

# Use of Insect Growth Regulators and Changing Whitefly Control Costs in Arizona Cotton

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## Abstract

*In 1996, two Insect Growth Regulators (IGRs), pyriproxyfen (Knack®) and buprofezin (Applaud®) became available to Arizona cotton growers for control of whitefly, Bemisia argentifolii under a Section 18 EPA exemption. This study makes use of a section-level database to examine (a) factors explaining IGR adoption and (b) how adopters of IGRs altered their overall insecticide use to control whiteflies. IGR adoption can be explained to a large extent by location effects. Adoption was more likely on sections where an index of whitefly susceptibility to synergized pyrethroids was low and on sections with higher whitefly control costs in the previous year. Adoption was inversely related to local population density. On sections where growers adopted IGRs, expenditures on synergized pyrethroid and other whitefly-specific tank mix applications fell by \$62.52 per acre. On sections with no IGR adoption, tank mix expenditures fell less, by \$44.37 per acre. On adopting sections, net costs of controlling whiteflies fell by \$29.62 per acre, or by over \$11,000 per farm.*

## Introduction

Whitefly *Bemisia argentifolii* is a major pest in Arizona cotton. Whitefly causes damage primarily to cotton lint quality rather than yield, although yield losses do occur at high infestation rates. Whiteflies secrete honeydew, introducing sugar into the lint and making it sticky and discolored. Sticky cotton is more costly to gin and receives price discounts at mills. Arizona cotton growers experienced two resistance episodes in the 1990s. By 1992, whiteflies developed significant resistance to pyrethroid insecticides, the primary method of whitefly control. Insecticide applications rose from 1.8 in 1991 to 5.1 in 1992 and whitefly control costs rose from \$25.20 to \$91.80 per acre (Williams, 1991-1992). Growers shifted to the use of synergized pyrethroids (pyrethroids mixed with organophosphate or carbamate insecticides). By 1994, there were already signs of renewed resistance. In 1995, whiteflies exhibited significant in-field resistance to synergized pyrethroids. In the most affected areas, growers made 8-12 applications, with costs ranging from \$200-\$300 per acre without necessarily controlling pest damage (Dennehy et al., 1997). Despite high control costs, Arizona growers received discounts for stickiness. In some cases, price discounts were as high as 5-6 cents, a reduction of 7-8 percent of gross revenues.

In 1995, the University of Arizona, USDA's Agricultural Research Service, the Arizona Cotton Growers Association and Cotton Incorporated undertook collaborative research to gain an EPA Section 18 exemption to use two insect growth regulators (IGRs) and to develop an integrated resistance management (IRM) plan. In 1996, EPA granted the Section 18 exemption for the use of the IGRs Knack® and Applaud®. The Section 18 exemption allows for a maximum of one application each of the IGRs. The IRM called for a diversification of insecticide use to limit pest exposure (and resistance development) to any single class of pesticides. The plan also called for limited or delayed use of pyrethroids. Another important aspect of the IRM is the continued monitoring of resistance trends through insect sampling and laboratory bioassays. Such sampling and testing programs can help track resistance trends and suggest interventions and changes in recommendations *before* field failures of insecticides occur.

## Methods

This report presents some preliminary findings of a broader study tracking pesticide use in Arizona cotton over space and time. The study uses a geographical information system (GIS) to combine two uniquely detailed data-

bases. By overlaying the spatial data layers, one can construct measures of pesticide use intensity, by pesticide type at the section (square mile) level for the entire state. This study makes use of the section-level database to examine (a) factors explaining IGR adoption and (b) how adopters of IGRs altered their overall insecticide use to control whiteflies.

## Data

Data on pesticide use at the section (square mile) level is available from the Arizona Department of Agriculture (ADA) Form 1080 Pesticide Use Reports. The ADA system mandates the reporting of three types of pesticide applications: (a) all commercial pesticide applications (treatments made by professional applicators), (b) applications of chemicals on the Arizona groundwater list and (c) applications of all Section 18 products. The Arizona Department of Environmental Quality (ADEQ) Groundwater Protection List includes soil-applied products that can negatively affect groundwater quality. Section 18 exemptions are temporary, emergency registrations of products to respond to specific pest problems. The 1080 report lists the crop treated, the pounds or gallons of product used, the number of acres treated, the combination of different pesticides, method of application, date of application, and location information.

This rich data set has two limitations for use in statistical analysis of pesticide use. First, the 1080 report does not track fields through a growing season. It is impossible, using the 1080 data alone, to determine the number of acres under cultivation and treatments per acre. For example, the 1080 data does not distinguish between a section where two 100-acre fields received one application and a section where one 100-acre field received two applications. Second, submission of 1080 forms is not required for certain treatments, such as grower-applied ground applications of non-groundwater list or non-Section 18 chemicals. So, the 1080 forms do not provide an entirely comprehensive accounting of all applications.

For this study, it was possible to address both of these concerns. First, we obtained data on Arizona cotton acreage by section from the Arizona Cotton Research and Protection Council (ACRPC). By overlaying the ACRPC section-level data on cotton acreage on the 1080 data for section-level cotton pesticide applications, we obtained section-level measures of pesticide use intensity (average number of treatments per acre). In this way, each section of the state where cotton is grown becomes an observational unit. This measure masks variation within a section but makes it possible to construct a large, geo-coded database on pesticide use intensity with the number of observations on the order of 1,500-2,000 per year. To get a sense of how disaggregate this data set is, consider that a section is 640 acres, while a third of Arizona cotton farms are 500 acres or more (USDA, 1999). These farms accounted for three-quarters of Arizona's cotton acreage in 1997. Over 60% of Arizona cotton farms (accounting for over 90% of cotton acreage) were over 250 acres (USDA, 1999).

The overlapping of these two different sources of data, while essential, is not perfect. Both datasets include missing data and errors. The ACRPC estimates that by 1998 their field acreages encompass approximately 95% of the cotton acres in Arizona (Haller). Previous years were not as complete. It is impossible at this time to know the completeness of the ADA 1080 data. Despite these limitations in the separate datasets, the degree of overlap is quite high. Over 90% of ACRPC acres are in sections with corresponding ADA 1080 data (Table 1). Similarly, over 92% of all application acres reported for cotton on the 1080 forms correspond to sections with acreage reported by the ACRPC. In this study, only sections where there were overlapping data from both data sets were included in the analysis.

The ADA system mandates the reporting of all commercial pesticide applications as well as Section 18 products. The insect growth regulators Knack® (pyriproxyfen) and Applaud® (buprofezin) were granted Section 18 status beginning in the 1996 season. Producers were limited to one application of each product and reporting was mandatory. So, it is reasonable to assume that IGR reporting in 1996 is complete within the limits of regulatory compliance. Arizona growers were quick to adopt IGRs. Out of 357,000 acres planted to cotton in 1996, 125,943 acres received Knack applications and 50,294 received Applaud applications (Table 2). The data does not allow us to determine how many acres received treatments of both Knack and Applaud. In 1996, Arizona growers spent about \$6.7 million to apply IGRs on cotton (Table 2).

The 1080 data should also include the bulk of non-IGR whitefly applications because whitefly pressure primarily occurs after the cotton canopy has closed over the rows, necessitating commercial aerial application of whitefly-targeted insecticides. Discussions with producers and extension agents indicate that use of specialized equipment needed for late-season ground applications is the exception. In many areas, heavy irrigation schedules would make use of this equipment impossible.

Another step in constructing the database was to distinguish whitefly-targeted applications from applications targeting other pests. To do this, we focused on certain tank mix combinations. As a result of grower experience with, and extension research on, whitefly infestations in Arizona, by 1995 the efficacy of pyrethroid-organophosphate combinations was already widely recognized (Dennehy et al. 1995). Explicit insect resistance management (IRM) guidelines were developed recommending that non-pyrethroids be employed against other pests to maintain efficacy of pyrethroids singly and synergized by an organophosphate or carbamate (Ellsworth and Diehl, 1996).

This study utilizes acreage data on the IGRs, a variety of tank mix combinations that include combinations of active ingredients indicated in extension publications (Ellsworth et al, 1994, Ellsworth and Watson, 1996) and an overall tank mix aggregate. The most commonly used whitefly tank mix in 1995 is an acephate-fenprothrin (Orthene®-Danitol®) combination. Five other specific mixes are also considered. The aggregate tank mix acreage was considered because so many different permutations of potential whitefly-targeted active ingredients were used in 1995. There were 488 different tank mix combinations including up to five active ingredients. The aggregate tank mix variable included 280 of these combinations. In the tank mix variable, all combinations include at least one pyrethroid and a non-pyrethroid. We removed combinations including the pink bollworm pheromone gossypure and whitefly-specific imidacloprid (Admire®) and all non-cross-family mixes (i.e. two organophosphates, chlorpyrifos and acephate (Lorsban® and Orthene®). These latter mixes are not deemed effective against whiteflies.

ACRPC work units provide location information on cotton production. The ACRPC has assigned 21 work units based on locally similar conditions and practices. Dummy variables were included to indicate a section's unit membership. Coefficients on these variables account for location-specific fixed effects such as differences in climate, cropping practices, and cropping patterns on adjacent fields that may affect pest pressures.

The population data is derived from a GIS map based on census data. Section level population data is not available but census population numbers are geo-coded to create maps that demonstrate population density. A spatial join between geo-coded population data and a state map of sections provides a sum of the population data points within each section. The ability to extract useful data through spatial joins with a wide variety of GIS based maps is a relatively untapped source of data.

A whitefly susceptibility measure is used to reflect resistance to the most common whitefly tankmix combination. Danitol-Orthene was by far the most prevalent tank mix combination used to control whitefly. Susceptibility was determined using leaf-dip bioassays conducted by the Extension Arthropod Resistance Management Laboratory (EARML) at the University of Arizona. Whitefly populations from thirteen sites across the state were exposed to a combination of Orthene at 1000 micrograms per milliliter and Danitol ranging from .1 to 100 micrograms per milliliter (Dennehy et al., 1996, 1997). The susceptibility measure used was the percent mortality in the exposed population. The Danitol concentration of 10 micrograms per milliliter was used because that concentration was tested every year through the study period and provided a variable with no truncation at 100%. A susceptibility percentage was assigned to each work unit based on proximity to the bioassay sampling sites. Where necessary, scores were based on interpolations of susceptibility measures from sample sites.

## Results

We carried out a probit analysis (Maddala, 1983) of the probability that IGRs were adopted on a given section in 1996, and the results are reported in Table 3. The dependent variable in the regression equation equaled one if IGRs were used at all and zero otherwise. IGRs were used on 50.3 percent of the sections in the sample. The probit model correctly predicted sections where IGRs were or were not adopted 72.7 percent of the time. It did a better job at correctly predicting adoption (80 percent) than non-adoption (65.3 percent) (Table 3).

Seventeen dummy variables representing the ACRPC work units were included in the regression. Thirteen were significant at the one-percent level. Adoption was more likely on sections where the measure of whitefly suscepti-

bility to Danitol-Orthene was low. Adoption was also more likely where there were more tank mix applications to control whiteflies in the previous year. Not surprisingly, this suggests that IGR adoption was greater in areas with greater resistance problems and on sections where pest control costs were relatively high. Adoption was also inversely related to local population density and significant at the 5-percent level. Arizona law prohibits aerial spraying of pesticides in close proximity to schools, day care centers and certain health facilities. This and other factors may limit applications near population centers.

Next, we compared overall whitefly control costs between adopters and non-adopters for 1995 and 1996 (Table 4). For this comparison we excluded sections that received no whitefly-targeted applications in 1995 or in 1996. Table 4 shows what adopters' whitefly control costs were *prior* to adoption of IGRs. Application cost figures come from extension crop budgets. The tank material cost was assumed to be \$20.98 per acre. This was an average cost (weighted by acreage) of six of the most commonly applied tank mixes. Tank mix material costs range from about \$15 per acre to over \$35 per acre in some cases. Aerial application charges were assumed to be \$4.23 per acre.

Both adopters and non-adopters reduced tank mix applications, but adopters reduced tank mix applications by 2.48 while non-adopters reduced them by just 1.76. In 1996, both adopters and non-adopters made an average of one tank mix treatment per season. Yet in 1995, adopters averaged 3.53 applications in 1995 compared to 2.7 for non-adopters. On sections where growers adopted IGRs, expenditures on synergized pyrethroid and other tank mix applications fell by \$62.52 per acre. On sections with no IGR adoption, tank mix expenditures fell less, by \$44.37 per acre. Non-adopters may have benefited from positive externalities of their neighbors' adoption. There is some evidence that "with early, timely applications of IGRs in areas with historic high whitefly populations, neighboring field have seen fewer whitefly numbers (Rayner, 1996, p. 26)." Some growers also believe that a relatively dry winter contributed to less overall whitefly pressures.

For sections adopting IGRs, total whitefly control costs fell by \$29.62 per acre between 1995 and 1996. This amounts to a statewide cost reduction of over \$6 million. A conservative estimate of the per-farm cost reductions would be over \$11,000 per adopting farm. (According to the most recent *Census of Agriculture*, there are 534 cotton farms in Arizona counties where IGR adoption occurred).

## **Discussion**

The data illustrates the importance of using IGR adopter sections as their own controls (Table 4). If one were to only compare adopting and non-adopting sections in 1996, one would get a misleading picture of the impact of IGRs. If one only looked at the 1996 column for Table 4, one would see that IGR adopters had higher whitefly control costs than had non-adopters. However, one would miss the fact that they started from a base of even higher control costs in 1995. Adopters and non-adopters appear to be very different populations. Selection into one group or other is non-random. Failure to account for this in statistical analysis can lead to sample selection bias (Maddala, 1983). Although IGR adopting sections did reduce their overall whitefly control expenditures, it remains to be determined how much of this reduction can be explained by IGR adoption alone and how much is due to other factors. Future research will econometrically estimate the impact of IGR adoption on overall whitefly control costs, controlling for potential sample selectivity bias and controlling for other factors affecting pesticide use.

## **Funding**

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Table 1. The Overlap of ACRPC and ADA 1080 Data, 1995 and 1996

ACRPC Cotton Acres			
	Total Acres	Acres Without ADA 1080 Data	Percent of Acres with Corresponding ADA 1080 Data
1995	434,885	42,993	90.1%
1996	365,630	33,966	90.7%

ADA 1080 Application Acres <sup>a</sup>			
	Total Application acres	Application Acres Without ACRPC Acres	Percent of Application Acres with Corresponding ACRPC Acres
1995	2,985,116	228,713	92.3%
1996	2,232,843	169,335	92.4%

a. Application acres represent the total number of ingredient applications made throughout the growing season. A single application containing two ingredients is counted as 2 application acres as would be 2 applications containing a single ingredient.

Table 2. Arizona IGR application acres and expenditures, 1996

	Applaud	Knack
Acres receiving IGR applications	50,294	125,943
Material cost per acre	\$26.25	\$36.75
Application cost per acre	\$4.23	\$4.23
Total cost per acre	\$30.48	\$40.98
Total expenditures	\$1,532,961	\$5,161,144

Table 3. Probit analysis of the probability that IGRs are used in a section growing cotton, Arizona 1996

Explanatory Variables	Estimated Coefficient	Standard Error	Significance level (%)
Population density [1,000 persons / sq. mile]	-0.20556	0.0988	3.8
Cotton grown on section in previous year[= 1 for yes = 0 for no]	0.1698	0.1231	16.8
Index of whitefly susceptibility to Danitol-Orthene	-2.8177	0.3726	0.0
Number of tank mix applications to control whiteflies in previous year	0.1836	0.0185	0.0
Number of observations = 1938			
Dependent variable = 1 if IGRs used in section = 0 otherwise			
Percent correctly predicted (total) = 72.7			
Percent correctly predicted (non-adopting sections) = 65.3			
Percent correctly predicted (adopting sections) = 80.0			
Chi-squared statistic (20 d.f.) = 623.50			
Regression significance level (%) = 0.00000			

a. Seventeen regional dummy variables were included in the regression equation, but omitted from table.

Table 4. Comparison of whitefly control costs for IGR adopters and non-adopters, 1995 and 1996

	1995	1996
<b>Adopters</b>		
Acres in adopter sections	224,750 <sup>a</sup>	203,489
IGR costs per acre	\$0	\$32.90
Tank mix applications per acre	3.53	1.05
Tank mix cost per acre per application	\$25.21	\$25.21
Tank mix costs per acre	\$88.99	\$26.47
Reduction in tank mix costs per acre		\$62.52
Reduction in whitefly control costs per acre		\$29.62
Reduction in whitefly control costs		\$6,028,190
<b>Non-Adopters</b>		
Acres in non-adopter sections	144,660	120,819
Tank mix applications per acre	2.7	0.94
Tank mix cost per acre per application	\$25.21	\$25.21
Tank mix cost per acre	\$68.07	\$23.70
Reduction in whitefly control costs per acre		\$44.37

a. Figure corresponds to 1995 cotton acreage in sections adopting IGRs in 1996.