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Effect of Pink Bollworm on Agronomic Properties of Resistant and Susceptible Cotton[1]

F. D. Wilson and B. W. George[2]

ABSTRACT

Little is known about the differential effects of the attack of pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), on agronomic properties of resistant and susceptible cottons, *Gossypium* spp. The major objective of this study was to determine and compare those effects in a susceptible cultivar and a resistant breeding stock of upland cotton, *G. hirsutum* L., and a susceptible cultivar of Pima cotton, *G. barbadense* L. Other objectives were to compare an x-ray method with a visual boll-grading method of determining damage done by the insect, and to study the relationship of seed damage with selected agronomic properties. The three cottons were grown for two seasons in untreated field plots and in plots treated for PBW control. Seed cotton was harvested weekly as bolls opened, seed samples were x-rayed to determine seed damage, and agronomic properties were measured. At the end of the season, all bolls were removed from five plants/plot and bolls were graded into damage classes. Pink bollworm mainly damaged rather than destroyed seed. Damaged bolls did not abscise but remained on the plant. The Pima entry, 'Pima S-5' had more dry, unharvestable bolls than the two upland entries, 'Deltapine 61' and AET-5. Damage was higher in unsprayed than in sprayed plots. The resistant AET-5 had less seed damage and fewer damaged bolls than the other two entries, and its agronomic properties were less affected by PBW attack. The x-ray method failed to integrate data from unharvestable bolls, and the graded-boll method failed to quantify the amounts of damage in the damaged-boll category. The percentages of variation in decreases in agronomic properties, attributable to increases in seed damage, were higher in unsprayed than in sprayed plots, but also differed among the three cottons. Thus, direct comparison of the effects of PBW on agronomic properties among cottons in unsprayed plots could be misleading because these effects would be superimposed on different natural patterns of decrease in those properties as the season progressed.

Additional index words: ***Gossypium barbadense* L., *Gossypium hirsutum* L., *Pectinophora gossypiella* (Saunders), Host plant resistance, Yield components, Insecticides, Genotype × environment interaction.**

LARVAE of the pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), may develop in flowerbuds (squares) or bolls of plants of cotton, *Gossypium* spp. Larvae in squares have little effect on lint or seed yield, but larvae in bolls can reduce markedly both lint and seed yield and quality (1,2,3,4,5,6,7).

Several methods have been used to determine the amount of PBW damage to the cotton boll. Among those methods are examination of dissected green bolls (10), lint and seed yield losses (1), lint and seed quality reduction (1), dissecting seeds to detect larvae (5), and x-raying seeds (5,10). We use the x-ray method routinely to screen cottons for natural resistance to PBW. However, little is known about the relationships between percent seed damage, as estimated by the x-ray method, and agronomic properties. In this paper we present the results of a study done to determine those relationships. We also present ancillary data from a method that we used more recently: that of grading bolls into classes based on a visual estimate of PBW damage.

The objectives of our study were as follows: determine the effects of PBW on cotton yield and other agronomic properties, as influenced by insecticide use and by diverse germplasm; to relate results from the x-ray method of measuring seed damage to those obtained from grading bolls visually into damage classes; and to determine the relationship of seed damage to selected agronomic properties.

MATERIALS AND METHODS

Field tests were grown for 2 years, 1979 and 1980, at the Ariz. State Univ. Farm Laboratory, Tempe, Ariz. Soil type was Contine clay loam, a member of the fine, mixed, hyperthermic Typic Haplargids. Entries were 'Deltapine 61' (DPL-61), a commercial upland (short-staple) cultivar, *G. hirsutum* L.; 'Pima S-5', a commercial American Pima (extra-long staple) cultivar, *G. barbadense* L.; and AET-5, an experimental upland breeding stock, previously shown to have some resistance to PBW (8,9,10).

Experimental design was a 3 × 2 factorial arranged in randomized complete blocks with five replications. Plot size was four rows 9.1 m long; rows were spaced 1 m apart. Two plots/replication of each entry were planted in mid-April each year. Plants were hand-thinned to 30 cm apart in the row. One plot/replication of each entry was not treated with insecticide, while the other plot was hand sprayed on a 6-day schedule from mid-July to early October with 2.24 kg a.i./ha carbaryl (1-naphthyl methylcarbamate) for PBW control and, in 1979, 0.31 kg a.i./ha dicofol [4,4'-dichloro-α-(trichloromethyl) benzhydrol] for control of spider mites, *Tetranychus* spp. In 1980, the dicofol inexplicably was left out of the spray mixture until a spider-mite population had developed in the sprayed plots of the upland cottons. Spider mite populations did not develop on unsprayed upland, or on sprayed or unsprayed Pima cotton. Other cultural practices were standard for the area.

As bolls began to open (early August), seedcotton was harvested weekly from 20 plants in one row of each plot. The harvested bolls were counted each time. From ginned samples, at each harvest date, 200+ seed from each plot were x-rayed (10), and seed damage percentages were estimated from the ensuing radiographs.

Data obtained were percent seed damage; yield (lint/plant); seedcotton, lint, and seed weight/boll; lint index (g lint/100 seed); seed index (g seed/100 seed), lint percentage (percentage of seedcotton that is lint); bolls harvested/plant; and seed/boll. On 5 Nov. 1979 and 23 Oct. 1980, all bolls were harvested from an additional five plants/plot, counted and graded visually into the following classes: green (bolls that would not have opened because they had been produced too late); dry (bolls that did not open but dried on the plant); PBW damaged; and undamaged.

A combined analysis of variance was used to analyze the data. For interpretive purposes, a fixed model was assumed. Under this assumption, the residual (error) mean square is used as the error term for all main effects and interactions. Regression and correlation analyses also were conducted on a plot basis (seven harvests × five replications, 1979; six harvests × five replications, 1980) to examine associations among seed damage, percent damaged bolls, and selected agronomic properties.

RESULTS

For DPL-61, lint yield and all other agronomic properties except bolls harvested/plant were significantly lower in unsprayed than in sprayed plots (Table 1). For AET-5, only four agronomic properties were significantly lower in sprayed plots. For both upland entries, percent seed dam-

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[2] Research geneticist and research entomologist, respectively, USDA-ARS, Western Cotton Res. Lab., 4135 East Broadway Rd., Phoenix, AZ 85040.

Table 1. Agronomic properties (2-year means, 1979 and 1980) in two upland cottons and one Pima cotton, unsprayed or sprayed for protection from pink bollworm.

Cotton	Spray level	Lint/ plant	Weight/boll Seedcotton	Weight/boll Lint	Weight/boll Seed	Lint index	Seed index	Lint	Bolls harvested/ plant	Seeds/ boll
		g	g	g	g	g	g	%	no.	no.
Deltapine 61	Sprayed	54.8a†	4.19a	1.58a	2.53a	5.95b	9.37b	38.2c	32.6ab	26.6a
Deltapine 61	Unsprayed	41.1b	3.55b	1.31c	2.12b	5.20c	8.32c	37.2d	29.3bc	24.8b
AET-5	Sprayed	40.7b	3.48bc	1.39b	2.0b	5.79b	8.27c	40.2a	27.2c	23.8bc
AET-5	Unsprayed	40.9b	3.31c	1.26c	1.87c	5.38c	8.08c	39.5b	30.5a-c	22.9c
Pima S-5	Sprayed	37.9b	2.85d	1.05d	1.82c	6.33a	10.87a	36.1e	34.0a	16.6d
Pima S-5	Unsprayed	26.8c	2.47e	0.19e	1.49d	6.00b	9.80b	37.2d	27.4c	15.0e
Source	**df**	Analysis of variance—mean squares								
Years (Y)	1	23.6	0.57**	0.01	0.59**	1.57**	6.49**	157.8**	0.3	13.1**
Replications/Y	8	249.9	0.05	0.01	0.04	0.06	0.87**	2.2	131.0	1.9
Entries (E)	5	4972.7**	3.59**	0.58**	1.21**	1.77**	12.07**	24.3**	535.3**	220.3**
Cottons (C)	2	7596.4**	7.51**	1.17**	2.29**	1.53**	24.48**	53.9**	190.7	533.7**
Spray level (S)	1	6266.9**	2.40**	0.51**	1.28**	3.76**	8.87**	0.7	487.6	32.0**
C × S	2	1702.0*	0.27*	0.03	0.08*	0.25	1.25**	6.4**	903.8**	1.0
Y × E	5	1186.3**	0.34**	0.04*	0.04	0.28*	0.24	3.2**	1045.4**	5.1*
Y × C	2	3358.7**	0.44**	0.05*	0.03	0.68**	0.43	6.0**	2441.8**	1.5
Y × S	1	670.7	0.66**	0.07**	0.13*	0.02	0.03	2.9*	3.1	17.4**
Y × C × S	2	260.3	0.18	0.01	0.01	0.01	0.30	0.6	170.1	2.6
Error	40	298.5	0.06	0.01	0.02	0.08	0.19	0.5	135.5	1.5

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† Means with letters in common, within a column, are not significantly different at the 0.05 level of probability, according to the restricted LSD test.

Table 2. Seed damage and graded-boll data (2-year means, 1979 and 1980) in two upland cottons and one Pima cotton, unsprayed, or sprayed for protection from pink bollworm.

Cotton	Spray level	Seed damage	Graded bolls Green	Graded bolls Dry	Graded bolls Damaged	Graded bolls Undamaged	Total bolls/ plant
		%	%	%	%	%	no.
Deltapine 61	Sprayed	2.3d†	8.0b	2.1c	11.3bc	78.6a	31.7b
Deltapine 61	Unsprayed	27.6a	13.9a	5.1c	37.8a	43.2d	33.7ab
AET-5	Sprayed	1.7d	6.3b	2.3c	8.6c	82.8a	25.0c
AET-5	Unsprayed	15.8c	12.2a	1.8c	21.7b	64.3bc	28.1bc
Pima S-5	Sprayed	4.0d	4.4b	22.2b	18.3c	55.1c	38.2a
Pima S-5	Unsprayed	22.9b	4.9b	32.2a	43.4a	19.5e	38.7a
Source	**df**	Analysis of variance—mean squares					
Years (Y)	1	21.4	1 684.3**	1 551.9**	8.4	9.4	35.3
Replications/Y	8	26.5	40.3	37.9	112.7	83.0	64.6
Entries (E)	5	1 278.5**	154.6**	1 698.3**	2 010.7**	5 500.1**	295.6**
Cottons (C)	2	210.6**	212.1**	3 971.6**	1 255.9**	6 753.1**	705.9**
Spray level (S)	1	5 652.3**	253.7**	265.5**	6 998.4**	13 098.2**	50.1
C × S	2	159.5**	47.5	141.4**	271.5	452.6*	8.0
Y × E	5	5.7	17.3	325.1**	138.6	233.3	31.1
Y × C	2	0.6	28.4	892.3**	364.3	306.1	56.1
Y × S	1	18.3	4.5	113.7*	111.5	13.6	43.0
Y × C × S	2	4.5	27.2	134.5*	41.8	270.3	25.9
Error	40	17.2	18.6	18.5	115.9	122.1	39.5

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† Means with letters in common, within a column, are not significantly different at the 0.05 level of probability, according to the restricted LSD test.

age, green bolls, and damaged bolls were significantly higher, and percent undamaged bolls was significantly lower in unsprayed than in sprayed plots, but percentages of dry bolls, and total number of bolls/plant were not significantly different (Table 2).

For Pima S-5, all agronomic properties except lint percentage, lint yield and yield components were lower in unsprayed than in sprayed plots. Percent seed damage, dry bolls, and damaged bolls were significantly higher in unsprayed than in sprayed plots, and percent undamaged bolls was significantly lower, but green and total bolls/plant were not significantly different.

In the combined analysis, differences between years were significant for eight of the 15 properties (Tables 1 and 2). Differences among cottons were nonsignificant only for bolls harvested/plant. Differences between sprayed and unsprayed plots were significant for every property except lint percentage, bolls harvested/plant, and total bolls/plant.

Cottons × spray level (C × S) interactions were significant for nine of the 15 properties studied. Years × cottons (Y × C) interaction effects were significant for seven properties and years × spray level (Y × S) effects were significant for six. The Y × C × S interaction effect was significant only for percent dry bolls.

Correlations between percent seed damage and the three selected agronomic properties lint weight/boll, seed weight/boll, and seed/boll were negative and highly significant for all unsprayed plots with the following nonsignificant exceptions: for Pima S-5, lint weight/boll in 1980 and seed/boll both years; for DPL-61, seed/boll in 1979 (Table 3). On the other hand, correlations for sprayed plots in 1979 and 1980 were nonsignificant except for the three correlations involving AET-5 in 1979, which were negative and significant or highly significant.

Table 3. Correlation coefficients (r) between seed damage caused by pink bollworm and three agronomic properties of cotton.

		Y variable					
		Lint weight/boll (Y_1)		Seed weight/boll (Y_2)		Seed/boll (Y_3)	
Cotton and X variable	Spray level	1979	1980	1979	1980	1979	1980
Seed damage % (X):							
Deltapine 61	Sprayed	−0.29	−0.17	0.06	−0.11	0.25	−0.18
	Unsprayed	−0.85**	−0.93**	−0.78**	−0.88**	−0.20	−0.77**
AET-5	Sprayed	−0.51**	−0.34	−0.49**	−0.31	−0.40*	−0.35
	Unsprayed	−0.82**	−0.73**	−0.75**	−0.72**	−0.59**	−0.69**
Pima S-5	Sprayed	−0.15	−0.14	0.06	−0.13	0.26	−0.05
	Unsprayed	−0.70**	−0.35	−0.66**	−0.55**	−0.13	−0.29

*,** Correlation coefficient significant at the 0.05 and 0.01 levels of probability (33 df in 1979, 28 df in 1980), respectively.

Correlations between percent damaged bolls and the same three agronomic properties (2 years combined) were not significant except for lint/boll in unsprayed plots of DPL-61 ($r = -0.81$, 8 df). Percent seed damage and percent damaged bolls were significantly correlated over all plots ($r = 0.73$, 58 df); but not in unsprayed plots ($r = 0.22$, 28 df).

DISCUSSION

The major effect of PBW attack on all three cottons was to damage rather than to destroy seed, as shown by the larger loss in weight than in number of seed. Also, most damaged bolls remained on the plant rather than abscising. Very few bolls of DPL-61 and AET-5 were unharvestable even though damaged, but substantial numbers of bolls of Pima S-5 were unharvestable because they dried on the plant and failed to open. In 1979, 40% of the bolls in both sprayed and unsprayed plots of Pima S-5 were graded as dry, which shows that factors other than PBW damage caused some of the boll drying. In 1980, however, almost all of the dry bolls were damaged by PBW, and the percentage of dry bolls in unsprayed plots (24%) was significantly higher than in sprayed plots (5%). This result led to the only significant Y × C × S interaction effect in our analysis.

Pink bollworm affected lint yield, most other agronomic properties, and seed and boll damage differently in the three cottons, as shown by the numerous significant C × S interaction effects. For example, lint yield of the resistant AET-5 was virtually the same in both sprayed and unsprayed plots but was reduced significantly in unsprayed plots of DPL-61 and Pima S-5. The higher yield potential of DPL-61, when protected by insecticide, was shown because AET-5 and Pima S-5 yielded only 74 and 69% as much lint, respectively, as DPL-61 in sprayed plots.

The three cottons also responded differently to PBW attack in the two seasons, as shown by the significant Y × C interaction effects for lint yield and several other agronomic properties. For example, in 1979, DPL-61 yielded 23% more lint in sprayed plots but 15% less lint in unsprayed plots than AET-5, whereas in 1980, DPL-61 yielded more lint than AET-5 in both sprayed and unsprayed plots. Thus, AET-5 is capable of outyielding DPL-61 when exposed to a sufficient population of PBW, even though its inherent yield potential is significantly lower than that of the cultivar. The smaller difference in 1980 than in 1979 of lint/plant in sprayed vs. unsprayed plots of the two upland cottons also contributed to the Y × C interaction. This difference was attributed to the depressions in yield caused by spider mites in sprayed plots in 1980.

The significant Y × S interaction effects for several agronomic properties were caused by larger differences in sprayed vs. unsprayed plots in 1979 than in 1980. These larger differences presumably reflect the effects of higher seed damage on agronomic properties in 1979 than in 1980 but the Y × S interaction effect was not significant for either percent seed damage or lint/plant.

Percent seed damage, as estimated by the x-ray method, is a direct measure of resistance to PBW because the insect develops in the seed. Also, percent seed damage is negatively correlated with yield and its components. The reduced seed damage of AET-5 in the tests reported in this paper agrees well with previous results (8) and emphasizes the value of using percent seed damage to identify resistant germplasm. However, this measure of damage fails to integrate information from unharvestable bolls. This is a minor problem if unharvestable bolls constitute a small percentage of the total, or if the percentages do not vary much among entries, as in DPL-61 and AET-5. The problem is more serious if there are differences. For example, in unsprayed plots, DPL-61 had significantly more seed damage than Pima S-5 (27.6 vs. 22.9%) but lost less lint/plant in unsprayed as compared to sprayed plots (25 vs. 30%) because Pima S-5 had more unharvestable bolls.

The graded boll data also revealed the PBW resistance of AET-5. Graded boll data measure a different facet of resistance than seed damage data. An advantage of the graded-boll method is that it estimates the percentage of unharvestable bolls. A possible disadvantage, however, is that the damaged category includes bolls that are only slightly to extensively damaged. This variability may help to explain why percent damaged bolls was not significantly correlated with percent seed damage or with agronomic properties.

Another disadvantage of the graded boll method is that it would not reveal internal-boll antibiosis, i.e., a type of resistance that would not restrict entry of the larvae into the boll but would affect their growth and development after they had penetrated the boll.

On the other hand, graded boll data could be used as a substitute for seed damage to identify cottons that have an advantage because of earliness or that have antixenosis (e.g., oviposition nonpreference). In fact, bolls could be graded on the plant and would not have to be harvested.

As expected, the percentages of the variation of seed and lint weight/boll attributed to percent seed damage by PBW ($r^2 \times 100$; r values listed in Table 3) were always higher in unsprayed than sprayed plots. However, the effects of PBW attack, as measured by seed damage, were superimposed on differences in natural production patterns of agronomic properties over time among the three cottons.

Lint and seed weight means for the two upland cottons, in both sprayed and unsprayed plots, were highest at first or second harvest, then declined steadily at each subsequent harvest. However, weights declined at a more rapid rate in sprayed plots but at a slower rate in unsprayed plots of AET-5 than of DPL-61. Combined effects of seed damage and a natural decrease over harvests accounted for <1 to 8% of the decrease in these two properties in sprayed plots of DPL-61, and for 10 to 26% of the decrease in sprayed plots on AET-5. In the unsprayed plots, comparable values were 61 to 86% for DPL-61 and 52 to 67% for AET-5 (Table 3).

Pima S-5 displayed a third production pattern. Lint and seed weight means were low at first harvest (which coincided with the second harvest of the two upland entries), higher and fairly uniform at second and third harvest and sometimes at the fourth, then declined subsequently. The effects of seed damage plus natural decrease over harvests accounted for <1 to 2% of the variation in the two properties in sprayed plots of Pima S-5, about the same as in DPL-61, but only 12 to 49% of the variation in unsprayed plots, much less than in DPL-61.

Our data for Pima S-5 do not agree well with those of Fry et al. (1978) and K.E. Fry (personal communication), who calculated from two separate sets of data that 95 and 96% of the variation in lint weight/boll of this cultivar could be accounted for by percent seed damage by PBW. However, their results were based on much higher seed damage percentages than ours ($\bar{x}$ = 53% and 67% in their two samples) because they sampled only late-season bolls, whereas our results were obtained from samples harvested sequentially throughout the boll opening period. Their results for the upland cultivar 'Deltapine 16' (DPL-16), in which percent seed damage accounted for 77 and 97% of the variation in lint weight/boll in their two samples, agree reasonably well with our results obtained for DPL-61, even though seed damage was much higher for DPL-16 in their experiment ($\bar{x}$ = 45% and 52% in their two samples) than for DPL-61 in ours.

The different patterns of change among the three cottons also are shown by the correlation coefficients for percent seed damage × seed/boll, but results are not as consistent as for the other two agronomic properties because of the relatively minor effects of pink bollworm on changes in seed number.

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