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Comparison of Chemigated and Aerially-Applied Chlorpyrifos and Fenvalerate for Control of European Corn Borer (Lepidoptera: Pyralidae) Larvae

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ABSTRACT Aerial and overhead center-pivot irrigation system (chemigated) applications of chlorpyrifos 4 emulsifiable concentrate (EC) and fenvalerate 2.4EC significantly reduced numbers of first- and second-generation European corn borer, *Ostrinia nubilalis* Hübner, larvae in field corn, *Zea mays* L. The number of first-generation *O. nubilalis* larvae, pupae, or cavities per plant in plots chemigated with chlorpyrifos in 1984 was significantly less than in plots where chlorpyrifos was applied aerially. A similar trend was observed for fenvalerate in 1985. No significant differences among application methods were observed for second-generation *O. nubilalis* treatments. Chlorpyrifos and fenvalerate were effective *O. nubilalis* control agents but efficacy differences between these two insecticides were variable. Corn yields did not vary significantly among application methods.

KEY WORDS Insecta, *Ostrinia nubilalis*, Chemigation, Aerial application

THE APPLICATION OF agricultural chemicals through irrigation systems (chemigation) was first accomplished in Arkansas during the late 1950s when Bryan & Thomas (1958) mixed fertilizer with water. This solution was then applied through a sprinkler irrigation system. Insecticides were first applied through overhead center-pivot irrigation systems in Colorado in 1976 by W. Hantsbarger and S. Pilcher (Pilcher & Peairs 1987). Herbicides (Heikes 1981) and fungicides (Franc et al. 1983) have subsequently been applied through irrigation systems in Colorado.

The advantages and disadvantages of chemigation have been discussed by several authors (Chalfant & Young 1982; Myers 1985; Threadgill 1981, 1985; Witkowski et al. 1984). Reduced costs are probably the principal factor responsible for the recent increase in chemigation as a pesticide application technique. However, there is little scientific data that compares pest control using chemigation with control by conventional application methods.

Because corn insecticides in Colorado have traditionally been applied by aircraft, replicated side-by-side comparisons of aerial and chemigated applications of chlorpyrifos and fenvalerate were conducted to determine efficacy of control of European corn borer, *Ostrinia nubilalis* (Hübner), during its first and second generation,

and to determine resulting yield for each application method-insecticide combination.

Materials and Methods

The study site was located in the eastern sandhills region of Colorado, in Yuma County. Three center-pivot irrigation systems (circles) were used in 1984 and four were used in 1985. These fields were chosen because of their similarity of soil type, irrigation well capacities, irrigation systems, and cultural practices. Circle sizes ranged from 42.8 to 64.8 ha and each was considered a repetition of a split-plot design. Each circle was randomly divided into an aerially treated and chemigated half, and each half was subdivided into insecticide treated and untreated plots. Differences between the two types of equipment used to apply insecticides limited plot design. Thus, plot dimensions and size were dissimilar between aerially treated and chemigated halves. Aerially treated plots (2) were segments parallel to rows, averaging 5.5 and 6.1 ha in 1984 and 1985 respectively. Chemigated plots (2) were sectors (wedge-shaped) and averaged 6.7 and 5.4 ha in 1984 and 1985, respectively. Because the study was conducted on private land, untreated plot sizes were minimal and randomization was restricted. Untreated check plots in 1984 were one 3-ha segment (parallel to rows) within each aerially treated whole plot, and two 2-ha sectors within each chemigated whole plot (data from each sector were combined before data analysis). In 1985, untreated check plots were two adjoining 2.8-ha sectors that were sit-

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uated between aerially treated and chemigated halves. The sector situated nearest the midline of each circle was assigned the untreated portion of the aerially treated whole plot.

Insecticide treatments were chlorpyrifos (Lorsban 4 emulsifiable concentrate [EC], Dow Chemical Company, Midland, Mich.) applied at 1.12 kg (AI)/ha, and fenvalerate (Pydrin 2.4EC, Shell Chemical Company, Houston, Tex.) at 0.17 kg (AI)/ha.

The aircraft used to apply insecticide was an Ag Cat G164 A600 with a 12.3-m wingspan, and a 9.85-m spray boom. Twenty whorljet 1/8 B10 nozzles on the spray boom applied a spray volume of 28.4 liters/ha at a pressure of 200 kPa, while traveling at 168 km/h.

The center-pivot irrigation systems (Lockwood electric drive Model 2200, Lockwood Corp., Gering, Nebr.) were equipped with 360° Senninger impact nozzles and operated at 300–400 kPa water pressure. Each system delivered 0.83 cm of water during the 18-h rotations used during insecticide applications. Irrigation water was pumped from the Ogallala aquifer and had 0.325 MMhos/cm electroconductivity, a pH of 7.2, 7.3 ppm NO₃-N, 0.7 ppm SO₄-S, 25.5 ppm Ca, 8 ppm Mg, 11.5 ppm Na, 17.5 ppm Cl, and 369.5 ppm total dissolved solids (analysis by Weld Laboratories, Greeley, Colo.).

Chemigated insecticides were injected through stainless steel one-way injection ports (5 mm inner diameter) that extended 9.5 cm into irrigation pipes (20.3 cm inner diameter) by either a Hydracone (Interpace Corp., Rochester, N.Y.) Model R1 cone diaphragm pump operating at 8,274 kPa pressure or a Milton Macroy (Milton Roy Company, Hartell Division, Ivyland, Pa.) M212-4-B02 tube diaphragm metering pump injecting at 1,069 kPa pressure. To eliminate recalibration of injector pumps between treatments, solutions were brought to equal volumes with water in a 113-liter nurse tank. Insecticide solutions were agitated manually.

The crop (*Zea mays* L., 'Os Gold 6882' [Asgrow Seed Company, Plainview, Tex.]) was planted on 3–9 May 1984 and 26 April–6 May 1985 in a sandy loam soil containing 0.567% organic matter, 7.7 ppm NO₃-N, 151.3 ppm K, 24.0 ppm P, 2.0 ppm S, 1.3 ppm Zn, 15.2 ppm Fe, with a pH of 5.6 (analysis by Ward Laboratories, Kearney, Nebr.). Planting rate was 72,500 seeds per ha with 76.2 cm between rows.

Timing of insecticide applications was based on *O. nubilalis* egg and larval infestation levels. Within each plot, 10 plants selected at random were carefully inspected for *O. nubilalis* egg masses at weekly intervals before insecticide application. In addition, larval infestation levels were determined before insecticide treatment by the presence of shot-holes (first generation) and by the number of larvae (all instars, second generation) found during weekly dissections of 10

randomly selected plants per plot. First-generation *O. nubilalis* treatments were applied on 5–6 July 1984 and 3–4 July 1985 to whorl-stage plants (stages V15–V18, Ritchie & Hanway [1984]). During the first-generation treatment period in 1984, 14.4% of the plants were infested with *O. nubilalis* eggs, had shot-holes, or both, and the average maximum and minimum temperatures were 30.3 and 16.2°C. *O. nubilalis* eggs and shot-holing were observed on 12.4% of the plants inspected before first-generation treatment in 1985. Maximum and minimum temperatures during the treatment period averaged 34 and 12°C. Second-generation treatments were applied on 12–13 August 1984 and on 13–16 August 1985 to milk stage corn (R3 stage, Ritchie & Hanway [1984]). Accumulated infestations of *O. nubilalis* eggs and larvae before application of second-generation treatments were 12.0 and 9.8% in 1984 and 1985, respectively. Averaged maximum and minimum temperatures during second generation application were 33.9 and 16.4°C in 1984, and 27.5 and 14.2°C in 1985.

Efficacy of first-generation treatment was determined by selecting 10 *O. nubilalis*-damaged plants at four (1984) and two (1985) random sites per plot. Damaged plants were selected to ensure that plants were infested with *O. nubilalis* larvae at the time of insecticide application. These plants were split lengthwise from the tassel to the first root node and the number of cavities (any size), pupae, and larvae (third to fifth instars) were recorded. Evaluations for control of first-generation *O. nubilalis* were made on 27 and 30 July 1984, and on 17–18 July 1985.

Evaluation of second-generation *O. nubilalis* control differed from the methods used during the first generation in that 10 randomly chosen plants rather than damaged plants were split from tassel to the first root node, as was the ear shank. In addition, only *O. nubilalis* larvae (third to fifth instars) were recorded. Randomly selected plants were used to evaluate second-generation *O. nubilalis* treatments because presence of visual damage would not ensure that plants were infested before insecticide application (i.e., damage observed may have been caused by first-generation larvae). Treatment evaluations were made on 15–16 September 1984, and on 27–28 August 1985.

To determine yield, ears from all plants in 0.0004 ha (5.34 row-m) were collected at four (25 October 1984) and two (15 October 1985) randomly chosen locations per plot, and were weighed in the field. From each sample, a random four-ear subsample was saved and later weighed and shelled. The shelled grain was then weighed and percent moisture was recorded. Weights were adjusted to 15.5% moisture for the entire sample and data were converted to metric tons per hectare. Yield was not determined in

Table 1. Comparison of two insecticides applied aerially and through overhead center-pivot irrigation systems (chemigated) for control of European corn borer larvae

Subplot treatment ^a	No. per plant, $\bar{x} \pm \text{SEM}$			
	First generation ^b		Second generation ^c	
	Aerial	Chemigated	Aerial	Chemigated
	1984			
Untreated	1.8 \pm 0.2	1.5 \pm 0.3	2.4 \pm 0.2	2.7 \pm 0.4
Chlorpyrifos	1.2 \pm 0.2	0.2 \pm 0.1	2.2 \pm 0.3	1.0 \pm 0.1
Fenvalerate	0.8 \pm 0.1	0.7 \pm 0.1	0.9 \pm 0.1	0.8 \pm 0.2
	1985			
Untreated	1.4 \pm 0.2	1.3 \pm 0.1	0.1 \pm 0.1	0.2 \pm 0.1
Chlorpyrifos	0.7 \pm 0.1	0.4 \pm 0.1	0.2 \pm 0.1	0.1 \pm 0.1
Fenvalerate	1.1 \pm 0.1	0.6 \pm 0.1	0.1 \pm 0.1	0.3 \pm 0.1

Least significant difference values (mean no. per plant) at $P = 0.05$ for means within a column (application method and year): first generation 1984, 0.9; 1985, 0.4. Second generation 1984, 1.2. For means within a row (differences between application method within a treatment): first generation 1984, 0.7; 1985, 0.4; second generation 1984, 1.6.

^a Chlorpyrifos 4EC and fenvalerate 2.4EC were applied at 1.12 and 0.17 kg (AI)/ha, respectively.

^b Third to fifth instars, pupae, and cavities found in corn stalks during plant dissections [$n = 120$ (1984), $n = 80$ (1985)].

^c Third to fifth instars found in corn stalks during plant dissection [$n = 120$ (1984), $n = 80$ (1985)].

untreated portions of chemigated main plots in 1984.

Statistical Analysis. All data were subjected to square root ($x + 0.5$) transformation and were analyzed as a split-plot design by analysis of variance using the Statistical Analysis System general linear models procedure (SAS Institute 1985). Variation among replications and main-plot (application method) treatments was tested over the block-by-application method interaction. Subplot (insecticide and untreated check) treatment effects and remaining interactions were tested over the residual error mean square. Orthogonal contrasts (SAS Institute 1985) were used to test for differences among subplot treatments and included untreated check versus insecticide treated and chlorpyrifos versus fenvalerate. Differences were considered significant at $P < 0.05$. Differences between subplot treatment means within an application method, as well as differences between application methods within a subplot treatment, were determined by calculating least significant difference values ($t = 0.05$ [Little & Hills 1975]). Untransformed means are presented.

Results and Discussion

First-Generation *O. nubilalis*. First-generation *O. nubilalis* infestation levels in untreated plots following application of insecticides averaged 1.7 and 1.4 larvae, pupae, and cavities per plant in 1984 and 1985, respectively (Table 1). Analyses indicated that significant differences occurred among application methods (1984: $F = 155.37$; $df = 1, 2$; $P < 0.01$. 1985: $F = 62.86$; $df = 1, 3$; $P < 0.01$) and treatments (1984: $F = 25.65$; $df = 2, 58$; $P < 0.01$. 1985: $F = 31.79$; $df = 2, 30$; $P < 0.01$). In addition, a significant application method \times treatment interaction was observed in 1984 ($F = 7.97$; $df = 2, 58$; $P < 0.01$).

Significantly fewer first-generation *O. nubilalis* larvae, pupae, and cavities were detected in chemigated than in aerially treated plots after insecticide application (mean larvae, pupae, and cavities per plant in 1984: aerially-applied, 1.2; chemigated, 0.8. In 1985: aerially-applied, 1.1; chemigated, 0.7). In practice, however, aerially applied carbofuran granules rather than aerially applied liquids would be the standard alternative to chemigated liquids. Average 1980–1984 first-generation *O. nubilalis* control with aerially applied carbofuran granules in eastern Colorado studies was 88% (Pilcher & Peairs 1987). In this study, aerially applied liquids averaged only 38% control.

Orthogonal contrasts indicated that the number of first-generation *O. nubilalis* larvae, pupae, and cavities in untreated check plots was significantly greater than in insecticide treated plots (mean larvae, pupae, and cavities per plant in 1984: untreated, 1.7; insecticide treated, 0.7. In 1985: untreated, 1.4; insecticide treated, 0.7 [1984: $F = 50.20$; $df = 1, 58$; $P < 0.01$. 1985: $F = 55.49$; $df = 1, 30$; $P < 0.01$]). Statistical differences between first generation *O. nubilalis* densities in plots treated with chlorpyrifos and fenvalerate were observed only in 1985 (mean larvae, pupae, and cavities per plant: chlorpyrifos, 0.6; fenvalerate, 0.9 [$F = 8.09$; $df = 1, 30$; $P < 0.01$]).

In 1984, first-generation *O. nubilalis* densities in untreated portions of aerially treated main plots were significantly greater than in plots where fenvalerate was applied aerially (Table 1). In 1985, the number of *O. nubilalis* larvae, pupae, and cavities in plots treated with aerially applied chlorpyrifos were significantly less than in the untreated check. Within chemigated main plots in 1984, first-generation *O. nubilalis* densities in plots treated with chlorpyrifos were significantly less than in untreated plots (Table 1).

In 1985, first-generation *O. nubilalis* densities in plots chemigated with chlorpyrifos and fenvalerate were significantly less than in untreated plots. Differences between levels of control with chlorpyrifos and fenvalerate between main plots may have contributed to the significant application method \times treatment interaction observed in 1984.

In 1984, chlorpyrifos provided greater control of first-generation *O. nubilalis* when chemigated than when applied aerially (Table 1). In 1985, fenvalerate was more effective at reducing first-generation *O. nubilalis* when applied through the pivot than when applied aerially.

Second-Generation *O. nubilalis*. In 1984, an average of 2.6 second-generation *O. nubilalis* larvae were observed per plant in untreated plots after insecticide application but only 0.2 larvae per plant were found in untreated plots in 1985 (Table 1). Egg mass counts were similar in both years, so larval survivorship must have been lower in 1985.

Statistical differences were observed among treatments in 1984 ($F = 36.3$; $df = 2, 58$; $P < 0.01$) as was a significant application method \times treatment interaction ($F = 6.73$; $df = 2, 58$; $P < 0.01$). Because of low second-generation *O. nubilalis* infestation levels observed after insecticide application in 1985, treatment effects could not be substantiated.

Orthogonal contrasts indicated that the number of second-generation *O. nubilalis* larvae in untreated plots in 1984 was significantly greater than in insecticide treated plots (mean larvae per plant: untreated, 2.6; insecticide treated, 1.2 [$F = 54.3$; $df = 1, 58$; $P < 0.01$]). In addition, the number of second-generation *O. nubilalis* larvae in fenvalerate treated plots was significantly less than in plots treated with chlorpyrifos (mean larvae per plant: chlorpyrifos, 1.6; fenvalerate, 0.8 [$F = 18.3$; $df = 1, 58$; $P < 0.01$]).

Within aerially treated main plots in 1984, second-generation *O. nubilalis* larval densities in plots treated with fenvalerate were significantly less than in plots treated with chlorpyrifos or left untreated (Table 1). The number of second-generation *O. nubilalis* larvae in plots chemigated with chlorpyrifos and fenvalerate was significantly less than in the untreated portions of chemigated main plots. Differences between second-generation *O. nubilalis* control with chlorpyrifos applied aerially and chemigated may have led to the significant application method \times insecticide interaction observed in 1984.

Yield. Yields varied considerably between plots (Table 2). However, significant yield differences were observed only among subplot treatments in 1985 ($F = 7.66$; $df = 2, 30$; $P < 0.01$).

Orthogonal contrasts indicated that plots treated with insecticide in 1985 yielded significantly more grain than untreated plots (mean

Table 2. A comparison of yields in plots treated with two insecticides applied aerially and through overhead center-pivot irrigation systems (chemigated) for control of European corn borer larvae

Subplot treatment ^b	Yield (metric tons per ha), $\bar{x} \pm \text{SEM}^a$	
	Aerial	Chemigated
1984		
Untreated	11.7 \pm 0.4	nd
Chlorpyrifos	13.0 \pm 0.3	12.1 \pm 0.5
Fenvalerate	12.0 \pm 0.6	12.6 \pm 0.5
1985		
Untreated	10.7 \pm 0.7	11.3 \pm 0.3
Chlorpyrifos	11.8 \pm 0.4	13.3 \pm 0.4
Fenvalerate	11.4 \pm 0.7	12.8 \pm 0.3

Least significant difference values (Mton/ha) at $P = 0.05$ for means within a column (application method and year): 1984, 2.4; 1985, 1.7. nd, not determined.

^a Yields determined from four-ear subsamples at four (1984) and two (1985) random locations per plot ($n = 12$, 1984; $n = 8$, 1985).

^b Chlorpyrifos 4EC and fenvalerate 2.4EC were applied at 1.12 and 0.17 kg (AI)/ha, respectively.

metric tons per hectare: untreated check, 11.0; insecticide treated, 12.3, [$F = 14.05$; $df = 1, 30$; $P < 0.01$]).

No statistical differences in yield were observed among subplot treatments in 1984 within either application method. However, plots chemigated with chlorpyrifos in 1985 yielded significantly more grain than the untreated portions of chemigated main plots (Table 2).

Even though *O. nubilalis* pressure during this study was relatively light, yields in chemigated plots were expected to be higher than in aerially treated plots because of differences in first-generation *O. nubilalis* control among main plots treated with chlorpyrifos in 1984 and fenvalerate in 1985. Possible yield differences among application methods and insecticide treatments may have been negated by the small sample size used to determine yield.

Conclusion. In view of the questionable future of carbofuran granules (the standard formulation used for management of insect pests in whorl-stage field corn in eastern Colorado), chemigation is becoming an increasingly important insecticide application technique. Data presented in this study suggest that chemigation is a viable alternative to the aerial application of liquid insecticides for control of *O. nubilalis* larvae. Chlorpyrifos and fenvalerate were effective *O. nubilalis* control agents when chemigated and efficacy differences between these insecticides appeared negligible. Although yields varied considerably, the data further suggest that insecticide application using either method limits grain loss from pest feeding.

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