Cotton Water Stress, Arthropod Dynamics, and Management of *Bemisia tabaci* (Homoptera: Aleyrodidae)

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ABSTRACT The effects of plant water stress on beneficial and pest insects infesting Deltapine-50 short-staple cotton, *Gossypium hirsutum* L., and Pima S-7 long-staple cotton, *Gossypium barbadense* L., were studied in 1993 and 1994 in large replicated field plots in central Arizona. Seasonal densities of eggs, nymphs, or adults of the sweetpotato whitefly, *Bemisia tabaci* (Gennadius), were reduced 45–69% and 22–36% in plots irrigated weekly compared with those irrigated biweekly in 1993 and 1994, respectively. In 1993, DPL-50 had more whiteflies of all stages than Pima S-7, but crop termination dates had no effect on seasonal densities of whiteflies. In 1994, fenpropathrin and acephate insecticide applications provided greater control of whiteflies than buprofezin, an insect growth-regulating insecticide. Application thresholds of 1 adult whitefly per leaf resulted in lower whitefly densities than thresholds of 5 or 10 adults per leaf. In 1994, pink bollworm larvae, *Pectinophora gossypiella* (Saunders), were reduced in plots treated with fenpropathrin and acephate and in plots treated for *B. tabaci* at the threshold of 1 adult per leaf. More *Lygus hesperus* Knight were found in plots irrigated weekly than biweekly in both years. Leaf water potentials (-bars), measured at 3, 7, or 14 d after irrigation in 1993, indicated greater plant water stress in cotton irrigated biweekly at 7 and 14 d after irrigation than in that irrigated weekly at 7 d after irrigation. Yields of seedcotton were greater at thresholds of 1 than at 5 or 10 adult whiteflies per leaf. Combining reduced plant water stress of weekly irrigation with fenpropathrin and acephate applied at a threshold of 1 adult whitefly per leaf provided the best control of *B. tabaci*.

KEY WORDS *Bemisia tabaci, Pectinophora gossypiella, Lygus hesperus, Gossypium* spp., irrigation, pest management

The sweetpotato whitefly, *Bemisia tabaci* (Gennadius), strain B (recently proposed as a new species, *Bemisia argentifolii* Bellows & Perring) (Bellows et al. 1994) continues to be an economically important pest of greenhouse and field crops throughout equatorial areas of the world (De Barro 1995). The widespread distribution of *B. tabaci* is attributed to its exceptionally wide host range (Cock 1986), short generation time (Butler et al. 1986), and resistance to insecticides (Toscano et al. 1995). A formidable amount of research effort has been directed toward the development of control methods for this insect (USDA 1992, Butler et al. 1995). Despite important advances in understanding the basic biology of *B. tabaci*, the agricultural producer has limited available control measures for this pest.

The sweetpotato whitefly is a serious problem in a number of agricultural crops in the southern United States. In the Southwest, whiteflies use numerous weed and ornamental hosts that provide continuous sources of infestation for vegetable crops as well as cotton, *Gossypium* spp. (Watson et al. 1992). Cotton production in the southwestern United States suffers economic losses from *B. tabaci* each year through yield reductions and reduced grade because of lint contamination by honeydew (Henneberry et al. 1995). Producers rely primarily on fenpropathrin and acephate insecticides applied under varying criteria. Preservation of insecticide efficacy depends on rotation of classes of chemicals, mixes of ≥2 chemicals with independent modes of action, full-strength applications, and use only when necessary (Dennehy et al. 1995a). During the 1995 production season, it became clear that the efficacy of available insecticides used in whitefly control programs in Arizona was seriously reduced in some cotton-growing areas (L. Antilla, personal communication).

Cultural practices can provide significant reductions in whiteflies on cotton. We have shown previously that reducing cotton plant water stress through supplemental (Flint et al. 1994) or drip (Flint et al. 1995) irrigation significantly reduces the density of all stages of whitefly. Reducing cotton plant water stress also improves yields (Radin et al. 1989, Chu et al. 1995). Combining these cultural practices with less susceptible cultivars (Flint and Parks 1990, Wilson et al. 1993) and efficient use of insecticides should reduce exposure to damaging levels of whiteflies.

This research furthers our examination of the effect of plant water stress in cotton on yield and fiber quality factors and on densities of pest species, including *B. tabaci*, *Pectinophora gossypiella* (Saunders), *Lygus hesperus* Knight, and various species of beneficial insects. In 1993, we compared the effect of weekly or biweekly irrigation and 2 dates of crop termination on pest and natural enemy densities on upland and pima cottons. On the basis of these and previous results (Flint and Parks 1990, Flint et al. 1992, 1995), we extended our studies in 1994 to examine the implications for pest management of *B. tabaci*. We used weekly or biweekly irrigation to manipulate plant water stress. We also applied either fenpropathrin and acephate or buprofezin insecticides using action thresholds of 1, 5, or 10 adults per leaf.

Materials and Methods

Tests were conducted on the University of Arizona Maricopa Agricultural Center (MAC) farm, Maricopa, AZ, in 1993 and 1994. The soil type on the farm is sandy loam (fine loamy, mixed, hyperthermic typic haplargid) and the growing season is ≈245 d. Cotton was planted, fertilized, and maintained by the farm manager using standard grower practices for the area. No totally untreated plots were included in the tests because this is not a grower option and because such plots are destroyed by insects before the end of the test periods. Untreated plots also serve as a source of insect pests for surrounding experiments.

The 1993 study compared the effects of weekly or biweekly furrow irrigation (every 7 or 14 d, respectively) and irrigation termination date on insect densities in a short-staple cultivar, *Gossypium hirsutum* L., 'Deltapine 50' (DPL-50), and a long-staple cultivar, *Gossypium barbadense* L., 'Pima S-7'. DPL-50 carries the Deltapine smoothleaf trait (Lee 1985) and has reduced susceptibility to whiteflies (Flint et al. 1992). Pima S-7 also has the smoothleaf trait and is a current commercial, long-staple cultivar grown in the Southwest. The experimental design was a split-split plot with irrigation interval as whole plots, irrigation termination dates as split plots, and cultivars as split-split plots. Whole plots measured 24 rows wide (1.01-m row centers) by 165 m long, split plots measured 12 rows by 165 m, and split-split plots measured 12 rows by 82 m (0.1 ha). There were 3 replicate plots for each of 8 treatments for a total of 24 plots. The cultivars were planted with an in-furrow application of phorate (American Cyanamid, Wayne, NJ; 2.24 kg [AI]/ha) on 6 April. All plots were irrigated on 25 April and 26 May to produce a uniform stand. The weekly and biweekly irrigation schedules began on 4 and 11 June, respectively. All plots received 12.7 cm of water on biweekly dates and the plots irrigated weekly received a supplemental 7.6 cm on a weekly basis. Access to the field was provided by irrigating every other row. The additional weekly irrigations were made on rows not irrigated the preceding week. Plots that were terminated 27 August received a total of 183 or 107 cm of water in plots irrigated weekly or biweekly, respectively. Plots that were terminated 10 September received a total of 208 or 122 cm of water, respectively. Early-terminated cotton was defoliated 17 September and late-terminated cotton on 1 October by applying ethephon (Rhone-Poulenc, Research Triangle Park, NC; 1.68 kg [AI]/ha). All plots were sprayed with acephate (Valent USA, Walnut Creek, CA; 0.56 kg [AI]/ha) for *L. hesperus* on 30 June and 9 July. Insecticide applications for whitefly control were made on 3 August (endosulfan, FMC, Philadelphia, PA; fenpropathrin, Valent USA, 0.83 and 0.17 kg [AI]/ha, respectively) 7, and 13 August (fenpropathrin and acephate, 0.17 and 0.56 kg [AI]/ha respectively). All applications of insecticides were made by using a ground rig and delivering 280 liters of spray per hectare in both years.

In 1994 a complete factorial design was used to compare the effects of weekly or biweekly irrigations, insect control with fenpropathrin and acephate or buprofezin, and 3 levels of insecticide control provided by action thresholds of 1, 5, or 10 adult *B. tabaci* per leaf on DPL-50. The experimental design was a randomized complete block with 12 treatments and 4 replicate plots per treatment for a total of 48 plots. Each plot was 12 rows by 82 m (0.1 ha). All plots were planted on 4 April with DPL-50 treated with a side dressing of phorate (2.24 kg [AI]/ha). All plots were irrigated 5 April, 2, 23 May, and 6 June with 12.7 cm water to produce a uniform stand. The weekly and biweekly irrigations began on 10 and 17 June, respectively. All plots received 12.7 cm of water on biweekly dates, and plots irrigated weekly received a supplemental 7.6 cm weekly. The final irrigation of 12.7 cm of water was made to all plots on 12 August (total water for weekly, 152 cm; biweekly, 114 cm). All plots were defoliated with ethephon (1.68 kg [AI]/ha) on 1 September. The insecticide applications consisted of either fenpropathrin and acephate (0.17 and 0.56 kg [AI]/ha, respectively) or the insect growth regulator buprofezin (AgroEvo, Wilmington, DE; 0.28 kg [AI]/ha; Akey et al. 1993). Applications were made to a set of plots once the average density of adults for a particular treatment exceeded the action threshold. After the initial application of buprofezin, the decision to spray with this material was based on insect density in fenpropathrin and acephate plots of the same irrigation and threshold treatments because buprofezin does not affect adults. These insecticides were applied 2–5 times, depending on whitefly densities, between 12 July and 24 August (Table 1). In addition, an application of acephate (0.56 kg [AI]/ha) was made to all plots on 6 July for *L. hesperus* and an application of chlorpyrifos

Table 1. Insecticide application schedule and actual numbers of whitefly (WF) adults at application, MAC farm, 1994

Irrigation	Threshold, adults/leaf	No. applications	Application dates[a]	Adult WF/leaf at application[b]	
				Fenpropathrin/acephate	Buprofezin
Weekly	1	4	1, 2, 4, 5	2.9	6.5
	5	2	2, 4	10.0	13.1
	10	2	3, 5	13.3	10.5
Biweekly	1	5	1, 2, 3, 4, 5	4.8	5.2
	5	3	2, 4, 5	8.5	21.6
	10	2	2, 4	10.4	16.4

[a] 1, 12 July; 2, 26 July; 23, 2 August; 4, 16 August; 5, 24 August. Fenpropathrin and acephate applied at 0.17 and 0.56 kg (AI)/ha, respectively; buprofezin applied at 0.28 kg (AI)/ha, both in 280 liter of solution per ha. Applications do not include acephate (0.56 kg [AI]/ha) on 6 July for lygus bugs and chlorpyrifos (2.13 kg [AI]/ha) on 8 August for beet armyworm.

[b] Mean density over all sample dates that resulted in a decision to apply insecticides.

(DowElanco, Indianapolis, IN; 2.13 kg [AI]/ha) on 8 August for beet armyworm, *Spodoptera exigua* (Hübner).

Whitefly Infestations. In both years, we estimated the density of adult *B. tabaci* using the leaf-turn method of Naranjo and Flint (1995), in which 5th main-stem node leaves counted from the top of the plant are gently turned to count the adult flies on the underside. All adult whitefly counts were made during reduced flight activity at 0700–0900 hours (MST), although the time-of-day counts might not have affected the outcome (Diehl et al. 1995). In 1993, we counted adults on 15 randomly selected 5th main-stem node leaves in the central area of each plot on 16 sample dates from 24 May to 16 September. In 1994, we similarly counted adults on 20 leaves per plot on 11 sample dates from 31 May to 16 August. These adult samples were used to determine the need to spray insecticides based on threshold averages of 1, 5, or 10 adult whiteflies per leaf. Sampling was usually conducted midweek, and the indicated insecticide sprays were applied the day following sampling.

Densities of eggs and nymphs (crawler through "pupal" stages) were determined from 3.88-cm^2 disks taken from sector 2 of the 5th main-stem node (Naranjo and Flint 1994). Samples of 15 leaves were collected randomly from the central area of each plot on the same schedule as the counts of adults on leaves previously described. Specimens of whiteflies from field plots in 1993 and 1994 were identified by A. C. Bartlett (USDA-ARS; Phoenix, AZ) as "B" strain of *B. tabaci* by randomly amplified polymorphic DNA-polymerase chain reaction analysis (Gawel and Bartlett 1993). Subsequently, this strain was proposed as a new species, *B. argentifolii* Bellows & Perring (Bellows et al. 1994). Specimens from these tests are held at the Western Cotton Research Laboratory, Phoenix, AZ.

Pink Bollworm Infestations. In 1993, samples of 50 susceptible bolls (firm bolls ≈14–21 d old) were collected from the central area of each plot on 7 dates between 9 August and 16 September. A further sample of 150 bolls per plot was collected on 23 October; these bolls were hand-dissected for diapause larvae, which is the overwintering stage of the pink bollworm. In 1994, samples of 25 bolls per plot were collected on 5 dates between 13 July and 6 September. There were no late-season bolls for sampling because the early termination of the crop allowed maturation of the bolls on the plants (precisely the reason for short-season cotton production). All bolls collected during the season were supported on wire screens above paper towels in ventilated plastic boxes for 2 wk at 27°C and 50–70% RH before counts of cut-out larvae, pupae, and adults were recorded. This method allowed small larvae, which might be missed if bolls were opened for observation, to complete development and to exit bolls.

Sweep Net Samples. Sweep net samples of 100 sweeps were collected from each plot on 6 dates from 24 May to 21 June in 1993 and on 4 dates from 16 June to 6 July in 1994. Sweeps were made with a net (40 cm diameter) through 2 separate but centrally located rows in each plot (50 sweeps per row combined). In both years, sweep net sampling was discontinued when insecticide applications began. Collections were held in plastic bags, which were then frozen before sorting in the laboratory. In 1993, collections were sorted for the following 8 beneficial insects: *Collops vittatus* (Say); convergent lady beetle, *Hippodamia convergens* Guérin-Méneville; minute pirate bug, *Orius tristicolor* (White); the lacewing *Chrysoperla carnea* Stevens; *Geocoris punctipes* Say; damsel bugs, *Nabis* spp.; and combined assassin bugs, *Zelus* spp. and *Sinea* spp. Spiders were separated as a group without species identification. The following 4 pest insects also were counted: *L. hesperus* (combined nymphs and adults); cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter); and the stinkbugs *Chlorochroa* spp. and *Thyanta* spp. In 1994, collections were sorted into 13 beneficial species, including those observed in 1993 or other arthropod groups (such as spiders), and 3 damaging species: *P. seriatus*, *L. hesperus* (adults and nymphs combined), and stinkbugs.

Leaf Water Potential. In 1993, we measured the effect of the 2 irrigation schedules on plant water stress. Leaf water potential was measured in plots of DPL-50 and Pima S-7. A pressure chamber (Soilmoisture Equipment, Santa Barbara, CA) was used to measure the total water potential of cotton leaves according to the methods of Meron et al. (1987) for leaf collection and Turner (1987) for operation of the chamber. Leaf water potential is an index of plant water stress and is obtained from the pressure (-bars) required to cause the exudation of interstitial leaf sap. Leaves were collected from the 5th main-stem node of cotton

Table 2. Effects of irrigation frequency, cultivar, and termination date on mean seasonal densities of *B. tabaci*, MAC farm, 1993

Main factor	No. eggs/cm²	F^a	No. nymphs/cm²	F^a	No. adults/leaf	F	df
Irrigation Frequency							
Weekly	16.4 ± 2.5	99.4**	4.3 ± 0.5	350.4**	5.2 ± 0.3	25.3*	1, 2
Biweekly	41.6 ± 6.5	—	10.4 ± 2.2	—	9.5 ± 1.3	—	—
Cultivar							
DP50	31.0 ± 7.1	39.4**	10.0 ± 2.2	96.3**	8.2 ± 1.3	5.8*	1, 8
Pima S-7	20.9 ± 3.7	—	4.7 ± 0.7	—	6.5 ± 0.9	—	—
Termination							
Early	27.0 ± 4.0	0.4	5.8 ± 0.9	2.6	6.4 ± 0.7	1.0	1, 4
Late	30.9 ± 7.7	—	8.9 ± 2.3	—	8.3 ± 1.4	—	—

F and degrees of freedom for main factor; *, $P < 0.05$; **, $P < 0.01$. All insect densities reported as mean ± SE, $n = 12$.

plants by shading and placing a humidified plastic bag over the leaf, excising the leaf, expressing the air from the bag, sealing the bag, then placing the bag in an insulated storage chest containing ice. Readings of leaf water potential were made in the laboratory within 1 h of excision. All leaves were collected between 0900 and 1100 hours (MST) at 3 and 7 d after irrigation in plots irrigated weekly (irrigation began after leaf collection on day 7) and at 3, 7, and 14 d after irrigation in those irrigated biweekly. This schedule provided data for maximum water stress at the end of the interirrigation periods. We collected 3 leaves from the interior of each plot on each sample date beginning 7 June following an irrigation of all plots 3 d earlier. Sampling was discontinued after 3 September.

Yield, Fiber Properties, and Sugar Content of Lint. Machine-picked samples of seedcotton for yield determination were collected 10 October (1993) and 17 October (1994) using a 2-row spindle picker. Thirty meters each of 3 adjacent rows (total of 60 m of row) were picked from the central area of each plot, and the seedcotton was weighed and microginned at the laboratory to determine percentage lint (1993 only). Samples of the lint were commercially tested (Starlab, Knoxville, TN) to determine micronaire, fiber length, percentage elongation to breaking, and fiber strength.

Sugar contamination of lint by honeydew was determined from samples of hand-picked seedcotton collected from the lowest fully open boll on each of 20 plants centrally located in each plot on 22 September 1993 or 19 and 31 August 1994. Typical summer rainfall in both years undoubtedly reduced sugar contamination, but no rainfall preceded the samples for at least 2 wk. Stickiness was also determined for the 1994 samples using thermodetector tests conducted by H. H. Perkins (Cotton Quality Research Station, USDA, Clemson, SC). Thermodetection tests heat cotton between aluminum plates and then determines the number of sticky spots resulting from caramelized sugar (Brushwood and Perkins 1993). Amounts of soluble sugars (combined glucose, fructose, and sucrose) were determined in 1993 and 1994 by high-performance liquid chromatography and a colorimetric method using a microplate assay as described by Hendrix and Peelen (1987) and Hendrix (1993).

Statistical Analysis. Insect density, water stress, yield, and lint quality data were tested by ANOVA for split-split plot (1993) or randomized complete block (1994) experimental design using SAS (SAS Institute 1988) and MSTAT-C (Michigan State University 1990). All insect counts were transformed by $\ln(x + 1)$ to normalize the data for analyses, but all densities are presented as untransformed in the results. Mean comparisons involving >2 means were separated using the Tukey studentized range test. All insect and water stress data were analyzed on the basis of seasonal averages for each plot. In 1993, seasonal means for insect density for early- and late-terminated plots were based on samples collected between 24 May and 14 September and 24 May and 30 September, respectively. In 1994, seasonal means for insect density were based on samples collected between 31 May and 30 August. We further examined treatment effects on *B. tabaci* density separately for each sample date.

Results

Whitefly Infestations. In 1993, cotton plants irrigated biweekly during the season had 2.5, 2.4, and 1.8 times greater average densities of eggs ($P < 0.01$), nymphs ($P < 0.01$), and adults ($P < 0.05$), respectively, than cotton plants irrigated weekly (Table 2). DPL-50 had 1.8, 2.1, and 1.3 times greater average densities of eggs ($P < 0.01$), nymphs ($P < 0.01$), and adults ($P < 0.05$), respectively, than Pima S-7. There was no significant effect of irrigation termination date (27 August or 10 September) on whitefly densities. There were no significant 3-way interactions in these comparisons ($P > 0.05$). Whitefly densities in both DPL-50 and Pima S-7 increased slowly during the period 24 May to 21 July, densities then increased sharply in samples collected 28 July (Fig. 1), reflecting the immigration of adults that is a typical occurrence in cotton fields on the MAC farm (Flint et al. 1992). Applications of insecticide on 3, 7, and 13 August reduced the

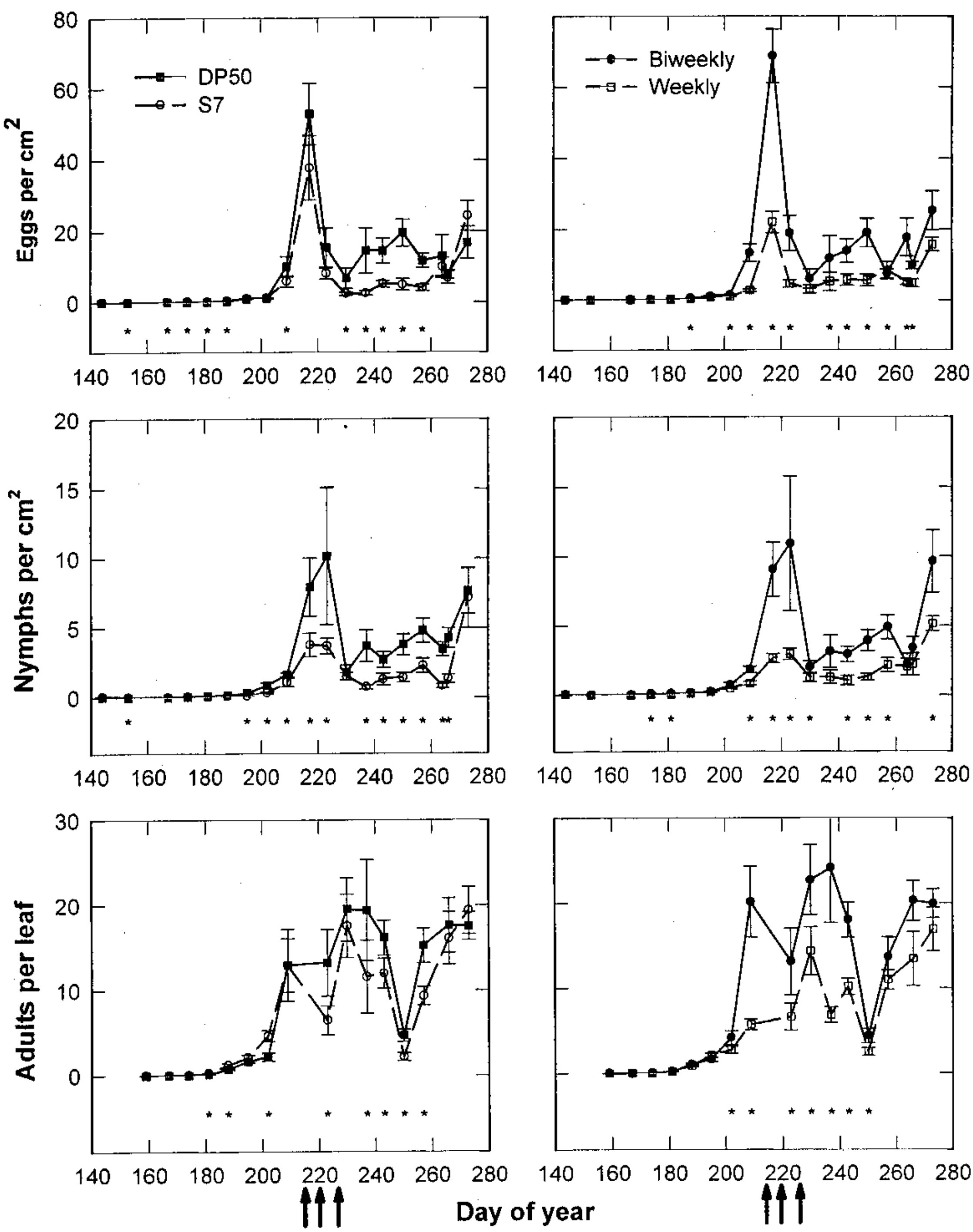

Fig. 1. Densities of eggs, nymphs, and adults of *B. tabaci* on short-(DPL-50) and long-(Pima S-7) staple cotton irrigated weekly or biweekly, MAC farm, 1993. Arrows indicate insecticide applications to control whiteflies; asterisks denote significant differences ($P < 0.05$) between cultivars or irrigation regimes.

numbers of adults on leaves. Thereafter, DPL-50 plots generally had greater numbers of eggs and adults than Pima S-7, and plots irrigated biweekly had higher densities than those irrigated weekly.

Similarly, in 1994, cotton plants irrigated biweekly during the season had greater densities of all stages of *B. tabaci;* however, the difference between irrigation regimes was less marked. There

Table 3. Effects of irrigation frequency, insecticidal control, and action thresholds for initiating control on mean seasonal densities of *B. tabaci*, MAC farm, 1994

Factor	No. eggs/cm^2	*F*	No. nymphs/cm^2	*F*	No. adults/leaf	*F*	df
			Main factors				
Irrigation							
Weekly	2.6 ± 0.5	8.1**	0.6 ± 0.1	6.0**	2.9 ± 0.3	7.8**	1, 33
Biweekly	4.1 ± 0.9	—	0.9 ± 0.2	—	3.7 ± 0.5	—	—
Insecticide							
Fenpro/aceph[a]	1.3 ± 0.2	137.1**	0.4 ± 0.1	95.9**	2.3 ± 0.2	81.5**	1, 33
Buprofezin	5.4 ± 0.9	—	1.2 ± 0.2	—	4.4 ± 0.4	—	—
Threshold							
1/leaf	1.8 ± 0.5b	24.8**	0.4 ± 0.1b	26.9**	1.9 ± 0.2b	43.2**	2, 33
5/leaf	3.8 ± 0.9a	—	0.8 ± 0.1a	—	3.9 ± 0.5a	—	—
10/leaf	4.4 ± 1.2a	—	1.1 ± 0.3a	—	4.1 ± 0.5a	—	—
			By insecticide				
Fenpro/aceph[a]							
1/leaf	0.5 ± 0.1c	59.8**	0.2 ± 0.0b	22.9**	1.5 ± 0.3b	24.0**	2, 15
5/leaf	1.4 ± 0.2b	—	0.4 ± 0.1a	—	2.4 ± 0.1a	—	—
10/leaf	1.9 ± 0.3a	—	0.6 ± 0.1a	—	2.9 ± 0.3a	—	—
Buprofezin							
1/leaf	3.1 ± 0.6b	4.9*	0.7 ± 0.1b	8.7**	2.4 ± 0.2b	20.9**	2, 15
5/leaf	6.3 ± 1.3ab	—	1.2 ± 0.1a	—	5.5 ± 0.5a	—	—
10/leaf	6.8 ± 2.1a	—	1.7 ± 0.4a	—	5.2 ± 0.9a	—	—

*, $P < 0.05$; **, $P < 0.01$. All insect densities reported as mean ± SE, with n = 16–24 for main factors and n = 8 for thresholds by insecticides. Means followed by the same letter are not significantly different (Tukey studentized range tests, $P = 0.05$).
[a] Fenpropathrin/acephate.

were 1.6, 1.5, and 1.3 times greater average densities of eggs ($P < 0.01$), nymphs ($P < 0.01$), and adults ($P < 0.01$), respectively, than cotton plants irrigated weekly (Table 3). Cotton plants treated with buprofezin had 4.2, 3.0, and 1.9 times greater numbers of eggs ($P < 0.01$), nymphs ($P < 0.01$), and adults ($P < 0.01$), respectively, than plants treated with fenpropathrin and acephate. Regardless of the insecticide materials applied, the lowest application threshold of 1 adult per leaf provided significantly greater reductions in eggs, nymphs, and adults compared with thresholds of 5 or 10 adults per leaf, which generally were not significantly different from one another.

There were significant interactions for irrigation × insecticide × threshold for eggs ($F = 5.2$; df = 2, 33; $P < 0.05$), nymphs ($F = 6.8$; df = 2, 33; $P < 0.01$), and adults ($F = 13.4$; df = 2, 33; $P < 0.01$), primarily because of inconsistencies in the effectiveness of the insecticides used. Therefore, data for the effects of threshold levels were further tested separately for each insecticide. As before, for fenpropathrin and acephate treatments, the threshold of 1 adult whitefly per leaf provided greater reductions in eggs ($P < 0.01$), nymphs ($P < 0.01$), and adults ($P < 0.01$), than did thresholds of 5 or 10 adult whiteflies per leaf. Treatments of buprofezin provided greater control of eggs ($P < 0.05$) when applied at a threshold of 1 adult whitefly per leaf than at 10 adults per leaf, and greater control of nymphs ($P < 0.01$) and adults ($P < 0.01$) than thresholds of either 5 or 10 adults per leaf. As in 1993, the numbers of adults found on leaves increased sharply in the samples collected in late July (Fig. 2) and attained spray thresholds in 44 of 48 plots. Response to spraying depended upon thresholds and insecticides used. Overall, the lowest densities of immature and adult stages in 1994 occurred in plots of cotton irrigated weekly and treated with fenpropathrin and acephate applied at a threshold of 1 whitefly per leaf. A reduction of ≈68% in seasonal densities of nymphs per plot, for example, was achieved by this combination compared with biweekly irrigation and buprofezin applied at a threshold of 10 adult whiteflies per leaf.

As expected, progressively more insecticide applications were needed over the season as the action threshold was reduced (Table 1). In plots irrigated biweekly, 5, 3, and 2 applications were needed using action thresholds of 1, 5, and 10 adults per leaf. The overall lower densities of *B. tabaci* in plots irrigated weekly resulted in a reduction of 1 insecticide application at the 2 lower action thresholds of 1 and 5 adults per leaf. The plots sprayed with buprofezin received the same number of treatments as those sprayed with the fenpropathrin and acephate insecticide because only the first applications were made on the basis of adult density. As noted in *Materials and Methods,* all subsequent applications for these plots were made on the basis of adult densities in fenpropathrin and acephate plots because buprofezin does not directly affect the adult stage. Finally, the average density of adults at the time of insecticide application differed from the action threshold, particularly at thresholds of 1 and 5 adults per leaf. For example, the average density triggering a spray application for thresholds of 1, 5, and 10 adults per

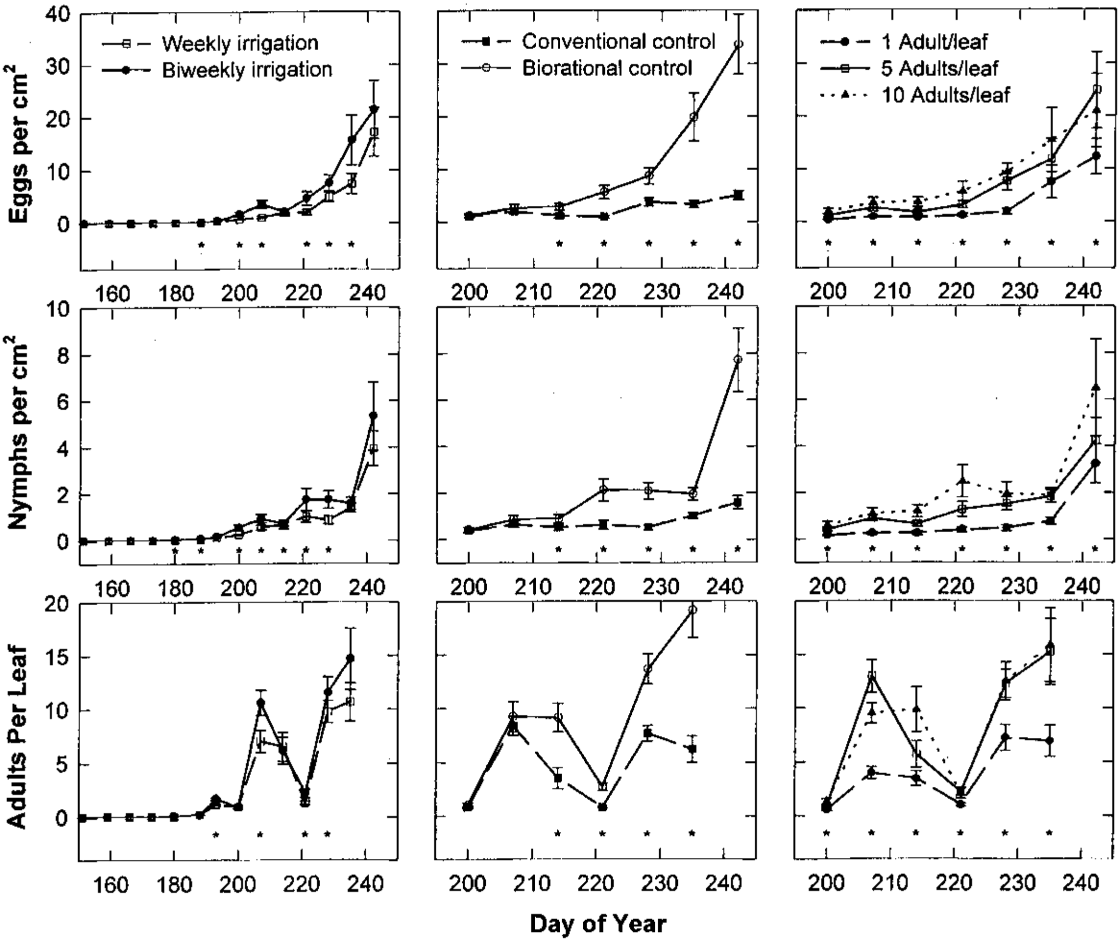

Fig. 2. Numbers of eggs, nymphs, and adults of *B. tabaci* on short-staple (DPL-50) cotton irrigated weekly or biweekly and treated with fenpropathrin and acephate or buprofezin applied at action thresholds of 1, 5, or 10 adult whiteflies per 5th main-stem leaves. Asterisks denote significant differences ($P < 0.05$) between irrigation regimes, insecticide type or action threshold for control.

Table 4. Response of pink bollworm (PBW) to effects of irrigation frequency, cultivar, and termination date, MAC farm, 1993

Factor	Total PBW/plot during season ± SE	F (df)	Diapause larvae/plot end of season ± SE	F (df)
Irrigation				
Weekly	9.7 ± 1.5	7.32*	126.2 ± 36.7	0.98
Biweekly	15.3 ± 2.4	(1, 10)	119.3 ± 25.7	(1, 8)
Cultivar				
DPL-50	13.4 ± 2.6	0.00	211.5 ± 23.2	36.91**
Pima S-7	11.5 ± 1.5	(1, 10)	33.9 ± 7.2	(1, 4)
Termination				
Early	—	—	139.7 ± 36.8	0.01
Late	—	–	105.8 ± 24.7	(1, 8)

*, $P < 0.05$; **, $P < 0.01$. Sample of 350 bolls per plot during season, 150 bolls per plot end season, 24 total plots. All insect densities reported as mean ± SE with $n = 12$.

leaf were 4.8, 8.5, and 10.4 adults per leaf, respectively, for plots irrigated biweekly receiving fenpropathrin and acephate. This result occurred because we sampled and made spray decisions on a weekly basis rather than more often.

Pink Bollworm Infestations. In 1993, there were 1.6 times greater densities of pink bollworms in bolls from plots irrigated biweekly than from plots irrigated weekly ($P < 0.05$) in samples collected during the season (before early and late termination dates; Table 4). There was a significant interaction for irrigation × cultivar ($F = 8.65$; df = 1, 10; $P < 0.05$) because DPL-50 had greater infestations than Pima S-7 under weekly but not biweekly irrigations. Late-season hand-dissected bolls collected 23 October contained 6.2 times greater numbers of diapause larvae from plots of DPL-50 than from Pima S-7 ($F = 36.9$; df = 1, 4; $P < 0.01$). Because no differences in boll infesta-

Table 5. Response of pink bollworm (PBW) to effects of irrigation frequency, insecticidal control, and action thresholds of whitefly infestation, MAC farm, 1994

Factor	Treatment	Total PBW/plot during season	*F*
		Main factors	
Irrigation	Weekly	51.5 ± 21.7	1.4
	Biweekly	57.0 ± 25.6	(df = 1, 33)
Insecticide	Fenpro/aceph[a]	38.5 ± 16.3	67.5**
	Buprofezin	70.5 ± 18.8	(df = 1, 33)
Threshold	1/leaf	49.0 ± 6.9b	3.7*
	5/leaf	56.7 ± 6.0a	(df = 2, 33)
	10/leaf	57.2 ± 4.8a	—
		By Insecticide	
Fenpro/aceph[a]	1/leaf	28.8 ± 3.9b	7.0**
	5/leaf	39.6 ± 5.6ab	(df = 2, 5)
	10/leaf	47.1 ± 6.1a	—
Buprofezin	1/leaf	69.3 ± 8.6	0.3
	5/leaf	73.8 ± 6.2	(df = 2, 5)
	10/leaf	67.3 ± 5.6	—

*, $P < 0.05$; **, $P < 0.01$. Sample of 125 bolls per plot, 48 total plots. All insect densities reported as mean ± SE with n = 16–24. Means followed by the same letter are not significantly different (Tukey studentized range tests, $P = 0.05$).

[a] Fenpropathrin/acephate.

tion were found between DPL-50 and Pima S-7 during the season, we have no explanation for greater numbers of diapause larvae in bolls of DPL-50. There were no significant interactions for any of the main treatment effects.

In 1994, irrigation scheduling had no significant effect on pink bollworm infestations but plots treated with fenpropathrin and acephate (intended for whitefly control) had ≈1/2 as many pink bollworms as plots treated with buprofezin ($P < 0.01$; Table 5). More frequent spraying at the threshold of 1 adult whitefly per leaf also significantly reduced infestations of pink bollworm ($P < 0.05$). There were significant interactions for insecticide × threshold ($F = 3.38$; df = 2, 33; $P < 0.05$) and irrigation × insecticide × threshold ($F = 5.04$; df = 2, 33; $P < 0.05$) because buprofezin was less effective than fenpropathrin and acephate at each threshold. A comparison of insecticide treatments indicated that increased applications at the threshold of 1 whitefly per leaf with fenpropathrin and acephate caused reductions in pink bollworm infestations compared with fewer applications for the threshold of 10 whiteflies per leaf ($P < 0.01$). Increased applications of buprofezin did not have an effect on pink bollworms.

Sweep Net samples. Most of the arthropods sampled occurred at low densities (<3 per 100 sweeps), and only those for which significant treatment effects occurred are shown (Table 6). In 1993, the density of *G. punctipes* was greater in plots of cotton irrigated biweekly, whereas densities of *C. carnea* and *L. hesperus* were greatest in those irrigated weekly. Plots of Pima S-7 had more *H. convergens* and *C. vittatus* than plots of DPL-50. Other arthropods for which there were no significant differences, but whose overall average numbers exceeded 3 per 100 sweeps, were *Nabis* spp. (10.0 ± 0.6) (mean ± SE) and spiders (11.8 ± 0.9). In 1994, greater numbers of *L. hesperus*, *P. seriatus*, *C. vittatus*, and spiders were found in plots irrigated weekly. Arthropods for which there were no significant differences were *G. punctipes* (7.4 ± 0.3), *Nabis* spp. (3.6 ± 0.3), *O. tristicolor* (5.0 ± 0.3), and *H. convergens* (3.6 ± 0.3). There were no significant differences for any of the other insect species or combined groups for either year.

Leaf Water Potential. The seasonal average leaf water potentials (-bars) indicated greater plant water stress in plots irrigated biweekly than in those irrigated weekly (20.1 ± 0.30, 18.3 ± 0.17 −bars, respectively, $F = 12.2$; df = 1, 5; $P < 0.05$), and greater water stress in Pima S-7 than in DPL-50 plants (20.0 ± 0.34, 18.8 ± 0.26 −bars, respectively, $F = 30.2$; df = 1, 40; $P < 0.01$). Plants had lower water stress 3 d following irrigation than at 7 d and lower stress at 7 d than at 14 d (3 d, 18.2 ± 0.20; 7 d, 19.2 ± 0.21; 14 d, 22.0 ± 0.39; $F = 60.5$, df = 2, 40; $P < 0.01$; Tukey studentized range test, $P = 0.05$). There were no significant interactions between main factors. These results indicate that plants irrigated biweekly had greater plant water stress than those irrigated weekly during their additional week between irrigations.

Yield, Sugar Content of Lint, and Fiber Properties. In 1993, yield of seedcotton was 21% great-

Table 6. Average numbers of indicated arthropods in samples of 100 sweeps per plot for which significant differences existed, MAC farm, 1993, 1994

Year	Species	Irrigation		Cultivar		F^a	Significance
		Weekly	Biweekly	DPL-50	Pima S-7		
1993[b]	*L. hesperus*	20.0 ± 1.7	13.3 ± 1.1	—	—	19.2	0.000
	G. punctipes	11.0 ± 0.7	14.9 ± 1.0	—	—	10.9	0.001
	C. carnea	4.1 ± 0.5	2.3 ± 0.3	—	—	16.0	0.000
	H. convergens	—	—	6.8 ± 0.5	11.5 ± 0.8	38.5	0.000
	C. vittatus	—	—	11.1 ± 1.0	17.2 ± 1.4	37.6	0.000
1994[b]	*L. hesperus*	17.2 ± 1.2	15.0 ± 1.0	—	—	5.2	0.030
	P. seriatus	1.4 ± 0.2	0.9 ± 0.1	—	—	10.4	0.004
	C. vittatus	5.5 ± 0.4	4.4 ± 0.4	—	—	7.4	0.010
	Spiders	8.8 ± 0.5	7.5 ± 0.5	—	—	6.0	0.020

[a] Factorial analysis of variance (MSTAT-C).

[b] Average number per plot for 5 sweep net samples collected 24 May–21 June 1993 or 4 samples collected 16 June–6 July 1994.

Table 7. Effects of irrigation frequency, cultivar, and termination date on seed cotton yields and sugar content of lint, MAC farm, 1993

Factor	Seed cotton, kg/ha	F	Mg sugar/g lint[a]		
			22 Sept	F	df
Irrigation					
Weekly	4,377 ± 138	279.4**	0.34 ± 0.03	11.1*	1, 2
Biweekly	3,458 ± 128	—	0.28 ± 0.02	—	—
Cultivar					
DP50	4,190 ± 164	6.8*	0.36 ± 0.03	6.8*	1, 8
Pima S-7	3,644 ± 183		0.26 ± 0.01		
Termination					
Early	3,963 ± 207	0.6	0.31 ± 0.03	0.3	1, 4
Late	3,871 ± 175	—	0.32 ± 0.02	—	—

F value and degrees of freedom for main factor; *, $P < 0.05$; **, $P < 0.01$. Mean ± SE with $n = 12$.
[a] Total milligrams of soluble sugar (combined glucose, fructose, sucrose) per gram of lint measured colorimetrically by the methods of Hendrix (1993).

er in plots irrigated weekly than in those irrigated biweekly ($P < 0.01$; Table 7). Also, yield was 13% greater in plots of DPL-50 than in those of Pima S-7 ($P < 0.05$). Irrigation termination date did not have a significant effect on yields, and there were no significant 2-way interactions ($P > 0.05$). Analysis for soluble sugars (glucose, fructose, and sucrose) in lint samples collected 22 September indicated greater sugar content in cotton from plots irrigated weekly ($P < 0.05$). DPL-50 lint had significantly more sugar than did Pima S-7 lint ($P < 0.05$). There was no effect of termination date on the sugar content of lint.

In 1994, yield of seedcotton was 8% greater in plots irrigated biweekly compared with those irrigated weekly ($P < 0.01$, Table 8). Yield in plots treated with fenpropathrin and acephate was 16% greater than yield from plots treated with buprofezin ($P < 0.05$). Plots that were treated at a threshold of 1 adult whitefly per leaf had 10% greater yield than plots treated at 5 adults per leaf and 16% greater yield than plots treated at 10

Table 8. Effects of irrigation frequency, insecticidal control, and action thresholds for initiating control for *B. tabaci* on lint yields, stickiness and sugar content of lint, MAC farm, 1994

Factor	Seed cotton, kg/ha	F	Stickiness[a], 19 Aug.	F	Stickiness[b], 31 Aug.	F	Mg sugar/g lint[c], 19 Aug.	F	df
				Main factors					
Irrigation									
Weekly	3,325 ± 91	12.3**	2.4 ± 0.7	1.4	3.7 ± 0.6	1.8	0.52 ± 0.05	9.6**	1, 33
Biweekly	3,599 ± 111	—	3.7 ± 0.9	—	4.9 ± 0.8	—	0.73 ± 0.06	—	—
Insecticide									
Fenpro/aceph[d]	3,712 ± 108	27.8**	2.8 ± 0.7	0.3	4.1 ± 0.6	0.2	0.59 ± 0.06	1.0	1, 33
Buprofezin	3,211 ± 72	—	3.4 ± 0.9	—	4.5 ± 0.8	—	0.66 ± 0.06	—	—
Threshold									
1/leaf	3,749 ± 169a	14.1**	1.5 ± 0.4	2.0	3.0 ± 0.4	2.2	0.56 ± 0.07	1.0	2, 33
5/leaf	3,416 ± 72b	—	3.8 ± 1.2	—	4.5 ± 0.8	—	0.64 ± 0.06	—	—
10/leaf	3,222 ± 90b	—	3.9 ± 1.1	—	5.4 ± 1.3	—	0.68 ± 0.09	—	—
				By insecticide					
Fenpro/aceph[d]									
1/leaf	4,225 ± 173a	26.1**	1.5 ± 0.7	1.4	3.4 ± 0.6	0.4	0.40 ± 0.07a	5.8*	2, 15
5/leaf	3,590 ± 46b	—	4.2 ± 1.8	—	4.6 ± 1.4	—	0.62 ± 0.09ab	—	—
10/leaf	3,323 ± 145b	—	2.5 ± 0.9	—	4.4 ± 1.1	—	0.76 ± 0.13b	—	—
Buprofezin									
1/leaf	3,283 ± 166	0.7	1.5 ± 0.5	2.2	2.6 ± 0.6	3.4	0.73 ± 0.09	1.1	2, 15
5/leaf	3,243 ± 108	—	3.4 ± 1.8	—	4.4 ± 1.1	—	0.66 ± 0.09	—	—
10/leaf	3,120 ± 103	—	5.3 ± 2.1	—	6.5 ± 2.0	—	0.59 ± 0.12	—	—

*, $P < 0.05$; **, $P < 0.01$. Mean ± SE with $n = 16$–24. Means with the same letter are not significantly different (Tukey studentized range test, $P = 0.05$).
[a] Thermo-detector readings 2 wk before defoliation.
[b] Thermo-detector readings after defoliation.
[c] Total milligrams of soluble sugar (combined glucose, fructose, sucrose) per gram of lint measured colorimetrically by the methods of Hendrix (1993).
[d] Fenpropathrin/acephate.

adults per leaf ($P < 0.01$). Further analysis comparing thresholds within the 2 classes of insecticide treatment indicated that for fenpropathrin and acephate treatments, a threshold of 1 adult whitefly per leaf produced 18 and 27% greater yield than thresholds of 5 or 10 adults per leaf, respectively ($P < 0.01$). However, threshold did not have an effect on yield when buprofezin was applied.

Lint percentages derived from microginning samples of machine-picked seedcotton were greater for fenpropathrin and acephate than for buprofezin (41.14 ± 0.14 compared with 40.64 ± 0.09%, respectively; $F = 8.4$; df = 1, 30; $P < 0.01$), but there were no other treatment effects. Stickiness tests of cotton lint obtained 19 August and repeated 31 August following final irrigations on 12 August indicated no significant effects for any of the treatments (range 2.6–6.5). Thermodetector readings of <5 are considered to be uncontaminated lint (readings of 5–30 are increasingly sticky; Brushwood and Perkins 1993, Perkins and Brushwood 1995), thus none of the lint from our 1994 test was sticky by this scale. Soluble sugar tests indicated <1 mg/gm of lint (a noneconomic concentration; D. Hendrix, personal communication) in all treatment samples. There was 29% greater sugar in samples from plots irrigated biweekly than weekly ($P < 0.01$) and 35 and 47 % greater sugar content in lint from samples treated with fenpropathrin and acephate at 5 or 10 adults per leaf, respectively, compared with 1 adult per leaf ($P < 0.05$). In aggregate, these tests of stickiness and sugar content generally did not indicate significant treatment effects or economic levels of sugar contamination in 1993 and 1994 tests.

Significant treatment effects on fiber qualities were found primarily between cultivars in 1993 (because of fundamental differences in short- and long-staple cottons) and between irrigation treatments in 1994 (Table 9). Micronaire, a measure of fiber fineness, was greater in cotton irrigated biweekly in both 1993 ($P < 0.05$) and 1994 ($P < 0.01$). Micronaire ratings of up to 5.0 as found in all tests are acceptable, but lower ratings are desirable. In 1993, Pima S-7 had greater fiber length ($P < 0.01$), lower elongation (a measure of fiber stretch under tension; $P < 0.01$) and greater fiber strength ($P < 0.01$) than DPL-50. There was a significant interaction in the fiber length test for cultivar × irrigation ($F = 5.38$; df = 1, 12; $P < 0.05$) because lengths for both cultivars were numerically longer under weekly irrigation but were disproportionately shorter for DPL-50 under biweekly irrigation.

In 1994, weekly irrigation, in addition to reduced micronaire, resulted in greater elongation ($P < 0.01$) and lower fiber strength ($P < 0.01$). There was a significant interaction for irrigation × insecticide in micronaire ($F = 4.48$; df = 1, 36; $P < 0.05$) because the effect of insecticide treatments depended on the irrigation treatment under which they were applied. There were no other significant interactions in any of the fiber quality tests. In addition, fiber strength was greater from cotton treated with fenpropathrin and acephate compared with buprofezin ($P < 0.01$), although none of the fibers met the desirable strength of 200 mN/tex or greater. In this experiment, fiber length was less affected by environmental factors than were the other fiber qualities. All the fiber qualities for the various treatments were economically acceptable.

Discussion

Leigh et al. (1974) found greater total numbers of arthropods, including *L. hesperus*, in cotton maintained under wet conditions. Lygus bugs are well established as more severe pests of well-wa-

Table 9. Fiber tests in which significant effects occurred, MAC farm, 1993, 1994

Year	Factor	Treatment	Mean ± SE	F
1993	Micronaire	Weekly	4.53 ± 0.08	5.26*
		Biweekly	4.73 ± 0.08	(df = 1, 12)
		DPL-50	4.83 ± 0.05	10.95**
		Pima S-7	4.43 ± 0.07	(df = 1, 4)
	Length, mm	DPL-50	28.49 ± 0.20	209.73**
		Pima S-7	33.78 ± 0.21	(df = 1, 4)
	% elongation	DPL-50	9.08 ± 0.14	68.45**
		Pima S-7	7.54 ± 0.11	(df = 1, 4)
	Strength, mN/tex	DPL-50	168.57 ± 1.69	12,107.64**
		Pima S-7	305.58 ± 2.38	(df = 1, 4)
1994[a]	Micronaire	Weekly	4.62 ± 0.04	18.04**
		Biweekly	5.00 ± 0.04	(df = 1, 36)
	% elongation	Weekly	7.93 ± 0.08	44.13**
		Biweekly	7.52 ± 0.05	(df = 1, 36)
	Strength, mN/tex	Weekly	169.16 ± 1.41	28.82**
		Biweekly	178.85 ± 1.37	(df = 1, 36)
		Fenpro/aceph[b]	177.29 ± 1.58	13.22**
		Buprofezin	170.72 ± 1.57	(df = 1, 36)

*, $P < 0.05$; **, $P < 0.01$. Mean ± SE, $n = 12$ (1993), $n = 24$ (1994).

[a] There were no significant treatment effects for fiber length in 1994; test average fiber length was 29.15 ± 0.43 mm.

[b] Fenpropathrin/acephate.

tered cotton (Zwick 1985, Leggett 1993), and our results confirm this finding. Survey for lygus bugs by sweep net sampling or assessing square damage is simple, and control is obtained with a variety of insecticides (Ellsworth et al. 1994), many of which are also suitable for pink bollworm. Previously, we found larger numbers of diapause pink bollworms in cotton irrigated weekly compared with that irrigated biweekly (Flint et al. 1994). However, our current results indicate greater numbers of pink bollworms in cotton irrigated biweekly during the 1993 season and no difference because of irrigation frequency in 1994. Thus, there is no consistent conclusion from our data for the effects of irrigation frequency on pink bollworm abundance.

Buprofezin, a chitin inhibitor affecting immature insects only (primarily Homoptera), was the most effective of 11 insecticides tested for control of immature *B. tabaci* on the MAC farm in 1994 (Akey and Henneberry 1995). We used the same rate of active ingredient in the 1994 test, but our applications were made by using methods used by growers. These methods do not provide the coverage obtained by Akey and Henneberry (1995) because of fewer spray nozzles per row, lower operating pressure, and less total spray applied per hectare. Our insecticide combination of fenpropathrin (synthetic pyrethroid) and acephate (organophosphate) is a widely used and recommended treatment (Dennehy et al. 1995a) for whiteflies and is still effective in most areas of the Southwest using current grower practice methods. We note that recommended use of mixes containing pyrethroids begins at a threshold of ≥5 adult whiteflies per leaf turn (Ellsworth et al. 1994, Dennehy et al. 1995b).

Weekly irrigation provided relatively small changes in leaf water potential compared with biweekly irrigation in our current study. For example, leaf water potentials at 7 and 14 d for DPL-50 irrigated biweekly averaged 9 and 17% lower than the leaf water potential in those irrigated weekly at 7 d. However, these differences in 1993 were associated with reductions in the abundance of eggs, nymphs, and adults of ≈60% in cotton irrigated weekly compared with that irrigated biweekly. However, Pima S-7 had significantly greater plant water stress during the season than DPL-50 yet had significantly fewer eggs, nymphs, and adults of *B. tabaci*. Thus, cultivar also influences infestation, with Pima S-7 inherently having lower rates of infestation than DPL-50 in our 1993 test. In 1994, cotton irrigated weekly averaged ≈30% reduction in whiteflies compared with cotton irrigated biweekly. We have previously shown similar reductions in eggs and nymphs for cotton irrigated weekly compared with that of biweekly (Flint et al. 1994). Our previous (Flint et al. 1994) and current studies show these reductions are caused by fewer adult whiteflies on leaves rather than lower survival rates for immature forms as suggested by Mor (1987). Mor et al. (1982) first noted increased numbers of immature *B. tabaci* on water-stressed cotton in Israel and suggested that avoiding cotton plant water stress in August could serve as a cultural control method (Mor 1986). These reductions in whiteflies also can be achieved by midseason supplemental irrigations timed to coincide with boll development or daily drip irrigation (Flint et al. 1995).

In our 1993 and 1994 tests, we used 42 and 25% more water, respectively, on cotton irrigated weekly than biweekly (32% more water in 1992 tests; Flint et al. 1994). This increase in irrigation water represents a sizable investment, particularly in areas where water is scarce. Greater water use may not be necessary to achieve reductions in whiteflies (Flint et al. 1995). In 1993, weekly irrigation resulted in 919 kg/ha greater seedcotton yield, but in 1994, weekly irrigation resulted in a loss of 274 kg/ha of seedcotton compared with biweekly irrigation (overall yields in 1994 were lower than in 1993). The reason for the 1994 loss is not readily apparent. We suggest that greater numbers of lygus bugs in cotton irrigated weekly and a single application of insecticide for their control in 1994 (compared with 2 applications in 1993) may have resulted in midseason loss of squares (cotton flower buds) because of their feeding. The earlier termination of the 1994 crop on 12 August (versus 27 August–10 September in 1993) did not permit late-season plant growth to compensate for any earlier loss of squares.

Our results in 1994 demonstrated that reducing water stress through more frequent irrigation can lower the number of insecticide applications for suppression of *B. tabaci* densities. Using action thresholds of 1 and 5 adults per leaf, we were able to eliminate 1 spray application in plots irrigated weekly in comparison with those irrigated biweekly. However, given the logistical problems which did not permit us to put equal amounts of water on both weekly and biweekly plots over the season, the extra cost of water used in the weekly plot likely offsets the savings in insecticide cost. Previous results (noted above; Flint et al. 1995) suggest that reductions in whitefly densities can be achieved with equal but better-timed applications of water. Thus, it is possible that savings in insecticide costs could be significant.

The action threshold at which we initiated insecticide applications had a significant effect on both densities of *B. tabaci* and on cotton yields, especially when using fenpropathrin and acephate for control. The cost of better insect control using an action threshold of 1 adult per leaf was an additional 2–3 sprays in comparison with that of 5 or 10 adults per leaf. However, this additional outlay resulted in average yield increases of 333 or 527 kg/ha of seedcotton over the thresholds of 5 or 10 adults per leaf, respectively. Unfortunately, there are several factors that complicate the interpretation of which threshold is operationally best for management of *B. tabaci*. Most significant is the problem of multiple pest impact. *L. hesperus* was consistently present during both years of our study. In 1994, we treated all our plots for this pest on 6 July; however, it is very likely that our 1st application of fenpropathrin and acephate on 12 July in the plots of 1 adult per leaf threshold provided additional control of lygus bugs. The first applications for *B. tabaci* in the plots with 5 and 10 adults per leaf were not made until at least 2 wk later. This additional lygus bug control in the former plots coincided with flowering and the 1st set of bolls and may have played a significant role in the larger yields observed. A similar pattern was observed by Ellsworth and Meade (1994) at the same field site. They reported that control of lygus bugs by pyrethroid combinations first applied for control of *B. tabaci* at a threshold of 1 adult per leaf on 10 July significantly enhanced yields in comparison with plots in which whitefly control was initiated later (21 July or 10 August) at thresholds of 10 or 25 whiteflies per leaf.

An additional factor that makes interpretation of our action thresholds difficult was the difference between the target threshold (1, 5, or 10) and the actual density at which treatments were made (see Table 1). As previously noted, this was caused by weekly sampling and decision-making for pest control, which is a typical grower practice. The currently recommended action threshold for cotton in Arizona is 5 adults per leaf (Ellsworth et al. 1995). Weekly sampling is suggested; however, once densities approach the threshold more frequent sampling is recommended. Thus in practice, there is less chance of exceeding the intended threshold as we did in our study. In reality, our lowest *B. tabaci* densities and highest yields were associated with average action thresholds of 2.9 and 4.8 adults per leaf, respectively. These results compare favorably with several recent studies. Based on studies relating pest density to maximal yield, Chu et al. (1994) reported an action threshold of 4.1 adults per leaf. Further, results from a regional study over 3 states suggested that densities of *B. tabaci* and associated lint yields did not differ when using action thresholds of 2.5, 5, or 10 adults per leaf (Naranjo et al. 1996).

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