Monitoring And Management Of Whitefly Resistance To Insecticides In Arizona

T. J. Dennehy, Livy Williams, III, June S. Russell,
Xiaohua Li and Monika Wigert
Extension Arthropod Resistance Management Laboratory
University of Arizona,
Tucson, AZ

Abstract

Monitoring of whitefly resistance in the major cotton-producing areas of Arizona confirmed the presence of an over 100-fold resistance to the mixture of Danitol® + Orthene® (fepropathrin + acephate). Strong evidence was found of cross-resistance affecting the other principle pyrethroid insecticides used to control whiteflies (Asana®, Capture®, Karate®). Susceptibility to Ovasyn® varied widely in leaf-disk bioassays; lesser variation was observed in whitefly susceptibility to endosulfan. A provisional resistance management strategy (IRM) for Arizona whiteflies was formulated and evaluated in a 200 acre field trial in 1995. A key element of the strategy was diversifying as much as possible the insecticides used against whiteflies. Contrasts of this (rotation) strategy with a more conventional (less diverse) regime showed that rotation slowed but did not prevent resistance from developing. By seasons end, both the IRM and conventional plots had very high and comparable levels of resistance to Danitol® + Orthene®. This large field trial illustrated clearly the seriousness of the whitefly resistance problems faced in Arizona. It showed that whitefly populations cannot be managed effectively solely with the products currently registered for this purpose in Arizona. The large shift to lower susceptibility took place with as few as 3 insecticide treatments. In concert, our field and laboratory results indicated unequivocally that Arizona growers will be forced by resistance to greatly reduce reliance on pyrethroid insecticides in the future. This underscores the urgency for obtaining approval of novel new insecticides for whitefly control and for deploying new products within the framework of a resistance management strategy that limits their use.

Introduction

Since the beginning of this decade, Arizona growers have had the profitability of cotton, vegetable and melon production severely challenged by whiteflies (Byrne & Bellows 1991). The increased severity of whitefly problems in North America coincided with the spread of a new biotype of *Bemisia tabaci* (Costa & Brown 1991). Subsequently declared a new species, *Bemisia argentifolii* (Bellows et al. 1994), this pest is now often the most abundant arthropod pest of cotton in Arizona. These whiteflies are inherently difficult to control in Arizona cotton. In low desert areas, growers may apply 6 to 12 applications of insecticide mixtures per season to combat populations. As has occurred elsewhere in the world (Byrne & Devonshire 1991, Cahill and Denholm 1993, Horowitz & Ishaaya 1994, Prabhaker et al. 1992), control failures have become acute in areas with intensive insecticide use in Arizona, as populations have become increasingly resistant to insecticides.

In 1994 collaboration between the University of Arizona, the USDA/ARS Western Cotton Research Laboratory, the Arizona Cotton Growers Association and Cotton Incorporated resulted in initiation of programs to enhance documentation and management of whitefly resistance to insecticides in Arizona. Additionally, a multi-state consortium of pest managers formed the Southwest Whitefly Resistance Working Group to promote dissemination of resistance information and to formulate and evaluate integrated resistance management strategies for whiteflies. These cooperative activities have fostered the advancements in whitefly resistance detection and management detailed in this paper. We summarize 1995 activities in the following areas:

1. Statewide monitoring of whitefly resistance to insecticides.
2. Formulating and field testing of a provisional whitefly IRM.
3. Breaking the whitefly resistance treadmill in Arizona cotton.

Materials and Methods

Statewide monitoring of whitefly resistance to insecticides.

Whitefly were collected from 13 locations representing the major cotton production areas of Arizona. Adult whiteflies were vacuum-collected directly from cotton foliage into plastic vials using a Makita® cordless vacuum (4071D). The samples were transported in ice chests directly to the Extension Arthropod Resistance Management Laboratory (EARML), in Tucson, where they were released into cages containing young cotton (Pima S-7) plants. Adult whitefly were maintained in these cages until they were placed in bioassays (<7 days). Susceptibility of each population was estimated to the following insecticide treatments: 1) endosulfan, 2) Ovasyn® (amitraz), 3) Ovasyn® + endosulfan, and a fixed concentration of 1,000 µg/ml of active ingredient Orthene® combined with the pyrethroid insecticides 4) Asana® (esfenvalerate), 5) Capture® (bifenthrin) 6) Danitol® (fenpropathrin) and 7) Karate® (lambda-cyhalothrin).

Leaf disk method.

The leaf disk method (Rowland et al. 1991) used leaf punches taken from cotton plants 18 to 26 days old. The leaf disks were dipped for 10 s in formulated insecticide diluted in water. After drying, the disks were placed individually on a base of agar (1.6%) within upright 20 ml glass scintillation vials. Within 2h of dipping, 20-30 adult whitefly were aspirated into each vial. Assays were then held in an incubator at 27°C for 48 h, after which they were scored using a binocular microscope. Vials were tapped on the counter 10 times after which whiteflies not exhibiting repetitive movement of more than one appendage were scored as dead. At least five different concentrations and ten bioassay replications per concentration were evaluated for each insecticide tested.

Field testing of the 1995 IRM.

The provisional 1995 IRM (Dennehy et al. 1995) was evaluated in a 200 acre field trial at the University of Arizona, Maricopa Agricultural Center. This trial contrasted the chemical rotation scheme prescribed by the whitefly IRM, with a much less diverse pyrethroid regime. Both regimes used mixtures of insecticides, since these were necessary to achieve acceptable control in cotton. Nested within the IRM and conventional plots was a total of twelve different treatments comprising two application methods (air and ground) and three treatment thresholds. Each treatment was replicated three times and each replicate comprised a block of at least five acres in size. Treatment thresholds were based on numbers of adult whitefly per leaf (thresholds of 1, 2.5 and 5) estimated using a leaf-turn sampling procedure (Ellsworth et al. 1994, Naranjo and Flint 1995). Table 1 provides details of the two chemical use regimes contrasted. Air or ground insecticide applications were made on an as-needed basis once plots reached their pre-determined treatment thresholds. Plots were monitored twice-weekly for adult whitefly density. Additionally, immature and egg stages of whitefly were monitored on a weekly basis throughout the season. Both air and ground application conditions were modeled after conventional grower practice.

Development of resistance throughout the season was documented in the IRM and conventional plots by conducting leaf-disk bioassays of adult whitefly susceptibility to mixtures of varying concentration of Danitol® plus a fixed concentration (1000 µg/ml) of Orthene®. Collections from plots for bioassays were made prior to application of any whitefly treatments in 1995, approximately mid-way through the period of whitefly severity (mid-August) and in the late-season (early-September) but prior to the period of intensive movement of whitefly populations in the fall. Adult whitefly were either aspirated or vacuum-collected in the field, cooled in ice chests and transported to the laboratory in Tucson to be bioassayed. Bioassay parameters were as noted above for the statewide resistance monitoring.

Results and Discussion

Statewide monitoring of whitefly resistance to insecticides.

Resistance to the mixture of Danitol + Orthene is clearly a serious problem in Arizona (Fig. 1a, Table 2). We detected an >100-fold resistance to this insecticide combination in 1994 (Dennehy et al. 1995) and have confirmed that finding in 1995. As illustrated in Fig. 1a, populations such as Yuma and Parker exhibited higher mortality in treatments of 1 µg/ml Danitol® (+ 1,000 µg/ml Orthene®) than did the least susceptible populations in treatments of 100 µg/ml Danitol® (+ 1,000 µg/ml Orthene®). Populations with low mortality in bioassays of 10 µg/ml Danitol® (+ 1000 µg/ml Orthene®) were generally from areas that reported decidedly poor results of this insecticide mixture in the field in 1995.

Survey results in 1995 provided strong evidence of cross-resistance between pyrethroids (Table 2). Populations with reduced susceptibility to Danitol® + Orthene® were also generally much reduced in susceptibility to Orthene plus: 1) Asana® (Fig. 1b), 2) Capture® (Fig. 1c) and 3) Karate® (Fig. 1d). It appears that cross-resistance between pyrethroid insecticides imperils activity of essentially all the previously most effective insecticide mixtures used against whiteflies in Arizona. Clearly there continue to exist areas where whiteflies remain comparatively susceptible to the synergized pyrethroids. This is especially apparent with the finding that populations from the eastern and western regions of Arizona were most susceptible to pyrethroid mixtures. We hypothesize that this is attributable to higher proportions of unsprayed hosts of whitefly in these areas; alfalfa may serve an important role as a buffer of resistance.

Susceptiblity to non-pyrethroid insecticides varied widely between chemicals and locations (Figs. 1e-f, Table 2). Endosulfan was comparatively uniform in toxicity to populations. Susceptibility to Ovasyn® varied more widely between locations. With the reduced efficacy of pyrethroid mixtures, non-pyrethroid compounds, such as endosulfan and amitraz, will undoubtedly be considered for use more frequently by growers. However, our monitoring result should caution against over-reliance on these materials. From the variation that we have documented within and between populations in susceptibility to these insecticides, it appears likely that resistance could be selected rapidly to endosulfan and Ovasyn®. Such insecticides serve a important role in diversifying the chemical use regime against whiteflies. They should be managed carefully and continue to be monitored to detect losses of effectiveness, should they occur.

Formulating and field testing the 1995 IRM.

The provisional whitefly IRM failed to keep resistance from developing to Danitol® + Orthene®. Monitoring of susceptibility to Danitol® + Orthene® revealed that all treatments shifted dramatically to higher resistance levels from July to September (Figs. 2-3). However, the IRM strategy clearly slowed the progression to higher resistance levels. This large field trial illustrated clearly the seriousness of the whitefly resistance problems faced in Arizona. It showed that whitefly populations cannot be managed effectively solely with the products currently registered for this purpose in Arizona. The large shift to lower susceptibility took place with as few as 3 insecticide treatments. These results indicated that producers will be compelled to greatly reduce reliance on pyrethroid insecticides in the coming season.

Breaking the whitefly resistance treadmill in Arizona cotton.

The situation with whitefly control in Arizona cotton is critical. Resistance bioassays and field trials have revealed very intense resistances to synergized pyrethroid mixtures, as well as evidence of severe cross-resistance problems. Clearly, Arizona growers are facing a treadmill in which resistance causes them to increase insecticide use and increased insecticide use exacerbates resistance.

Breaking the whitefly resistance treadmill will require new insecticide groups combined with major changes in the way that cotton growers select and use pesticides. Foremost will be reducing the number of insecticide treatments made per season and delaying use within the season of insecticides toxic to natural enemies. A major cooperative effort is underway inArizona to gain registration for two very promising insect growth regulators, buprofezin and pyriproxifen. Equally important is the effort to strictly limit the use of these new products, perhaps to as little as one application per season. If approved and used sparingly, these growth regulators could offer a way out of the current predicament of whitefly resistance in Arizona cotton and point us down the road to more sustainable chemical use patterns.

Acknowledgments

We gratefully acknowledge financial support provided by the Arizona Cotton Growers Association, Cotton Incorporated, USDA/ARS Western Cotton Research Laboratory and the University of Arizona College of Agriculture. We thank D. Akey, P. Ellsworth, T. Henneberry, I. Kirk, R. L. Nichols, A. Simmons, N. Toscano and the participants of the Southwest Whitefly Resistance Working Group for leadership and cooperation in formulating and evaluating the resistance management strategy. Special recognition is given to I. Denholm, and M. Cahill (Rothamsted Experimental Station), S. Castle (USDA/ARS) and N. Prabhaker (University of California) for sharing their experience and knowledge of resistance detection and management. Thanks to B. Anthony, P. Else and the staff of the University of Arizona Campus Agricultural Center for assistance with the many needs that arose in establishing the Extension Arthropod Resistance Management Laboratory.

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Table 1. Chemical use regimes contrasted in the 1995 field evaluation of the Arizona whitefly IRM strategy.

Application number	*Conventional (Low Diversity)*	*1995 IRM (Rotation)*
1	Danitol + Orthene	Endosulfan + Ovasyn
2	Danitol + Orthene	Vydate + Curacron
3	Danitol + Orthene	Danitol + Orthene
4	Danitol + Orthene	Endosulfan + Ovasyn
5	Capture + Orthene	Danitol + Vydate
6	Karate + Orthene	Capture + Lorsban
7	Asana + Orthene	Karate + PenncapM
8	Baythroid + Orthene	Capture + Lannate
9	Karate + Orthene	Asana + Curacron
10	Asana + Orthene	Karate + PenncapM

Legend: Figures 1a-f. Locations read from left to right on all figures.

1. Buckeye
2. Casa Grande
3. Gila Bend #1
4. Gila Bend #2
5. Gila River Basin #1
6. Gila River Basin #2
7. Laveen #1
8. Laveen #2
9. Marana
10. Maricopa (M.A.C.)
11. Parker Valley
12. Safford (S.A.C.)
13. Yuma Valley (Y.A.C.)

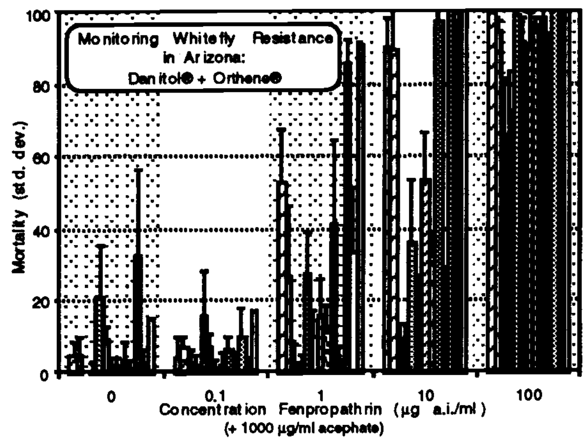


Figure 1a. Response in 1995 of Arizona populations of whitefly to leaf-disk bioassays with varying concentrations of fenpropathrin (Danitol®) and a fixed concentration of acephate (Orthene®).

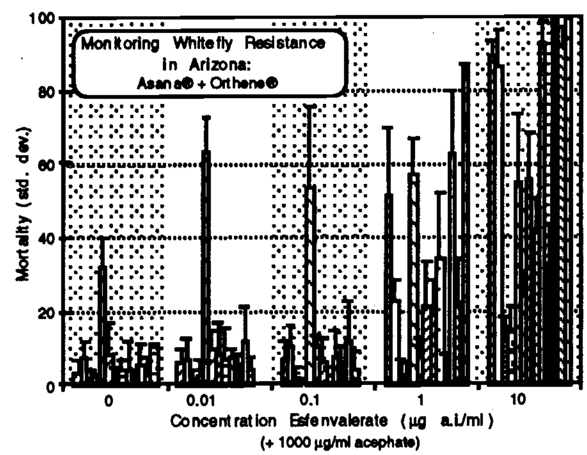


Figure 1b. Response in 1995 of Arizona populations of whitefly to leaf-disk bioassays with varying concentrations of esfenvalerate (Asana®) and a fixed concentration of acephate (Orthene®).

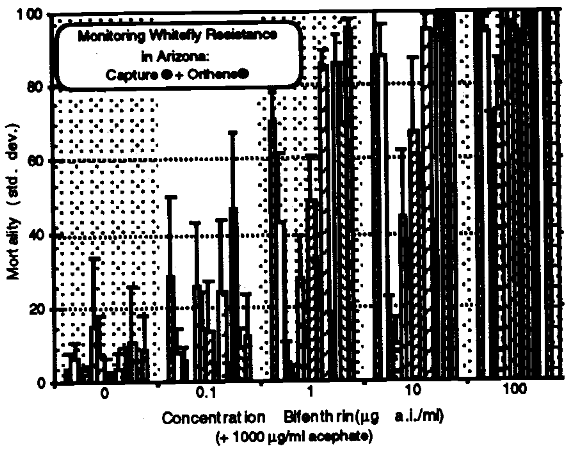


Figure 1c. Response in 1995 of Arizona populations of whitefly to leaf-disk bioassays with varying concentrations of bifenthrin (Capture®) and a fixed concentration of acephate (Orthene®).

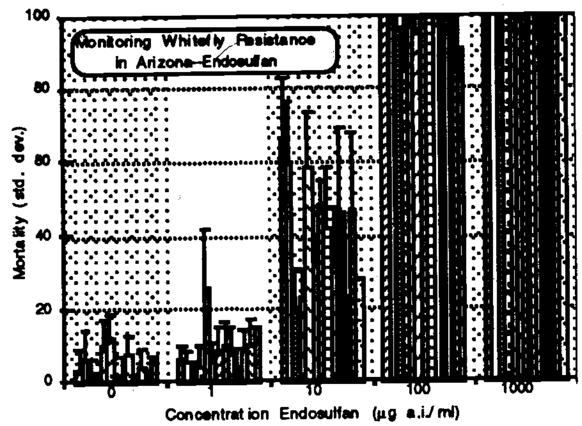


Figure 1e. Response in 1995 of Arizona populations of whitefly to leaf-disk bioassays with endosulfan.

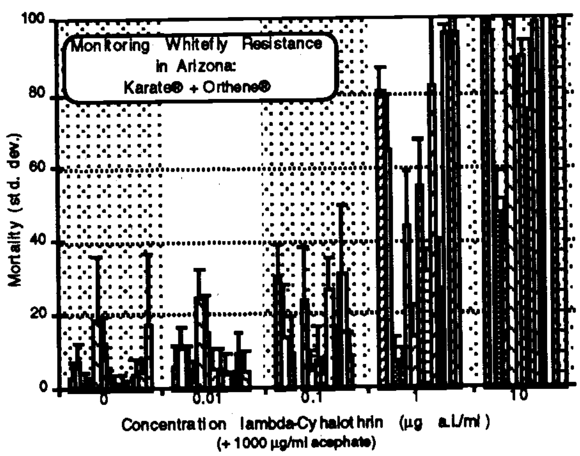


Figure 1d. Response in 1995 of Arizona populations of whitefly to leaf-disk bioassays with varying concentrations of lambda-cyhalothrin (Karate®) and a fixed concentration of acephate (Orthene®).

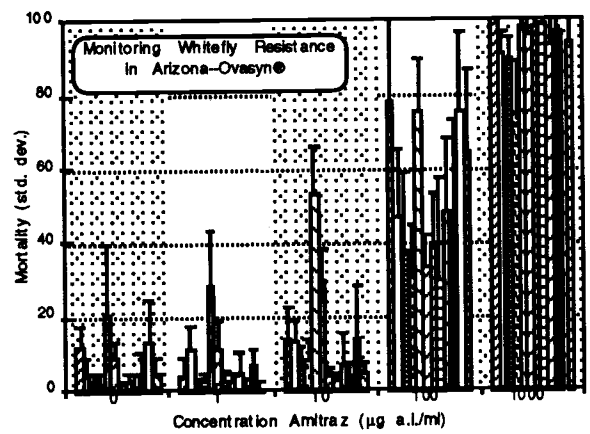
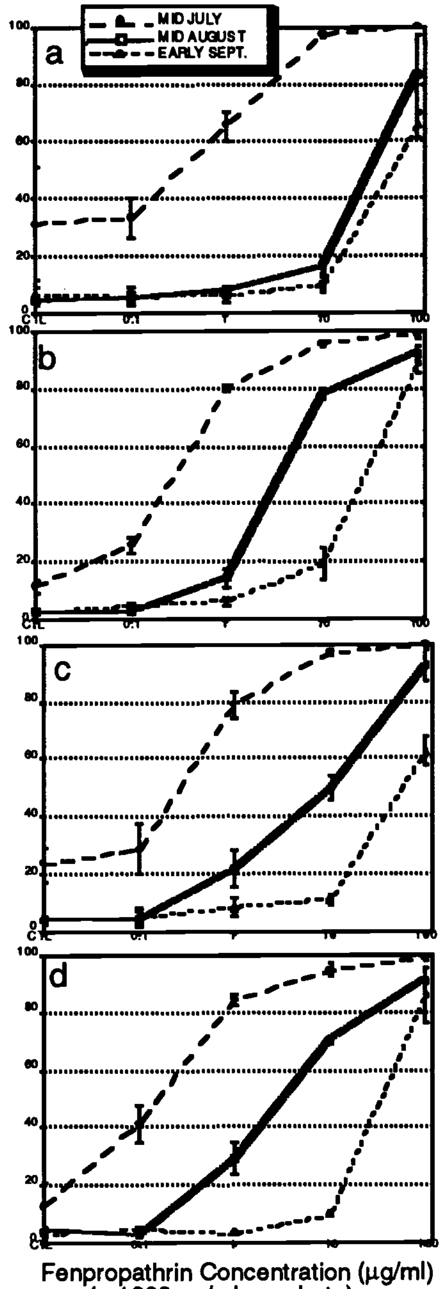
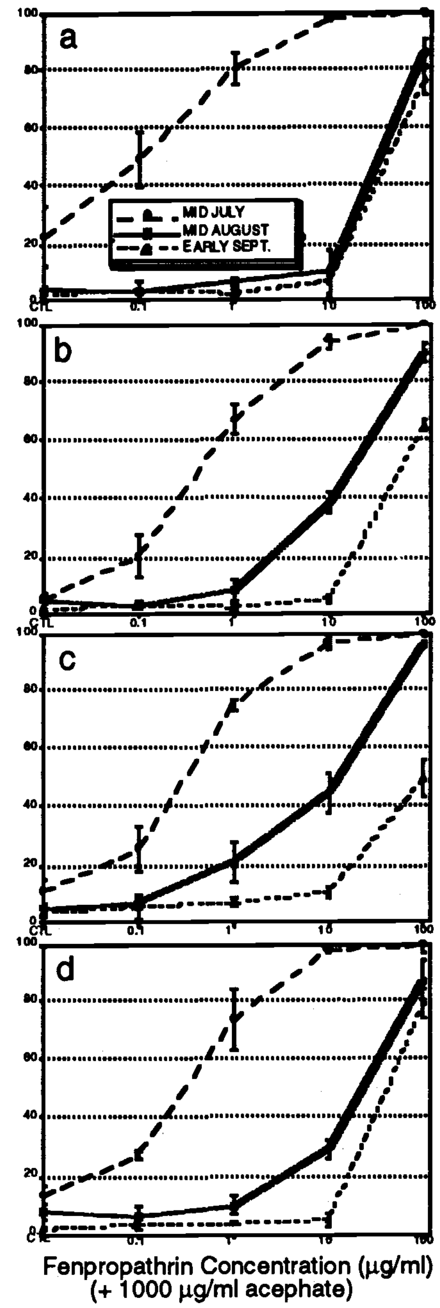


Figure 1f. Response in 1995 of Arizona populations of whitefly to leaf-disk bioassays with Ovasyn® (amitraz).



Figures 2a-d. Whitefly IRM strategy treatments. Seasonal development of resistance to Danitol+Orthene in replicated five acre plots in which the whitefly IRM strategy, involving a rotation of maximal diversity of effective registered whitefly insecticides, was evaluated under the following conditions: a) air application/threshold of 1 adult per leaf; b) air application/threshold of 5 adults per leaf; c) ground application/threshold of 1 adult per leaf; ground application/threshold of 5 adults per leaf.



Figures 3a-d. Conventional insecticide use treatments. Seasonal development of resistance to Danitol+Orthene in replicated, five acre plots in which a low diversity of pyrethroid mixtures was evaluated under the following conditions: a) air application/ threshold of 1 adult per leaf; b) air application/threshold of 5 adults per leaf; c) ground application/threshold of 1 adult per leaf; ground application/ threshold of 5 adults per leaf.

Table 2. Susceptibility of Arizona whitefly populations to insecticides, as estimated by leaf-dip bioassays conducted in 1995.

A. Danitol® + Orthene®	0	0.1	1.0	10	100
Buckeye	5.0 (3.0)	4.4 (5.9)	53 (14)	89 (8.8)	99 (1.8)
Casa Grande	5.2 (4.5)	6.9 (3.0)	27 (19)	89 (11)	94 (3.4)
Gila Bend #d1	0 (0)	2.8 (3.4)	2.9 (5.1)	8.7 (4.9)	66 (15)
Gila Bend #2	0.69 (1.7)	1.8 (3.0)	2.7 (2.1)	7.8 (5.5)	72 (11)
Gila River Basin #1	21 (15)	16 (13)	27 (12)	36 (17)	99 (2.1)
Gila River Basin #2	8.9 (3.9)	7.0 (3.6)	10 (7.1)	19 (7.5)	92 (6.4)
Laveen #1	1.9 (2.1)	1.3 (2.0)	15 (11)	54 (13)	91 (8.2)
Laveen #2	1.9 (2.2)	2.1 (3.7)	12 (6.3)	33 (6.9)	96 (2.1)
Marana	3.6 (4.5)	6.6 (3.7)	41 (23)	97 (2.5)	98 (2.3)
Maricopa (M.A.C.)	1.3 (2.0)	3.0 (2.3)	3.7 (3.4)	19 (10)	81 (12)
Parker Valley	32 (24)	9.7 (8.4)	85 (7.0)	100 (0)	100 (0)
Safford (S.A.C.)	2.7 (3.4)	1.9 (2.1)	33 (17)	97 (2.1)	100 (0)
Yuma Valley (Y.A.C.)	15 (6.4)	17 (17)	90 (6.6)	100 (0)	100 (0)

B. Asana® + Orthene®	0	0.01	0.1	1.0	10
Buckeye	3.5 (3.1)	5.7 (3.9)	6.9 (4.9)	51 (19)	89 (4.0)
Casa Grande	7.0 (4.8)	6.8 (5.5)	10 (6.0)	22 (6.0)	87 (9.4)
Gila Bend #d1	1.5 (2.3)	1.5 (2.4)	1.7 (2.7)	2.5 (4.1)	12 (6.25)
Gila Bend #2	.66 (1.6)	2.8 (3.5)	0 (0)	2.7 (3.3)	14 (6.6)
Gila River Basin #1	32 (8.2)	64 (8.9)	54 (22)	57 (10)	55 (18)
Gila River Basin #2	8.5 (8.3)	10 (4.4)	10 (2.7)	8.4 (4.3)	24 (6.3)
Laveen #1	1.3 (3.3)	8.1 (9.0)	5.8 (7.0)	21 (12)	56 (13)
Laveen #2	4.0 (2.6)	6.9 (8.1)	2.6 (2.0)	20 (9.2)	42 (8.3)
Marana	4.2 (7.6)	7.7 (1.8)	7.3 (7.0)	34 (18)	93 (5.4)
Maricopa (M.A.C.)	1.4 (2.2)	5.1 (3.3)	5.8 (4.7)	4.5 (4.0)	33 (10)
Parker Valley	5.4 (5.4)	12 (9.0)	12 (11)	63 (17)	99 (1.6)
Safford (S.A.C.)	4.1 (3.6)	4.0 (3.6)	3.5 (5.6)	22 (12)	92 (5.6)
Yuma Valley (Y.A.C.)	11 (7.3)	no data	no data	86 (10)	100 (0)

C. Capture® + Orthene®	0	0.1	1.0	10	100
Buckeye	3.6 (4.8)	29 (21)	70 (8.0)	88 (14)	100 (0)
Casa Grande	6.2 (4.7)	8.0 (6.2)	43 (19)	88 (8.7)	95 (4.7)
Gila Bend #d1	1.5 (2.3)	5.8 (3.6)	4.8 (6.3)	15 (8.4)	66 (7.1)
Gila Bend #2	2.0 (2.2)	0 (0)	1.3 (3.1)	10 (7.0)	73 (14)
Gila River Basin #1	15 (19)	26 (17)	28 (12)	44 (18)	100 (0)
Gila River Basin #2	7.3 (10)	14 (9.7)	11 (4.0)	25 (13)	86 (11)
Laveen #1	2.5 (3.8)	14 (13)	49 (12)	67 (20)	92 (11)
Laveen #2	1.1 (1.8)	1.9 (3.2)	20 (12)	51 (9.0)	95 (5.5)
Marana	3.4 (4.2)	24 (19)	85 (4.2)	96 (3.8)	100 (0)
Maricopa (M.A.C.)	3.3 (6.4)	1.7 (3.0)	10 (8.2)	31 (12)	82 (13)
Parker Valley	11 (15)	46 (21)	86 (7.7)	99 (1.6)	100 (0)
Safford (S.A.C.)	3.0 (2.4)	9.3 (5.0)	69 (17)	100 (0)	100 (0)
Yuma Valley (Y.A.C.)	8.9 (8.5)	12 (11)	95 (3.3)	99 (2.1)	100 (0)

D. Karate® + Orthene®	0	0.01	0.1	1.0	10
Buckeye	3.2 (4.1)	6.3 (5.8)	30 (8.6)	80 (6.3)	99 (1.7)
Casa Grande	7.3 (5.1)	11 (6.0)	14 (14)	64 (16)	96 (8.0)
Gila Bend #d1	1.8 (2.8)	5.4 (6.3)	9.3 (10)	7.1 (7.0)	48 (11)
Gila Bend #2	1.3 (2.0)	3.3 (4.0)	0 (0)	4.9 (6.5)	39 (12)
Gila River Basin #1	19 (17)	24 (8.1)	24 (14)	44 (15)	99 (1.5)
Gila River Basin #2	12.5 (7.0)	15 (10)	5.3 (5.5)	14 (8.6)	76 (12)
Laveen #1	2.5 (3.0)	5.5 (5.8)	7.5 (9.0)	54 (13)	90 (4.8)
Laveen #2	1.5 (2.4)	5.4 (5.4)	3.8 (4.6)	32 (5.4)	75 (19)
Marana	1.1 (2.7)	4.2 (5.3)	27 (8.2)	82 (20)	99 (2.9)
Maricopa (M.A.C.)	.64 (1.6)	2.2 (2.4)	9.2 (7.3)	26 (14)	74 (12)
Parker Valley	3.9 (4.2)	9.5 (6.0)	31 (19)	96 (2.0)	100 (0)
Safford (S.A.C.)	4.4 (3.8)	4.8 (5.6)	9.0 (6.1)	90 (11)	100 (0)
Yuma Valley (Y.A.C.)	17 (20)	no data	no data	96 (9.3)	100 (0)

E. Endosulfan	0	1.0	10	100	1000
Buckeye	3.6 (5.5)	6.6 (3.8)	65 (17)	100 (0)	100 (0)
Casa Grande	6.0 (8.5)	5.3 (3.0)	60 (17)	99 (1.6)	100 (0)
Gila Bend #d1	2.4 (4.1)	2.2 (3.7)	20 (11)	96 (5.5)	100 (0)
Gila Bend #2	1.2 (1.8)	4.4 (5.8)	23 (6.8)	86 (16)	100 (0)
Gila River Basin #1	10 (6.9)	25 (16)	58 (16)	100 (0)	100 (0)
Gila River Basin #2	12 (6.4)	7.4 (3.4)	32 (7.2)	96 (10)	99 (3.5)
Laveen #1	.66 (1.6)	8.6 (6.2)	48 (6.4)	99 (1.8)	100 (0)
Laveen #2	1.9 (4.8)	10 (6.2)	42 (16)	99 (1.8)	100 (0)
Marana	7.4 (5.2)	8.1 (7.0)	32 (15)	97 (2.3)	100 (0)
Maricopa (M.A.C.)	.64 (1.5)	4.5 (4.4)	46 (23)	100 (0)	100 (0)
Parker Valley	4.3 (5.0)	8.2 (6.0)	17 (6.3)	100 (0)	100 (0)
Safford (S.A.C.)	1.3 (2.1)	9.9 (7.4)	47 (21)	100 (0)	100 (0)
Yuma Valley (Y.A.C.)	7.2 (5.3)	15 (4.7)	28 (13)	90 (18)	100 (0)

F. Ovasyn®	0	1.0	10	100	1000
Buckeye	12 (5.7)	4.0 (5.0)	14 (8.6)	79 (23)	100 (0)
Casa Grande	4.1 (5.4)	11 (6.8)	13 (5.5)	47 (19)	91 (5.9)
Gila Bend #d1	2.3 (2.6)	1.4 (2.2)	6.3 (5.7)	38 (21)	90 (5.4)
Gila Bend #2	1.8 (3.0)	2.6 (2.1)	8.2 (5.6)	31 (14)	75 (14)
Gila River Basin #1	20 (19)	28 (16)	53 (13)	75 (14)	98 (2.5)
Gila River Basin #2	9.1 (4.0)	11 (8.0)	30 (8.3)	33 (8.8)	96 (4.0)
Laveen #1	.66 (1.6)	2.6 (3.0)	3.6 (3.1)	40 (13)	98 (2.0)
Laveen #2	2.3 (2.5)	2.8 (2.2)	3.3 (1.6)	30 (28)	99 (2.1)
Marana	1.3 (3.1)	4.6 (6.1)	7.3 (7.8)	49 (20)	93 (10)
Maricopa (M.A.C.)	5.2 (5.5)	1.4 (2.1)	4.0 (3.6)	48 (25)	97 (3.9)
Parker Valley	13 (11)	7.3 (4.1)	14 (14)	75 (21)	no data
Safford (S.A.C.)	4.9 (4.0)	.66 (1.6)	4.7 (2.7)	64 (22)	94 (7.0)
Yuma Valley (Y.A.C.)	no data	no data	no data	no data	no data