CONTROL OF BOLL WEEVIL AND BEET ARMYWORM WITH AIR-ASSISTED GROUND SPRAYER

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Abstract

Control of boll weevils and beet armyworms in cotton using air-assisted ground application of insecticides was studied in field and laboratory bioassays, and by insecticide residue analysis with gas chromatography. A Hardi Twin air-assisted ground sprayer was used to apply malathion (1.0 lb/A) and Spod-X LC (100 ml/A). Laboratory bioassays of individual leaves and squares using boll weevils were used to compare applications with and without air assistance. A field bioassay also was conducted by caging boll weevils on individual plants. Bioassays of cotton treated with Spod-X LC were conducted by caging beet armyworm larvae on the undersides of leaves at mid-canopy. In these tests, the effectiveness of angling the air curtain was compared to application with the air oriented straight down. Air assistance did not significantly increase boll weevil mortality in the bioassays of individual leaves. Nor were there differences in malathion residues on leaves at top and mid-canopy. Bioassays of squares, caged plant bioassays, and residue analysis of squares showed enhanced efficacy when air assistance was used. Application with air assistance enhanced beet armyworm mortality. Angling the air curtain forward 30° increased beet armyworm mortality above that of the other treatments in one test and produced numerically higher, though not significant, mortality in another test. Air assistance shows potential for enhancing the control of troublesome cotton pests such as the boll weevil and beet armyworm.

Introduction

The most effective means of controlling any insect pest with insecticides is by a timely and uniform spray application. Decreased spray deposition on the plant diminishes the effectiveness of insecticides and generally is the result of application method and environmental factors, chiefly wind, high temperature, and humidity . Ware et al. (1970) determined that less than 50% of the insecticides applied by aircraft in Arizona reach their target. Though environmental factors are less influential during ground application compared to that by aircraft, off-target movement is still a problem. Tests in Arizona showed that the percent of the spray deposited in short cotton (29") was 39 % on the plant and 34% on soil; and in rank cotton (49"), 83% was deposited on the plant and 6% on the soil (Ware et al. 1975). In some cases, insecticide failures thought to be due to insect resistance may have actually been caused by application during adverse environmental conditions or poor application methods.

One promising method of improved application by ground is through the use of air-assisted sprayers. Air assistance is attracting much attention due to its potential for reducing drift (Cook and Hislop 1987, Gaultney et al. 1996, Howard et al 1994, Taylor et al. 1989) and increasing canopy penetration (Bode 1988, Quanquin et al. 1989, Womac et al. 1992). Watson and Wolff (1985) compared percent coverage of applications made with aircraft, hydraulic ground sprayer, and a hydraulic ground sprayer equipped with an air carrier system. The air carrier system improved deposition by as much as 400 and 900% on soybeans and corn, respectively. There are several models of air assisted ground sprayers presently manufactured for use in row crops. Each uses air to force the spray down into the canopy. One model, the Hardi Twin (Hardi International, Davenport, IA), has the capability of angling the air and the nozzle forward or backward 30°. Air-assisted sprayers are not currently being used for insect control in cotton. However, given the large volume of insecticide used in cotton and the difficulty associated with controlling insect pests feeding in protected areas of the cotton plant (i.e. squares and the underside of leaves), this new technology may be well suited for control of cotton insect pests. Manor et al. (1989) showed that a Degania (John Bean, Inc., Jonesboro, AR) air-assisted sprayer increased coverage in cotton for control of sweetpotato whitefly. However, sweetpotato whitefly control was not different from conventional hydraulic nozzle application. Manor et al. (1991) then developed a "canopy air jet" to penetrate the cotton canopy from all sides. The canopy air jet provided much greater coverage than conventional over-the-top application. Womac et al. (1992) showed increased deposits of bifenthrin on cotton leaves and squares during application with a Hardi Twin air-assisted sprayer. In a separate test comparing air-assisted application of thiodicarb with that of a conventional dropped nozzle sprayer with three nozzles (one over-the-top and two dropped) per row, they found that mortality of beet armyworm larvae caged on the leaf underside was not increased by air-assistance.

The morphology of the cotton plant and the behavior of cotton insect pests present a challenge for application technology. The most troublesome pests in cotton are those whose feeding and oviposition behavior keep them and their offspring protected from insecticide residues. For example, whiteflies, aphids, spider mites, and beet armyworms all inhabit the underside of the cotton leaf. The tobacco budworm, cotton bollworm, and plant bug feed on the flower bud protected by bracts; and boll weevil and pink bollworm larvae develop inside the flower bud. Therefore,

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it is little wonder that the most troublesome pests of cotton are those that inhabit areas of the plant that are difficult for insecticides to reach.

This research was aimed at determining how well air-assisted application penetrated the cotton canopy and deposited insecticide on squares and the underside of cotton leaves. Two serious pests of cotton, the boll weevil and the beet armyworm, were selected as bioassay organisms for determining how well air-assistance at targeted these protected parts of the cotton plant. In addition, insecticide residue analyses were conducted to determine efficiency of deposition, canopy penetration, and longevity on the plant.

Materials and Methods

All tests were conducted during August, 1996 in cotton planted in 40 inch rows at Stoneville, MS. All applications were made with a PTO driven Hardi Twin air-assisted ground sprayer mounted on a high-clearance tractor.

Boll Weevil Tests

Malathion (Cythion 5 EC, Cyanamid, Wayne, NJ) was applied at a 1.0 lb/A [1.12 kg(AI)/ha] rate using a Hardi Twin sprayer with and without air-assistance on 7 August. The spray parameters were as follows: nozzle, Hardi 4110-08 (0.082 gpm at 45 psi); pressure, 45 psi; speed, 5 mph; volume, 5 gpa; air-speed, full (35 - 40 m/s); air angle, straight down. Wind speed during application was 0-6 mph (0-3 m/ss). Application was made to plots 12 (40") rows × 200' of DPL 5415 cotton in full canopy planted 6 May 1996. There was a 12 row buffer between each replicate.

Bioassay

Leaves from the upper and mid canopy were collected at 0, 24, 48, and 72 hours after application and placed in petri dishes (15 × 100 mm) containing one boll weevil (4-5 d old). Boll weevils were obtained from a colony maintained at the Gast Rearing Facility, USDA-ARS, Mississippi State, MS. Mortality was determined after 24 and 48 hours by pinching the weevil's rostrum. Those that did not move were recorded as dead. In addition to bioassays of individual leaves, plant-cage bioassays were conducted in the field. Fibre-air Plant Sleeves (20.3 × 48.3 × 55.9 cm, Kleen Test Products, Brown Deer, WI) were used to cage weevils on the upper third of individual plants. These plant sleeves gave the weevils freedom to feed on the terminal and 4-5 squares. Ten cages per replicate were used with 5 weevils in each cage. Cages were placed in plots 24 h after treatment. Weevils remained on plants in the cages for 24 h, at which time mortality was determined. Surviving weevils were transferred to petri dishes and held for 48 and 72 h mortality recordings.

Squares (4-8 mm) from the upper canopy were collected and bioassayed in 35.0 ml plastic diet cups containing a 0.64 mm layer of gelled agar in the bottom. One adult boll weevil (4-5 d old) was placed in each cup. Mortality was recorded at 24 and 48 h.

Residue

Cotton leaves were collected from the 4th node down from the terminal of 10 plants in each replicate. Leaves were placed in plastic bags on ice and transported to the laboratory. Malathion residues were removed with 3 ml of 100% ethanol from the upper and lower surfaces of cotton leaves using Dual Side Leaf Washers (Carlton 1992). Aliquots (2ml) were placed in auto-sampler vials for analysis by gas chromatography. Squares from the upper third of the plant were collected in the field, transported on ice to the laboratory, weighed, and placed in beakers containing 10 ml of 100% ethanol. The squares were shaken for 5 m at 150 cps to remove malathion residues. The rinseate was evaporated to 2.5-5 ml, then a 2.5 ml aliquot was placed in an autosampler vial for analysis by gas chromatography.

Residue analyses were performed on a Hewlett-Packard 5890 gas chromatograph equipped with a flame photometric detector and auto-sampler. The gas chromatograph was operated with Hewlett-Packard's Chemstation software. The parameters of our residue analysis method were as follows: injector temperature, 200 C; detector temperature, 200 C; oven program, 120 C initial temperature with a 25 C/min increase to 250 C for 1 min, then a 25 C/min increase to 280 C for 4 min. A Hewlett-Packard Ultra-1 cross-linked methyl silicone gum phase column (25m × 0.32 mm × 0.52 µm) with a 2.65 ml/min flow of helium was used. Retention time of malathion was 5.597 min.

Beet Armyworm Test

Spod-X LC (100 ml/A), a beet armyworm nucleopolyhedrovirus, was applied to cotton in six row (40") x 100' plots using a Hardi Twin air-assisted sprayer with only half the boom turned on. There was a six row buffer between each replicate. Two separate tests were conducted on 14 and 15 August. The treatments in each test were: air straight down, air back 30 , air forward 30 , and no air-assistance. The spray parameters were as follows: nozzle, Hardi 4110-08 (0.18 gpm at 45 psi); pressure , 50 psi; speed, 4 mph; volume, 10 gpa; air-speed, full (35 - 40 m/s); boom height, 16-20" (40-50 cm) above the crop. Wind speed during application was 0-6 mph (0-3 m/s). Third to fourth instar beet armyworm larvae, obtained from Biosys (Decatur, IL) were caged for 48 h on the undersides of leaves at mid canopy immediately after the spray had dried. Larvae were confined in hair-clip cages constructed from 1" diameter PVC pipe and fine mesh cloth. After 48 h, larvae were collected, brought to the laboratory, and transferred to artificial diet (35 ml plastic cups) and held at 27°C for 7 d, at which time mortality was recorded.

Data Analysis

The experimental design of all mortality tests was a randomized complete block with 4 replicates per treatment.

Percent mortality data were adjusted by using an arcsin transformation. and then analyzed using PROC GLM (SAS Institute, 1990). Means were separated by least significant difference where appropriate. Residue data were analyzed as a split-split plot with treatment as main plot and canopy location and leaf surface as split plots. Data were analyzed using PROC MIXED (SAS Institute, 1990).

Results

Boll Weevil Test

Immediately after application, the percent mortality (48 h) among weevils placed on leaves from upper canopy treated with and without the air-curtain were 80 and 62%, respectively. Weevils on treated leaves collected from the mid canopy had mortalities of 52% with air and 42% without air-assistance. However, neither of these mean comparisons were significant at P = 0.05 (Table 1). Immediately after treatment, there were no significant differences in malathion residue ($\mu g/cm^2$) found on leaves treated with and without air-assistance at either the upper or mid canopy (Table 1). Malathion residues on leaves from the upper canopy treated without air-assistance (2.07 $\mu g/cm^2$) were numerically higher than leaves treated with air-assistance (0.78 $\mu g/cm^2$). Main effect means for canopy location were significantly different (F = 7.6, 1,6, P = 0.033), with higher residues detected on upper canopy leaves (1.42 $\mu g/cm^2$) than on mid-canopy leaves (0.72 $\mu g/cm^2$). The interaction between treatment and leaf surface was not significant. However, higher (F = 22.92, 1,6, P = 0.003) residues, averaged over treatments, were found on the upper leaf surface (1.7 ug/cm) than on the lower surface (0.41 ug/cm). No residues were found at 24 and 48 h after treatment.

The results of a bioassay of squares collected immediately after application showed significantly higher percent mortality (F = 18.47, 2, 8, P = 0.0006) on squares treated with air-assistance (51%) than on squares treated without air-assistance (17%) (Table 2). Futhermore, immediately after treatment, there were significantly greater residues (F = 11.85, 1, 3, P = 0.04) on squares treated with air assistance (45.0 mg/g of square) than on squares treated with no air assistance (18.0 mg/g of square) (Table 2). Air assistance had no effect on the longevity of malathion on squares. Boll weevil mortality and residues on squares at 24 and 48 h after treatment were not significantly different.
The results of the bioassay in which weevils were caged on plants in the field 24 h after treatment showed that both 48 and 72 h weevil mortalities were higher (F = 22.36, 2, 6, P = 0.0001) in the air-assistance treatment (28 and 36%, repectively) than without air-assistance (16 and 21%, respectively) (Table 3).

Beet Armyworm Tests

Results from the two tests were significantly different (F = 4.24, 1, 31; P = 0.0481). Therefore, Tests 1 and 2 were analyzed separately. In the first test bioassay results showed that when the air was oriented forward 30°, beet armyworm mortality (32%) was higher (F = 15.15, 4, 32; P = 0.0001) than when the air was either oriented back 30° (15%) or turned off (15%) (Table 4). There were no differences in armyworm mortality in sprays applied with air oriented straight down (23%) or back 30° (15%). Futhermore, there were no significant differences in armyworm mortality in sprays applied back 30° or with no air (15%)

In the second test, all treatments with air assistance resulted in higher (F = 7.29, 4, 12, P = 0.0015) beet armyworm mortality than without air assistance. Although not significant, air forward 30° again resulted in the highest mortality (40%), followed by air down (35%), and air back 30° (32%) (Table 4).

Discussion

Higher mortalities occurred in all bioassays when application was made with air assistance. Significant differences were observed in the cage bioassay and the bioassay of individual squares, while numerically higher moralities were found for the air assistance treatment when individual leaves were bioassayed. Higher malathion residues were obtained in residue analysis of squares treated with air assistance, but not in residue analysis of leaves. Also, residue analysis did not show significant differences in canopy penetration between the treatments.

While no significant increases in deposits on leaves occurred from application with air assistance as determined by residue analysis, air assistance was shown to increase the mortality of boll weevils caged on plants in the field and on squares bioassayed in the laboratory. Boll weevils caged on plants are in a more natural environment and have less restrictions on mobility and thus have a greater probability of encountering malathion residues deposited on stems and squares. Also, in preliminary tests in which fluorescent dye was applied to cotton plants, it was observed that more dye penetrated between the bracts and was deposited on the inner surface of bracts and on flower buds when the air was turned on than when application was made without air; however, residues were not quantitated.

Beet armyworm mortality also was increased by the use of air assistance, especially when the air was angled forward 30°. Air-assistance seems to have deposited greater amounts of virus on the underside of leaves since this was where the larvae were caged. Taylor and Andersen (1989) reported an increase in plant deposits of 74% for fine droplet sprays angled forward with air assistance compared to medium droplet sprays applied straight down without air assistance. Also, Hislop et al. (1995) showed that compared with a medium droplet spray applied straight down without air assistance, forward-angled air-assisted very fine/fine droplet sprays increased deposits on spring wheat by 71%.

The results of this research indicate that air assistance can significantly enhance the efficacy of insecticides for control of two cotton pests that are difficult to control with conventional application methods.

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Table 1. Percent mortality (48 h) of boll weevils and malathion residues on leaves collected immediately after applications made with and without air assistance.

Treatment	Residue(μg/cm^2)	% Mortality
	Top Leaf	
Air	0.78 a	80 a
No Air	2.07 a	62 a
Control	---	0 b
	Mid-Leaf	
Air	0.64 b	52 a
No Air	0.82 b	42 a
Control	---	0 b

Means in a column not followed by the same letter are significantly different (P = 0.05) as determined by least significant difference.

Table 2. Percent mortality of boll weevils and malathion residues on squares treated with and without air assistance.

Treatment	Residue	Mortality
	0 HAT	
Air	45.0 a	51 a
No Air	18.0 b	17 b
Control	---	2 c
	24 HAT	
Air	1.6 a	10 a
No Air	3.3 a	10 a
Control	---	4 a
	48 HAT	
Air	0.4 a	4 a
No Air	0.2 a	11 a
Control	---	2 a

Means in a column under each time period not followed by the same letter are significantly different (P = 0.05) as determined by least significant difference.
HAT = Hours after treatment.
Residue = Micrograms of malathion per gram of square tissue.

Table 3. Percent mortality of boll weevils caged on cotton plants 24 h after treatment with malathion.

Treatment	24 h Mort	48 h Mort	72 h Mort
No Air	8 a	16 b	21 b
Air	12 a	28 a	36 a
Control	4 a	10 c	2 c

Means in a column not followed by the same letter are significantly ($P = 0.05$) different as determined by least significant difference.

Table 4. Percent mortality of beet armyworm larvae caged on the underside of cotton leaves treated with Spod-X LC using air assisted application with variation in the angle of the air curtain.

Treatment	Test 1 Mortality	Test 2 Mortality
Air Forward 30°	32 a	40 a
Air Down	23 ab	35 a
Air Back 30°	15 bc	32 a
No Air	15 bc	15 b
Control	2 c	0 c

Means in a column not followed by the same letter are significantly different ($P = 0.05$) as determined by least significant difference.