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# Drift during Center-Pivot Chemigation of Chlorpyrifos with and without Crop Oil

Matthew E. Byers,[1] Shripat T. Kamble,[2] and John F. Witkowski[3]

[1]Community Research Service, Kentucky State University, Frankfort, Kentucky 40601, USA; [2]Environmental Programs—IANR, University of Nebraska, Lincoln, Nebraska 68583–0818, USA; and [3]Department of Entomology, University of Nebraska, Lincoln, Nebraska 68583–0816, USA

Pesticide drift during conventional ground and aerial applications has been studied (Bode et al. 1976; Draper and Street 1981; Ware et al. 1969a and 1969b; Ware et al. 1970). However, there have been no reported studies of insecticide drift during application through a center-pivot irrigation system (chemigation), even though it is becoming a common method of application. Depending on the amount of water needed to accomplish the chemigation, an average application may take from 18 to 72 hrs. During this relatively long application time, climatic conditions may vary dramatically and drift conditions can occur.

A major concern associated with insecticide drift is human exposure outside the target application area. Worker exposure associated with chemigation inside the field application area has been quantified (Byers et al. 1992; Kamble et al. 1992). But measurement of insecticide drift during chemigation and estimation of human exposure to insecticide beyond the target area of application has not been published.

The purpose of this study was to: 1) measure drift during chemigation of chlorpyrifos with and without crop oil, and 2) estimate potential human exposure (risk) from off-target drift.

## MATERIALS AND METHODS

Chlorpyrifos (Lorsban® 4 Emulsifiable Concentrate, DowElanco, Indianapolis, IN)) was applied at 1.12 kg of active ingredient (AI)/ha without and in combination with a non-emulsifiable crop oil. The crop oil (Sunoco® 11N, Cornbelt Chemicals, McCook, NE) was applied at 0.45 L/ha. Applications were made in 0.64 cm of irrigation water to R3 stage corn (milk stage), in Dixon County, Nebraska. Insecticide applications were made with a high angle, high pressure 4.23 kg/cm (60 psi), 384.3 m (1260 ft) center-pivot irrigation system (Lindsay® Model 1234, Lindsay, NE). The insecticide was injected midstream into the irrigation line through a one-way check valve by a positive displacement

Send reprint requests to Dr. Shripat T. Kamble at above address

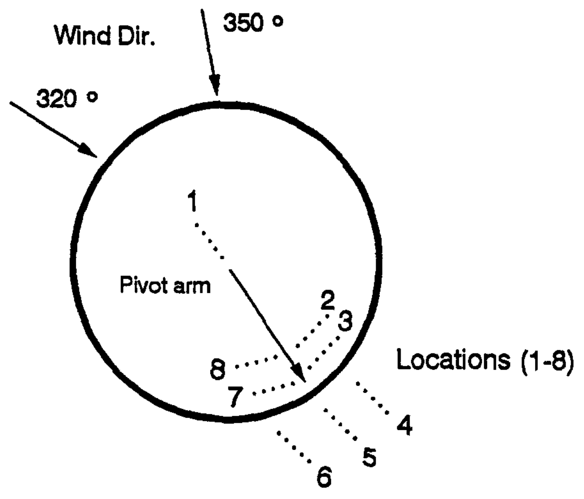


Figure 1. Five Chlorpyrifos drift monitoring stations (each dot representing 20, 40, 60, 80, and 100 m away from the pivot arm) at each of 8 locations around a center-pivot irrigation system.

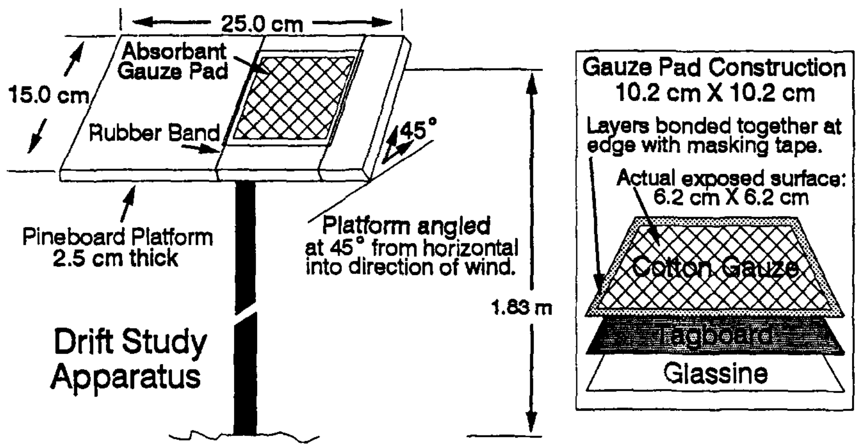


Figure 2. Insecticide drift monitoring apparatus and gauze monitoring pad construction.

diaphragm pump (PULSA-feeder Microflo 680, Interpace Corporation, Rochester, NY). Pivot arm position was determined by initial wind direction and aligned with the air flow (325°) and remained stationary (Fig. 1) throughout each application. Chlorpyrifos was applied through a center-pivot irrigation system for 10 min in each treatment and was replicated three times.

A CR-21 Micrologger (Campbell Scientific, Logan, UT) equipped with a cup anemometer (stall of 0.5 m/sec), wind directional vane, pyronometer, and a thermistor/relative humidity probe (Campbell Scientific Model 201, Logan, UT) were located within the study site to record the microclimatic conditions.

Drift was monitored for 60 min (10 min during application plus 50 min post-application period). Insecticide drift was measured using adsorbent gauze pads (Durham and Wolfe 1962) which consisted of three layers: bottom layer of glassine paper (10.2 x 10.2 cm), middle layer of tagboard (10.2 x 10.2 cm) and the exposed layer of 12-ply surgical gauze (10.2 x 10.2 cm) (Johnson and Johnson Co., New Brunswick, NJ). The three layers were bound with adhesive masking tape, leaving an exposed gauze surface of 6.4 x 6.4 cm area. Preliminary analysis indicated exposure pads contained no materials that would interfere with chlorpyrifos detection. Gauze exposure pads were fastened with rubber bands to drift monitoring apparatus composed of 15.2 x 38.1 cm pine board backing, installed at $45^0$ angle facing the pivot, atop 0.3 and 1.83 m lengths of 1.3 cm id rigid conduit for outside and within field monitoring, respectively (Fig. 2). Drift monitoring apparatuses were stationed around the pivot at each of eight locations. Stations were 20, 40, 60, 80, and 100 m radiating away from the pivot arm (Fig. 1). After each 60 min monitoring period, the pre-labeled exposure pads were removed from the monitoring stations, placed individually in ziploc bags (Dow Consumer Products Inc, Indianapolis, IN), stored on ice in coolers, transported to the laboratory, and stored at -20 °C until extraction. Field fortified samples were prepared by spiking gauze pads (n=3) with 10 $\mu$g (AI) of chlorpyrifos in 1 mL of hexane. Fortified samples were stored, extracted and analyzed in the same manner as the other pads to determine chlorpyrifos stability during handling and storage.

Chlorpyrifos from exposed gauze pads was extracted by placing only the central 12-ply-gauze (6.4 X 6.4 cm) sample in an 250 mL ehrlenmeyer flask containing 35 mL chromatography grade n-hexane. Flasks containing samples were capped with neoprene stoppers wrapped with plastic cling sheets and mechanically agitated for 30 min on a wrist action shaker (Burrell® Model 75, Pittsburgh, PA). All extracts were stored at -20 °C until chemical analysis. Mean extraction efficiency for chlorpyrifos from gauze pads was 93.3%. Recovery rate of field fortified samples for chlorpyrifos after 4 months averaged 93.7%. All drift samples were processed within 2 wks of collection.

Chlorpyrifos was analyzed using a gas-liquid chromatograph (Varian® 6000 Vista Series, Sunnyvale, CA) equipped with a $Ni^{63}$ Electron Capture Detector (ECD) operated at 350 °C. The column used was a 2.0 m x 2.0 mm (id) glass column packed with 3% OV-101 on gas chrom Q, 80/100 mesh. Injector and column temperatures were 250 and 220 °C, respectively. Carrier gas (nitrogen) flow rate was set at 60 mL/min. The minimal detection limit for chlorpyrifos was 0.005 ng/$\mu$L. Chlorpyrifos amounts from exposed pads were converted from ng/$\mu$L to ng/cm$^2$. Data were analyzed with Proc General Linear Model (GLM), Repeated

Measures Analysis, SAS Institute 1985. Mean detectable quantities from chlorpyrifos treatments, with and without crop oil were compared using regression analysis (Lotus Development Corp. Version 2.0).

Potential human exposure to insecticide drift was estimated by quantifying the residue on the exposed surface (40.96 $cm^2$) of the adsorbent gauze pads (representing a contaminated location around the pivot) and expressing as $ng/cm^2$. Multiplying this quantity by the average human body surface area of 21,000 $cm^2$ (Dubois and Dubois 1916), yielded an estimate of total exposure in ng, which was then converted to mg. The total amount of chlorpyrifos exposure to an unclothed body was compared to acute dermal $LD_{50}$ values. The estimated exposure was also based on the assumption that the subject remained in that field for the 60 min exposure period.

## RESULTS AND DISCUSSION

Temperature and relative humidity variables were minimal during this study. Wind direction varied between 330-360°. Wind during chlorpyrifos applications (without and with crop oil) averaged 6.2 (5.4 - 7.2) m/sec, and were in the upper range of normal application.

Off-target depositions of chlorpyrifos applied without crop oil are presented in Table 1. There were significant differences in mean chlorpyrifos deposited among locations and distances. However, locations 1, 2, 3, and 8 were not in line with the air flow and had no chlorpyrifos detected beyond 40 m. Location 5 was directly in line with the air flow and had significantly greater amounts of chlorpyrifos detected ($ng/cm^2$). Chlorpyrifos quantities were the highest at 20 m when compared with all other distances, and declined as the distance from the pivot increased for all locations.

Chlorpyrifos chemigated in combination with crop oil drifted farther (Table 2) than when chemigated without the crop oil. The drift patterns were similar indicating that locations 1, 2, 3 and 8 were not in line with the wind direction and had the lowest levels of chlorpyrifos beyond 40 m. Locations 4, 5, 6, and 7 had chlorpyrifos residue detected to the farthest monitoring distance of 100 m. Most chlorpyrifos was found at locations 5 and 6. The locations with the highest levels of detected chlorpyrifos residue were in line with the air flow. Over all locations, the chlorpyrifos residue declined significantly as the distance increased from the site of application.

In general, drift patterns of chlorpyrifos applied with and without crop oil at all distances are presented in Fig. 3. According to these data, chlorpyrifos applications with crop oil consistently yielded greater insecticide drifts than those without crop oil. The addition of crop oil likely affected drift. It may have either affected the spray directly by increasing the net amount of detectable drift through

Table 1. Drift of chlorpyrifos (Lorsban® 4E) when applied through a center-pivot irrigation system to corn, Dixon County, Nebraska, 1988.

| Location[b] | Distance (m)[a] 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|
| | Chlorpyrifos ng/cm² | | | | |
| | Mean[c] ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| 1. | 6.5 ± 11.3b[d] | 0.0 ± 0.0b | 0.0 ± 0.0b | 0.0 ± 0.0a | 0.0 ± 0.0a |
| 2. | 4.7 ± 6.1b | 0.0 ± 0.0b | 0.0 ± 0.0b | 0.0 ± 0.0a | 0.0 ± 0.0a |
| 3. | 2.4 ± 2.6b | 1.0 ± 1.0b | 0.0 ± 0.0b | 0.0 ± 0.0a | 0.0 ± 0.0a |
| 4. | 3.3 ± 3.2b | 3.2 ± 5.6ab | 2.3 ± 4.0ab | 0.0 ± 0.0a | 0.0 ± 0.0a |
| 5. | 47.7 ± 36.1a | 10.7 ± 9.4ab | 8.5 ± 9.7a | 1.7 ± 3.0a | 0.3 ± 0.2a |
| 6. | 14.4 ± 11.2b | 14.1 ± 18.7a | 4.4 ± 3.8ab | 2.2 ± 1.8a | 0.0 ± 0.0a |
| 7. | 10.2 ± 10.8b | 2.7 ± 4.6ab | 2.6 ± 4.4ab | 1.1 ± 2.0a | 0.0 ± 0.0a |
| 8. | 6.2 ± 3.4b | 0.4 ± 0.7b | 0.0 ± 0.0b | 0.0 ± 0.0a | 0.0 ± 0.0a |

[a]Distance away from center-pivot area of application, n=5.
[b]Monitoring locations around the pivot, n=8.
[c]Mean chlorpyrifos residue for three replications.
[d]Means followed by the same letter within each column are not significantly different (P ≤ 0.05), Fisher's protected LSD test (SAS Institute 1985).

Table 2. Drift of chlorpyrifos (Lorsban® 4E) when applied with crop oil through center-pivot irrigation to corn, Dixon County, Nebraska, 1988.

| Location[b] | Distance (m)[a] 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|
| | Chlorpyrifos ng/cm² | | | | |
| | Mean[c] ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| 1. | 0.0 ± 0.0d[d] | 3.6 ± 3.1c | 0.0 ± 0.0b | 0.0 ± 0.0b | 0.0 ± 0.0b |
| 2. | 4.2 ± 1.0cd | 0.0 ± 0.0c | 0.0 ± 0.0b | 0.0 ± 0.0b | 0.0 ± 0.0b |
| 3. | 0.9 ± 1.6d | 0.0 ± 0.0c | 0.3 ± 0.6b | 0.0 ± 0.0b | 0.0 ± 0.0b |
| 4. | 12.3 ± 10.3bcd | 6.0 ± 4.6c | 6.0 ± 3.1b | 3.2 ± 4.2b | 7.1 ± 6.2ab |
| 5. | 46.7 ± 63.1abc | 37.3 ± 6.7a | 30.0 ± 24.1a | 22.5 ± 22.0a | 13.0 ± 11.3a |
| 6. | 61.5 ± 27.9ab | 16.6 ± 12.0b | 25.8 ± 5.6a | 9.1 ± 9.8ab | 4.2 ± 5.5b |
| 7. | 62.4 ± 21.0a | 19.1 ± 6.0b | 4.3 ± 2.6b | 8.9 ± 11.7ab | 0.2 ± 0.4b |
| 8. | 12.5 ± 4.8bcd | 4.3 ± 5.6c | 0.9 ± 1.2b | 0.0 ± 0.0b | 0.0 ± 0.0b |

[a]Distance away from center-pivot area of application, n=5.
[b]Monitoring locations around the pivot, n=8.
[c]Chlorpyrifos residue for three replications.
[d]Means followed by the same letter within each column are not significantly different (P ≤ 0.05), Fisher's protected LSD test (SAS Institute 1985).

the processes that contribute to creation of more driftable droplets, or increased the ability of drifting particles to adhere to the monitoring surfaces. The physical properties of materials being sprayed influence drift potential (Coutts and Yates 1968). The effects of several spray adjuvants on water recovery have been studied (Bouse and Merkle 1975), and the use of paraffin, diesel and mineral oils in sprays resulted in greater drift losses than did water sprayed from a flat fan nozzle alone.

The log transformed detected quantities regressed over distance (Fig. 4) resulted in correlation coefficients of 0.98 and 0.86 for application made with and without crop oil, respectively. Using the model for chlorpyrifos with oil, it was predicted that detectable residues could be found up to 149 m beyond the chemigation area.

The present data clearly indicate that spray drift of chemigated chlorpyrifos can be documented beyond the targeted area of application. However, mean quantities of chlorpyrifos (applied with crop oil) detected at 20 m were less than 0.2% of the applied rate (14 mg AI/L solution). Chemigation drift under similar wind conditions was studied using the non-volatile tracer KCL which was not detected beyond 72 m, and the quantities detected beyond 20 m were less than 0.01% of the applied rate (Kohl et al. 1987).

To estimate human exposure, the mean maximum amount of chlorpyrifos detected at any station within a location around the pivot was during application of chlorpyrifos with crop oil at 20 m from the pivot at location 7. As a result, 1.31 mg of chlorpyrifos would have been exposed to 21,000 $cm^2$ human body surface area. Assuming an average human body mass of 70 kg, estimated exposure was 0.02 mg/kg (assuming homogeneous exposure to unclothed body and one hour exposure). Based on these data, this estimation was the highest possible prediction of exposure for an unclothed individual. The acute dermal $LD_{50}$ for chlorpyrifos is 2000 mg/kg (Worthing 1987), therefore the estimated exposure was 0.001% of the published value. These data indicated the risk of an acute dermal toxic dose of chlorpyrifos down-wind from chemigation during this study was low.

Based on results from this study, quantities of detected chlorpyrifos decreased with increasing distance from the center-pivot irrigation system and were greatest at locations around the system in line with the air flow. Chlorpyrifos was detected 100 m down wind and chlorpyrifos plus crop oil predicted to have been deposited to 149 m. The addition of crop oil increased the quantities of detected chlorpyrifos. The increased levels of chlorpyrifos detected when crop oil was used indicated either greater insecticide drifting or the oil addition caused the chlorpyrifos to better adhere to the pad surface. If the latter is true, it may adhere to a nontarget organism more efficiently. Human exposure downwind from a chemigation operation can occur. However, the acute risk of toxicity due to dermal exposure under the conditions of this study was estimated to be low.

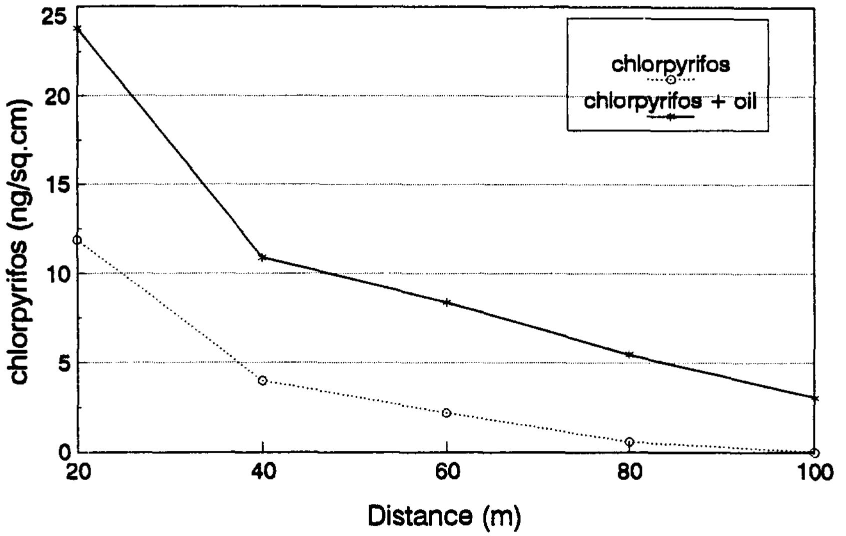


Figure 3. Drift of chlorpyrifos (Lorsban 4E) applied with and without crop oil (Sunoco 11N) to corn through center-pivot irrigation, Dixon County, Nebraska, 1988.

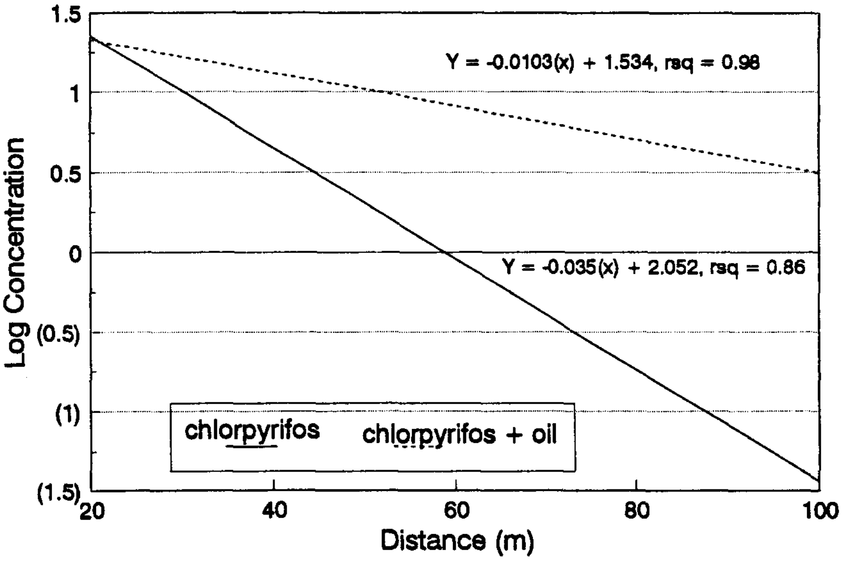


Figure 4. Regression analysis of log concentration (ng/sq.cm) vs. distance from center pivot, Dixon County, Nebraska, 1988.

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## REFERENCES

Bode LE, Butler BJ, Goering CG (1976) Spray drift and recovery as effected by spray thickener, nozzle type, and nozzle pressure. Trans ASAE 19(2):213-218

Bouse LF, Merkle MG (1975) Comparison of recoveries from a tower-mounted dual sprayer. Trans ASAE 18(3):467-470

Byers ME, Kamble ST, Witkowski JF, Echtenkamp G (1992) Exposure of a mixer-loader to insecticides applied to corn via a center-pivot irrigation system. Bull Environ Contam Toxicol 49:58-65

Coutts HH, Yates WE (1968) Analysis of spray droplet distributions from agricultural aircraft. Trans ASAE 11:25-27

Draper WM, Street JC (1981) Drift from a commercial, aerial application of methyl and ethyl parathion: An estimation of potential human exposure. Bull Environ Contam Toxicol 26:530-536

DuBois D, Dubois EF (1916) Clinical calorimetry. 10th paper. A formula to estimate the approximate surface area if height and weight be known. Arch Intern Med 17:863-871.

Durham WF and Wolfe HR (1962) Measurement of the exposure of workers to pesticides. Bull Wld Hlth Org 26:75-91

Kamble ST, Byers ME, Witkowski JF, Ogg CL, Echtenkamp GW (1992) Field worker exposure to selected insecticides applied to corn via center-pivot irrigation. J Econ Entomol 85:974-980

Kohl RA, Kohl KD, DeBoer DW (1987) Chemigation drift and volatization potential. Applied Eng Agr 3:174-177

Lotus Development Corporation (1986) Version 2.0 Lotus 123

SAS Institute (1985) SAS user's guide: Statistics. Cary, North Carolina

Ware GW, Apple EJ, Cahill WP, Herhardt PD, Frost KR (1969a) Pesticide drift. II. Mist-blower vs. aerial application of sprays. J Econ Entomol 62:844-846

Ware GW, Estesen BJ, Cahill WP, Herhardt PD, Frost KR (1969b) Pesticide drift. I. High-clearance vs. aerial application of sprays. J Econ Entomol 62:840-843.

Ware GW, Cahill WP, Gerhardt PE, Witt JM (1970) Pesticide drift. IV. On-target deposits from aerial applications. J Econ Entomol 63:1982-1983.

Worthing CR (Ed) (1987) The Pesticide Manual, a World Compendium. 8th Edition. British Crop Protection Council.

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