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The Effect of Insecticide Treatments in Cotton Fields on the Levels of Parasitism of *Bemisia tabaci* (Gennadius) *sl.*[1]

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Populations of whiteflies [*Bemisia tabaci* (Gennadius) *sl.*] and the rates at which they were parasitized in cotton fields in Israel and California were monitored over a number of years. Studies took place both in fields that were treated with insecticides and in untreated fields and permitted us to assess the influence of insecticidal treatments upon percentage parasitism. The results showed that, in many cases, insecticide treatments had only a minor effect on levels of parasitism and that high levels of parasitism were sustained in insecticide-treated fields. However, many repeated treatments, especially if monocrotophos was used, resulted in significant reductions in levels of parasitism in Israel. Our findings suggest that the species of parasitoids we observed may be no more severely impacted by certain insecticides than nymphal whiteflies that serve as hosts. Nonetheless, reductions in parasitoid abundance may have important consequences for the biological control of *B. tabaci* over time and over larger areas, and judicious use of insecticides in commercial cotton fields is warranted. © 1998 Academic Press

***Key Words: Encarsia; Eretmocerus; Bemisia tabaci; B. argentifolii;* buprofezin; monocrotophos; cotton IPM; percentage parasitism.**

INTRODUCTION

The whiteflies *Bemisia tabaci* (Gennadius) and later *B. argentifolii* Bellows & Perring have been pests of cotton in various parts of the world for more than 50 years (Husain and Trehan, 1933; Gerling *et al*, 1980). During the past 20 years, control efforts have attempted to concentrate on integrated pest management (IPM) techniques. These techniques strive to maximize the effects of nondisruptive controlling agents, such as parasitoids, predators, diseases, and cultural manipulation of the crop. Ideally, toxic insecticides are used only if the control achieved by the former is inadequate. Moreover, it is instrumental to the success of IPM programs that only minimal damage to the natural enemy fauna will incur from the use of insecticides. Thus, in order to develop and conduct a successful IPM program, both the potential of natural enemies as pest-reducing agents and the degree to which they are susceptible to various insecticide treatments in the field should be known and taken into account.

Parasitoids have traditionally been successful in suppressing whitefly populations (Onillon, 1990; Gerling, 1992). Therefore, much effort has been invested in the study of parasitoids of *B. tabaci* to evaluate their effectiveness and to examine possibilities for their utilization as controlling agents. From early observations (Gerling, 1986) it appeared that percentage parasitism of *B. tabaci* populations often did not decline when only a few applications of commercial insecticides were made in cotton fields. Later, more detailed studies showed similar results (e.g., Gerling, 1996).

These results warranted a thorough investigation into the degree of parasitoid activity and impact in cotton under commercial field conditions. In order to gain insight as to the generality of the results, it was desirable to run similar studies in more than one region, so that we might include the responses of parasitoid populations to insecticide applications that are customary to varied cotton growing practices. In the present study we examine parasitoid populations and activity levels in cotton fields of two regions in Israel and in one region of California (U.S.A.). We attempt to examine the level of sensitivity of *B. tabaci* parasitoids to commercial insecticide treatments and to draw practical conclusions as to the desired practices in management of this pest.

MATERIALS AND METHODS

Israel

Cotton in Israel is grown along the coast up to ca. 30 km inland from the Mediterranean, and in the interior

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valleys of the Galilee and Bet Shean. Whitefly and parasitoid samples were taken in the fields of several farms (kibbutzim) located in the coastal plain. Maximal daily temperatures for July–September in this area average about 29–34°C. Samples also were taken in the Bet Shean area which is a low lying valley (ca. 250 m below sea level) with maximal daily temperatures for July–September averaging about 35–42°C. Cotton is planted in the coastal region from mid- to late April and in the Bet Shean region during the second half of March.

Summary information on the fields sampled is presented in Table 1. All sites except the Eden experimental farm were commercial farms, but untreated cotton plots, otherwise identical to the commercial fields, were placed at our disposal. Samples were taken from both the untreated controls and the commercial plots that were treated from the air according to standard agricultural practices for the region. The number of insecticide treatments on commercial fields varied between two (Zora 1992) and nine (Zora 1993, Revadim 1995) per season and most treatments were made against various cotton pests such as *Heliothis armigera* Hbn., pink bollworm, *Pectinophora gossypiella* (Saunders), and the spiny bollworm, *Earias insulana* (Boisd). All insecticide treatments were made at dawn in still air to minimize drift. At the Eden farm the cotton was treated with specifically selected insecticides, which included the insect growth regulators (IGR) buprofezin and diafenthiuron, using a tractor-drawn boom sprayer. Sampling at all sites began in late May or early June, when the plants were 1–2 months old, and ended in September when the cotton was defoliated.

Within all fields (commercial and experimental) we were allotted a plot of ca. 1–4 ha of untreated cotton that was divided into six subplots ranging in size from 10 × 8 m each to 36 × 36 m each. Six subplots of the same size also were established within the insecticide-treated area of each field. In each case, subplots were separated from one another by buffer zones at least as large as the subplot. Untreated plots were also separated from treated areas by at least 30 m. Immature whiteflies were sampled weekly by randomly choosing 10 plants in each subplot. On each of these, mainstem leaves at the fifth to seventh node from the plant top were inspected and the leaf containing the greatest number of large nymphs ["maximally infested" leaves of Gerling *et al.* (1980)] was collected and examined in the laboratory under a stereomicroscope. Parasitized and unparasitized third and fourth instar nymphs were counted and recorded. An index of parasitism was calculated as the quotient of the total number of parasitized nymphs and the total number of parasitized plus unparasitized third and fourth instar whiteflies.

Statistical differences in mean levels of parasitism between insecticide-treated and untreated plots were tested by performing *t* tests following an arcsine square-root transformation (Sokal and Rohlf, 1981). Seasonal patterns of parasitoid activity were summarized by determining maximal values for percentage parasitism and calculating mean percentage parasitism over the season. Regression analysis was used to examine relationships between rates of parasitism and host density. Host density 1 and 2 weeks previous was used as the independent variable to reflect host population density at the time of parasitization (Gerling, 1986).

California, U.S.A.

Studies of parasitoid activity in California, U.S.A., were conducted as part of a regional three-state effort to develop action thresholds for insecticidal management of *B. tabaci* (Naranjo *et al.*, 1996b). The studies described here were conducted at the Irrigated Desert Research Station in Brawley, California, in 1994 and 1995. Brawley is in the Imperial Valley (ca. 30 m below sea level) with an average maximal temperature of

TABLE 1

Summary of Field Locations, Years, Insecticides, and Cotton Varieties in Israel

Field name	Location	Cotton variety	Insecticides	Application dates
Eden 1988	Bet Shean valley	Eden 1	Buprofezin (2.5 g/l)	10, 31 August
Eden 1989	Bet Shean valley	Eden 1	Buprofezin (20 g/l)	23 August, 13 September
			Diafenthiuron (20 g/l)	23, 31 August, 21 September
Maale Gilboa 1992	Bet Shean valley	Eden 1	Commercial practice[a]	
Maale Gilboa 1993	Bet Shean valley	Eden 1	Commercial practice	
Zora 1992	Coastal foothills	Acala SJ1	Commercial practice	
Zora 1993	Coastal foothills	Acala SJ1	Commercial practice	
Revadim 1995	Coastal foothills	Acala SJ1	Commercial practice	
Zuba 1995	Coastal foothills	Acala SJ1	Commercial practice	

Note. All cottons are varieties of *G. hirsutum*.
[a] Some of the more commonly used insecticides were bifenthrin, buprofezin, carbosulfan, diafenthiuron, endosulfan, monocrotophos, and pyriproxyfen.

40–43°C for July–September. Typically, cotton is planted in early March.

Plots of Deltapine 5415 cotton were established on 7 and 10 March in 1994 and 1995, respectively. The study was identical in both years and consisted of five experimental treatments in which whitefly populations were treated whenever densities exceeded predetermined thresholds. Populations of adult *B. tabaci* were monitored weekly by the method of Naranjo and Flint (1995) beginning 1 month after planting, and a mixture of fenpropathrin and acephate (0.11 and 0.56 kg AI/ha) was applied by tractor-drawn boom-sprayer whenever densities exceeded an average of 2.5, 5, 10, or 20 adults per leaf (a single threshold was use in each experimental plot throughout the season). Individual plots were ca. eight 1-m rows by 15 m (0.012 ha) and were separated from one another by ≈4 m. All applications were made in the early morning to minimize drift. Unsprayed plots served as controls. Insecticide treatments were continued through defoliation in late August. All experimental treatments were replicated five times in a Latin square design. The experimental area was surrounded by other cotton and vegetable research plots.

We began to sample populations of *Eretmocerus* spp. and *Encarsia* spp. parasitoids on a weekly basis on 15 and 19 June in 1994 and 1995, respectively. This approximately coincided with the first application of insecticides in plots with the lowest threshold (2.5 adults per leaf). In 1994 we monitored parasitoids in experimental plots being treated at 5 and 20 adults per leaf, and in untreated control plots (15 total plots). In 1995 we monitored all treated and untreated plots (25 total plots). To sample parasitoid and host populations we randomly selected 30 plants in each plot. On each of these, mainstem leaves from the fifth to seventh node from the terminal were inspected and the leaf containing the greatest number of large nymphs was collected and examined in the laboratory under a stereomicroscope. We counted and recorded any parasitized and unparasitized third and fourth instar nymphs on each leaf. Parasitoids were recorded by genera when possible; young parasitoid larvae could not be differentiated. In order to identify species, a subsample of leaves from the last sample date was held for parasitoid emergence. An index of parasitism was calculated as the quotient of the total number of parasitized nymphs and the number of parasitized plus unparasitized third and fourth instar whiteflies.

Analysis of variance (SAS, 1989) for randomized block (1994) and Latin square (1995) was performed to test for differences in levels of percentage parasitism in relation to the frequency of insecticide application following an arcsine square-root transformation. Dunnett's test was used to compare each treatment to the untreated control. Regression analysis was used to examine relationships between rates of parasitism and host density. Again, host density 1 and 2 weeks previous was used as the independent variable.

RESULTS

Israel

The only whitefly outbreak occurred in Zora 1993 with a peak density of 92.8 whitefly nymphs/leaf (Fig. 1D). All other populations were low, fluctuating between an average of 2.8 and 14.6 nymphs/leaf. Although the patterns of whitefly population growth were not consistent across sites and years, they had some common characteristics. Populations were always low until July, after which the first increases occurred. The first population increase was minor, except in Zora 1993 where it reached 55 nymphs/leaf. Later, the populations fluctuated reaching one or more peaks between August and October (Figs. 1 and 2). Most insecticide treatments reduced whitefly populations. This was especially evident in Eden 1989 and Zora 1993 (Figs. 1A and 1D, respectively), and in Eden 1988 and Maale Gilboa 1992 (Figs. 2A and 2D, respectively).

Despite numerous releases of *Encarsia luteola* Howard, *En. transvena* (Timberlake), and *Eretmocerus eremicus* Rose and Zolnerowich (Gerling, unpublished), the parasitoid species that were found in all of our surveys were the native species *En. lutea* (Masi) and *Er. mundus* Mercet. These species occurred in all fields, although their proportions differed among fields and years (Lazare, 1994). Species were pooled for further analysis.

Immature parasitoid populations also varied greatly from year to year in both their densities and their dynamics. Percentage parasitism usually started low and rose within a month or 6 weeks from the appearance of the pest to a level around which it fluctuated for the rest of the season. Except for Zora 1992, where *B. tabaci* and parasitoids occurred for only 4 weeks and Eden 1988 where percentage parasitism was comparatively low, the fluctuations around mean levels of parasitism ranged from ≈ ±16 to ±25%. In untreated plots peak rates of parasitism were lowest in Eden 1988 at 37%, and highest in Revadim 1995 (92%). In treated plots peak parasitism ranged from 54% at Eden 1989-diafenthiuron to 93% at Revadim and Zuba in 1995 (Table 2). Seasonal parasitism averaged between 17% for Eden 1988 to 58% for Revadim 1995 in untreated plots, and from 24 to 59% in treated plots at Maale Gilboa 1992 and Revadim 1995, respectively.

The type of insecticides used varied by field and over time (see Table 1). In most instances, only small and insignificant differences in parasitism occurred between the treated and untreated plots. Significant

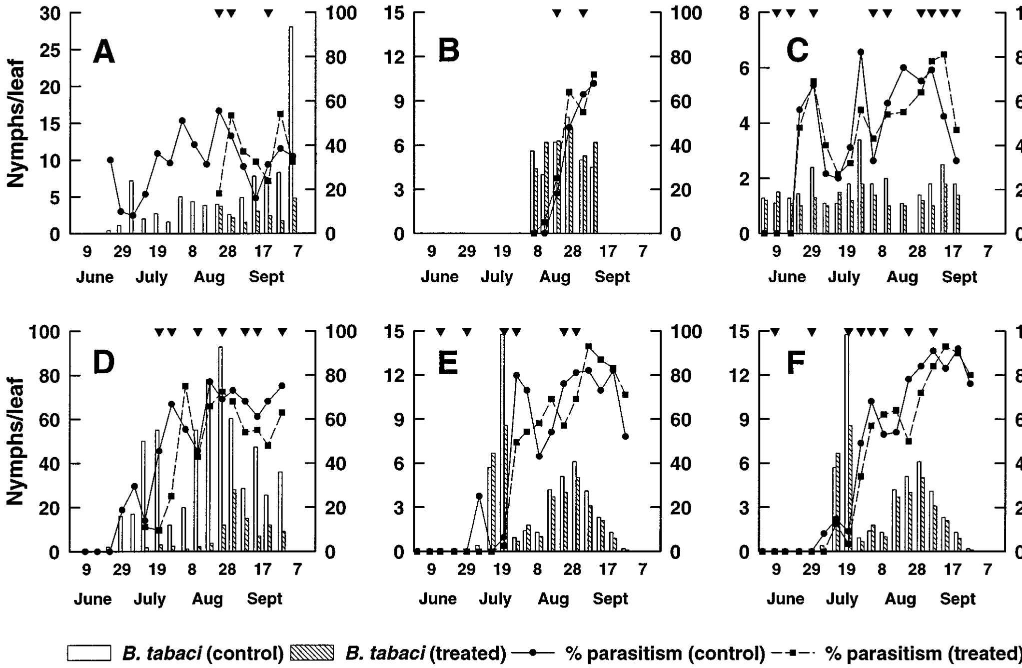

FIG. 1. Comparison of population density of *B. tabaci* nymphs and percentage parasitism from 1989 to 1995 in insecticide-treated and untreated plots in six cotton fields: (A) Eden 1989-diafenthiuron, (B) Zora 1992, (C) Maale Gilboa 1993, (D) Zora 1993, (E) Zuba 1995, and (F) Revadim 1995. In all of the fields no significant difference in the level of parasitism was observed in spite of treatments. Triangles above graphs indicate the dates of insecticide applications.

differences in percentage parasitism were observed at Eden in both 1988 and 1989 with buprofezin (Figs. 2A and 2B) where parasitism rose following treatments, and in 1989 when parasitism declined after using diafethiuron. Differences also were observed in Maale Gilboa on 23 August 1991 where parasitism dropped from 67% to 0 following the use of pyriproxyfen and on 26 September 1991 where parasitism dropped from 71 to 36% following treatment with monocrotophos (parasitism in the untreated control was ≈40%) (Fig. 2C). In 1992, consecutive treatments against *P. gossypiella* with monocrotophos in Maale Gilboa resulted in a drop from 86 to 6% parasitism while the control dropped from 64 to 25%. A week later, following one treatment with cypermethrin, the treated fields reached only 28% parasitism vs. 71% in the control (Fig. 2D). In contrast, the use of pyripoxyfen in both Zuba and Revadim in 1995 and the use of monocrotophos in Zuba at rates similar to those used in Maale Gilboa did not result in any significant changes in percentage parasitism (Figs. 1E and 1F).

There was a significant ($P < 0.05$) positive relationship between host density and rates of parasitism in the majority of sites in Israel (Table 3). These relationships were stronger when parasitism was regressed on host density measured 2 weeks earlier. They also were generally stronger and more consistent in untreated compared with insecticide-treated fields.

California, U.S.A.

Densities of *B. tabaci* were high in both years, exceeding an average of 140 fourth instar nymphs per leaf in untreated plots by late June in 1994 (Fig. 3) and 80 nymphs per leaf in early July in 1995 (Fig. 4). Based on adult population density, sprays of fenpropathrin + acephate commenced on 8 June and 13 June in plots with the lowest threshold treatment (=2.5 adults/leaf) in 1994 and 1995, respectively. The frequency of insecticide use varied greatly between treatments, but pest density remained relatively low throughout the rest of the season following the first or second application in all treatment plots and both years. All treatments significantly reduced populations of *B. tabaci* in comparison with untreated control plots (Naranjo *et al.*, 1996b; Figs. 3 and 4).

Eretmocerus spp. were first detected in early July in 1994 and late June in 1995. *Encarsia* spp. were first detected in early August, but densities of parasitoids of this genus were extremely low in both years. Because we could not differentiate young parasitoids it is possible that *Encarsia* spp. were present earlier. Based on leaves held for parasitoid emergence, all the *Encarsia* spp. were *En. luteola* Howard, and the vast majority of *Eretmocerus* spp. were the native *Er. eremicus*. Two of 173 specimens examined were exotic *Eretmocerus* spp. that had been released in the Brawley area (K. Hoelmer,

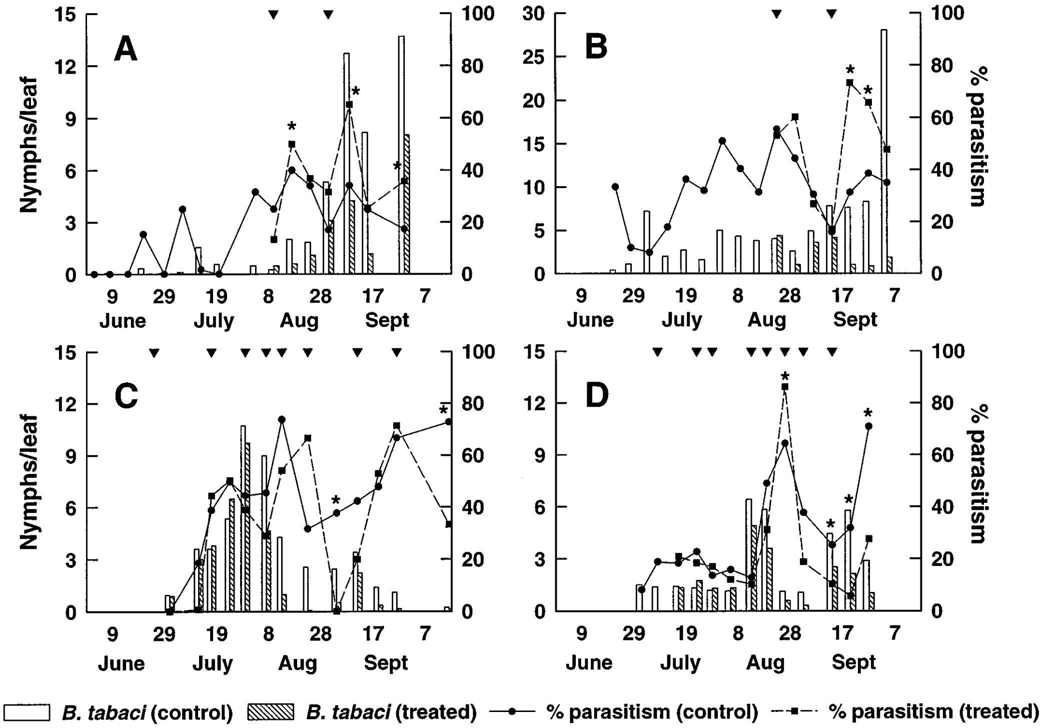

FIG. 2. Comparison of population density of *B. tabaci* nymphs and percentage parasitism from 1988 to 1992 in insecticide-treated and untreated plots in four cotton fields: (A) Eden 1988, (B) Eden 1989-buprofezin, (C) Maale Gilboa 1991, and (D) Maale Gilboa 1992. In each of these fields, significant difference in the level of parasitism was observed following some of the treatments. Asterisks indicate significant differences in parasitism ($P < 0.05$) between treated and control plots. Triangles above graphs indicate the dates of insecticide applications.

personal communication). Due to the low densities of *En. luteola,* and the fact that young immature parasitoids could not be differentiated by genus, we combined the species for all further analyses.

Levels of parasitism varied greatly between years. In 1994 parasitism increased gradually in untreated control plots and never exceeded about 10%, averaging only 4.1% over the season (Fig. 3, Table 4). Patterns of parasitoid activity were markedly different in 1995 and more closely resembled those observed for many of the sites in Israel (Fig. 4). Rates of parasitism increased and declined quite rapidly in untreated control plots peaking at about 72% and averaging 35% over the season.

Likewise, the effect of insecticide treatments on levels of parasitism varied between years. In plots treated at an action threshold of 5 adults/leaf in 1994, parasitism was low but significantly different ($P < 0.05$) from the control on only one date in early August (Fig. 3A). In contrast, parasitism in plots treated at 20 adults/leaf rose quickly to a peak of almost 25%. The rate of parasitism was significantly higher ($P < 0.05$) in treated plots on 29 July, but significantly lower ($P < 0.05$) than the untreated control 2 weeks later. Percentage parasitism dropped sharply by mid-August and remained low to the last sample date regardless of treatment. In comparison with the control, the mean rate of parasitism over the season was significantly ($P < 0.05$) lower in the plots treated at 5 adults/leaf, but not different from plots treated at 20/leaf (Table 4). In 1995, parasitism in plots treated with insecticides differed relatively little from that observed in control

TABLE 2

Seasonal Mean (± Standard Error) and Peak Parasitism Values for *B. tabaci* in Israeli Cotton Fields

Field	Untreated		Treated	
	Mean % parasitism[a]	Peak % parasitism	Mean % parasitism	Peak % parasitism
Eden 1988	16.6 ± 3.5*	36.8	36.9 ± 5.2	65.2
Eden 1989 (buprofezin)	31.9 ± 3.3*	55.5	46.8 ± 5.5	73
Eden 1989 (diafenthiuron)	31.9 ± 3.3	55.5	36.1 ± 5.2	54.2
Maale Gilboa 1991	43.8 ± 5.7	73.7	40.5 ± 5.4	71.4
Maale Gilboa 1992	29.8 ± 5.4	70.8	23.5 ± 6.7	88.2
Maale Gilboa 1993	53.2 ± 5.5	82.0	53.4 ± 4.6	81.0
Zora 1992	32.8 ± 12.6	68.0	36.8 ± 12.7	72.0
Zora 1993	51.1 ± 6.2	76.0	49.2 ± 6.6	75.0
Revadim 1995	58.4 ± 8.5	92.0	58.5 ± 9.0	93.0
Zuba 1995	55.9 ± 8.1	79.7	57.8 ± 9.0	93.0

[a] Asterisks indicate that mean rates of parasitism in untreated and treated plots differed significantly.

TABLE 3

Relationship between Host Density and Parasitism in Cotton Fields, Israel and California, U.S.A.

	Untreated				Treated			
	Host density 1 week prior		Host density 2 weeks prior		Host density 1 week prior		Host density 2 weeks prior	
Field	r^2	P	r^2	P	r^2	P	r^2	P
Israel								
Eden 1988	0.123	0.20	0.069	0.36	0.311	0.25	0.394	0.26
Eden 1989	0.123	0.20	0.176	0.14	0.467	0.13	0.601	0.12
Maale Gilboa 1991	0.091	0.34	0.053	0.50	0.009	0.94	0.057	0.54
Maale Gilboa 1992	0.743	0.0003*	0.945	0.001*	0.639	0.005*	0.926	0.001*
Maale Gilboa 1993	0.480	0.004*	0.509	0.004*	0.565	0.001*	0.599	0.001*
Zora 1992	0.905	0.01*	0.949	0.02*	0.957	0.004*	0.922	0.03*
Zora 1993	0.550	0.001*	0.641	0.003*	0.236	0.12	0.156	0.26
Revadim 1995	0.388	0.02*	0.528	0.005*	0.282	0.07	0.446	0.01*
Zuba 1995	0.437	0.014	0.587	0.002*	0.274	0.08	0.395	0.03*
California, U.S.A.[a]								
1994	0.067	0.50	0.323	0.11	0.509	0.03*	0.082	0.46
1995	0.342	0.10	0.544	0.02*	0.001	0.94	0.188	0.24

[a] Treated plots were those sprayed at a threshold of 5 adult whiteflies per leaf.

plots (Fig. 4). Percentage parasitism was significantly ($P < 0.05$) higher on 1–2 dates in treated plots compared with control plots, and peak rates of parasitism typically exceeded 85%. Also, rates of parasitism remained relatively high on the last sampling date in plots treated at 2.5 and 10 adults/leaf. On a seasonal basis there were no differences in rates of parasitism between treated and control plots in 1995 ($P > 0.10$) (Table 4).

There appeared to be little relationship between levels of parasitism and specific applications of insecticides. In 1995, rates of parasitism continued to increase through midseason in all treated plots despite sometimes frequent applications, and late-season declines occurred even in untreated control plots. A similar pattern was evident in 1994, at least in plots treated at 20 adults/leaf. Heavy use of insecticides in the 5/leaf plots probably caused the low percentage parasitism observed in those plots.

The relationships between host density and rates of parasitism were relatively poor and inconsistent between years in California (Table 3). The only significant ($P < 0.05$) regressions indicated positive relationships between parasitism and host density 1 week prior in treated plots in 1994 and host density 2 weeks prior in untreated plots in 1995.

DISCUSSION

Because cotton is grown as an annual crop, whitefly and parasitoids must arrive in the field anew each

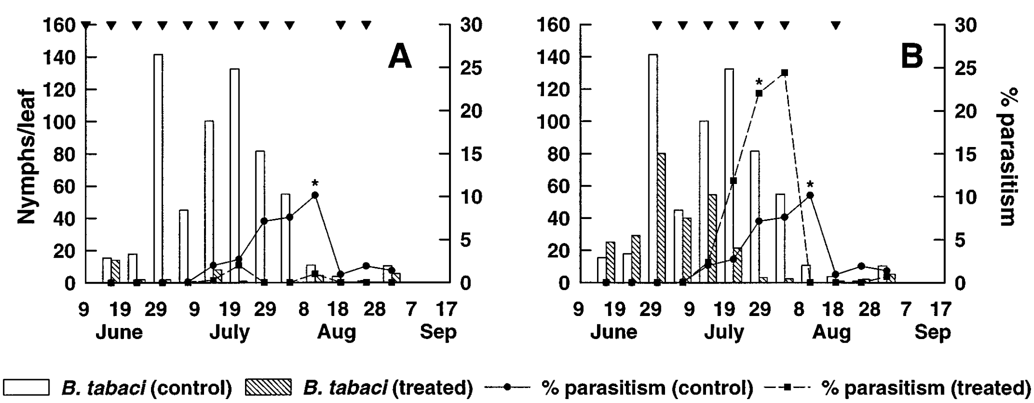

FIG. 3. Comparison of population density of *B. tabaci* nymphs and percentage parasitism in untreated control plots and (A) plots treated at an action threshold of 5 adults/leaf and (B) plots treated at an action threshold of 20 adults/leaf, Brawley, CA, 1994. Asterisks indicate significant differences in parasitism ($P < 0.05$) between treated and control plots. Triangles above graphs indicate the dates of insecticide applications.

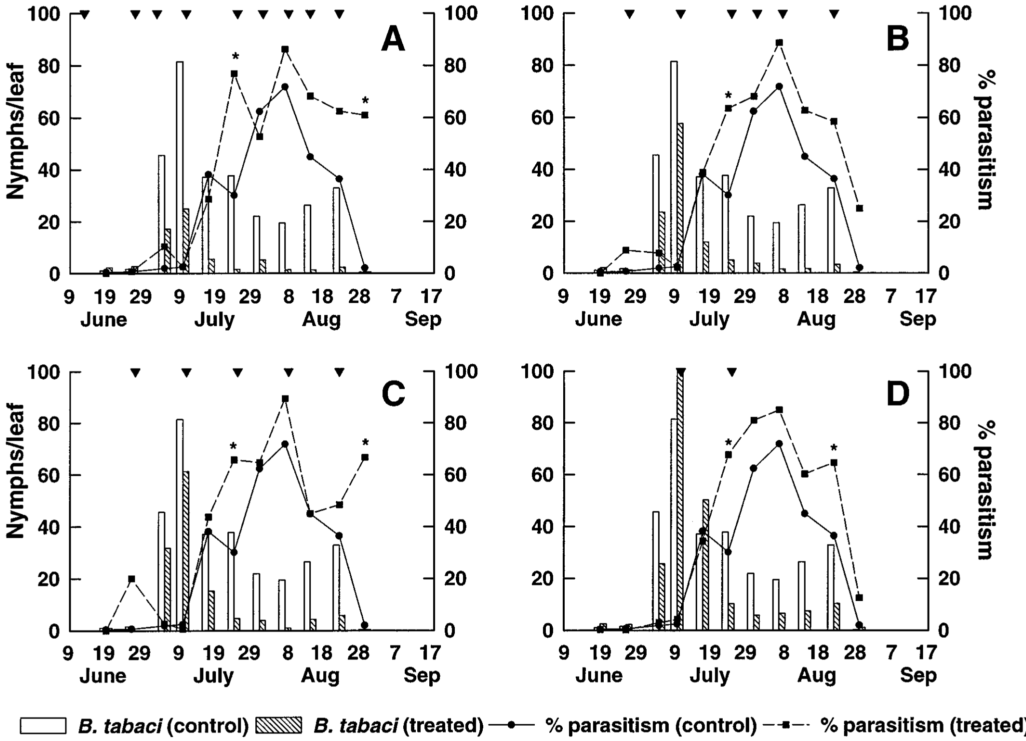

FIG. 4. Comparison of population density of *B. tabaci* nymphs and percentage parasitism in untreated control plots and (A) plots treated at an action threshold of 2.5 adults/leaf, (B) plots treated at an action threshold of 5 adults/leaf, (C) plots treated at an action threshold of 10 adults/leaf, and (D) plots treated at an action threshold of 20 adults/leaf, Brawley, CA, 1995. Asterisks indicate significant differences in parasitism ($P < 0.05$) between treated and control plots. Triangles above graphs indicate the dates of insecticide applications.

season. In Israel whitefly nymphs were first found in June and, in most cases, some of them were already parasitized. Percentage parasitism often fluctuated strongly within the same field. This was most clearly tied to the synchrony of parasitoid populations with fluctuations of their hosts in Maale Gilboa 1992 and Zora 1993. In other cases the intensity of normally occurring fluctuations could have been exaggerated due to the relatively low host populations. This was especially true early in the season, when host density was less than 2 whitefly nymphs per leaf. In the Imperial Valley of California whitefly nymphs can be found in cotton as early as April (Naranjo *et al.*, 1996a,b); however, we did not detect parasitized nymphs until mid to late June in 1994 or 1995. After this point percentage parasitism gradually increased to a peak by early August and then declined. There were no strong patterns of fluctuation in either year despite changing host population densities over the season.

TABLE 4

Summary of Parasitoid Activity and Insecticide Applications in Brawley, CA, 1994–1995

Treatment	1994 Mean % parasitism[a] ± SE	1994 Peak parasitism	1995 Mean % parasitism ± SE	1995 Peak parasitism
Untreated	4.1 ± 0.9	10.1	35.1 ± 3.8	71.7
2.5 adults/leaf	—	—	39.5 ± 9.2	86.2
5 adults/leaf	1.4 ± 0.7*	2.0	34.9 ± 5.2	88.6
10 adults/leaf	—	—	30.7 ± 4.3	89.5
20 adults/leaf	4.9 ± 1.6	24.4	36.1 ± 3.8	84.9

[a] Asterisks indicate that mean rates of parasitism differed significantly from the untreated control.

Insecticides are applied to commercial fields in both Israel and the United States for a variety of different pests. They often are applied in a sequence and may include one or more materials per application. Because most of our observations in Israel were made on commercial farms with variable spray schedules, they permit only a general estimate of insecticide influence upon parasitoids. However, an examination of all 11 fields studied leads to the following conclusions: overall, when insecticide treatments are made from the air, percentage parasitism was often not altered significantly compared with untreated plots. The principal exceptions were monocrotophos and pyriproxyfen, the applications of which caused severe reductions in parasitism. The detrimental influence of pyriproxyfen was only noted once, in Maale Gilboa 1991, whereas that of monocrotophos was more prevalent, following either one or several applications. Monocrotophos is commonly used for control of *P. gossypiella* in Israel but is no longer registered in the United States. Pyriproxyfen also is widely used in Israel for whitefly control and has been available in the United States since 1996 under an emergency registration. Studies are currently underway in Arizona to evaluate the effects of this material on both whitefly parasitoids and generalist predators. The noncommercial experiment conducted with buprofezin resulted in higher parasitism compared with the controls. This pattern repeated in 1988 and 1989 and was probably because buprofezin has only a slight effect on *B. tabaci* parasitoids (Gerling and Sinai, 1994), and its effect on whiteflies is mainly in the early immature stages. Thus, buprofezin reduces whitefly populations with minimal harm to the parasitoid or to the late nymphal instars which serve as their hosts.

Similar conclusions can be drawn from studies in the United States under perhaps even more severe pressure from highly toxic insecticides. A mixture of fenpropathrin and acephate is a standard treatment used for control of whitefly in Arizona and California cotton (Akey *et al.*, 1992; Ellsworth and Meade, 1994). Despite numerous applications of this mixture (Figs. 3 and 4) percentage parasitism was generally unaffected in comparison with untreated control plots and there were several dates in both years on which rates of parasitism were actually greater in treated plots.

Several factors could be involved in the general lack of differences in percentage parasitism between treated and control plots in Israel and the United States. First, it is possible that parasitoids continually colonized treated plots from surrounding areas. This is unlikely in Israel where the untreated plots were surrounded by large areas of commercial production fields that received routine insecticide applications. It also seems unlikely in California because much of the surrounding area consisted of other research plots, many of which were subject to insecticide applications throughout the season. Second, given the relatively small size of our plots it is possible that adult parasitiods moved freely between untreated and treated areas leading to somewhat depressed densities of immature parasitoids in untreated plots. We observed high levels of parasitism in untreated plots where host densities were extremely large, particularly at Zora in 1993 and both years in California. If adult parasitoids from untreated areas were being killed in treated areas we would have expected to see some depression of parasitism in untreated plots. Nonetheless, it is possible that insecticide effects could have been underestimated. A third consideration is that the parasitized nymphs we observed in treated plots were already dead and would then tend to accumulate on sampled leaves leading to a distorted level of parasitism. This is unlikely because we routinely observed parasitoid exuviae on the leaves we sampled. The most likely explanation is that parasitoids were no more severely impacted by certain insecticides than nymphal whiteflies that served as hosts. Thus, parasitoid populations declined in response to insecticide use, but so did population densities of whitefly hosts resulting in steady rates of parasitism. This hypothesis deserves further testing under more controlled conditions. Overall, it is difficult to separate host density and parasitism when only immature stages of hosts and parasitoids are sampled. Samples of adult parasitoids would have allowed an independent assessment of the effect of insecticides on host and parasitoid densities. Densities of adult parasitoids are difficult to estimate and standard sampling techniques are not currently available. This is an important area for future research.

The direct effect of insecticides on whitefly parasitoids has not been widely studied. Gerling (1967) showed that percentage parasitism of *B. tabaci* in cotton fields of the Coachella and Imperial valleys of California was strongly reduced when a mixture of parathion and endrin was used, but declined much less, or even rose, following the use of trichlorfon. Jones *et al.* (1995a) have shown in laboratory experiments that two species of *Encarsia* and two of *Eretmocerus* were highly susceptible to a series of contact insecticides when adults were directly exposed to the toxicants on treated leaves. Many of these materials also may negatively affect immature stages of parasitoids; however, these studies are less conclusive (Jones *et al.*, 1995b).

Parasitism levels often were in excess of 50% over large portions of the season in both Israel and the United States. Because *En. lutea*, *En. luteola*, *Er. mundus*, and *Er. eremicus* are solitary parasitoids, the development of each parasitoid individual is at the expense of one whitefly. Although it is difficult to predict the impact of a given level of parasitism on a host population characterized by overlapping generations, we could clearly expect an increase in the whitefly population in the absence of parasitoids. Without parasitism such an increase could potentially cause many low pest populations to reach outbreak levels, and intensify even further the damage caused by present outbreaks, especially in southern California. Moreover, such outbreaks would require additional insecticide applications, resulting in increased control costs, potentially faster development of insecticide resistance, and reduction or elimination of many species in the native natural enemy complex. Therefore, even a small reduction in parasitism may have an undesired effect and should be avoided. The results of our study suggest that the present arsenal of insecticides in cotton includes materials that may have no, or only minor, effects on levels of host parasitism. However, even the careful use of these insecticides would be expected to reduce parasitoid populations within an area and have detrimental consequences on the longterm biological control provided by parasitoids on different crops attacked by *B. tabaci* within the agricultural ecosystem. Further experiments should be conducted to determine the direct effects of commonly used materials on parasitoid abundance and parasitism, and utilize this knowledge to develop more effective pest management programs that more fully utilize the activity of natural enemies.

Pest management of *B. tabaci* in cotton fields should take into account all of the factors that may have a negative affect on pest population growth. These include, in addition to parasitoids, predators and entomopathogenic fungi. Fungi have not been found to be important in the cotton agroecosystems of Israel and California. However, predators may contribute toward regulating whitefly populations in both Israel and the southwestern United States (Gerling, 1996; Gerling *et al.*, 1997; Naranjo and Hagler, 1998; Naranjo *et al.*, 1997). The influence of insecticides on predators may differ from that on parasitoids. For example, Naranjo and Chu (1996) found that conventional insecticides significantly reduced populations of several abundant species of predators, including *Geocoris* spp. in the Imperial Valley. We might expect that predators also may be adversely affected by insect growth regulators, both because of their specialized behaviors and because of the susceptibility of immature stages. Laboratory and field studies are currently underway to examine the effects of insect growth regulators on native predator species in Arizona.

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REFERENCES

Akey, D. H., Chu, C. C., and Henneberry, T. J. 1992. Application equipment and under-leaf coverage of cotton with cotton seed oils, soap, and fenpropathrin/acephate against the sweetpotato whitefly, *Bemisia tabaci*. *In* "Proceedings of the Beltwide Cotton Conference" (D. J. Herber and D. A. Richter, Eds.), pp. 701–702. National Cotton Council, Memphis, TN.

Ellsworth, P. C., and Meade, D. L. 1994. Action thresholds for whiteflies in Arizona. *In* "Proceedings of the Beltwide Cotton Conference" (D. J. Herber and D. A. Richter, Eds.), pp. 878–881. National Cotton Council, Memphis, TN.

Gerling, D. 1967. Bionomics of the whitefly parasite complex associated with cotton in Southern California. *Ann. Entomol. Soc. Amer.* **60,** 1306–1321.

Gerling, D. 1986. Natural enemies of *Bemisia tabaci*, biological characteristics and potential as biological control agents: A review. *Agric. Ecosystems Environ.* **17,** 99–111.

Gerling, D. 1992. Approaches to the biological control of whiteflies. *Fla. Entomol.* **75,** 446–456.

Gerling, D. 1996. Status of *Bemisia tabaci* in the Mediterranean countries: Opportunities for biological control. *Biol. Control* **6,** 11–22.

Gerling, D., and Sinai, P. 1994. Buprofezin effects on two parasitoid species of whitefly (Homoptera: Aleyrodidae). *J. Econ. Entomol.* **87,** 842–846.

Gerling, D., Motro, U., and Horowitz, A. R. 1980. Dynamics of *Bemisia tabaci* (Gennadius) (Homoptera: Aleurodidae) attacking cotton in the Coastal plain of Israel. *Bull. Entomol. Res.* **70,** 213–319.

Gerling, D., Kravchenko, V., and Lazare, M. 1997. Dynamics of common green lacewing (Neuroptera: Chrysopidae) in Israeli cotton fields, in relation to whitefly (Homoptera: Aleyrodidae) populations. *Environ. Entomol.* **26,** 815–827.

Husain, M. A., and Trehan, K. N. 1933. The life history, bionomics and control of the whitefly of cotton (*Bemisia gossypiperda* M. & L.). *Indian J. Agric. Sci.* **3,** 701–753.

Jones, W. A., Wolfenbarger, D. F., and Kirk, A. A. 1995a. Response of adult parasitoids of *Bemisia tabaci* to leaf residues of selected cotton insecticides. *Entomophaga* **40,** 153–162.

Jones, W. A., Wolfenbarger, D. F., and Ciomperlik, M. 1995b. Insecticide effects on immatures of native and imported *Eretmocerus* spp. *In* "Silverleaf whitefly: 1995 Supplement to the 5-Year National Research and Action Plan—Third Annual Review" (T. J. Henneberry, M. C. Toscano, R. M. Faust, and J. R. Coppedge, Eds.) p. 120. U. S. Dept. Agric. 1995-2.

Lazare, M. 1994. Population dynamics, with and without insecticide treatments, of the natural enemies attacking Bemisia tabaci in cotton fields. M. S. Thesis, Tel Aviv University, Tel Aviv, Israel.

Naranjo, S. E., and Chu, C. C. 1996. Effects of insecticidal management of *Bemisia tabaci* on abundance and impact of indigenous natural enemies. *In* "Technology Transfer in Biological Control: From Research to Practice," p. 242. IOBC-WRPS Bulletin No. 19.

Naranjo, S. E., and Flint, H. M. 1995. Spatial distribution of adult *Bemisia tabaci* in cotton and development and validation of fixed-precision sequential sampling plans for estimating population density. *Environ. Entomol.* **24,** 261–270.

Naranjo, S. E., and Hagler, J. R. 1998. Characterizing and estimating the impact of heteropteran predation. *In* "Predatory Heteroptera in Agroecosystems: Their Ecology and Use in Biological Control" (M. Coll, and J. Ruberson, Eds.). Thomas Say Symposium Proceedings, Entomological Society of America. [in press]

Naranjo, S. E., Chu, C. C., and Henneberry, T. J. 1996a. Economic injury levels for *Bemisia tabaci* in cotton: Impact of crop price, control costs, and efficacy of control. *Crop Protect.* **15,** 779–788.

Naranjo, S. E., Ellsworth, P. C., and Diehl, J. W. 1997. Partial life table studies of *Bemisia* in cotton fields subject to different management strategies. *In* "Silverleaf Whitefly: 1997 Supplement to the 5-Year National Research and Action Plan—Progress Review, Technology Transfer, and New Research and Action Plan" (T. J. Henneberry, M. C. Toscano, T. M. Perring, and R. M. Faust, Eds.), p. 71. U. S. Dept. Agric. 1997-2.

Naranjo, S. E., Chu, C. C., Ellsworth, P. C., Henneberry, T. J., Nichols, R. L., Riley, D. G., Toscano, N. C., and Watson, T. F. 1996b. Results of a two year regional project to determine an action threshold to manage whiteflies in cotton. *In* "Proceedings of the Beltwide Cotton Conference" (D. A. Richter, and J. Amour, Eds.), pp. 132–133. National Cotton Council, Memphis, TN.

Onillon, J. C. 1990. The use of natural enemies for the biological control of whiteflies, *In* "Whiteflies: Their Bionomics Pest Status and Management" (D. Gerling, Ed), pp. 287–313. Intercept Andover, UK.

SAS Institute. 1989. "SAS/STAT User's Guide, Version 6," 4th ed. SAS Institute Inc., Cary, NC.

Sokal, R. R., and Rohlf, F. J. 1981. "Biometry." Freeman, New York.