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Field Worker Exposure to Selected Insecticides Applied to Corn Via Center-Pivot Irrigation

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ABSTRACT Field workers were monitored for dermal and respiratory exposure to chlorpyrifos (with and without crop oil), carbaryl, and permethrin at reentry intervals of 2, 4, 8, 24, and 48 h after application. Insecticides were applied to R3 stage corn through an overhead center-pivot irrigation system. Dermal exposure was measured by analyzing 18 gauze pads attached to the clothing of workers to represent human body regions. Hand exposure was determined using cotton gloves. Respiratory exposure was determined using portable air samplers equipped with polyurethane foam plugs to trap ambient insecticide residues. Gas liquid chromatography was used to quantify residues of chlorpyrifos and permethrin in gauze pads, gloves, and foam plugs. Carbaryl residues in pads, gloves, and foam plugs were analyzed using high-performance liquid chromatography. Highest dermal and respiratory exposures were found at the 2-h reentry interval. Exposures decreased as reentry interval increased. Dermal exposure was primarily confined to the hands. Residues detected by air samplers ranged from 0 to 0.03 μg/liter. Based on the estimated percentages of acute toxic dose (all <0.00038%), the risk of acute toxicity to workers at the intervals studied was low.

KEY WORDS Insecta, human exposure, reentry, insecticide

RESEARCH ON HUMAN EXPOSURE to pesticides applied by conventional ground or aerial means has been done for various agricultural pesticide–worker situations to estimate the real and potential health problems associated with agrichemicals (Batchelor & Walker 1954, Wolfe et al. 1967, Coutts 1980, Knaak et al. 1980, Popendorf & Leffingwell 1982, Popendorf 1985, Waldron 1985, Fenske 1989). Cloud et al. (1988) reported the foliar residue transfer of permethrin to the clothing of crop consultants working in aerially sprayed soybean fields. Data describing exposure of crop scouts or field workers who enter chemigated cornfields are lacking, despite a significant increase in application of insecticides through center-pivot irrigation systems. The high volume of water associated with chemigation provides thorough plant and soil coverage and workers in these situations may be exposed to insecticides dermally (via physical contact of contaminated plant and soil surfaces) and through inhalation of airborne residues.

The chemical class of the insecticide, its formulation, rate of application, and the time of reentry after application will all influence exposure. If addition of crop oil increases the amount of insecticide retained on the plant after chemigation (Young 1981), there may be greater potential for exposure of workers to insecticides.

The purpose of our study was to measure field workers' dermal and respiratory exposure to residues of three insecticides applied through an overhead center-pivot irrigation system to corn, *Zea mays* (L.), and to assess potential risk to humans.

Materials and Methods

Insecticide Applications. All insecticide applications were made to pie-shaped quadrants of land (≈2.05 ha) in 0.64 cm of irrigation water with a high-angle, high-pressure (4.23 kg/cm, 414 kPa), 384.3-m center-pivot irrigation system (Lindsey Manufacturing Company, Lindsey, Nebr.) to R3 (milk) stage corn (Ritchie & Hanway 1984), in Dixon County, Nebr. Buffer zones (≈1.02 ha) were established between plots to eliminate insecticide drift onto bordering plots. Corn density was ≈64,000 plants per ha and row spacing was 76 cm. Insecticides applied in 1987 included chlorpyrifos (Lorsban 4 emulsifiable concentrate [EC]; Dow Chemical, Midland, Mich.), carbaryl (Sevin 80 soluble powder [SP]; Rhône-Poulenc, Research Triangle Park, N.C.) and permethrin (Pounce 3.2 EC; FMC Corporation, Philadelphia, Pa.). The application rates were 1.12, 1.68, and 0.22 kg (AI)/ha, respectively. In 1988, only Lorsban 4 EC was applied, but

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with and without crop oil (Sunoco 11N, Cornbelt Chemical, McCook, Nebr.). The rate per hectare of chlorpyrifos was the same as in 1987. Crop oil was added at a rate of 0.45 liter/ha. Insecticides were injected midstream into the irrigation line through a one-way check valve by a positive displacement diaphragm pump (PULSA-feeder Microflo 680; Interpace Corporation, Rochester, N.Y.).

Experimental design was a randomized complete block with three replications. A watered untreated check plot was included in each replicate. Insect scouting procedures used by field workers ($n = 3$) were similar to those used by professional crop consultants. Field workers entered plots and conducted 30-min scouting exercises at intervals of 2, 4, 8, 24, and 48 h after application. Scouts checked for insect activity on at least 10 plants in each of five areas in each plot at each reentry interval.

Exposure Monitoring. Field workers' dermal exposure to insecticides was monitored using modified adsorbent gauze pad techniques (Durham & Wolfe 1962) and cotton gloves. Gauze pads were constructed in three layers: glassine paper (10.2 by 10.2 cm) bottom layer, tagboard (10.2 by 10.2 cm) middle layer, and 12 ply (10.2 by 10.2 cm) surgical gauze exposed layer (Steri-pad, Johnson & Johnson Company, New Brunswick, N.J.). Edges were bound with masking tape, leaving an exposed surface area of 6.4 by 6.4 cm. Preliminary analysis indicated that the exposure pads contained no material that would interfere with chlorpyrifos, permethrin, and carbaryl detection. Field workers wore a protective one-piece hooded Tyvek coverall (Kappler, Guntersville, Ala.). Eighteen gauze pads were used per worker. Ten gauze pads were attached to the exterior of the coverall (as exterior pads with gauze side exposed), one each on both shoulders + both forearms + both thighs + both ankles + front trunk (chest) + back trunk (back). The gauze side of the remaining eight pads was covered with a cotton–polyester cloth swatch overlay (50:50 blend, 10.2 by 10.2 cm, fabric weight of 248 g/m^2, thread count of 35 horizontal by 22 vertical yarns per cm and with a square weave), representing the worker's clothing fabric. These eight pads were attached to the coverall (as inner pads representing penetration exposure to skin), one each on both shoulders + both thighs + both ankles + front trunk (chest) + back trunk (back). Penetration of insecticide through the swatch onto the gauze pad was meant to be analogous to penetration of an insecticide through a clothing layer to bare skin. Percentage penetration was calculated by dividing the insecticide quantity that penetrated to the gauze through the swatch by the total quantity on swatch plus gauze and multiplying by 100. Total hand exposure was determined using 100% cotton beauty gloves (Donley Medical Supply Company, Lincoln, Nebr.) over protective polyvinyl chloride gloves.

After each reentry interval (exposure), gauze pads, swatches, and cotton gloves were removed and placed individually in Ziploc bags (Dow Consumer Products, Indianapolis, Ind.), stored on ice in a cooler, transported to the laboratory, and stored at −20°C until extraction. The Tyvek coveralls were removed and discarded. Samples fortified in the field were prepared and later analyzed to measure sample storage and handling stability of insecticides. This procedure consisted of spiking gauze pads ($n = 3$) with 10 μg (AI) of each insecticide in 1 ml of hexane applied with a Pipetman (Rainen Instrument Company, Woburn, Mass.) each day of operation. Fortified pads were stored, extracted, and analyzed with the field workers' exposure pads. Recovery rates of fortified samples for chlorpyrifos, permethrin, and carbaryl were 94, 101, and 100%, respectively, indicating an excellent storage stability for these insecticides.

Inhalation exposure was measured using a portable air sampler (Telematic Model 150A, Bendix Corp., Lewisburg, W.Va.). The air sampler's impinger intake tube was attached to one end of a Tygon tube (15 mm inner diameter). The other end of the Tygon tube was attached to a glass sleeve that contained a 20 by 35 mm polyurethane foam plug (Dispo-plug, American Hospital Supply, McGaw Park, Ill.). The foam plug was used for trapping the insecticide residue in ambient air. The air sampler was fastened around each worker's waist with the Tygon tube extended to the area of the jugular notch ('v' of neck) and inverted to approximate human nostril orientation. Air samplers were calibrated and operated at an airflow rate of 2 liters/min. Each foam plug was removed from the glass sleeve with acetone-rinsed forceps and individually stored in prelabeled Ziploc bags at −20°C until extraction.

Extraction Analysis. After removal of taped borders of all exposure pads, the tagboard and glassine paper layers were discarded because the 12 layers of gauze used in preparation of pads were enough to absorb all insecticide residue. The remaining 6.4 by 6.4 cm exposed gauze from each pad was placed in an erlenmeyer flask that contained 35-ml of chromatography-grade *n*-hexane for chlorpyrifos and permethrin, and 35 ml of chromatography-grade methanol for carbaryl (Gold et al. 1982). These flasks were capped with neoprene rubber stoppers and mechanically agitated for 30 min on a wrist action shaker (Burrell Model 75, Pittsburgh, Pa.). Insecticide residues on swatches and foam plugs were extracted using similar extraction procedures. Residues from cotton gloves were extracted with the same procedure, except 70 ml of *n*-hexane for chlorpyrifos and permethrin, and 70 ml of chromatographic-grade methanol for carbaryl were used. Extracts were stored at −20°C until chemical analysis.

Chlorpyrifos analysis included gas liquid chromatography (Varian 6000 Vista Series gas chromatograph, Sunnyvale, Calif.) equipped with a Ni^{63} Electron Capture Detector operated at 350°C. The column used was a 2 m by 2 mm (inner diameter) glass column packed with 3% OV-101 on gas chrom Q, 80/100 mesh. Injector and column temperatures were 250°C and 220°C, respectively. Carrier gas (nitrogen) flow rate was 60 ml/min. The minimal detectable level was 0.005 ng/μl.

Permethrin was analyzed using gas liquid chromatography and electron capture detector. Analytical parameters included a 3% OV-210 glass packed column, nitrogen flow rate of 60 ml/min, injection, column, and detector temperatures of 250, 220, and 320°C, respectively. Minimal detectable level was 0.1 ng/μl.

Carbaryl was analyzed using high-performance liquid chromatography (HPLC) (ISCO Model 2350 Dual-Pump System, Lincoln, Nebr.), coupled with an ultraviolet–visible absorbance detector (ISCO Model V4). The column used was an ISCO C18 operated in a reverse-phase mode. A methanol–water solvent (70:30) mixture was used to elute the carbaryl. Minimal detectable level was 0.05 ng/μl.

Calculation of Insecticide Exposure. Insecticide quantities were converted from nanograms per microliter of analyzed sample to nanograms per square centimeter (based on pad extracts, 41 cm^2 per gauze pad) and then to micrograms per hour per body region. Average body surface area (square centimeters) for the field workers was calculated from their height and mass (Dubois & Dubois 1916). Using the procedure of Berkow (1931), total body surface area was divided into body regions. Total dermal exposure was determined by combining the unclothed and clothed body regions' exposure with the hand exposure. The unclothed body regions were: head, face plus "V"-front neck, back of neck, and forearms. The exposure to head was assessed by multiplying the head surface area with mean exposure rates for exterior pads on both shoulders + chest + back. An exposure to remaining unclothed body regions (face plus "V"-front neck, back of neck, and forearms) was estimated by multiplying the area of each region with appropriate exposure rate for exterior pads (chest, back, and forearms, respectively). Exposure to clothed body regions (front trunk, back trunk, thighs, and lower legs) was determined by multiplying the area of each region with the appropriate exposure rate for interior pads (chest, back, thighs, and lower legs, respectively). Hand exposure was assessed by adding the insecticide amounts detected on right and left gloves. Respiratory exposure in breathing zone was calculated from the insecticide extracted from the foam plug in the air sampler (nanograms per microliter) and multiplying this amount by the average respiration rate of a man engaged in light work, 1,740 liters/h (Durham & Wolfe 1962). For field workers, acceptable tolerances of chlorpyrifos and carbaryl in air have been established at 0.2 and 5.0 μg/liter, respectively (American Conference of Government and Industrial Hygienists [ACGIH] 1989).

The percentage of toxic dose per hour (*PTDPH*) was calculated based on the formula of Durham & Wolfe (1962) as follows:

$$PTDPH = \frac{\text{Dermal exposure (mg/h)} + [\text{respiratory exposure (mg/h)} \times 10]}{\text{Dermal } LD_{50} \text{ (mg/kg)} \times \text{mean weight of worker}} \times 100$$

Mean weight of workers was 83.4 and 89.4 kg in 1987 and 1988, respectively. The dermal LD_{50} for chlorpyrifos, carbaryl, and permethrin are 2,000, 4,000 and 2,000 mg/kg, respectively (Worthing 1987).

The margin of safety (*MOS*) for insecticide is an index to indicate the degree of risk; lower the *MOS*, higher the risk. The *MOS* for field workers was determined using the procedure described by Severn (1984) as follows:

$$MOS = \frac{\text{No observed effect level}}{\text{Quantity absorbed (mg/kg/d) [dermal exposure} \times 0.1 + \text{respiratory exposure]}}$$

The no-observed-effect level values for chlorpyrifos, carbaryl, and permethrin are 0.03, 200, and 100 mg/kg/d, respectively (Worthing 1987). For *MOS* calculations, the insecticide quantity absorbed was based on the 10% absorption rate for dermal exposure plus 100% absorption rate for respiratory exposure. The 10% dermal absorption rate has been commonly used by researchers based on findings of Feldmann & Maibach (1974), who reported that typical absorption over a range of compounds was between 5 and 20%, based on excretion in urine after 120 h.

Statistical Analysis. Data were subjected to an analysis of variance to establish significant differences in worker exposure among treatments, body regions, and reentry intervals (SAS Institute 1985). Mean comparisons were determined by Fisher's protected least significant difference (LSD) test (Snedecor & Cochran 1967).

Results and Discussion

Field Worker Exposure. The estimated mean dermal exposure and respiratory exposure to the

Table 1. Estimated dermal exposure (µg/h) to field workers (n = 3, 3 replicates) involved in crop scouting after center-pivot application of chlorpyrifos (Lorsban 4E) to corn (R3 stage), 1987

Body region	Area,[a] cm²	Reentry intervals, h: 2	4	8	24	48
		Chlorpyrifos (µg/h), $\bar{x}$ ± SE				
Hands	968.6	97.9 ± 56.3a[b]	37.5 ± 27.8a	13.9 ± 7.0a	9.9 ± 5.2a	6.2 ± 5.0a
Lower legs	3,916.0	8.4 ± 3.5b	8.5 ± 5.4bc	6.5 ± 12.1b	0.4 ± 1.1b	1.5 ± 2.5b
Thighs	3,814.0	14.8 ± 11.6b	2.2 ± 3.8bc	1.0 ± 2.4bc	1.1 ± 1.1b	0.0 ± 0.0b
Forearms	1,442.7	6.9 ± 7.1b	3.8 ± 4.9bc	1.4 ± 1.3bc	0.7 ± 1.1b	0.1 ± 0.4b
Head	474.0	2.1 ± 0.7b	1.7 ± 1.2c	0.4 ± 0.3c	0.0 ± 0.0b	0.0 ± 0.0b
Face + V-neck	948.1	4.8 ± 4.9b	6.1 ± 8.9bc	0.9 ± 0.9c	0.2 ± 0.6b	0.0 ± 0.0b
Upper arms	1,400.9	2.2 ± 2.1b	0.3 ± 0.5c	0.5 ± 1.2c	0.3 ± 0.8b	0.0 ± 0.0b
Front trunk	3,957.1	3.9 ± 5.1b	0.8 ± 2.4c	0.8 ± 2.3c	0.7 ± 2.9b	0.0 ± 0.0b
Back trunk	3,565.5	1.4 ± 2.8b	0.0 ± 0.0c[c]	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b
Back of neck	103.1	0.1 ± 0.1b	0.1 ± 0.1c	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b
Total	20,590.8	143.5 ± 94.1	60.8 ± 55.2	26.3 ± 26.3	13.4 ± 12.9	7.9 ± 8.0

[a] Average body region surface area of three workers.
[b] Similar letter designations indicate statistical similarity ($P < 0.05$) within each column determined by Fisher protected LSD test (SAS Institute 1985).
[c] Below minimal detectable level (0.005 ng/µl) for chlorpyrifos.

Table 2. Estimated dermal exposure (µg/h) to field workers (n = 3, 3 replicates) involved in crop scouting after center-pivot application of carbaryl to corn (R3 stage), 1987

Body region	Area,[a] cm²	Reentry intervals, h: 2	4	8	24	48
		Carbaryl (µg/h), $\bar{x}$ ± SE				
Hands	968.6	117.7 ± 108.9ab[b]	58.9 ± 27.4ab	35.9 ± 29.9a	31.5 ± 12.3a	5.1 ± 6.3a
Lower legs	3,916.0	57.0 ± 120.8abc	59.7 ± 127.9ab	0.0 ± 0.0b[c]	0.0 ± 0.0c	0.0 ± 0.0b
Thighs	3,814.0	18.6 ± 55.9c	20.5 ± 61.5b	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
Forearms	1,442.7	135.5 ± 174.9a	40.2 ± 43.3ab	25.4 ± 20.2b	16.9 ± 34.2b	0.0 ± 0.0b
Head	474.0	12.4 ± 15.8c	14.4 ± 12.4b	2.5 ± 7.4b	2.3 ± 4.6c	1.2 ± 3.5b
Face + V-neck	948.1	0.0 ± 0.0c[c]	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
Upper arms	1,400.9	50.7 ± 152.0bc	8.2 ± 24.7b	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
Front trunk	3,957.1	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
Back trunk	3,565.5	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
Back of neck	103.1	0.0 ± 0.0c	3.2 ± 4.7b	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
Total	20,590.8	391.5 ± 628.3	205.8 ± 302.8	63.7 ± 37.2	51.7 ± 54.1	6.2 ± 9.8

[a] Average body region surface area of three workers.
[b] Similar letter designations indicate statistical similarity ($P < 0.05$) within each column determined by Fisher protected LSD test (SAS Institute 1985).
[c] Below minimal detectable level (0.05 ng/µl) for carbaryl.

Table 3. Estimated dermal exposure (µg/h) to field workers (n = 3, 3 replicates) involved in crop scouting after center-pivot application of permethrin to corn (R3 stage), 1987

Body region	Area,[a] cm²	Reentry intervals, h: 2	4	8	24	48
		Permethrin (µg/h), $\bar{x}$ ± SE				
Hands	968.6	58.4 ± 36.4a[b]	44.8 ± 14.8a	31.4 ± 16.1a	19.4 ± 15.2a	14.8 ± 16.0a
Lower legs	3,916.0	0.0 ± 0.0b[c]	0.0 ± 0.0b	0.8 ± 2.3b	0.0 ± 0.0b	0.0 ± 0.0b
Thighs	3,814.0	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
Forearms	1,442.7	3.7 ± 8.9b	2.1 ± 6.3b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
Head	474.0	5.9 ± 4.6b	0.4 ± 0.7b	0.3 ± 0.6b	0.0 ± 0.0b	0.0 ± 0.0b
Face + V-neck	948.1	2.0 ± 4.6b	0.6 ± 1.7b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
Upper arms	1,400.9	0.0 ± 0.0b	1.2 ± 3.7b	0.6 ± 1.4b	0.0 ± 0.0b	0.0 ± 0.0b
Front trunk	3,957.1	0.0 ± 0.0b	2.3 ± 7.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
Back trunk	3,565.5	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
Back of neck	103.1	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
Total	20,590.8	70.0 ± 54.5	51.4 ± 34.2	33.2 ± 20.8	19.4 ± 15.2	14.8 ± 16.0

[a] Average body region surface area of three workers.
[b] Similar letter designations indicate statistical similarity ($P < 0.05$) within each column determined by Fisher protected LSD test (SAS Institute 1985).
[c] Below minimal detectable level (0.1 ng/µl) for permethrin.

Table 4. Estimated dermal exposure (μg/h) to field workers (n = 3, 3 replicates) involved in crop scouting after center-pivot application of chlorpyrifos (Lorsban 4E) without crop oil to corn (R3 stage), 1988

Body region	Area,[a] cm^2	Reentry intervals, h: 2	4	8	24	48
		Chlorpyrifos (μg/h), $\bar{x}$ ± SE				
Hands	997.1	118.2 ± 70.1a[b]	79.9 ± 24.5a	42.2 ± 21.4a	23.6 ± 16.9a	12.6 ± 2.5a
Lower legs	4,031.0	16.1 ± 18.0b	17.1 ± 11.5b	2.4 ± 7.1b	0.0 ± 0.0b[c]	1.4 ± 2.8b
Thighs	3,924.8	14.7 ± 8.3b	11.2 ± 9.9bc	2.3 ± 4.2b	0.0 ± 0.0b	0.0 ± 0.0c
Forearms	1,485.1	14.7 ± 6.3b	10.9 ± 2.4bc	2.2 ± 0.0b	1.8 ± 2.6b	0.0 ± 0.0c
Head	488.0	8.9 ± 12.7b	1.6 ± 1.2d	0.9 ± 0.9b	0.0 ± 0.0b	0.0 ± 0.0c
Face + V-neck	975.9	5.8 ± 2.3b	5.8 ± 2.3cd	1.9 ± 4.3b	0.0 ± 0.0b	0.0 ± 0.0c
Upper arms	1,442.6	2.5 ± 1.9b	0.7 ± 1.2d	0.1 ± 0.4b	0.0 ± 0.0b	0.0 ± 0.0c
Front trunk	4,073.3	2.4 ± 4.4b	3.8 ± 7.5cd	4.1 ± 6.3b	0.0 ± 0.0b	0.0 ± 0.0c
Back trunk	3,670.2	2.1 ± 3.1b	1.6 ± 4.8d	0.0 ± 0.0b[c]	0.0 ± 0.0b	0.0 ± 0.0c
Back of neck	106.1	0.2 ± 0.2b	0.3 ± 0.4d	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0c
Total	21,193.8	185.7 ± 127.4	132.9 ± 65.8	56.1 ± 44.7	25.4 ± 19.5	14.0 ± 5.3

[a] Average body region surface area of three workers.
[b] Similar letter designations indicate statistical similarity ($P < 0.05$) within each column determined by Fisher protected LSD test (SAS Institute 1985).
[c] Below minimal detectable level (0.005 ng/μl) for chlorpyrifos.

insecticide residues over the five reentry intervals are listed in Tables 1–6. There was a consistent trend of decreasing detectable insecticide residues over time (Tables 1–5). There were significant differences ($P < 0.05$) in detectable residues for all insecticides over body regions. Insecticide residues were detected on the hands at all reentry intervals. Higher percentages of the total insecticide residues were found on hands with increasing reentry intervals. By 24 h after application, chlorpyrifos was found on hands, lower legs, thighs, forearms, face + V-neck, and front trunk in 1987; however, carbaryl residues were present only on hands, forearms, and head at that same reentry interval. Permethrin was detected only on hands 24 h after application in 1987. In 1988, chlorpyrifos was present only on hands, forearms, and head after 24 h reentry interval. Generally, insecticide residues were found only on hands, 48 h after application in 1987 and 1988.

Insecticide residues measured in the air by air samplers attached to workers were not detected for permethrin and carbaryl, and were <0.03 μg/liter for chlorpyrifos (alone or with oil) at all reentry times. All insecticide residue detections were well below acceptable standards (ACGIH 1989) for workers (Table 6).

Mean chlorpyrifos penetration through the 50:50 cotton–polyester swatches on gauze pads ranged from 16.5 to 26.2%. Highest chlorpyrifos penetration (34.1%) through cotton–polyester swatches was observed when it was applied with oil to corn. Mean carbaryl penetration through 50:50 cotton–polyester swatches on gauze pads varied from 12.3 to 18.7%. No permethrin pene-

Table 5. Estimated dermal exposure (μg/h) to field workers (n = 3, 3 replicates) involved in crop scouting after center-pivot application of chlorpyrifos (Lorsban 4E) with crop oil to corn (R3 stage), 1988

Body region	Area,[a] cm^2	Reentry intervals, h: 2	4	8	24	48
		Chlorpyrifos (μg/h), $\bar{x}$ ± SE				
Hands	997.1	97.5 ± 38.4a[b]	74.3 ± 32.6a	34.4 ± 10.7a	12.9 ± 3.8a	10.1 ± 4.9a
Lower legs	4,031.0	28.4 ± 6.3b	19.5 ± 6.8a	8.7 ± 9.3b	0.0 ± 0.0b	0.0 ± 0.0b
Thighs	3,924.8	14.9 ± 12.3cd	12.2 ± 2.0bcd	0.3 ± 0.9c	0.0 ± 0.0b	0.0 ± 0.0b
Forearms	1,485.1	17.9 ± 3.9bc	11.3 ± 5.6bcde	1.1 ± 0.0c	0.4 ± 1.3b	0.0 ± 0.0b
Head	488.0	3.0 ± 1.3de	2.8 ± 1.0def	0.1 ± 0.2c	0.0 ± 0.0b	0.0 ± 0.0b
Face + V-neck	975.9	4.2 ± 4.3de	6.6 ± 1.1def	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b
Upper arms	1,442.6	1.3 ± 1.8e	0.2 ± 0.4f	0.2 ± 0.5c	0.0 ± 0.0b	0.0 ± 0.0b
Front trunk	4,073.3	3.1 ± 9.3de	1.5 ± 3.1ef	0.8 ± 2.1c	0.0 ± 0.0b	0.0 ± 0.0b
Back trunk	3,670.2	7.5 ± 13.1cde	8.6 ± 12.9cdef	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b
Back of neck	106.1	0.9 ± 0.5e	0.7 ± 0.6f	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b
Total	21,193.8	178.7 ± 91.4	137.8 ± 66.1	45.6 ± 23.7	13.4 ± 5.2	10.1 ± 4.9

[a] Average body region surface area of three workers.
[b] Similar letter designations indicate statistical similarity ($P < 0.05$) within each column determined by Fisher protected LSD test (SAS Institute 1985).

Table 6. Respiratory exposure of field workers (n = 3, 3 replicates) to insecticides applied to corn (R3 stage) through center-pivot irrigation

Reentry interval, h	Exposure (μg/h), $\bar{x} \pm$ SD				
	1987			1988 Chlorpyrifos	
	Chlorpyrifos EC	Carbaryl SP	Permethrin EC	No oil	With oil
2	25.7 ± 17.3	nd[a]	nd[a]	42.4 ± 25.1	50.4 ± 9.6
4	10.9 ± 12.3	nd	nd	16.2 ± 12.5	17.2 ± 4.2
8	3.5 ± 9.1	nd	nd	6.1 ± 3.6	0.9 ± 1.9
24	nd[a]	nd	nd	0.1 ± 0.1	nd
48	nd	nd	nd	nd	nd

[a] Below minimal detectable level (0.005, 0.05, and 0.1 ng/μl for chlorpyrifos, carbaryl, and permethrin, respectively).

tration through cotton–polyester swatches was recorded at the 0.1 ng/μl detection level. Laughlin et al. (1986) reported that maximum methyl parathion penetration through cotton–polyester swatches on gauze pads was 3.5% under laboratory conditions. Further, these authors indicated that formulation was not a significant factor in penetration. According to our data, insecticide penetration through clothing of field workers may be much higher under field conditions than under laboratory conditions, possibly from continuous movement of workers during the insect scouting process.

Risk Analysis. Estimated percentages of toxic dose per hour (*PTDPH*) indicated decreasing trends as reentry intervals increased (Table 7). The *PTDPH* values for all treatments at all intervals were extremely small and indicated minimal risk of potential acute poisoning to workers who entered the treated areas. The highest *PTDPH* was 0.00038% for chlorpyrifos applied with crop oil at the initial 2-h interval.

The margins of safety (*MOS*) values increased as the exposure interval increased (Table 7). *MOS* ≈1.0 indicates that the exposure may cause some health effects, including acetylcholinesterase enzyme inhibition. *MOS* values for chlorpyrifos exposures were ≈2.02 at 2-h reentry interval but values were >100 at 48 h. Carbaryl and permethrin exposures yielded *MOS* values of >10,000 at all reentry intervals.

Risks associated with these types of assessments are contingent on individual absorption rate and susceptibility to various effects of the insecticide active ingredients. Absorption rate in this research was assumed to be 10%. However, absorption rates in general are not easily predicted, and are far from 100% as indicated by Matsumura & Madhukar (1980). Individuals may possess unique rates of absorption and individual body regions also have different rates of absorption (Maibach et al. 1971).

Insecticide exposures assessed with gauze-pad methodology helped indicate the potential risk for field workers. These data indicate that the relative safety for field workers who enter chemigated cornfields depends upon the reentry intervals. The risk of exposure to workers declined as the reentry intervals increased. For carbaryl and permethrin, the insecticide label specifies reentry when the chemigated corn plants have dried. According to our data, the low *PTDPH* and large *MOS* values for carbaryl and permethrin indicate that workers may be able to enter the cornfield 2 h after the chemigation. For chlorpyrifos, the federally labeled reentry interval can be interpreted as 24 h. Our data yielded low *PTDPH* and large *MOS* values at 24 h, and indicate that workers may be able to enter the cornfield 24 h after chemigation with a minimal risk.

The data show that dermal exposure was generally confined to hands, and further indicate that the amount of insecticide inhaled by workers while crop scouting at the examined reentry intervals is very low. In general, exposure to the

Table 7. The percentage of toxic dose per hour (*PTDPH*) and the margin of safety (*MOS*) for field workers exposed to chlorpyrifos, permethrin, and carbaryl applied through a center-pivot irrigation system at five reentry intervals after application, 1987 and 1988

Reentry interval, h	1987						1988			
	Chlorpyrifos		Carbaryl		Permethrin		Chlorpyrifos		Chlorpyrifos with oil	
	PTDPH	*MOS*	*PTDPH*	*MOS*	*PTDPH*	*MOS*	*PTDPH*	*MOS*	*PTDPH*	*MOS*
2	0.00024	2.60	0.000120	17,752	0.00003	49,652	0.00034	1.83	0.00038	1.64
4	0.00013	6.25	0.000060	33,869	0.00002	67,613	0.00017	3.75	0.00017	3.61
8	0.00004	16.85	0.000019	109,110	0.00001	104,932	0.000066	9.48	0.00003	20.60
24	0.000008	76.10	0.000015	161,160	0.000001	179,211	0.000014	44.00	0.000007	83.60
48	0.000005	130.40	0.000002	1,363,326	0.000008	234,797	0.0000078	81.08	0.000006	110.70

insecticides tested in this study with this method of application was well below levels considered to cause acute toxicity.

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References Cited

American Conference of Governmental and Industrial Hygienists (ACGIH). 1989. Threshold limit values and biological exposure indices. Cincinnati, Ohio.

Batchelor, G. S. & K. C. Walker. 1954. Health hazards involved in use of parathion in fruit orchards of North Central Washington. American Medical Association Arch. Indust. Hyg. 10: 522–529.

Berkow, S. G. 1931. Value of surface area proportions in the prognosis of cutaneous burns and scalds. Am. J. Surg. 11: 315–317.

Cloud, R. M., D. J. Boethel & S. M. Buco. 1988. Protective clothing for crop consultants: Field studies in Louisiana, pp. 597–604. *In* S. Z. Mansdorf, R. Sager & A. P. Nelsen [eds.], Performance of protective clothing: Second Symposium, American Society for Testing & Materials, ASTM STP 989, 1988. Philadelphia, Pa.

Coutts, H. H. 1980. Field worker exposure during pesticide application, pp. 39–45. *In* W. F. Tordoir and E.A.H. van Heemstra [eds.], Elsevier, New York.

DuBois, D. & E. F. DuBois. 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, W. F. & H. R. Wolfe. 1962. Measurement of the exposure of workers to pesticides. Bull. W.H.O. 26: 75–91.

Feldmann, R. J. & H. I. Maibach. 1974. Percutaneous penetration of some pesticides and herbicides in man. Toxicol. Appl. Pharmacol. 28: 126–132.

Fenske, R. A. 1989. Validation of environmental monitoring by biological monitoring, pp. 79–88. *In* G. M. Wang, C. A. Franklin, R. C. Honeycutt & J. C. Reinert [eds.], Biological monitoring for pesticide exposure. ASC Symposium Series 382, 1989, Washington, D.C.

Gold, R. E., J.R.C. Leavitt, T. Holcslaw & D. Tupy. 1982. Exposure of urban applicators to carbaryl. Arch. Environ. Contam. Toxicol. 11: 63–67.

Knaak, J. B., T. Jackson, A. S. Fredrickson, K. T. Maddy & N. B. Akesson. 1980. Safety effectiveness of pesticide mixing-loading and application equipment used in California in 1976. Arch. Environ. Contam. Toxicol. 9: 217–211.

Laughlin, J. M., C. B. Easley, R. E. Gold & R. M. Hill. 1986. Fabric parameters and pesticide characteristics that impact on dermal exposure of applicators, pp. 136–150. *In* R. L. Barker & G. L. Coletta [eds.], Performance of protective clothing, American Society for Testing and Materials (ASTM), STP 900, Philadelphia, Penn.

Maibach, H. I., R. J. Feldman, T. H. Milby and W. F. Serat. 1971. Regional variation in precutaneous penetration in man. Arch. Environ. Health. 23: 208–211.

Matsumura, F. & B. V. Madhukar. 1980. Exposure to insecticides. Pharmac. Ther. 9: 27–49.

Popendorf, W. J. & J. T. Leffingwell. 1982. Regulating OP pesticide residues for farm worker protection. Res. Rev. 82: 125–201.

Popendorf, W. J. 1985. Advances in the unified field model for reentry hazards, pp. 323–340. *In* R. C. Honeycutt, G. Zweig & N. N. Ragsdale [eds.], Dermal exposure related to pesticide use. American Chemical Society Symposium Series 273, 1985, Washington, D.C.

Ritchie, S. W. & J. L. Hanway. 1984. How a corn plant develops. Special Report No. 48. Iowa State University of Science and Technology, Cooperative Extension Service, Ames, Iowa.

SAS Institute. 1985. SAS user's guide: statistics. Cary, N.C.

Severn, D. J. 1984. Use of exposure data for risk assessment, pp. 13–19. *In* M. Siewierski [ed.], Determination and assessment of pesticide exposure. Studies in Environment Science 24, 1984. Elsevier, New York.

Snedecor, G. W. & W. G. Cochran. 1967. Statistical methods. 6th Edition. Iowa State University Press. Ames, Iowa.

Waldron, A. C. 1985. The potential for applicator-worker exposure to pesticides in greenhouse operations, pp. 311–319. *In* R. C. Honeycutt, G. Zweig & N. N. Ragsdale [eds.], Dermal exposure related to pesticide use. American Chemical Society Symposium Series 273, 1985, Washington, D.C.

Wolfe, H. R., W. F. Durham & J. F. Armstrong. 1967. Exposure of workers to pesticides. Arch. Environ. Health. 14: 622–633.

Worthing, C. R. (ed.) 1987. The pesticide manual, a world compendium, 8th ed. British Crop Protection Council.

Young, J. R. 1981. Chemigation: insecticides applied in irrigation water for control of the corn earworm and fall armyworm in sweet and field corn. Proceedings, First National Symposium on Chemigation, August 1981. Rural Development Center, Tifton, Ga.

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