It was assumed that parasitoids received from commercial suppliers would be 50% female and have 60% emergence under greenhouse conditions. Weekly assessments at one site (Fairview Farms) showed these assumptions to be correct. Use of only 15 release cups in greenhouses containing 1,200 to 3,200 plants (ave. of one release cup per 18 m^2 across all four biological control greenhouses) provided successful control of both whitely species.

Experience at the other three sites pointed out unforeseen difficulties in practical use of *E. eremicus*. First, growers received different numbers of parasitoid pupae than anticipated (based on numbers ordered) because the supplier over filled orders to compensate for reduced parasitoid emergence. Second, one grower (Konjoian) released more parasitoids than intended because fewer plants (3,193) were used to fill the biological control greenhouse at that site than were originally estimated (4,000). Third, grower practices affected the success of whitefly biological control at some sites. At two locations, plants used in the trial were infested with *T. vaporariorum* that appeared to have come from retail sales areas near where cuttings were rooted. At one site, composting of whitefly-infested plants near air intake vents allowed whiteflies to enter the biological control greenhouse, and insecticides were required to control the localized infestation within the biological control greenhouse. These events emphasize the need for biological control agents to be used in a proper IPM context to avoid such problems. Although plants actually treated with pesticide sprays were excluded from whitefly sampling, parasitoid mortality from contact with foliar residues on these plants may have reduced overall efficacy of biological control in this greenhouse.

Costs of biological control were 27 fold greater than costs of chemical control. Costs of chemical control in this trial ($0.08) were similar to those reported by Hoddle & Van Driesche (1996) in an earlier trial ($0.09) with *E. formosa* for control of *B. argentifolii*

on poinsettia. Costs of biological control in the trial reported here were higher ($2.14 per plant) than those in Hoddle & Van Driesche (1996), where cost was $1.02 per plant. In contrast to the Hoddle & Van Driesche (1996) trial with *E. formosa*, whitefly biological control with *E. eremicus* produced adequate pest suppression.

To be economically feasible, substantially lower release rates of *E. eremicus* will be required. Based on a subsequent trial in 1997 (Van Driesche et al., unpublished), release of as few as 1 adult parasitoid per plant per week should be able to provide whitefly control in commercial poinsettia crops if supplemented with limited use of insect growth regulators. Also, recognizing that the supplier provides additional parasitized nymphs in shipments to compensate for less than 100% emergence, ordering 2 parasitoid pupae per plant per week would be adequate to achieve this lower release rate. Cost for this low release rate would be $0.35 per plant for 16 weekly releases, just 16% of the total cost reported for *E. eremicus* in this trial.

Acknowledgment

We thank participating growers for their cooperation and the use of their greenhouses. We thank Beneficial Insectaries, Inc. and Koppert Biological Systems, Inc., and Dr. Oscar Minkenberg for providing *E. eremicus* to us free or at a reduced price. We thank the MA Department of Food and Agriculture (Agriculture Environmental Technology Grant), the Bedding Plant Foundation, and the MA IPM Program at the University of Massachusetts for financial support. Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the specific granting agencies.

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