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EFFECTS OF INSECT GROWTH REGULATORS ON INSECTICIDE USE AND COSTS IN ARIZONA COTTON

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Abstract

In 1996, Arizona cotton growers began using insect growth regulators (IGRs) to control silverleaf whitefly. This study uses GIS data recording pesticide use at the section level for the entire state to address two questions. First, what factors explain the intensity of IGR adoption? Second, how has IGR adoption affected overall insecticide use? A two-stage model is estimated that accounts for both the endogeneity and censoring of the adoption intensity variable. Results suggest conventional insecticide use fell by 3.66 applications for every IGR application. Statewide, net insecticide costs savings in 1996 alone were $9.5 million, over $28,000 per adopting operator.

Introduction

Whitefly *Bemisia argentifolii* has been a major pest in Arizona cotton. Damage caused by whitefly is primarily to cotton lint quality rather than yield, although yield losses occur at high infestation rates. Whiteflies secrete honeydew, increasing the sugar content of the lint and making it sticky. Sticky cotton can slow cotton gin output (in bales per hour) by 25 percent and increase wear and maintenance requirements at textile mills. With severe problems, mills must shut down for thorough machinery cleaning (Ellsworth et al., 1999). Because it raises ginning and milling costs, sticky cotton receives price discounts.

Arizona cotton growers experienced two episodes of whitefly resistance to insecticides in the early 1990s. By 1992, whiteflies developed significant resistance to pyrethroid insecticides, the primary method of whitefly control. Insecticide applications per acre 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, based on laboratory bioassays of the whitefly population (Dennehy et al., 1996, 1997). 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 6 cents.

In 1995, a group of public and private institutions undertook collaborative research to gain EPA Section 18 exemptions to use two insect growth regulators (IGRs) for use on whiteflies. These included the University of Arizona College of Agriculture, Arizona Department of Agriculture, Western Cotton Research Laboratory of USDA's Agricultural Research Service, the Arizona Cotton Growers Association and Cotton Incorporated, along with the chemical companies AgrEvo and Valent. EPA granted Section 18 exemptions for two IGRs that were made available in time for the 1996 crop year. Based on insect hormones, growth regulators disrupt the development of insects. IGRs selectively target insect-specific growth functions, not nervous systems and are usually not broadly toxic to avian or mammalian species. They also exhibit less negative impacts on non-target beneficial insects. One IGR, buprofezin (trade name Applaud®) is a chitin inhibitor specific to whiteflies. Chitin is the principal polymer building block of the insect's exoskeleton. Without the proper formation of chitin, the insect will rupture during molting and die. The other IGR receiving a Section 18 exemption is pyriproxyfen (trade name Knack®). Knack is a juvenile hormone mimic that impedes insect development, disrupting egg fertility, egg hatching, and metamorphosis. As part of the integrated resistance management (IRM) plan approved under the Section 18 exemptions, only one application per cotton season was permitted for each IGR. The plan also called for limitations and postponement for as long as possible, the use of pyrethroids. Out of 357,000 acres planted to cotton in Arizona in 1996, nearly 126,000 acres received an application of Knack and over 50,000 received an application of Applaud.

Research Questions

The adoption of IGRs has been widely credited with improving control over whiteflies and reducing total insecticide use and application costs in Arizona cotton (Dennehy et al., 1997; University of Arizona, 1999). Yet, non-adopters also reduced their whitefly targeted insecticide applications in 1996 and non-adopters applied less conventional insecticides per acre than adopters did. However, adopters reduced their use of conventional insecticides by greater amounts than did non-adopters. In this study, we are concerned with two basic questions. First, what factors explain the intensity of IGR adoption in 1996? Second, how did IGR adoption affect use of conventional insecticides in 1996, controlling for other factors? To address these questions, this study uses a geographical information system to combine two uniquely detailed databases. By overlaying the spatial data layers, one can construct measures of pesticide use intensity for cotton, by pesticide type at the section (square mile) level for the entire state.

Pesticide and Cotton Acreage Data

Data on pesticide use at the section level are 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. The 1080 report lists the crop treated, the pounds or gallons of product used, 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 data on cotton acreage on the 1080 data for 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 a unit of observation. This measure masks variation within a section but makes it possible to construct a large, geo-coded database on pesticide use intensity with over 1,500 observations 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 ADA system mandates the reporting of all commercial pesticide applications as well as Section 18 products. The insect growth regulators Knack and Applaud 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. 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, the efficacy of pyrethroid-organophosphate combinations was already widely recognized by 1995 (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 uses acreage data on the IGRs and a variety of tank mix combinations that include combinations of active ingredients indicated in extension publications (Ellsworth et al, 1994, Ellsworth and Watson, 1996). The most commonly used whitefly tank mix in 1995 is an acephate-fenpropathrin (Orthene®-Danitol®) combination. 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 gossyplure and all non-cross-family mixes (i.e. two organophosphates, chlorpyrifos and acephate (Lorsban® and Orthene®). Use of these latter mixes were discouraged because they were deemed ineffective against whiteflies (Ellsworth and Watson, 1996).

The data set is not a complete census of cotton acreage in the state, but it is close. We omitted sections that made no whitefly-targeted applications in either 1995 or 1996. These were mostly in the southeastern part of the state where whitefly infestations are more rare. We also excluded some sections where the ADA 1080 data and the ACRPC acreage data were inconsistent. Even with these omissions, over 90 percent of Arizona's cotton acres are accounted for in the sample. Also because ADA pesticide use reporting requirements mandate reporting Section 18 compounds, the data set accounts for 99 percent of IGR applications in 1996.

Econometric Specification

The two equations to be estimated are:

(1) $y_1^* = \beta_1'\mathbf{X}_1 + u_1$
$y_1 = y_1^*$ if $y_1^* > 0$
$y_1 = 0$ otherwise

(2) $y_2^* = \beta_2'\mathbf{X}_2 + \gamma_2 y_2^* + u_2$.

In equation (1), the dependent variable, y_1, is the intensity of adoption of the new pest control technology (IGRs) in 1996, measured as the average number of IGR applications per acre. In 40 percent of the sections, no adoption is observed ($y_1 = 0$). Because IGR applications are limited to one each per season, this variable has an upper limit of 2. However, while a substantial number of observations were at the lower limit, few were actually at the upper limit.

The dependent variable in equation (2), y_2, is the change in conventional insecticides used to control whitefly from 1995 to 1996. The mean of y_2 = -2.047, but the variable takes on both positive and negative values. The term $\boldsymbol{X}_1$ is a vector of exogenous variables explaining the intensity of adoption. The term $\boldsymbol{X}_2$ is a vector of exogenous variables explaining changes in conventional insecticide use between 1995 and 1996. The terms β_1 and β_2 are vectors of parameters to be estimated. Our primary interest is the impact of adoption of the new pest control technology (IGRs) on conventional insecticide use, measured by the parameter γ_2.

Because of the mechanism of action for IGRs against whiteflies, growers would normally have them applied early in the season. IGRs do not kill whiteflies directly, but impede their growth and development. They are not effective against whiteflies at later stages of development. If whitefly populations exceeded treatment thresholds later in the season, growers would have conventional insecticides applied subsequently. As part of the Integrated Management Plan submitted to gain Section 18 approval, extension publications and training sessions explicitly recommended that pyrethroids not be applied prior to IGRs (Ellsworth and Diehl). For these reasons, we treat use of IGRs and conventional insecticides as sequential rather than simultaneous. This recursive approach could also be applied to examination of adoption of seed varieties on pesticide use. For example the first decision could be intensity of adoption of herbicide resistant or pest resistant seed (such as Roundup Ready or Bt varieties). The second equation would be change in use of herbicides or insecticides.

Direct estimation of equation (2) is problematic for two reasons. First, both IGR adoption and demand for conventional insecticides will be affected by common, unobserved variables, such as grower or PCA characteristics or the whitefly pest population at the beginning of the season. The error terms u_1 and u_2 will likely be correlated and estimating (2) by ordinary least squares will lead to biased and inconsistent estimates of γ_2 and β_1. Estimation of (2) by standard two-stage least squares methods is also inappropriate because the endogenous regressor, y_1, is censored.

Nelson and Olsen considered estimation of a two-equation simultaneous system where one endogenous variable is continuous, but the other censored. They suggested a two-step estimation procedure. First, the reduced form for y_1 is estimated by tobit maximum likelihood methods and the reduced form for y_2 by ordinary least squares. Second, the predicted values of y^*_1 and y_2 are used to estimate the structural equations. Maddala (1983, Section 8.8) and Greene (p. 735) have outlined methods for estimating the correct asymptotic covariance matrix for Nelson and Olsen's model. We adapt the Nelson-Olsen-Maddala-Greene approach to our particular specification, which is recursive rather than fully simultaneous.

Determinants of Adoption Intensity

The benefits of insecticide use are the reduction of economic damage in the form of yield losses, price discounts for lower quality, or both. IGRs cost more per acre than conventional tank mix applications. One would then expect IGR adoption in areas where they would reduced damage more effectively than tank mixes, where physical damage is greater, and where the revenue losses from damage would be higher, such as areas with higher expected pre-damage yields. Section-level data on yield or pest infestations are not available. The Arizona Cotton Research and Protection Council (ACRPC), however, organizes their outreach activities based on sub-county regions called Work Units. Sections within Work Units have similar soil types, microclimates, and pest pressures. To account for location-specific effects not captured by other variables, we include Work Unit dummy variables in the adoption intensity equation, equal to one if a section lies within a particular Work Unit and equal to zero otherwise.

The expected gains to IGR adoption will be higher in sections where potential whitefly damage is greater and where resistance to conventional insecticides is greatest, or conversely where whitefly susceptibility is lowest. Section-level data for pest population or damage were not available. Instead, intensity of local whitefly pressure was proxied by two variables. The first was average treatments per acre of whitefly-targeted insecticide applications in 1995, the year prior to IGR availability. The second variable was whitefly insecticide treatments per acre in the adjoining 8 sections. Data were also available reflecting whitefly resistance to Danitol-Orthene (fenpropathin-acephate), the most prevalent tank-mix combination used to control whitefly. A susceptibility measure was determined using leaf-dip bioassays conducted by the Extension Arthropod Resistance Management Laboratory (EARML) at the University of Arizona. Whitefly populations from multiple sites across the state were sampled, then exposed in the laboratory to a combination of Orthene at 1000 micrograms per milliliter and Danitol ranging from 0.1 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 percent. A susceptibility score 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.

Adoption studies have proxied grower technical ability or innovativeness by previous adoption of new practices such as forward contracting or new technologies such as computers (McNamara, Wetzstein and Douce; Fernandez-Cornejo; Khanna). We use relative reliance on pheromones to control pink bollworm in cotton in 1995 as a predictor of IGR adoption in 1996. Specifically, the variable used was pheromone applications as a proportion of total applications for pink bollworm in a section. Pheromones and IGRs are more management intensive than broad-spectrum insecticides. They have selective activity on specific pests, break down relatively quickly in the environment, and are only effective at particular phases of target insect development.

Table 1 shows statistics for these variables for non-adopting sections, sections with an adoption intensity greater than zero but less than one, and sections with adoption intensity greater than one. Non-adopting sections in 1996 averaged fewer tank mix applications in 1995 than adopters did. Although non-adopting sections actually received lower tank mix treatments per acre in 1996, adopting sections reduced their tank mix intensity by greater amounts (Table 1). The susceptibility of whiteflies to conventional insecticides was higher on average in non-adopting sections in 1996. Pheromone use in 1995 was relatively higher on adopting sections than non-adopting sections.

Past studies have found farm size to be important in explaining adoption of new technologies (Daberkow and MacBride; Dinar, Campbell and Zilberman; Fuglie and Bosch). The ADA data does not provide direct information on farm size, but does provide information about the geographic extent of growers' operations. For example, the data indicates over how many sections a particular grower had pesticides applied. One then knows whether a grower operated over two versus twenty sections. This data was used to classify sections by the types of grower(s) operating there. Growers were divided into 5 classes: those operating across >35 sections, 26-35 sections, 16-25 sections, 11-15, and 6-10 sections, with the default being operators spanning 5 or fewer sections. Binary variables were used to signify whether the section had growers of different size classes operating there. In addition, to capture scale effects, we included cotton acreage per number of growers in a section as a separate variable.

We also wanted to test the hypothesis that proximity to population centers was a disincentive to apply pesticides. Arizona law prohibits aerial spraying of pesticides in close proximity to schools, day care centers, and certain health facilities. Residents living in close proximity to cotton fields are also more likely to call in complaints and request investigations of applicators to the Arizona Department of Environmental Quality. Population density in the section was also included as an explanatory variable.

Another hypothesis concerned the impact of cropping patterns on pest infestations and use of insecticides. Here the null hypothesis is that pest pressure and insecticide applications are not affected by the extent of cotton acreage grown in a given section and in adjoining sections. The alternative hypothesis is that pest pressures and insecticide applications will be greater in areas where cotton acreage is more concentrated. To test this hypothesis we include two variables: one for cotton acreage in a section and one for total cotton acreage in the eight neighboring sections.

In general, theoretical models of integrated pest management or demand for pesticides assume that it is the producer who is making the pesticide application decisions. In Arizona cotton production, however, the vast majority of producers employ pest control advisors (PCAs), who scout fields for pests, make pesticide application recommendations and make the arrangements for pesticide applications. The PCA, often more so than the grower, determines what types of pesticide applications are made. A PCA's incentive structure also differs from growers because they receive commissions of up to 10 percent of sales on applications they recommend. Attributes of PCAs may therefore be just as (if not more) important as grower attributes in determining pest control technology adoption decisions. While data on individual PCA attributes were not available, the 1080 data does include individual PCA identification numbers. We included dummy variables for the 58 largest PCAs, measured in terms of the number of sections covered. These PCAs covered 92 percent of the cotton acreage in the sample. The remaining 8 percent represented PCAs covering relatively small areas. These acres likely represent growers doing their own scouting but requiring a signature from a licensed applicator at a chemical dealership. These licensed applicators would also have individual PCA identification numbers.

Adoption Intensity Equation: Results

Table 2 shows results of the maximum likelihood estimation of the tobit equation for adoption intensity. The first column shows the regression coefficient, while the second shows the slope coefficient given a positive observation for intensity. Tank mix applications to control whitefly in 1995 were an important predictor of IGR adoption intensity in 1996. Both the coefficients for the TANK MIX_{95} variable and NEIGHBOR TANK MIX_{95} were significant, with the own section effects being larger. The coefficient for the synergized pyrethroid SUSCEPTIBILITY index also was highly significant and had the expected, negative sign. Where pest susceptibility to conventional pest control technology remained high, IGR adoption intensity was lower. Conversely, the results imply greater IGR adoption where resistance to conventional technology was also greater.

Use of PHEROMONES to control pink bollworm in the previous year also appears to have been a good predictor of IGR adoption in 1996. We had hypothesized the technical skills required to successfully use both technologies would be similar and that past use of pheromones would be a good predictor of IGR adoption.

Cotton acres in a section (ACRES) and neighboring sections (NEIGHBOR ACRES) also contributed to greater intensity of IGR use. Again, the neighborhood effects were weaker than the own section effects. There is some evidence that POPULATION density did discourage IGR use, although this variable is significant only at the 10 percent level. While some the variables intended to capture effects of scale of operation were significant, a clear systematic pattern is difficult to discern. The PCA dummy variables (not shown in Table 2) were jointly significant at the 0.1 percent level (based on a likelihood ratio test), as were the Work Unit variables. This suggests that, in the future, collecting data on PCA attributes may be worthwhile for empirical studies of pesticide use.

Effect of IGR Adoption on Conventional Insecticide Use

In this second stage (equation (2)), the change in tank mix applications between 1995 and 1996 is the dependent variable. IGR adoption intensity is an endogenous regressor. To account for this endogeneity, the predicted value of IGR adoption, $\hat{y}_1$, is derived from a reduced form tobit equation that uses exogenous variables from both equations (1) and (2). Maddala and Greene's procedure to obtain correct variance estimates are applied to equation (2). The coefficient on $\hat{y}_1$ is highly significant, with a standard error one-tenth the parameter estimate (Table 3). The coefficient implies that, among IGR adopters, one IGR acre-treatment substituted for 3.66 tank mix acre-treatments.

The coefficient for the change in susceptibility is highly significant and negative, suggesting that an increase in whitefly resistance to tank mixes leads to an increase in tank mix applications. Our empirical specification captures both the direct effect of resistance increasing demand for tank mix applications (Table 3) and the substitution effect of resistance stimulating a switch to IGRs (Table 2).

Cotton acreage in a section and in neighboring sections contributes to greater tank mix applications per acre. Neighborhood effects were weaker than the own section effects. Reductions in tank mix use were higher in more densely populated sections. The change in per acre tank mix use was inversely related to the change cotton acres per grower in a section. Looking at the size class variables, sections with larger growers, all else equal, tended to reduce their tank mix intensity less than growers operating across 5 or fewer sections did. The PCA and Work Unit dummy variables (not shown in Table 3) were jointly significant at the 0.1 percent level.

Economic Implications of IGR Adoption

Results from the second stage regression estimation can be used to estimate what the intensity of tank mix use would have been had IGRs not been adopted. From Table 3, without adoption, tank mix treatments per acre would have been higher by 3.66 for every per acre treatment of IGRs. The weighted-average impact of IGR adoption, which accounts for differences in adoption intensity and acreage within each section, is to reduce tank mix use by 3.123 per acre. This is a within sample estimate, but our sample includes over 90 percent of the cotton acreage in the state and 99 percent of IGR treatments.

In 1996, IGR adoption reduced net insecticide costs (tank mix costs – IGR costs) by $46.32 per acre (Table 4). Estimates of per acre costs of IGRs come from University of Arizona Cooperative Extension Crop Budgets and include the cost of materials and aerial applications. The average cost of IGRs was weighted by the share of Applaud and Knack treatments. The tank mix 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, bringing total tank mix costs per acre to $25.21.

Statewide, IGR expenditures were about $6.6 million, but cost savings from reduced tank mix applications were $16.1 million. IGR adoption led to a net reduction in insecticide costs to control whiteflies of $9.5 million. According to the ADA 1080 data, 332 different growers adopted IGRs in 1996. This implies net insecticide cost savings averaged $28,484 per adopting grower (Table 4).

Conclusions

This study used a recursive equation system with an endogenous qualitative variable to estimate the determinants of the intensity of adoption of new pest control technologies and to estimate how intensity of adoption affected use of conventional insecticides. Pest resistance to conventional pesticides had a direct, partial effect of increasing demand for conventional pesticides (all else equal), but also stimulated substitution to alternative, new pesticides. Given the detailed and comprehensive nature of the data set, the regression results allow for straightforward calculation of the statewide economic impacts of the adoption of the new pest control technology, insect growth regulators (IGRs). The adoption of IGRs led to reductions in net insecticide costs among Arizona cotton growers of $9.5 million in 1996, over $28,000 per adopting operator. The recursive estimation approach used here could also be applied to examination of adoption of seed varieties on pesticide use. For example the first decision could be intensity of adoption of herbicide resistant or pest resistant seed (such as Roundup Ready or Bt varieties). The second equation would be change in use of herbicides or insecticides.

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Table 1. Variable definitions and descriptive statistics by intensity of IGR adoption

Variable Name	**Mean Values and Standard Deviations** IGR = 0	0 < IGR < 1	IGR $\geq$ 1	**Description**
Number of Sections	618	542	369	
IGR	0.00	.65	1.28	Applications of insect growth regulators
	(0.00)[a]	(.29)	(.40)	(IGRs) per acre, 1996
TANK MIX_{95}	2.72	3.51	4.00	tank mix insecticide applications per acre,
	(1.75)	(1.73)	(1.89)	1995
NEIGHBOR	2.81	3.42	3.74	tank mix insecticide applications per acre in
TANK MIX_{95}	(1.51)	(1.30)	(1.39)	8 surrounding sections, 1995
TANK MIX_{96}	1.16	1.29	1.39	tank mix insecticide applications per acre,
	(1.19)	(1.07)	(1.11)	1996
Δ TANK MIX	-1.56	-2.22	-2.61	TANK MIX_{96} – TANK MIX_{95}
	(1.86)	(1.78)	(1.83)	
SUSCEPTIBILITY	72.81	65.76	60.38	index of whitefly susceptibility to Danitol-
	(27.47)	(28.62)	(28.30)	Orthene tank mix
PHEROMONES	0.21	0.37	0.35	Pheromone applications as a percent of total
	(0.37)	(0.41)	(0.41)	applications to control pink bollworm, 1995
ACRES	199.88	236.25	206.23	cotton acres cropped in section, 1996
	(135.70)	(129.09)	(125.88)	
NEIGHBOR ACRES	1010.95	1201.93	1028.21	cotton acres cropped in 8 surrounding
	(696.78)	(694.16)	(609.13)	sections, 1996
ACRES / GROWER	147.06	137.36	134.63	cotton acres cropped per grower operating
	(114.78)	(98.54)	(102.83)	in section, 1996
POPULATION	103.54	68.05	80.93	Population density in section, 1996
	(415.72)	(264.01)	(334.91)	
SIZE >35	0.10	0.17	0.16	binary variable (=1 if a grower operating in
	(0.30)	(0.37)	(0.36)	the section operated in > 35 sections; = 0 otherwise)
SIZE 26-35	0.04	0.05	0.04	binary variable (=1 if a grower operating in
	(0.19)	(0.21)	(0.20)	the section operated in 26-35 sections; = 0 otherwise)
SIZE 15-25	0.13	0.21	0.25	binary variable (=1 if a grower operating in
	(0.33)	(0.41)	(0.43)	the section operated in 15-25 sections; = 0 otherwise)
SIZE 10-14	0.32	0.28	0.28	binary variable (=1 if a grower operating in
	(0.47)	(0.45)	(0.45)	the section operated in 10-14 sections; = 0 otherwise)
SIZE 6-9	0.32	0.40	0.35	binary variable (=1 if a grower operating in
	(0.47)	(0.49)	(0.48)	the section operated in 6-9 sections; = 0 otherwise)

a. Standard deviations in parentheses.

Table 2. Determinants of Intensity of IGR Adoption: Tobit MLE Estimates

Dependent Variable: IGR - insect growth regulator applications per acre, 1996		
Variable Name[a]	**Coefficient, β_1 (β_1 / Standard error)**	**Marginal Effects, $\partial E[y \mid X_1]\ \partial X_1 = \Phi(\beta' X_1/\sigma)\beta$**
TANK MIX_{95}	0.07922 (5.76)****	0.05249
NEIGHBOR TANK MIX_{95}	0.04708 (2.51)**	0.00005
SUSCEPTIBILITY	-0.05284 (-4.22)****	-0.03501
PHEROMONES	0.19682 (2.95)***	0.13040
ACRES	0.00082 (3.33)***	0.00054
NEIGHBOR ACRES	0.00007 (1.77)*	0.00005
POPULATION	-0.00011 (-1.71)*	-0.00007
ACRES / GROWER	-0.00101 (-3.41)***	-0.00067
SIZE >35	-0.04976 (-.310)	-0.03297
SIZE 26-35	.562164 (3.12)***	0.37246
SIZE 15-25	0. 06596 (.99)	0.04370
SIZE 10-14	-0.11461 (-2.24)**	-0.07593
SIZE 6-9	0.01979 (.42)	0.01312
σ	0.69027 (39.18)****	
Number of Observations	1529	
Proportion Adopting	59.6%	

a. Coefficients and marginal effects for pest control advisor (PCA) and Work Unit dummy variables not shown.

* Statistically significant at 10% level

** Statistically significant at 5% level

*** Statistically significant at 1% level

**** Statistically significant at 0.1% level

Table 3. Determinants of change in tank mix insecticide applications

Dependent Variable: Δ TANK MIX - change in tank mix applications per acre between 1995 and 1996	
Variable Name[a]	**Regression Coefficient (Standard Error)**
$\hat{y}_1$ (predicted IGR)	-3.65991
	(-10.00)****
Δ SUSCEPTIBILITY	-0.2263
	(-4.07)****
Δ ACRES	0.00153
	(2.04)**
Δ NEIGHBOR ACRES	0.00065
	(2.61)***
POPULATION	-0.00072
	(-3.25)***
Δ ACRES / GROWER	-0.00330
	(-3.764)***
SIZE >35	1.21472
	(2.25)***
SIZE 26-35	2.07250
	(3.33)****
SIZE 15-25	0.50208
	(2.11)**
SIZE 10-14	-0.12780
	(-0.73)
SIZE 6-9	0.38288
	(2.32)***
Number of Observations	1529
Adjusted R^2	0.453

b. Coefficients for pest control advisor (PCA_m), Work Unit (*WU j*), dummy variables, and constant term not shown.

* Statistically significant at 10% level
** Statistically significant at 5% level
*** Statistically significant at 1% level
**** Statistically significant at 0.1% level

Table 4. Net insecticide cost savings attributable to IGR adoption, Arizona 1996

Total cotton acres in IGR adopting sections	204,146	
IGR acre treatments in adopting sections	174,216	
Cost per acre treated, insecticide tank mixes	$25.21	
Weighted average reduction in tank mix applications per acre, adopting sections	3.123	
Weighted average reduction in tank mix application costs per acre, adopting sections	$78.74	
Weighted average cost per acre treated, IGRs	$37.98	
IGR costs per acre of cotton in adopting sections	$32.42	
Net insecticide cost savings per acre of cotton in adopting sections		**$46.32**
1996 Tank mix cost savings ($ millions)	$16.1	
1996 IGR costs ($ millions)	$6.6	
Net insecticide cost savings ($ millions)		**$9.50**
Number of adopting operators	332	
Net insecticide cost savings per adopting operator		**$28,484**