Bull. Environ. Contam. Toxicol. (2000) 65:522–529

DOI: 10.1007/s001280000155

Bulletin of Environmental Contamination and Toxicology

Assessing Insecticide Drift During and After Center-Pivot Chemigation to Corn Using Glass Plates and Gauze Pads

M. E. Byers,[1] S. T. Kamble,[2] J. F. Witkowski[3]

[1] Zoeller Company, 3649 Cane Run Road, Louisville, KY 40256-0347, USA
[2] Department of Entomology-IANR, University of Nebraska, Lincoln, NE 68583-0816, USA
[3] University of Nebraska, Northeast Research and Extension Center, Norfolk, NE 68701-0812, USA

Received: 25 April 2000/Accepted: 19 June 2000

Insecticide application to corn through center-pivot irrigation systems (chemigation) is a common practice. According to Kohl et al. (1987), drift during and subsequent to chemigation may be a potential problem. Published data are available on pesticide drift from conventional applications (Bode et al. 1976; Byass and Lake 1977; Draper et al. 1981; Draper and Street 1981; Nordby and Skuterud 1975; Smith et al. 1982; Threadgill and Smith 1975; Ware et al. 1969, 1969, 1970; Yates et al. 1974). However, paucity of data exist regarding insecticide drift from chemigation (Byers et al. 1993). This study was undertaken to: a) measure drift using gauze pads and glass plates during and subsequent to chemigation of chlorpyrifos, permethrin, and carbaryl to corn; and b) estimate potential human exposure from drifted insecticides.

MATERIALS AND METHODS

Chlorpyrifos (Lorsban® 4 Emulsifiable Concentrate, Dow-AgroSciences, Indianapolis, IN), permethrin (Pounce® 3.2 Emulsifiable Concentrate, FMC, Philadelphia, PA), and carbaryl (Sevin® 80% Soluble Powder, Rhone Poulenc, Research Triangle Park, NC), were applied at rates of 1.12, O.22 and 1.68 kg of active ingredient (AI)/ha, respectively. Applications were made in 0.64 cm of irrigation water to R3 stage corn (milk stage), in Dixon County, Nebraska. Insecticides were applied with a high angle, high pressure 4.23 kg/cm^2 (60 psi), 384.3 m (1260 ft) center-pivot irrigation system (Lindsey® Model 1234, Lindsey, NE). The insecticides were injected mid-stream into the irrigation line through a one-way check valve by a positive displacement diaphragm pump (PULSA-feeder Microflo 680, Interpace Corporation, Rochester, NY). Pivot position was determined by wind direction, and was set perpendicular to the prevailing wind (Fig. 1). Insecticide drift was monitored downwind to air flowing perpendicular to the pivot. The pivot remained stationary during all applications. Insecticides were applied through the center-pivot irrigation system for 10 min in each treatment and were replicated two times in a completely random design.

A CR-21 Micro-logger (Campbell Scientific, Logan, UT) equipped with a cup

Correspondence to: S. T. Kamble

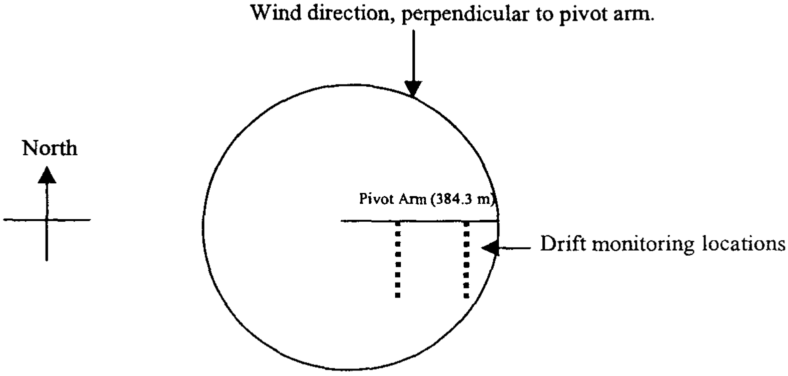

Figure 1. Eight drift monitoring stations (each location representing 9.1, 12.2, 15.2, 18.3, 24.4, 36.6, 54.9 and 70.2 m away from the pivot arm) around a center-pivot irrigation system.

anemometer (stall of 0.5 m/sec), wind directional vane, pyronometer, and a thermistor/relative humidity probe (Campbell Scientific Model 201, Logan, UT) was located within the study site to record micro-climatic conditions.

Drift was monitored using glass plate collectors (10.0 x 20.0 cm) and adsorbent gauze pads (Kamble et al. 1992). Chemical analysis indicated glass plates and gauze pads contained no materials that would interfere with detection of chlorpyrifos, permethrin and carbaryl. Glass plates and gauze pads were attached to drift monitoring apparatus (Byers et al. 1993) at 45^0 angles facing the pivot. Monitoring apparatuses were stationed in two lines (originating from the first and last wheel tracks) at distances of 9.1, 12.2, 15.2, 18.3, 24.4, 36.6, 54.9, and 70.2 m (Fig. 1).

During chemigation, glass plates and gauze surfaces were exposed to drift for 10 min. Subsequent to the chemigation, gauze pads were replaced with unexposed pads and drift was monitored for additional 50 min. Upon completion of exposure periods, all gauze pads were placed in individual ziploc bags. Glass plates were rinsed with 50 mL n-hexane each for chlorpyrifos and permethrin, and 50 mL methanol for carbaryl into borosilicate glass sample bottles. Gauze pads and plate rinsate were stored at -20 °C until extraction.

Extraction of insecticides from gauze pads included removing taped borders and using only the center 12 ply-gauze (6.4 X 6.4 cm). Insecticides from pads were extracted by placing each sample in a 250 mL erlenmeyer flask containing 35 mL HPLC grade n-hexane for chlorpyrifos and permethrin, and 35 mL HPLC grade methanol for carbaryl. Flasks were capped with neoprene stoppers wrapped with plastic cling sheets and mechanically agitated for a 30 min on a wrist action shaker (Burrell® Model 75, Pittsburgh, PA). All extracts were stored at -20 °C until chemical analysis. Mean extraction efficiencies for chlorpyrifos, permethrin and carbaryl were 93.3, 86.5, and 79.0%, respectively.

Chlorpyrifos was analyzed using gas-liquid chromatography (GC) (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 m x 2 mm (id) glass column packed with 3% OV-101 on gas chrom Q, 80/100 mesh. Injector and column temperatures were set at 250 and 220 °C, respectively. Carrier gas (nitrogen) flow rate was set at 60 mL/min. The minimum detection for chlorpyrifos was 0.005 ng/μL. Permethrin was analyzed using GC with Ni^{63} ECD and a 3% OV-210 glass packed column with a nitrogen flow rate of 60.0 mL/min. The temperatures for injection, column and detector were 250, 220, and 320 °C, respectively. The minimum detection for permethrin was 0.1 ng/μL. Carbaryl was analyzed using high performance liquid chromatography (HPLC), (ISCO® Model 2350 dual pump system, Lincoln, NE) coupled with an ultra-violet/visible absorbency detector (ISCO Model V4). The column used was an ISCO C18 operated in a reverse phase mode. A methanol-water mixture (70:30) was used to elute the carbaryl with a minimum detection level of 0.05 ng/μL.

Insecticide amounts from pads and glass plates were converted from ng/μL of analyzed sample to ng/cm^2. Potential human exposure to insecticide drift was estimated by multiplying the insecticide residue of ng/cm^2 by the mean human body surface area of 21,000 cm^2 (Berkow 1931). The insecticide amount of ng was converted to mg and later to mg/kg (based on mean body weight of 70 kg). The estimated exposure was also based on the assumption that the subject would have remained in that field for 60 min.

The exposure data were analyzed using an analysis of variance and the Duncan's Multiple Range mean comparison procedure (SAS Institute 1985).

RESULTS AND DISCUSSION

Micro-climatic variables were minimal during insecticide applications (Tab. 1). Temperatures (18.2 - 29.2 °C) and wind speeds (2.9 - 5.8 m/sec) were within the range of normal application. The relative humidity varied between 32.9-77.9%.

Off-target drifts of chlorpyrifos, permethrin and carbaryl collected at distances downwind are presented in Tables 2, 3 and 4. Insecticide quantities generally decreased as the distance from the center-pivot irrigation system increased. Chlorpyrifos was the only insecticide detected at 70 m. Permethrin was not detected beyond 54.9 m which may have been because of the low application rate. Carbaryl, although used comparatively at a higher application rate, was applied as a soluble powder. Insecticide adsorbed onto clay may be more likely to dislodge or not as likely to wet a surface as an insecticide emulsified in oil. The physical properties of material being sprayed may influence drifting potential (Coutts and Yates 1968), and perhaps affect the ability to trap and monitor.

Table 1. Micro-climatic conditions during the application of three insecticides to corn via a center-pivot irrigation, Dixon County, Nebraska, 1987.

Date	Time	Treatment (kg AI/ha)	Temperature °C	Wind (m/sec)	RH %
9-1	11:52 am	chlorpyrifos[a] (1.12)	26.0	2.9	53.5
9-1	2:08 pm	chlorpyrifos (1.12)	28.0	3.2	51.1
9-1	4:21 pm	permethrin[b] (0.22)	29.2	3.9	32.9
9-3	9:14 am	permethrin (0.22)	18.2	5.0	77.9
9-1	5:24 pm	carbaryl[c] (1.68)	26.6	3.8	34.9
9-3	12:28 pm	carbaryl (1.68)	23.3	5.8	67.0

[a]Lorsban 4E, [b]Pounce 3.2EC, [c]Sevin 80SP.

Table 2. Drift of insecticides (applied via center-pivot irrigation to corn, Dixon County, Nebraska, 1987) collected on glass plates during the application.

	Insecticide Quantity (ng/cm²)		
Distance (m)	chlorpyrifos[a]	permethrin[b]	carbaryl[c]
	Mean ± SE	Mean ± SE	Mean ± SE
9.1	42.11 ± 46.3[d]	45.37 ± 32.0	2.80 ± 3.7
12.2	15.11 ± 15.1	31.16 ± 18.3	5.41 ± 4.7
15.2	3.88 ± 3.9	18.98 ± 24.4	11.82 ± 9.7
18.3	1.16 ± 0.7	11.10 ± 15.6	5.87 ± 4.1
24.4	1.53 ± 1.3	4.54 ± 7.0	4.43 ± 1.9
36.6	1.29 ± 1.0	0.43 ± 0.9	2.16 ± 1.9
54.9	1.26 ± 1.8	0.47 ± 0.9	2.53 ± 3.8
70.2	0.34 ± 0.02	nd[e]	nd

[a]Lorsban 4E, [b]Pounce 3.2EC, [c]Sevin 80SP.
[d]Mean quantity resulting from two applications and two monitoring locations within the field followed by standard deviation.
[e]Not detected.

Tables 2 and 3 include insecticide quantities monitored during application using glass plates and gauze pads, respectively. Overall means for gauze and glass were 207.7 and 9.5 ng/cm^2, respectively, and were significantly different ($P>0.05$). However, over all insecticides, mean drift on gauze and glass plates at individual distances indicated significant differences only at 9.1 m ($P>0.05$). Gauze clearly trapped more chlorpyrifos than glass, but for permethrin and carbaryl, glass yielded higher amounts at the farthest distances monitored. Gauze surfaces likely

Table 3. Drift of insecticides (applied via center-pivot irrigation to corn, Dixon County, Nebraska, 1987) collected on gauze pads during the application.

Distance (m)	Insecticide Quantity (ng/cm^2) chlorpyrifos[a]	permethrin[b]	carbaryl[c]
	Mean ± SE	Mean ± SE	Mean ± SE
9.1	2599.6 ± 1747.4[d]	82.7 ± 63.4	78.2 ± 80.7
12.2	1457.8 ± 2618.1	53.6 ± 33.5	89.7 ± 75.6
15.2	93.1 ± 70.3	14.7 ± 17.4	17.5 ± 12.6
18.3	37.4 ± ·20.0	7.9 ± 15.8	7.3 ± 9.1
24.4	33.9 ± 9.5	nd[e]	nd
36.6	22.4 ± 8.6	nd	nd
54.9	22.6 ± 8.0	nd	nd
70.2	20.9 ± 0.6	nd	nd

[a]Lorsban 4E, [b]Pounce 3.2EC, [c]Sevin 80SP.
[d]Mean quantity resulting from two applications and two monitoring locations within the field followed by standard deviation.
[e]Not detected.

allowed wetting and entrapment of droplets which prevented entrainment. Surface materials are only one factor responsible for successful impaction. Small drops (<200 μm dia.) are deposited on surfaces by a mixture of sedimentation and inertial processes, (Elliot and Wilson 1983), and therefore the angular orientation of the collector was also important. The 45° angle orientation of the monitoring stations in this study provided a compromise between strictly vertical orientation, which would optimize for collection by inertial impact and interception, and the strictly horizontal which optimizes for sedimentation processes. The use of gauze pads at 45° angles will measure the amount of an airborne pollutant that will be deposited on a clothed surface. It will be a representative sample demonstrating impaction and exposure to that surface. This method of monitoring air pollutants may be more desirable than using suction-type air samplers, as they show pollutants suspended in an air column, but cannot estimate surface exposure.

Data on insecticides drift collected after chemigation are presented in Table 4. Means of insecticide drift after the application detected over all distances and locations for chlorpyrifos, permethrin and carbaryl were 107.4, O.O and 0.74 ng/cm^2, respectively. Post-application drift was detected. For chlorpyrifos, total mean drift collected (during and after application) was 695.2 ng/cm^2, and of that total, 15% was collected post-application. No permethrin was detected after application, perhaps due to its low vapor pressure (1.88×10^{-8} mmHg at 20°). Only 3% of total detected drift of carbaryl was attributable to post-application drift.

Table 4. Drift of insecticides (applied via center-pivot irrigation to corn, Dixon County, Nebraska, 1987) collected on gauze pads subsequent to application.

Distance (m)	Insecticide Quantity (ng/cm^2)		
	chlorpyrifos[a]	permethrin[b]	carbaryl[c]
	Mean ± SE	Mean ± SE	Mean ± SE
9.1	496.7 ± 927.9[d]	nd[e]	5.6 ± 11.1
12.2	70.7 ± 58.0	nd	nd
15.2	95.1 ± 130.1	nd	nd
18.3	25.3 ± 26.1	nd	nd
24.4	23.5 ± 15.9	nd	nd
36.6	21.8 ± 15.2	nd	nd
54.9	25.2 ± 25.3	nd	nd
70.2	19.8 ± 28.1	nd	nd

[a]Lorsban 4E, [b]Pounce 3.2EC, [c]Sevin 80SP.
[d]Mean quantity resulting from two applications and two monitoring locations within the field followed by standard deviation.
[e]Not detected.

Table 5. Estimated dermal exposure mg/kg and percentage of dermal LD_{50} from insecticides applied to corn via center-pivot irrigation.

Insecticide	During Chemigation		Post Chemigation	
	Highest[a] 9.1 m	Lowest[a] 54.9 m	Highest[a] 9.1 m	Lowest[a] 54.9 m
Carbaryl				
mg/kg	0.235	0.0008	0.00168	0[b]
% of LD_{50}	0.0006	0.00002	0.00004	0
Chlorpyrifos				
mg/kg	0.7797	0.00678	0.149	0.00594
% of LD_{50}	0.039	0.00033	0.0075	0.0003
Permethrin				
mg/kg	0.0249	0.00141	0	0
% of LD_{50}	0.0012	0.0000007	0	0

[a]Distance from the pivot wheel.
[b]Not detected

Over all mean ($\pm$ SE) quantities of insecticide drift collected at distal and proximal wheel track locations were 127.6 ($\pm$ 55.5) and 38.3 ($\pm$ 23.3), respectively. The influence of collection station placement by wheel track on the quantity of insecticide collected was expected to favor the distal placement due to the greater density of sprinkler heads in that region of the system.

These results indicate that during a chemigation operation there exists a potential for off-target deposition of insecticides. However, because center-pivot irrigation systems typically create a droplet spectrum that is of large VMD (Kohl 1974, Kohl and Deboer 1984), wind drift of insecticides applied via sprinkler irrigation systems is less than wind drift observed by conventional aerial or ground applications. Recently, conventional hydraulic sprayers were used, and spray drift of insecticide was quantified through bioassay, and mortality greater than 10% of *Pieris brassicae* (L.) was not determined to be past a 24 m buffer (Davis et al. 1993).

The estimates of human exposure to carbaryl, chlorpyrifos and permethrin are presented in Table 5. These results include the maximum and minimum insecticide residues detected during and immediately after the chemigation. During chemigation, the highest exposure amounts at 9.14 m down wind for carbaryl, chlorpyrifos and permethrin were 0.235, 0.7797 and 0.0248 mg/kg, respectively. However, these amounts represent 0.0006, 0.039 and 0.0012% of LD_{50} for carbaryl, chlorpyrifos and permethrin, respectively. The drift of carbaryl, chlorpyifos and permethrin at 54.9 m down wind during chemigation is negligible (Table 5) and it does not pose a potential problem for acute dermal exposure. Similarly, the exposure from drift to these insecticides subsequent to chemigation is so low that it is not a risk factor.

Acknowledgments. We thank Drs. Stephen Danielson and Dennis Berkebile for critical review of this manuscript and Mr. Raj K. Saran for the artwork. This research was funded in part by the North Central Region Pesticide Impact Assessment Program (NCR-PIAP). This is published as Journal Series No. 12991 Nebraska Agricultural Research Division and Contribution No.1072, Department of Entomology-IANR, University of Nebraska, Lincoln.

REFERENCES

Berkow SG (1931) Value of surface area proportions in the prognosis of cutaneous burns and scalds. American J Surg 11:315-317

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

Byass JB, Lake JR (1977) Spray drift from a tractor powered field sprayer Pestic Sci 8:117-126

Byers, ME, Kamble ST, Witkowski JF (1993) Drift during center-pivot chemigation of chlorpyrifos applied with and without crop oil. Bull Environ Contam Toxicol 51:60-67

Coutts HH, Yates WE (1968) Analysis of spray droplet distributions from agricultural aircraft. Trans ASAE 11:25-27
Davis BNK, Lakhani KH, Yates TJ, Frost AJ, Plant RA (1993) Insecticide drift from ground-based, hydraulic spraying of peas and brussels sprouts: bioassays for determining buffer zones. Agric Ecosys Environ 43:93-108
Draper WM, Gibson RD, Street JC (1981) Drift from and transport subsequent to a commercial, aerial application of carbofuran: An estimation of potential human exposure. Bull Environ Contam Toxicol 26:537-543
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
Elliot JG, Wilson BJ (Eds) (1983) The influence of weather on the efficiency and safety of pesticide application: The Drift of herbicides. O.P. 3. Report of the Research and Development Committee to the B.C.P.C.
Kamble ST, Byers ME, Witkowski JF, Ogg CL, Echtenkamp GE (1992) Field worker exposure to selected insecticides applied to corn via center-pivot irrigation. J Econ Entomol 85:974-980
Kohl RA (1974) Drop size distribution from medium-sized agricultural sprinklers. Trans ASAE 17:690-693
Kohl RA, DeBoer DW (1984) Drop size distributions for a low pressure spray type agricultural sprinkler. Trans ASAE 27:1836-1840
Kohl RA, Kohl KD, DeBoer DW (1987) Chemigation drift and volatization potential. Appl Eng in Agr 3:174-177
Nordby A, Skuterud R (1975) The effects of boom height, working pressure and wind speed on spray drift. Weed Res 14:385-395
SAS Institute (1985) SAS Users Guide: Statistics. Cary, North Carolina
Smith DB, Harris FD, Goering CE (1982) Variables affecting drift from ground boom sprayers. Trans ASAE 25:1499-1503
Threadgill ED, Smith DB (1975) Effects of physical and Meteorological parameters on the drift of controlled-size droplets. Trans ASAE 18:51-56
Ware GW, Apple EJ, Cahill WP, Herhardt PD, Frost KR (1969) Pesticide drift. II. Mist-blower vs. aerial application of sprays. J Econ Entomol 62:844-846
Ware GW, Cahill WP, Gerhardt PE, Witt JM (1970) Pesticide drift. IV. On-target deposits from aerial applications. J Econ Entomol 63:1982-1983
Ware GW, Estesen BJ, Cahill WP, Herhardt PD, Frost KR (1969) Pesticide drift. I. High-tolerance vs. aerial application of sprays. J Econ Entomol 62:840-843
Yates WE, Akesson NB, Cowden RE (1974) Criteria for minimizing drift residues on crops downwind from aerial sprays. Trans ASAE 17:627-632