

ENGINEERING AND GINNING

Novaluron as an Ovicide for Bollworm on Cotton: Deposition and Efficacy of Field-Scale Aerial Applications

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ABSTRACT

Novaluron, Diamond® 0.83 EC, was evaluated for deposition on cotton and ovicidal efficacy against bollworm, *Helicoverpa zea* (Boddie), due to the increasing need to use insecticides with modes of action different than synthetic pyrethroids. Rotary atomizers and conventional hydraulic nozzles were used to aerially apply Novaluron at two spray rates, with and without the addition of spray adjuvants. Additionally, aerially applied treatments of methomyl, Lannate® LV, were applied with conventional hydraulic nozzles at the lower spray rate. Treated plots were compared to each other as well as an untreated check. All treatment applications were selected to deliver the applied spray at a volume median diameter of 175 µm. Ovicidal efficacy was determined by collecting eggs from treated plots at 0, 1, and 5 days after treatment (DAT). Results indicated greater deposition from higher spray rate applications as well as lower rate application with the addition of the selected adjuvant. Overall, rotary atomizer treatments and conventional flat-fan treatments at a higher application rate, and the lower application rate with the selected adjuvant resulted in increased control. Novaluron showed greater long-term control than methomyl.

Bollworm, *Helicoverpa zea* (Boddie), is a polyphagous cotton pest that can develop on other row crops and native hosts. These bollworm populations can then move from these senescing hosts into cotton. There is evidence that tolerance/resistance to synthetic pyrethroids has developed in this insecticide class as demonstrated by headworm,

Helicoverpa zea (Boddie), control on sorghum in the Texas Coastal Bend (Pietrantonio et al., 2006). A similar situation is likely occurring in other areas of the cotton belt where pyrethroids are used to control pests such as tarnished plant bug, *Lygus lineolaris* Pallisot de Beauvois, and various species of stink bugs on cotton. As such, there is a need to continue evaluations of insecticides with other modes of action for control of cotton bollworm.

Novaluron (Diamond 0.83 EC, Chemtura USA Corp., Middlebury, CT) is an insecticide that has ovicidal activity for control of bollworm, *Helicoverpa zea* (Boddie) and tobacco budworm, *Heliothis virescens* (Fabricius) on cotton. Novaluron is an insect growth regulator (IGR) that acts on immature insect stages by inhibiting chitin synthesis and deposition of chitin in the exoskeleton of arthropods (Ishaaya et al. 1996, Weiland, 2003). Novaluron appears to act through ingestion and contact and is effective against leaf-feeding lepidopteran and piercing-sucking insects such as whiteflies (Ishaaya et al. 1996, Weiland and Whitehead, 2003). Because of the ovicidal activity of novaluron and its compatibility with beneficial insect conservation, it has potential for use in an integrated pest management program as well as with insecticides targeted for tolerant or resistant bollworm/budworm.

Numerous such insecticides are available but, novaluron (Diamond® 0.83) is a good candidate because of its ovicidal activity against lepidoterous pests and its compatibility with insect resistance management (IRM) strategies. Although novaluron is labeled as an ovicide for bollworm control on cotton, few studies have been reported which have evaluated its activity. In addition, no research has been reported on optimization of aerial application parameters for deposition and efficacy of novaluron.

Kirk et al. (2004) focused on applications with conventional hydraulic nozzles as well as rotary atomizers at spray rates ranging from 94 L/ha to 2 L/ha and droplet sizes from 230 µm to 415 µm. Kirk et al. (2004) found that rotary atomizers at 47 L/ha with smaller droplet sprays (240 µm) resulted

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in maximum deposition on wheat heads and Mylar collectors. A follow-up study performed the next year over three separate fields examined treatments applied with conventional flat-fan hydraulic nozzles with spray rates of 19, 47, and 94 L/ha and droplet sizes of 175 and 350 μm (Fritz et al., 2005). The results showed highest deposition amounts at the lowest spray rates with larger droplet sprays (Fritz et al., 2005).

Numerous studies have been reported on optimization of aerial application practices for pest control in cotton and corn, noting that optimum spray rate droplet size combinations are pest specific and vary from one pest or target area to another as well as insecticide mode of action (Bouse et al., 1992, Hoffmann et al., 1998, and Kirk et al., 1989, 1992, 1998 and 2001). Kirk et al. (1992) found that higher spray rates and larger droplet sizes resulted in increased insecticide deposits within the canopy of cotton plants. Hoffmann et al. (1998) found that smaller droplet sizes and lower spray rates resulted in increased levels of control for the targeted insect pest.

The objective of this study was to assess aerial application treatments for on-target deposition and to compare ovicidal efficacies of the applied treatments for control of bollworm on Bt cotton. Conventional hydraulic aerial nozzles were compared to rotary atomizers and lower application rates of 19 L/ha were compared to conventional application rates of 47 L/ha. Additionally, efficacy differences between insecticides and tank mixes with and without tank mix adjuvants were examined.

MATERIALS AND METHODS

Study Site and Application of Materials. The study was conducted within a center pivot irrigated Bt cotton field (30°30'21.90" N, 96°24'32.93" W, and 65-m above mean sea level) in the Brazos River

Valley near College Station, Texas in spring of 2005. Novaluron and methomyl were the ovicides evaluated for bollworm control. In addition to the active ingredient, the spray solutions consisted of water, Triton X-100 at 0.1% v/v, and Caracid Brilliant Flavine FFS fluorescent dye at 37 g/ha. Fluorescent dye was added as a tracer to measure deposition of spray during tests. Treatments (1-4) contained novaluron (Diamond 0.83 EC) at 875 ml/ha while Treatment 5 was a conventional treatment of methomyl (Lannate LV, E.I du Pont Nemours and Co., Wilmington, DE) at 292 ml/ha (Table 1). Methomyl was chosen due to its known effectiveness of controlling bollworms. Additionally, Treatment 3 was a combination of novaluron at 875 ml/ha and an adjuvant, Aero Dyne-Amic (Helena Chemical Co., Collierville, TN) at 146 ml/ha. Treatments 1, 2, 3, and 5 were applied at a rate of 18.7 L/ha, while Treatment 4 was applied at 46.8 L/ha. These rates were chosen to compare deposition and efficacy of conventional aerial applications to lower application rates. These treatment spray rates are typical of mid- to low- level aerial spray rates. Lower application rates have the potential to increase applicator productivity if efficacy proves to be comparable.

An Air Tractor 402B aircraft (Air Tractor, Inc., Olney, TX) was used in all tests. Spray applications were made with a boom height of 3-m above canopy and a swath width of 15.2-m. Three spray swaths were flown for each plot. A total of 18 plots were treated and arranged in a randomized complete block design with three replications per block (Figure 1). Plot size was 45-m x 183-m or 0.84 ha. Plots were located within the irrigated portion of the field and at least 100-m inside the field to minimize any field edge effects. During each test, the prevailing wind was approximately 90° across the cotton rows and parallel to the line of flight.

Table 1. Application treatment operational parameters and settings

Trt	Nozzle Type	Application Rate (L/ha)	Airspeed (km/h)	Pressure (kPa)	Orifice (mm)	Chemical	Mix Rate (ml/ha)
1	Rotary	18.7	209	276	4.8	Novaluron	875
2	CP	18.7	233	310	2.0	Novaluron	875
3	CP	18.7	233	310	2.0	Novaluron + Aero Dyne-Amic	875+146
4	CP	46.8	241	310	3.0	Novaluron	875
5	CP	18.7	233	310	2.0	Methomyl	292
6	Untreated Check						

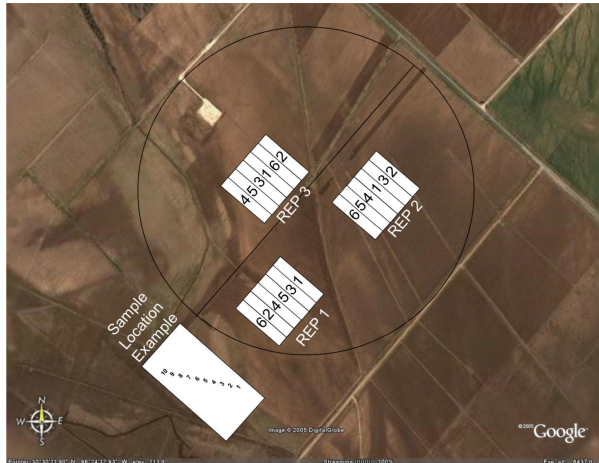


Figure 1. Aerial photo of study site showing site layout, randomization of treatments within replicates and sampling stations.

A Gill 3D propeller anemometer (Gill model 27005 UVW anemometer) was located approximately 10 meters upwind of the appropriate sampling line (to prevent influence of aircraft passing on wind speed readings) at a height of 1.8-m. Gill wind vane sensors sampled every 10 seconds with data being recorded every minute. Raw data collected from Gill anemometer was corrected using a cosine correction algorithm supplied by the manufacturer. Relative humidity was measured with an RM Young model 71372 temperature/relative humidity sensor. Two spray nozzles were selected to make the application treatments. A CP-03 flat fan nozzle (CP Products Company, Inc., Tempe, AZ), with a 90° deflection and spray pressure of 310 kPa was used to make 19L/ha applications with an orifice setting of 2.0 mm and airspeed of 233 km/h. The 46.8 L/ha application was made with an orifice setting of 3.0 mm and airspeed of 241 km/h. A rotary nozzle, the ASC-A10H Rotary Atomizer (Curtis Dyna-Fog Ltd., Westfield, IN), was used for comparison with a D-12 orifice plate and a 4.5 setting on the blades resulting in an atomizer rotational speed of 5,400 rpm. Both nozzles configurations were selected to produce a volume median diameter ($D_{V0.5}$) of 175 μ m, which has been shown to improve the efficacy of contact insecticides due to the greater number of smaller drops compared to larger droplet sprays. The droplet size was determined using USDA-ARS atomization nozzles (USDA-ARS, 2005) for the CP nozzle and manufacturer's literature for the ASC nozzle. Three replications of each treatment were initially treated; however it was later discovered that one of the replicates was not Bt (*Bacillus thuringiensis*) cotton.

This conventional cotton was planted as part of the 25% refugia requirement and was treated with a synthetic pyrethroid by another applicator after the study was completed because of bollworm pressure. This situation resulted in the loss of one replicate of efficacy data for each of the treatments for 1-5 days after treatment.

Spray Deposition Data Collection. Within each spray plot, ten sampling stations were established for sampling deposition and efficacy. These stations were diagonally spaced 10-m apart in the center swath to reduce contamination from adjacent plots. The first and last stations were 30-m inside the plot from either edge where the aircraft entered or left the field (Figure 1). Ten sets of horizontal samplers [100 x 100 mm Mylar cards and 26 x 76 mm water sensitive papers (WSP) (Spraying Systems Co., Wheaton, IL)] were placed immediately before treatment at each of the stations across the center swath on adjustable stands that held the cards at crop canopy height. One set of samplers was placed at each of the ten locations. Mylar cards and WSPs were collected approximately ten minutes after treatment. WSPs were placed in photo negative sleeves to protect the cards and then into a large zippered plastic bag. Mylar cards were individually placed in zippered plastic bags. All samples were labeled with treatment, replication, sample number, and sub-sample information.

Mylar cards were washed in 40 ml of ethanol in the collection bags. A 6 ml sample of the wash effluent was placed in a 12 x 75 mm borosilicate glass culture tube. The cuvettes were then placed into a spectrofluorometer (Shimadzu, Model RF5000U, Kyoto, Japan) with an excitation wavelength of 453 nm and an emission at 488 nm. The fluorometric readings were converted to μ g/cm² using the area of the Mylar card. The readings were corrected using tank samples from the actual spray in each test. The minimum detection level for the dye and sampling technique was 0.00007 μ g/cm².

WSP samples were processed with a computerized image analysis system (IMAQ Vision Builder V.5, National Instruments, Austin, TX) to determine droplet stain density and stain size. Stain size, diameter and minimum dimension were determined in three 0.75 cm² sample areas on each card. Each stain in the sample area was converted to droplet diameter with an experimentally determined spread factor (droplet size = 0.54*stain diameter - 8.5x10⁻⁵*stain diameter). These data then were used to calculate the

$D_{V0.1}$, $D_{V0.5}$ (volume median diameter, VMD), $D_{V0.9}$, relative span, droplet density (drops per cm^2), percent area covered and volume of spray less than 100 and 200 μm . $D_{V0.1}$ is the droplet diameter in which 10% of the spray volume is contained in droplets of lesser diameter. Likewise, $D_{V0.5}$ (VMD) and $D_{V0.9}$ are the 50% and 90% statistics for the spray.

Efficacy Data Collection. Eggs were collected from the center of each plot and pooled into a composite sample. These eggs were collected primarily from cotton terminals. The eggs were placed in 6.4 cm^2 clear plastic bags. Dry paper towels were placed inside each bag to absorb moisture from the leaves. Sample bags containing eggs were assembled and were kept inside ice coolers, and transported to the laboratory. Eggs were collected from cotton plants in the treated field on the same day before application (pretreatment) and shortly after application (0 DAT). Additional egg samples were collected on 1 and 5 DAT. In the laboratory, eggs were removed using a 0.85 cm^2 leaf plug and were placed individually in 22.5 ml squat Solo™ plastic cups containing artificial diet (Heliothis premix, Stonefly Industries, Bryan, TX) and capped with plastic lids. Eggs were classified as white, tan or black before they were placed in storage. Cups containing eggs were left in a room maintained at 23.9 ± 2.0 ° C and RH ~ 65% for ca. 3 wks. The ovicidal effect of novaluron was determined by examining egg color. Tan eggs killed by novaluron did not hatch. Black eggs with head capsules showing through the egg shell were considered to have died as eggs when larvae were unable to emerge. Larvae that emerged from the egg shell and died without feeding also were counted as dying due to ovicidal effects. This determination was made by observing whether fecal pellets were present atop the diet. Infertile eggs remained white. The species composition was based on the surviving adults. Large, dead larvae or pupae which did not emerge were identified to species, but not counted as having been killed by ovicidal effects.

Statistical Analyses. Due to natural variations across a field of pest populations, a randomized complete block design was chosen with replicates serving as the blocks. The treatment effects on WSP and mylar card deposition were analyzed using PROC GLM (Generalized Linear Model) in SAS (SAS Institute, 2001). Means were separated using Duncan's Studentized Mean Separation Tests where appropriate. All statistical inferences of significant differences refer to $\alpha=0.05$ level.

Efficacy data were analyzed by modeling the odds of survival (eggs/larvae not killed by pesticide application) using the GLIMMIX procedure in SAS (SAS Institute, 2005) with a binary distribution and a logit link function. Blocks were modeled as random factors. *A priori* (preplanned) contrasts were evaluated. Rotary atomizers (T1) were compared to CP nozzles (T2) with the same application parameters. Novaluron (T2) was compared to methomyl (T5) with all application parameters being equal. Application rates of 19 l/ha (T2) and 47 l/ha (T4) were compared for novaluron. Spray formulations of novaluron, with (T3) and without (T2) an adjuvant, were compared. To evaluate the amount of egg and larval mortality for the different treatments, a Beta regression was performed, again using the GLIMMIX procedure in SAS with a Beta distribution and a logit link function.

RESULTS AND DISCUSSION

Spray Deposition on Water Sensitive Paper and Mylar. Weather conditions varied somewhat between treatments but remained relatively steady throughout treatment applications (Table 2). Deposition analysis from the untreated check did not detect background fluorescent readings greater than 1% of the typical deposition reading. WSP results showed that the highest application rate of novaluron (T4) resulted in significantly more total spray deposition than the methomyl (T5) and novaluron + Aero Dyne-Amic (T3) treatments (Figure 2), where total spray deposition is defined as total deposited material which included water carrier and active ingredient. These latter treatments also had significantly higher total spray deposition than the rotary atomizer application of novaluron (T1) and the 19 L/ha (2 gpa) application of novaluron without a spray adjuvant (T2). The near two-fold increase in total spray deposition for T4 over T5 and T3 is not surprising as T4, while having equivalent active ingredient per area, was applied using 2.5 times the water, resulting in more spray droplets and increased total spray deposition measurements with the WSP. The other treatment differences can be further explained by examining the droplet spectra measurements from the WSP. There were highly significant treatment differences for $D_{V0.1}$ ($F=17.99$, $df=4,144$; $P<0.0001$), $D_{V0.5}$ ($F=18.17$, $df=4,144$; $P<0.0001$), $D_{V0.9}$ ($F=17.61$, $df=4,144$; $P<0.0001$), relative span ($F=4.19$, $df=4,144$; $P<0.0031$), droplet density

($F=21.63$; $df=4,144$; $P<0.0001$), percent area covered ($F=36.73$; $df=4,144$; $P<0.0001$), Volume<100 μm ($F=10.85$, $df=4,144$; $P<0.0001$) and Volume<200 μm ($F=6.81$, $df=4,144$; $P<0.0001$). The addition of the adjuvant (T3), Aero Dyne-Amic, was beneficial to the lower application rate of novaluron (T2) in terms of significantly increasing droplet density, percent area covered and the relative span (Table 3). The adjuvant likely lowered the evaporation rate of the spray solution, which allowed more of the droplets to deposit on the horizontal targets. In addition, the methomyl application at 19 L/ha (T5) resulted in significantly greater $D_{V0.1}$, VMD, $D_{V0.9}$, droplet density, and percent area covered compared to the novaluron treatment (T2) under the same application parameters. This is most likely just due to chemical formulation. As might be expected, the higher application rate (47 L/ha) of novaluron (T4) yielded significantly higher $D_{V0.1}$, VMD, $D_{V0.9}$, relative span, droplet density and percent area covered, compared to the 19 L/ha application (T2), but also

resulted in significantly less of the spray volume in droplets smaller than 200 μm (Table 3). Droplets less than 200 μm have a higher potential for off-target drift. When comparing the deposition from different atomizers, although the intention was to have a target VMD of 175 μm for all of the treatments, the mean VMD of the spray from the rotary atomizer was significantly smaller than all of the other treatments (102.6 μm). It is difficult to know exactly why, but was probably due to an error in the way the equipment was set up. As a result, the $D_{V0.1}$, VMD, and $D_{V0.9}$, were all significantly smaller than the treatment with conventional hydraulic nozzles (T2) and the volume of spray in droplets less than 100 and 200 μm was much higher. However, this treatment (T1) resulted in significantly higher droplet density on WSP than T2.

Table 2. Meteorological data (\pm SD) for field trials.

TRT	Wind Speed (m/sec)	Temp ($^{\circ}\text{C}$)	RH (%)
1	2.3 \pm 1.4	31.6 \pm 1.4	69.5 \pm 5.5
2	3.3 \pm 1.3	34.0 \pm 0.3	56.8 \pm 1.9
3	2.8 \pm 0.9	34.5 \pm 0.5	53.8 \pm 1.9
4	3.0 \pm 1.6	35.5 \pm 0.2	51.9 \pm 2.8
5	0.9 \pm 0.7	36.2 \pm 0.6	48.4 \pm 4.1

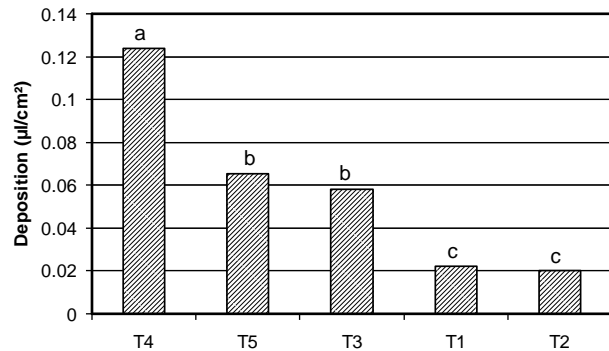


Figure 2. Deposition ($\mu\text{l}/\text{cm}^2$) of spray on water sensitive papers for each treatment. Treatments that share a common letter are not statistically different from one another according to Duncan's Multiple Range Test ($\alpha=0.05$).

Table 3. Spray droplet spectra measurements (\pm SD) from water sensitive cards by treatment.

	Treatments ^z				
	1	2	3	4	5
$D_{V0.1}$ (μm)	59.2 \pm 22.2 c	84.3 \pm 31.4 b	85.9 \pm 17.6 b	106.3 \pm 21.6 a	98.1 \pm 15.9 a
$D_{V0.5}$ (μm)	102.6 \pm 33.5 d	138.8 \pm 54.2 c	143.4 \pm 27.8 bc	195.9 \pm 59.3 a	162.9 \pm 28.9 b
$D_{V0.9}$ (μm)	139.7 \pm 53.1 d	175.8 \pm 68.2 c	207.4 \pm 52.1 bc	275.1 \pm 97.2 a	221.1 \pm 34.9 b
Relative Span	0.75 \pm 0.26 ab	0.64 \pm 0.21 b	0.85 \pm 0.27 a	0.83 \pm 0.20 a	0.76 \pm 0.16 ab
Droplet Density (drops/ cm^2)	23.9 \pm 18.3 c	8.8 \pm 9.6 d	33.8 \pm 12.8 ab	41.0 \pm 16.0 a	27.7 \pm 13.2 bc
Percent Area Covered	2.79 \pm 2.44 c	1.87 \pm 2.02 c	5.77 \pm 2.86 b	9.92 \pm 4.07 a	5.67 \pm 2.22 b
Vol<100 μm (%)	40.9 \pm 24.1 a	21.6 \pm 29.0 b	22.0 \pm 16.0 b	11.2 \pm 11.2 b	11.7 \pm 7.7 b
Vol<200 μm (%)	89.8 \pm 26.7 a	73.5 \pm 33.4 b	82.4 \pm 14.2 ab	58.3 \pm 24.9 c	70.8 \pm 20.0 bc

^zTreatments that share a common letter are not statistically different from one another according to Duncan's Multiple Range Test ($\alpha=0.05$).

The Mylar card deposition values are a measure of the dye deposition per area, independent of the water deposited, and thus, an indicator of the active ingredient deposited per area. There were highly significant treatment differences for dye deposition on Mylar ($F=21.08$, $df=4,146$; $P<0.0001$). The dye deposition trends were similar to those measured with WSPs (Figure 3). Over twice as much active ingredient, as measured by dye deposit, was deposited with the methomyl treatment (T5) than with the equivalent novaluron treatment (T2). And although the rotary atomizer (T1) was unintentionally set to produce a much smaller droplet spectrum, the resulting dye deposition on Mylar was significantly greater than that with conventional aerial nozzles (T2). In addition, the higher application rate (47 L/ha) of novaluron (T4) resulted in over three times the dye deposition of the 19 L/ha application (T2). However, when comparing dye deposition (i.e. active ingredient) on Mylar between novaluron applied at 47 L/ha (T4) and novaluron plus the adjuvant, Aero Dyne-Amic, applied at 19 L/ha (T3), there was no observable difference. This indicates that the addition of an adjuvant can increase the deposition of active ingredient of lower volume sprays to match that of higher volume sprays without adjuvant. When the application of novaluron with adjuvant (T3) is compared to the equivalent treatment without adjuvant (T2), the result is a three-fold increase in deposition. Again, the adjuvant likely lowered the evaporation rate of the spray solution, which allowed more of the droplets to deposit on the horizontal targets.

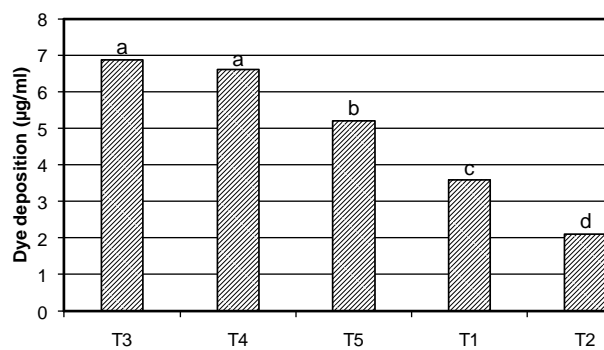


Figure 3. Deposition of spray on Mylar plates for each experimental treatment. Treatments that share a common letter are not statistically different from one another according to Duncan's Multiple Range Test ($\alpha=0.05$).

Chemical Efficacy. A procedural misunderstanding resulted in pretreatment egg samples not being collected from T1 plots. But, given that T1 was randomly assigned within each block, it was assumed that T1 initial populations were similar to the other treatments.

For the plots assigned to the other treatments, there were no significant treatment effects for the pretreatment egg ($F=0.91$; $df=4,10$; $P=0.4962$), larval ($F=0.24$; $df=4,10$; $P=0.9123$), and total ($F=0.54$; $df=4,10$; $P=0.7073$) mortality. Therefore, the population distribution of bollworm eggs was considered uniform throughout the field study area. The pretreatment mean egg mortality rates ranged from 14.4 to 36.3% while larval mortality rates ranged from 9.3 to 23.7%. The mean total mortality for the untreated check (Treatment 6) was 32.7, 22.6, and 24.6% for 0, 1, and 5 DAT, respectively.

The 0 DAT egg samples were collected from the field within four hours of completing the spray trials and represent mortality likely caused by direct contact of the spray with the eggs. At 0 DAT, all treatments caused significantly higher egg mortality than the untreated check (Figure 4); however, only T2 and T5 were significantly higher and lower ($P=0.04$ and $P=0.03$), respectively, than the untreated control for larval mortality (Figure 5). T5 (methomyl) was the only treatment where all the larvae that hatched survived. For the preplanned contrasts, T1 (rotary atomizers) yielded greater egg mortality ($P=0.04$) and total mortality ($P=0.02$, Figure 6) than T2 (CP nozzles). This may be due to the significantly smaller droplet spectra and higher droplet density for the rotary atomizers versus the CP nozzles (Table 3). T4 (47 L/ha) resulted in greater egg ($P=0.01$) and total ($P=0.05$) kill compared to T2 (19 L/ha) as a result of greater deposition of both total spray solution and active ingredient, as indicated in the WSP and Mylar data. In this case, a greater carrier volume (water) resulted in greater coverage, active ingredient deposition and efficacy. When contrasting active ingredients, T5 (methomyl) provided greater egg ($P=0.004$), larvae ($P=0.02$) and total ($P=0.03$) control than T2 (novaluron). Although the addition of Aero Dyne-Amic (T3) resulted in significantly greater droplet density, percent area covered and the maximum overall dye deposition compared to T2, it did not improve efficacy at DAT 0.

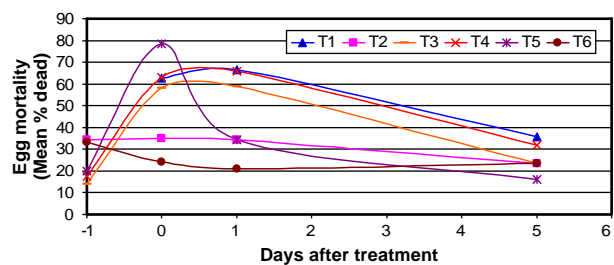


Figure 4. Bollworm egg mortality during the course of the study for each of the treatments. Pretreatment samples were not collected for T1.

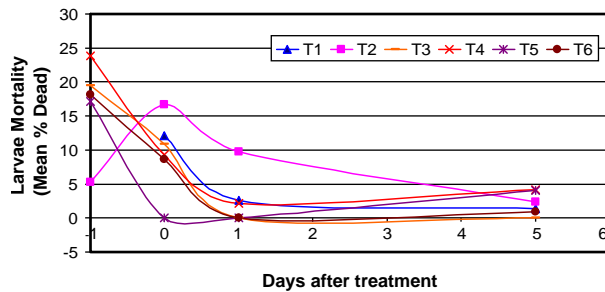


Figure 5. Bollworm larvae mortality during the course of the study for each of the treatments. Collected bollworm eggs had to survive to reach the larval stage, at which point they either died as larvae or continued to mature. Pretreatment samples were not collected for T1.

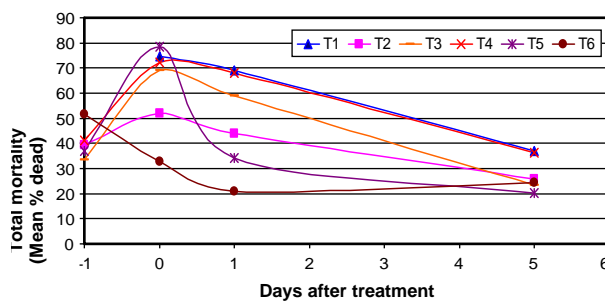


Figure 6. Total combined bollworm mortality for all treatments. No pre-treatment samples were collected for Treatment 1.

By 1 DAT, egg mortality was significantly higher for T1 (rotary atomizers), T3 (adjuvant) and T4 (highest application rate) than the other three treatments; however, larvae mortality was only significantly higher for T2 compared to the other treatments at 1 DAT. T1, T3 and T4 gave the most consistent improvement in control at 0 and 1 DAT. The *a priori* contrasts showed T1 (rotary atomizers) yielded significantly better ($P=0.01$) egg control than T2 (CP nozzles), but T2 provided better ($P=0.02$) larval control than T1. Again, this may be due to the differences in droplet spectrum between the two nozzles. Although the relative spans for T1 and T2 are indistinguishable, the smaller droplets and greater droplet density of T1 would have increased the likelihood of the active ingredient contacting the shell. When the eggs hatch and the larvae emerge within the shell, the larvae feed on the shell upon exiting. Any consumed toxicant on the shell could have ova-larvicidal activity and could kill the larvae prior to exiting the shell. In this study, anything remaining in the shell was considered an egg. Treatment 1 proved to have better ovicidal activity than T2. The benefit of adding an adjuvant (T3) became more apparent at 1 DAT as T3 resulted in greater egg mortality ($P=0.02$) than its counterpart T2, but had signifi-

cantly less larval mortality ($P=0.007$) than T2. This result may be due to the adjuvant reducing the surface tension of the spray so that it permeated the egg shell better than the treatment without adjuvant. By killing the eggs in the shell before they had a chance to emerge as larvae, this treatment showed the best ovicidal activity of the two treatments. Application volume also showed some interesting trends. T4 (47 l/ha) had better egg control ($P=0.01$) than T2 (19 l/ha) but T2 resulted in better larval control ($P=0.02$). The only difference between novaluron (T2) and methomyl (T5) was in larval control; novaluron showed greater larval efficacy ($P=0.007$).

At 5 DAT, several factors suggest that the insecticides had lost their ability to impact the *Heliothis* populations in the field. Only T1 had significantly higher egg mortality than the untreated check. None of the spray treatments had higher larvae mortality than the control. Only one of the *a priori* contrasts showed any difference; T1 (rotary atomizers) provided better egg control ($P=0.05$) than T2 (CP nozzles). There also were large increases in the number of eggs and larvae collected with the same amount of time and effort as was expended in the Pretreatment, 0, and 1 DAT field collections. This suggests that the *Heliothis* population in the field was significantly increasing and that the applied insecticides were having no impact on this buildup.

Methomyl did not appear to provide long-lasting control of *Heliothis zea* in this study. The only time that this treatment showed any improvement in control over the untreated check was 0 DAT egg mortality. There was no larval mortality for this compound at 0 and 1 DAT.

CONCLUSIONS

The use of a higher application spray rate or a lower spray rate with the addition of the selected adjuvant increased measured deposition. Active ingredient also played an important role in measured deposition. Methomyl resulted in an overall larger spray droplet spectrum than novaluron, but also produced increased coverage and droplet density, providing better deposition. The flat-plate deposition data (Mylar and WSP) did not fully explain the efficacy data as the rotary atomizer applied treatments generally had the lowest overall deposition but maximum biological efficacy. Based on the other treatments that provided the same level of control, this was likely due to the greater number of smaller droplets in the

applied spray which likely corresponded to greater filtration of the spray cloud within the plant canopy and increased deposition on leaf surfaces. Generally, all of the treatments were effective when compared to the control. The novaluron treatment provided better long-term control than methomyl. Overall, application of novaluron with rotary atomizers at a low application rate and small droplet spectrum or conventional flat fan nozzles at either increased application rates or lower application rates with the addition of the selected adjuvant provide maximum overall control of corn earworm on cotton.

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DISCLAIMER

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