

**BACILLUS THURINGIENSIS FOR USE AGAINST ARMYWORM,  
PSEUDALETIA UNIPUNCTA (LEPIDOPTERA: NOCTUIDAE),  
ON WHEAT**

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ABSTRACT

Spray table tests with *Bacillus thuringiensis* (Javelin WG) on wheat leaves against armyworm, *Pseudaletia unipuncta* (Haworth), showed that 1st and 3rd instars had  $LC_{50}$ s of 0.09 and 0.55 kg per ha, respectively, 7 d after treatment. Wheat sprayed in the field in 1995 with Javelin WG at rates of 0, 0.28, 0.56, 1.12, and 2.24 kg per ha resulted in 82% and 62% 1st instar mortality 7 d after feeding on treated flag and middle leaves, respectively, at the highest rate. In 1996, the test was repeated and mortality was higher, with 98, 97, and 92.9% 1st instar mortality 7 d after feeding on treated flag, middle, and bottom leaves, respectively, at the highest rate. Third instars were less susceptible, with 89, 81, and 76% mortality 7 d after treatment at the highest rate on flag, middle, and bottom leaves, respectively. Leaf position had little effect on spray droplet numbers or mortality of larvae fed treated leaves, indicating that spray distribution was relatively even throughout the wheat canopy.

Key Words: biological control, microbial control, spray distribution

#### RESUMEN

Pruebas de atomización en hojas de trigo con rocío de *Bacillus thuringiensis* (Javelin WG) contra el gusano cortador, *Pseudaletia unipuncta* (Haworth), demostraron que los 1er y 3er estadios tenían, respectivamente, los  $LC_{50}$ s de 0.09 y 0.55 kg por ha, 7 días después de las aplicaciones. Pruebas de campo llevadas a cabo 1995 en trigo rociado con Javelin WG con dosis de 0, 0.28, 0.56, 1.12, y 2.24 kg por ha resultaron en una mortalidad de 82% y 62% en el primer estadio 7 días después de alimentarse en las hojas terminales y medias, respectivamente, tratadas con la dosis más elevadas. En 1996, se repitieron las pruebas obteniendo una mortalidad más alta, con el 98, 97, y 92.9% de mortalidad del primer estadio después de 7 días de alimentarse en las hojas terminales, medias y basales, respectivamente, con las dosis más elevadas. El tercer estadio fue menos susceptible, con una mortalidad de 89, 81, y 76% 7 días después del tratamiento con las dosis más elevadas en hojas terminales, medias, y basales, respectivamente. La posición de la hoja tuvo un efecto pequeño en el número de gotas de rocío o en la mortalidad de las larvas que se alimentaron en hojas tratadas, indicando que la distribución del rocío fue relativamente uniforme a través de toda la corona del trigo.

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The armyworm, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae) is a pest of wheat in the US, with large acreages of heading wheat requiring treatment in some years (Breeland 1958, Guppy 1961, Clark et al. 1994). Biological insecticides are not registered in Arkansas for use on wheat. Three baculoviruses and six *B. thuringiensis* products were effective against *P. unipuncta* in laboratory assays on diet but were ineffective at a range of rates in field trials on commercial wheat (Steinkraus & Young 1994, Young & Steinkraus 1996). In those previous field trials, 4 and 7 d after treatment there were no significant differences between numbers of larvae in control and treatment plots. The main objective of this investigation was to determine if spray coverage significantly influenced performance of *B. thuringiensis* on wheat. This was tested by determining spray deposition throughout the wheat canopy with water sensitive cards and by feeding armyworm larvae treated leaves from three leaf positions.

#### MATERIALS AND METHODS

Gravid female armyworm moths were collected each year in early spring from an ultraviolet light trap. Moths were held in aquaria and fed a mixture of honey, beer, and water (9:7:14). Eggs were collected daily on folded wax paper fans attached to the sides of the aquaria and held at 29°C until hatch. Larvae were placed on semisynthetic diet (Burton 1969) in 270 ml wax-coated paper cups at 29°C until ready for use in the tests as either 1 - d old 1st instars or 3rd instars.

Wheat, ("Cardinal"), was planted 17 November 1995 and 15 September 1996 on the Arkansas Agricultural Research and Extension Center in Fayetteville, AR and grown according to commercial practices for the area.

#### Spray Table Test

On 15 May 1995, when heading wheat was in the soft dough stage [stage 7.7 of Zadoks et al. (1974)], middle leaves were cut from plants, placed in plastic bags to minimize drying, and brought to the laboratory. The leaves were placed upper surface up on a 91 by 91 cm board for spraying. Treatments were Javelin WG (Sandoz Crop Protection Corpora-

tion, Des Plaines, IL) at 0, 0.56, 1.12, and 2.24 kg per ha. Treatments were applied using a boom-type sprayer, with two TX-6 nozzles spaced 50.8 cm apart, at a pressure of 40 psi and a spray table with a speed of 4.8 km per h. The sprayed leaves were briefly air dried, then single leaves were placed individually into 28-ml plastic rearing cups. Either a 1st instar or 3rd instar was placed on the leaf, the cup capped and held at 29°C for 3 d. Treatments consisted of 25 larvae per instar per rate and the test was replicated four times for both 1st and 3rd instars. All larvae on treated leaves in cups were placed into sealed clear plastic containers that contained a wetted paper towel to minimize desiccation of the wheat leaves. After 3 d mortality was recorded and surviving larvae were transferred to semi-synthetic diet in individual 28-ml rearing cups. Larvae were held on diet until the 7th day after treatment and mortality was again recorded. Data were corrected for control mortality by Abbott's formula (Abbott 1925). The lethal concentration mortality response was estimated by the probit response (SAS Institute 1990). Failure of 95% confidence limits to overlap was used as a criterion for significant difference.

#### Field Tests

Field tests were conducted in 1995 and 1996 to determine penetration of *B. thuringiensis* spray droplets into the wheat canopy, specifically droplet numbers hitting flag, middle and bottom leaves. In all field tests, wheat was heading [stages 4.5-7.7 of Zadoks et al. (1974)]. Each test was a randomized complete block design, replicated four times over time (one replicate per day). Plots were 2.1 × 9.2 m with 1.8 m borders around plots. Treatment rates were Javelin WG at 0, 0.28, 0.56, 1.12, and 2.24 kg per ha. Treatments were applied using a backpack CO<sub>2</sub> sprayer with a 2-row boom and two TX-6 nozzles per row set 0.5 m apart calibrated to deliver 95 l per ha at 4.8 km per h. After the spray dried, 25 flag, middle, and bottom leaves were collected at random from each treatment, placed in plastic bags and transported to the laboratory. Assay of Javelin WG on these leaves was with 1st and 3rd instars as described in the spray table test above. Field tests were made on the following dates: 1st instars were tested 24-27 May 1995, 3rd instars were tested 14-17 May 1996 and 1st instars 20-23 May 1996. Mortality data were transformed by arcsin squareroot, analyzed with ANOVA, and means separated by LSD ( $P < 0.05$ ). Pearson correlation coefficients were determined for treatment rate correlation with mortality by day and leaf position (SAS Institute, 1990).

Water sensitive paper cards (Ciba-Geigy, Basle, Switzerland), 52 × 76 mm, were placed in the wheat field to monitor spray distribution at different heights of the wheat canopy. Card placement heights were based on the mean heights of flag, middle and bottom leaves on 25 randomly chosen plants in each year. Cards were held horizontally by metal, double-prong hair clips hot glued to wire flags placed in the plots. Each wire flag had cards at heights of 45, 28, and 14 cm from the ground in 1995 and 43, 23, and 13 cm in 1996. Two card-holding flags were randomly placed in each plot prior to spray application (2 cards per height per treatment per day). Cards were collected immediately after the spray dried and brought into the laboratory. Droplets were counted with a hand lens in four areas per card using a 0.25 cm<sup>2</sup> window placed at random on the water sensitive cards. Mean numbers of droplets per 0.25 cm<sup>2</sup> were determined for each leaf height and treatment. Means by rate within a leaf position and by leaf position within a rate were separated by LSD tests (SAS Institute 1990).

## RESULTS

#### Spray Table Test

The lethal concentration curve for Javelin WG-treated wheat leaves fed to 1st instars resulted in a LC<sub>50</sub> after 3 d of 0.53 kg per ha (Table 1). Mortality was much higher

TABLE 1. DOSAGE MORTALITY CURVES (KG/HA) FOR *P. UNIPUNCTA* LARVAE ON JAVELIN WG-TREATED WHEAT LEAVES USING A SPRAY TABLE.

Instar	Days after treatment	LC <sub>50</sub> (FI)	LC <sub>90</sub> (FI)	Slope	Chi-square P>
1st	3	0.53 (0.43-0.65)	5.52 (3.26-13.45)	1.256	0.001
	7	0.09 (0.05-0.12)	0.71 (0.56-1.04)	1.392	0.001
3rd	3	1.70 (1.34-2.38)	11.01 (6.51-24.14)	1.580	0.001
	7	0.55 (0.47-0.63)	4.12 (2.85-6.94)	1.458	0.001

7 d after treatment when the LC<sub>50</sub> was 0.09 kg per ha. Third instars were approximately 3 and 6 fold less susceptible than 1st instars after 3 and 7 d, respectively. These data show that *B. thuringiensis* killed small larvae on treated wheat leaves and has potential for *P. unipuncta* control on wheat when timed against small larvae. The LC<sub>50</sub> rates after 7 d for 1st and 3rd instar were lower than rates recommended for control of some lepidopterous larval pests on other crops (Johnson and Jones 1996).

#### Field Tests

At the time of the field tests, plant heights from base of stem to top of head in 1995 and 1996 were 57.5 (3.1) and 56.7 (1.9) cm, respectively [means, (SE)]. Heights of the flag, middle, and bottom leaves were 45.3 (1.8), 27.5 (0.9), 13.9 (0.7) cm in 1995, and 43.2 (0.9), 22.9 (0.6), and 12.6 (0.5) cm in 1996, above the ground, respectively [means, (SE)]. The spray distribution data (Table 2) indicated, that in most cases within a leaf position, significantly more droplets were found on cards in the control treatment (water only) than in the Javelin WG treatments (Table 2). There was seldom any difference in droplet density within a test and leaf position in those treated with Javelin WG. While in most cases significantly fewer droplets were counted on the bottom leaves relative to numbers on the flag leaves, it appears that inadequate penetration of the wheat canopy by *B. thuringiensis* sprays was not the cause of lack of efficacy in the field tests of Steinkraus & Young (1994) and Young & Steinkraus (1996).

In the 1995 field test, 1st instar mortality increased significantly with increases in Javelin rate at 3 and 7 d for flag and middle leaf positions (Table 3). Bottom leaves were senescing at the time of the test and therefore, data for this leaf position were not used. There were no significant differences in mortality due to leaf positions within a day, again showing that Javelin WG coverage of flag and middle leaves was similar. Mortality after 3 d was low in all treatments with only 47 and 25% mortality at the highest rate on the top and middle leaf, respectively. While the mortality at the higher rates was significantly higher at 3 d than the control, it was never greater than 50%. Mortality was higher after 7 d with 82 and 62% dead at the highest rate on the flag and middle leaves, respectively. Although most rates did not show a significant difference in mortality with leaf height (flag or middle leaf), in most cases mortality was higher on the flag leaf.

In the 1996 test using 1st instars, there was a significant positive correlation between increased Javelin WG rate and mortality for each day and leaf position (Table 4). In all cases significantly more larvae were killed in the Javelin WG treatments than the controls. Larval mortality after 3 d was higher than in the 1995 test with mortality at the highest rate reaching approximately 70% at all three leaf positions. Mortality after 7 d was higher reaching approximately 90% at 1.12 kg per ha at all

TABLE 2. NUMBERS OF *B. THURINGIENSIS* SPRAY DROPLETS ON WATER SENSITIVE PAPER CARDS AT HEIGHTS OF FLAG, MIDDLE, AND BOTTOM WHEAT LEAVES IN 1995 AND 1996 FIELD TESTS.

Javelin rate <sup>2</sup> (kg/ha)	Mean (SE) # droplets (per 0.25 cm <sup>2</sup> ) <sup>1</sup>		
	Card locations		
	Flag leaf <sup>3</sup>	Middle leaf <sup>4</sup>	Bottom leaf <sup>5</sup>
24-27 May 1995 Test			
0	66.9 (9.1) a A	60.8 (8.9) a A	40.4 (5.9) a B
0.28	37.0 (3.7) b A	33.4 (4.5) b A	21.4 (2.7) bc B
0.56	39.9 (3.8) b A	34.3 (2.9) b AB	30.9 (3.8) ab B
1.12	19.9 (3.1) c A	19.4 (3.2) c A	14.6 (2.3) c A
2.24	55.2 (5.5) a A	43.7 (3.7) b B	41.5 (4.4) a B
14-17 May 1996 Test			
0	68.2 (10.7) a A	61.6 (12.6) a A	66.4 (14.9) a A
0.28	47.7 (4.8) b A	44.1 (2.9) b AB	32.7 (4.6) b B
0.56	39.0 (4.6) b A	28.5 (3.0) b AB	22.2 (1.5) b B
1.12	38.6 (9.2) b A	41.6 (6.9) b A	30.7 (4.6) b A
2.24	42.6 (6.8) b A	35.2 (5.6) b AB	25.1 (7.4) b B
20-23 May 1996 Test			
0	72.0 (9.1) a A	57.9 (8.1) a A	55.8 (7.3) a A
0.28	51.4 (4.4) b A	42.6 (4.1) ab AB	37.9 (5.1) b B
0.56	55.9 (4.5) b A	48.9 (4.5) ab AB	41.5 (3.0) b B
1.12	43.0 (3.0) b A	37.8 (5.1) b A	25.4 (2.2) c B
2.24	52.5 (5.2) b A	39.4 (3.4) b B	41.8 (1.9) b B

<sup>1</sup>Means within a column followed by the same lower case letter or within a row followed by the same capital letter did not differ significantly (ANOVA, LSD).

<sup>2</sup>ANOVA statistics for rate: 24-27 May 1995 Test, 0 rate (F = 4.05; df = 2; P = 0.0219); 0.28 rate (F = 7.93; df = 2; P = 0.0008); 0.56 rate (F = 2.56; df = 2; P = 0.0851); 1.12 rate (F = 1.36; df = 2; P = 0.2648); 2.24 rate (F = 4.65; df = 2; P = 0.0128); 14-17 May 1996 Test, 0 rate (F = 0.14; df = 2; P = 0.8686); 0.28 rate (F = 4.12; df = 2; P = 0.0412), 0.56 rate (F = 5.85; df = 2; P = 0.0154), 1.12 rate (F = 0.69; df = 2; P = 0.5311); 2.24 rate (F = 5.47; df = 2; P = 0.0188); 20-23 May 1996 Test, 0 rate (F = 2.06; df = 2; P = 0.1565); 0.28 rate (F = 2.82; df = 2; P = 0.0859); 0.56 rate (F = 3.35; df = 2; P = 0.0580); 1.12 rate (F = 5.65; df = 2; P = 0.0125); 2.24 rate (F = 8.10; df = 2; P = 0.0031).

<sup>3</sup>ANOVA statistics for flag leaf card locations: 24-27 May 1995 test (F = 12.05, df = 4; P = 0.0001); 14-17 May 1996 test (F = 3.05; df = 4; P = 0.0395); 20-23 May 1996 Test (F = 3.65; df = 4; P = 0.0148).

<sup>4</sup>ANOVA statistics for middle leaf card locations: 24-27 May 1995 Test (F = 10.04; df = 4; P = 0.0001); 14-17 May 1996 Test (F = 4.40; df = 4; P = 0.0103); 20-23 May 1996 Test (F = 2.31; df = 4; P = 0.0792).

<sup>5</sup>ANOVA statistics for bottom leaf card locations: 24-27 May 1995 Test (F = 8.57; df = 4; P = 0.0001); 14-17 May 1996 Test (F = 9.18; df = 4; P = 0.0002); 20-23 May 1996 Test (F = 6.55; df = 4; P = 0.0006).

three leaf positions. There was no significant increase in mortality by increasing rate from 1.12 to 2.24 kg per ha. As in the 1995 test mortality was similar across leaf positions within a rate and day, showing that Javelin WG was penetrating the canopy and providing a similar dose to larvae feeding at all leaf positions.

In the 1996 test with 3rd instars, there was a significant positive increase in mortality with rate increases for all leaf positions and both days (Table 5). After 3 d, mor-

TABLE 3. PERCENTAGE MORTALITY OF 1ST INSTAR *P. UNIPUNCTA* FED *B. THURINGIENSIS*-TREATED FLAG AND MIDDLE WHEAT LEAVES TREATED IN THE FIELD (1995)<sup>1</sup>.

Javelin WG rate (kg/ha)	Mean (SE) % Mortality <sup>2</sup>			
	3 day		7 day	
	Flag leaf	Middle leaf	Flag leaf	Middle leaf
0	3.0 (1.0) a A	4.0 (2.8) a A	11.0 (3.4) a A	8.0 (3.6) a A
0.28	29.0 (9.7) b A	23.0 (9.9) b A	56.0 (9.5) b A	41.0 (9.3) b A
0.56	32.0 (11.2) b A	17.0 (3.0) b A	52.0 (5.6) b A	45.0 (2.5) b A
1.12	33.0 (5.9) b A	34.0 (9.0) b A	66.0 (8.2) ab A	62.0 (6.8) b A
2.24	47.0 (3.4) b A	25.0 (5.5) b B	82.0 (5.8) c A	62.0 (12.9) b B
r for rate <sup>3</sup>	0.70	0.58	0.81	0.76
P > r	0.0006	0.0074	0.0001	0.0001

<sup>1</sup>Bottom leaves were senescing and were not suitable food for the larvae, so data is not presented.

<sup>2</sup>Within day means in a column (lowercase) or row (upper case) followed by the same letter are not significantly different (ANOVA, LSD,  $P > 0.05$ ). ANOVA statistics for rate by leaf position within a day are as follows: df = 4 in all cases; 3 d statistics, (flag leaf  $F = 8.68$ ,  $P = 0.0016$ ), (middle leaf  $F = 4.34$ ,  $P = 0.0211$ ); 7 d statistics, (flag leaf  $F = 12.34$ ,  $P = 0.0003$ ), (middle leaf  $F = 7.90$ ,  $P = 0.0023$ ). ANOVA statistics for leaf position by day within a rate are as follows: df = 1 in all cases; 0 rate (3 day  $F = 0.01$ ,  $P = 0.9314$ ), (7 day  $F = 0.52$ ,  $P = 0.5239$ ); 0.28 rate (3 day  $F = 0.72$ ,  $P = 0.4571$ ) (7 day  $F = 5.74$ ,  $P = 0.0963$ ); 0.56 rate (3 day  $F = 0.85$ ,  $P = 0.4249$ ), (7 day  $F = 1.10$ ,  $P = 0.3706$ ); 1.12 rate (3 day  $F = 0.02$ ,  $P = 0.8865$ ), (7 day  $F = 0.29$ ,  $P = 0.6269$ ); 2.24 rate (3 day  $F = 21.8$ ,  $P = 0.0185$ ), (7 day  $F = 11.68$ ,  $P = 0.0419$ ).

<sup>3</sup>Pearson correlation coefficients (SAS 1990).

tality on flag leaves ranged from 17% at 0.28 kg per ha to 59% at 2.24 kg per ha. Mortality at 7 d was higher in most treatments and at the highest rate ranged from 76 to 89%. In no cases were there significant differences between mean mortalities due to leaf position within a day and rate.

#### DISCUSSION

The spray table test showed that greater than 50% mortality of 1st instar *P. unipuncta* could be achieved at recommended rates of *B. thuringiensis* on middle wheat leaves at either 3 or 7 days. Mortality occurred slowly and it was not possible to achieve a 50% mortality level at recommended rates of Javelin WG with 3rd instars at 3 d. Mortality levels in field-sprayed wheat tests were similar to those in the spray-table test indicating that spray distribution on leaves was satisfactory at all plant heights. Mortality in 3rd instars exposed to Javelin WG on wheat was slightly higher in the field test (Table 5) than would be expected based on the spray table data. For example, in the spray table test, even at 7 d, the  $LC_{50}$  was 4.12 kg per ha, whereas, in the field test, 89% were killed at 7 d at 2.24 kg per ha. This was unexpected since in the spray-table test mortality of 3rd instars had been several times less than that of 1st instar. Further testing will be required to explain these differences.

Results of the spray tests suggest that *B. thuringiensis* has potential to control *P. unipuncta* on wheat if treated as small larvae. These results are different from those of small-plot commercial wheat field tests in which several *B. thuringiensis* products failed to significantly reduce populations of *P. unipuncta* larvae (Steinkraus

TABLE 4. PERCENTAGE MORTALITY OF 1ST INSTAR *P. UNIPUNCTA* FED *B. THURINGIENSIS*-TREATED FLAG, MIDDLE, AND BOTTOM WHEAT LEAVES TREATED IN FIELD (1996).

Javelin rate (kg/ha)	Mean (SE) % Mortality <sup>1</sup>					
	3 day			7 day		
	flag leaf	middle leaf	bottom leaf	flag leaf	middle leaf	bottom leaf
0	1.0 (1.0) a A	1.0 (1.0) a A	3.0 (1.9) a A	3.0 (1.9) a A	2.0 (1.2) a A	12.0 (3.6) a B
0.28	26.2 (7.3) b A	22.1 (8.0) b A	54.3 (8.2) bc B	58.7 (8.4) b A	54.7 (6.9) b A	78.8 (11.6) bc B
0.56	54.0 (6.6) c A	50.0 (6.2) c A	49.7 (11.1) b A	88.0 (5.9) c A	84.0 (7.1) c A	74.2 (10.0) b A
1.12	56.0 (11.4) c A	65.0 (6.8) d A	66.7 (6.0) bc A	90.0 (4.8) c A	92.0 (1.6) cd A	89.9 (3.4) cd A
2.24	70.7 (11.5) c A	76.7 (6.0) e A	72.8 (5.9) c A	98.0 (1.2) c A	97.0 (1.9) d A	92.9 (1.9) d B
r for rate <sup>2</sup>	0.83	0.91	0.77	0.87	0.90	0.76
P > r	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

<sup>1</sup>Within day means in a column (lower case; ANOVA, LSD) or row (upper case, ANOVA, LSD) followed by the same letter are not significantly different ( $P > 0.05$ ). ANOVA statistics for rate by leaf position within a day are as follows: df = 4 in all cases; 3 d statistics, (flag leaf  $F = 19.28$ ,  $P = 0.0001$ ), (middle leaf  $F = 234.17$ ,  $P = 0.0001$ ), (bottom leaf  $F = 21.52$ ,  $P = 0.0001$ ); 7 d statistics, (flag leaf  $F = 66.53$ ,  $P = 0.0001$ ), (middle leaf  $F = 100.50$ ,  $P = 0.0001$ ), (bottom leaf  $F = 50.18$ ,  $P = 0.0001$ ). ANOVA statistics for leaf position by day within a rate are as follows: df = 2 in all cases; 0 rate (3 day  $F = 0.43$ ,  $P = 0.6679$ ), (7 day  $F = 5.95$ ,  $P = 0.377$ ); 0.28 rate (3 day  $F = 17.19$ ,  $P = 0.0033$ ); 0.56 rate (3 day  $F = 0.27$ ,  $P = 0.7690$ ), (7 day  $F = 2.77$ ,  $P = 0.14060$ ); 1.12 rate (3 day  $F = 0.42$ ,  $P = 0.6766$ ), (7 day  $F = 0.17$ ,  $P = 0.8497$ ); 2.24 rate (3 day  $F = 0.05$ ,  $P = 0.9483$ ), (7 day  $F = 5.71$ ,  $P = 0.0409$ ).

<sup>2</sup>Pearson correlation coefficient (SAS 1990).

TABLE 5. PERCENTAGE MORTALITY OF 3RD INSTAR *P. UNIPUNCTA* FED *B. THURINGIENSIS*-TREATED FLAG, MIDDLE, AND BOTTOM WHEAT LEAVES TREATED IN FIELD (1996).

Javelin rate (kg/ha)	Mean (SE) % Mortality <sup>1</sup>					
	3 day			7 day		
	flag leaf	middle leaf	bottom leaf	flag leaf	middle leaf	bottom leaf
0	6.0 (2.0) a	4.0 (2.3) a	10.0 (3.4) a	8.0 (3.2) a	9.0 (4.1) a	23.0 (5.2) a
0.28	17.0 (4.4) b	15.0 (4.7) ab	16.0 (4.9) ab	36.0 (5.9) b	32.0 (3.3) b	35.0 (10.4) ab
0.56	18.0 (3.5) b	20.2 (10.9) abc	21.0 (10.7) ab	50.0 (4.8) b	44.3 (13.2) bc	40.0 (14.1) ab
1.12	34.0 (6.6) c	37.0 (6.6) bc	35.0 (9.1) bc	56.0 (7.1) b	63.0 (10.7) cd	56.0 (10.3) bc
2.24	59.0 (7.4) d	44.0 (12.6) c	47.0 (13.8) c	89.0 (4.4) c	81.0 (4.1) d	76.0 (8.5) c
r for rate <sup>2</sup>	0.86	0.74	0.61	0.89	0.86	0.69
P > r	0.0001	0.0002	0.0043	0.0001	0.0001	0.0007

<sup>1</sup>Within day means in a column (lower case; ANOVA, LSD) followed by the same letter are not significantly different ( $P > 0.05$ ). No significant differences were found for mortality by leaf position within a day and treatment (statistics not presented). ANOVA statistics for rate by leaf position within a day are as follows: df was 4 in all cases; 3 d statistics, (flag leaf  $F = 33.50$ ,  $P = 0.0001$ ), (middle leaf  $F = 5.75$ ,  $P = 0.008$ ), (bottom leaf  $F = 6.15$ ,  $P = 0.0062$ ); 7 d statistics, (flag leaf  $F = 22.57$ ,  $P = 0.0001$ ), (middle leaf  $F = 11.61$ ,  $P = 0.0004$ ), (bottom leaf  $F = 8.53$ ,  $P = 0.0004$ ).

<sup>2</sup>Pearson correlation coefficient (SAS 1990).

& Young 1994, Young & Steinkraus 1996). This may have been due to unexamined factors such as larval size during the tests. The field populations treated in the efficacy tests of Steinkraus & Young (1994) and Young & Steinkraus (1996) were of mixed ages with most 3rd instars or older. As the tests show, larger larvae are more difficult to kill than smaller larvae.

Another factor is deactivation of *B. thuringiensis* by sunlight. In assays of *B. thuringiensis* sprayed on other crops it had an activity half-life of approximately 2 days (Ali & Young 1993). In the tests reported here, leaves were collected immediately after spray deposits dried (usually less than 30 min). This minimized potential degradation of *B. thuringiensis* deposits by sunlight. In addition, once treated leaves were picked, brought to the laboratory, and placed in cups, test larvae fed throughout the 3 d leaf-exposure period on undegraded *B. thuringiensis*. In the field tests of Steinkraus & Young (1994) and Young & Steinkraus (1996), in spite of the fact that the *B. thuringiensis* products were applied in late afternoon to minimize UV degradation, the *B. thuringiensis* deposits would still have been exposed to several hours of sunlight before the *P. unipuncta* larvae fed. Armyworms typically feed at night and rest on the ground during the day. Thus, in field tests with feral *P. unipuncta* larvae *B. thuringiensis* residues would be increasingly degraded by sunlight each day throughout the duration of a test.

A third possible explanation of the failure of *B. thuringiensis* products to reduce field armyworm populations, as reported by Steinkraus & Young (1994) and Young & Steinkraus (1996), could be movement of larvae between plots in field tests. It is possible that between the day of application, and assessments of larval populations 4 d later, armyworms moved between plots. If so, larvae counted in treated plots may have originated from outside treated areas and have been unexposed to *B. thuringiensis*. Such a situation could result in no significant differences in larval numbers between treated and control plots. Further tests are needed to fully explain the failure of *B. thuringiensis* to control *P. unipuncta* on heading wheat.

#### ENDNOTE

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