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# Pesticide Exposure During Greenhouse Applications. III. Variable Exposure Due to Ventilation Conditions and Spray Pressure

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The primary objective of this study was to determine the effect of different ventilation systems and application pressures on dermal and respiratory exposure. Three types of ventilation were evaluated: low velocity unidirectional (uni; <0.5 to 2.0 m/s), multidirectional (multi), and no ventilation (none). Under each condition, two application pressures were utilized: 284 kPa (40 psi) and 841 kPa (120 psi). Six workers were monitored by the traditional patch technique and personal air sampling during greenhouse handgunning applications. A commercially available fluorescent tracer was employed as a surrogate for pesticides. The magnitude of dermal exposure varied by ventilation type (multi > none > uni). Respiratory exposure also varied by ventilation type, but with a different pattern (none >> multi > uni). Application pressure had the greatest effect on respiratory exposure: low pressure (40 psi) values were less than high pressure (120 psi), regardless of ventilation type. The droplet size distribution created by the nozzle appears to have been the primary factor affecting both dermal and respiratory exposures. As application pressure increases, droplet size decreases, resulting in dramatic and consistent increases in both dermal and respiratory exposure. Results indicate that properly trained applicators can reduce their exposures by using unidirectional ventilation to their advantage (i.e., keep air flow at their backs, allowing spray mist to move away from them) and reducing the application pressure so that larger droplets are formed and fall out of the airspace quickly. METHNER, M.M.; FENSKE, R.A.: PESTICIDE EXPOSURE DURING GREENHOUSE APPLICATIONS. III. VARIABLE EXPOSURE DUE TO VENTILATION CONDITIONS AND SPRAY PRESSURE. APPL. OCCUP. ENVIRON. HYG. 11(3):174-180; 1996.

Ventilation has been employed for decades to control hazardous workplace emissions and reduce occupational exposures. In greenhouses, however, ventilation systems are designed and operated to maintain an atmosphere that is optimal for plant growth, primarily through temperature regulation.<sup>(1-4)</sup> Air exchange rates and specific patterns of air flow within the greenhouse will affect air concentrations and spray drift patterns, and thus can be expected to alter both respiratory and dermal exposures.

Some earlier greenhouse worker exposure studies focused on reentry issues<sup>(5,6)</sup> as well as surface and airborne residues,<sup>(7-16)</sup> but did not examine the effect of ventilation on applicator exposure. In fact, some of these studies indicated that airborne

levels of pesticides decreased dramatically when mechanical ventilation began after the spraying episode.<sup>(11,14-16)</sup> Recent greenhouse exposure studies have increased efforts to address the exposure of both general greenhouse workers (e.g., plant handlers, packagers, cultivators, etc.) and greenhouse pesticide applicators because dermal exposure often resulted despite the use of protective clothing.<sup>(5,7-10,12,16-21)</sup>

No studies to date have measured the effect of ventilation on greenhouse applicator exposure. One study measured a single worker's exposure to dicofol and deltamethrin.<sup>(22)</sup> A greenhouse handgunner and assistant were monitored for exposure to dimethoate and a synthetic pyrethroid.<sup>(23)</sup> Neither of these studies mentioned the status of the ventilation system. One study turned off the ventilation consistently during an evaluation of Fosetyl-Al exposure, but the effect of ventilation was not investigated.<sup>(24)</sup> A larger study examined greenhouse handgunners' exposure to four different pesticides under normal application conditions, and noted only that ventilation was "variable;" it is unclear to what extent variable ventilation contributed to the wide range of exposures reported.<sup>(25)</sup> A recent applicator study in a Florida greenhouse indicated that both ventilation during application and worker training can be effective in reducing dermal exposure.<sup>(26)</sup>

Another method of assessing exposure to pesticides in the greenhouse environment involves the use of biological monitoring. Some greenhouse studies have utilized this methodology to estimate the actual dose a worker receives by examining a specific biological matrix (e.g., blood, urine). This allows the determination of a specific metabolite or biomarker, which is used to calculate the magnitude of exposure. However, this type of monitoring does not differentiate between different routes of exposure.<sup>(7,17,27-30)</sup>

Since dermal exposure is considered the primary route of exposure for pesticide mixers and applicators, the use of fluorescent tracers for qualitative/quantitative exposure assessments has proven to be a useful exposure assessment and educational tool because: (1) a good correlation exists between tracer/pesticide deposition when mixed in a spray tank;<sup>(17,31-33)</sup> (2) the tracer can be used alone to serve as a surrogate for a pesticide to study body region deposition patterns;<sup>(19,26)</sup> and (3) visual examination of skin areas under ultraviolet light can provide useful information to workers about where exposure is occurring.<sup>(17,31,32,34)</sup>

This study was designed to characterize a range of ventila-

tion systems and application pressures employed in greenhouses and to determine their effects on applicator exposure.

**Materials and Methods**

**Experimental Design**

Six workers were monitored by the traditional patch technique and personal air sampling technique during greenhouse hand-gunning applications. Each subject participated in random order and was used as his own control. Two application pressures, 284 kPa (40 psi) and 841 kPa (120 psi), and three ventilation conditions were examined. This resulted in six separate applications for each worker.

A commercially available fluorescent whitening agent, 2,2'-(2,5-thiophenediyl) bis (5-tert-butylbenzoxazole), currently marketed as Uvitex OB (Ciba-Geigy, Hawthorne, New York), was employed as a surrogate for a pesticide. The tracer has virtually no acute toxicity. The oral LD-50 in the rat was found to be greater than 10 g/kg.<sup>(35)</sup> Also, no skin/eye irritation was noted in rabbits.<sup>(35)</sup> Patch tests on human subjects showed no primary skin irritation or sensitization, while chronic studies in rats and mice have not found it to be carcinogenic or teratogenic.<sup>(36)</sup> This compound has been approved as an optical brightener in food wrappers by the Food and Drug Administration [21 CFR 178.3297 (e)]. In addition, the U.S. Environmental Protection Agency (EPA) has exempted it from tolerances when applied to growing crops [40 CFR 180.1001 (d)]. Based on the small amount of tracer employed during this study and the short personal exposure period, it appears that this compound did not pose any significant health risk.

This compound was handled as a wettable powder formulation and dissolved in natural oil spray adjuvant (93% vegetable oil; Stoller, Inc., Houston, Texas). To isolate ventilation and application pressure as potential exposure variables, several experimental controls were incorporated into this study. Applicators always used the same spray equipment and always completed the same number of work cycles. Also, applicators never handled the tracer/oil formulation prior to the application.

**Greenhouse Construction and Characterization**

All applications were conducted in a 7.6 × 14.6 m Criterion Quonset-style greenhouse (X.S. Smith, Red Bank, New Jersey) at the New Jersey Agricultural Experiment Station Research Farm #3. This style of greenhouse allowed the evaluation of three different types of ventilation conditions, which we defined as: (1) low velocity unidirectional ventilation, which we define as air moving in a predictable, consistent manner at a velocity of 0.5 to 2.0 m/s; this type of air flow pattern is achieved by fan(s) located on a wall opposite mechanical intake louvers; (2) multidirectional ventilation, which involves random mixing of the greenhouse air, as defined below; and (3) no ventilation, which consists of all doors and intake louvers closed and all air-moving equipment turned off. The multidirectional ventilation pattern was created by the use of a perforated plastic ventilation tube attached overhead to the roof ridge and running the length of the greenhouse. A fan directed greenhouse air into the tube. Openings along its length directed air downward onto the plants. This type of

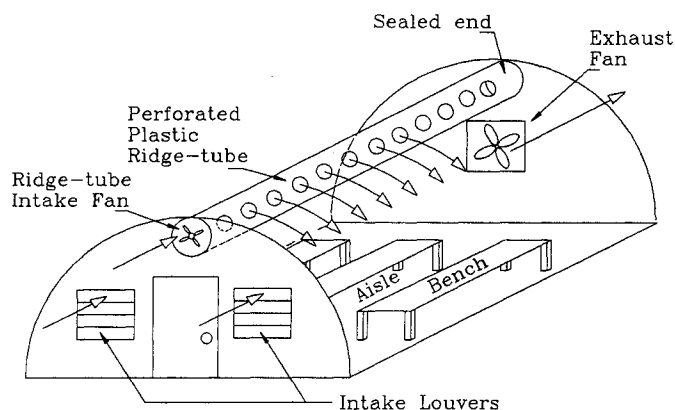


FIGURE 1. General diagram of greenhouse.

ventilation utilizes the low velocity unidirectional air flow in combination with the perforated ridge tube to effectively mix the air as it moves through the greenhouse. The mixing of air resembles a corkscrew air flow pattern with a variable air velocity and direction, and is intended to reduce temperature gradients within the greenhouse and control humidity. Both of these environmental variables must be controlled in order to provide an optimum growing environment. A general diagram of the greenhouse and its ventilation system is presented in Figure 1. The greenhouse interior layout was as follows:

Description	Dimension
Total floor surface area	112.0 m <sup>2</sup>
Total benchtop surface area	54.0 m <sup>2</sup>
Bench width	1.2 m
Bench length	11.0 m
Bench height	0.5 m
Number of benches	4
Aisle width	0.6 m
Aisle length	11.0 m

The ventilation system specifications were as follows:

Description	Dimension
Two motorized intake louver surface areas	0.84 m <sup>2</sup> each
Exhaust fan outlet surface area	0.5 m <sup>2</sup>
Overhead ridge tube length	13.4 m
Overhead ridge tube diameter	0.5 m
Overhead ridge tube height above floor	2.3 m
Overhead tube number of perforations	60
Individual perforation diameter	0.08 m

To maximize benchtop surface area relative to floor surface area, all benches were arranged so that each touched the end wall and provided no exit at the end of each aisle. Also, in an effort to measure only the aerosol deposition on the skin and air sampling filter, all plants were arranged so that no contact with foliage occurred.

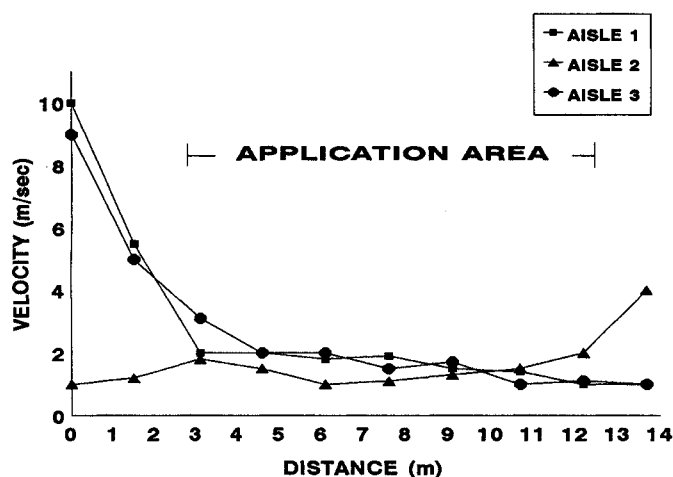


FIGURE 2. Unidirectional aisle air velocity as a function of distance from intake louvers.

#### Field Study Conditions

All workers operated a 114-L (30-gal) spray rig which consisted of a paddle-agitated tank, 2.2-kW (3-hp) gasoline engine, adjustable pressure pump, and 15.2-m (50-ft) detachable hose. Attached to the hose was a 1-m-long spray wand equipped with a single 80° flat fan NF 1080 nozzle (Bete Fog Nozzle Inc., Greenfield, Massachusetts).

Water volume and mass of tracer applied were adjusted to maintain constant tank concentration (528 ppm) and application time for the two pressure settings. Each tank applied at 284 kPa contained 30 g of tracer added to 56.8 L (15 gal) of water. When the application pressure was increased to 841 kPa, an increase in flow was expected so the amounts of tracer and water were doubled. The time necessary to complete each application ranged from 17 to 19 minutes. All applicators conducted normal spraying episodes which were aimed at achieving complete plant coverage. Temperature and relative humidity were measured before and after each application in the center of the greenhouse at a height of 1.5 m. This height also corresponded to the height of spray release for each applicator.

Greenhouse ventilation was characterized by measuring the air velocity in the application area and the volumetric flow rate of air passing through the greenhouse. Air velocity measurements were collected under unidirectional ventilation conditions at three points in each of three aisles at a height of 1.5 m. Under unidirectional ventilation conditions, air flow appeared to be channeled down each aisle in the application area. The uniformity of the unidirectional air flow pattern and velocity for this particular greenhouse is illustrated in Figure 2.

A greenhouse volumetric air flow rate of 125 m<sup>3</sup>/min (4400 ft<sup>3</sup>/min) was determined by employing an equation based on Bernoulli's principle.<sup>(37)</sup> For this particular greenhouse, a round-edged exhaust fan with a 76-cm (30-inch) diameter opening operating at a static pressure of 12.4 Pa (0.05 inches water gauge) was evaluated. The equation employed was

$$Q = C \times A \times \sqrt{P_1/p} \quad (1)$$

where:

- Q = volumetric flow rate (cubic feet/minute)
- C = unit conversion factor (1096.5)
- A = area of the orifice (4.91 ft<sup>2</sup>)
- P<sub>1</sub> = static pressure of fan outlet (0.05 inches water gauge)
- p = air density (pounds/cubic foot) = 0.075 at 70°F and 29.92 inches Hg barometric pressure

Efforts to characterize the multidirectional ventilation pattern proved futile due to a large variation in flow direction and velocity. No ventilation was characterized as having no measurable air movement at any point in the greenhouse (<0.2 m/s).

#### Exposure Sampling

All subjects received instruction on proper spray application technique. Prior to each application, 10 × 10 cm exposure patches made of polyethylene-backed alpha-cellulose were attached by tape to the outside of the applicators' clothing at the following locations: one on the middle of the back, slightly higher than shoulder blade level; one on the chest just below the collarbone; one on the top of each shoulder; one on the dorsal surface of each upper arm (bicep area); one on the dorsal surface of each forearm, slightly below the elbow; one on the ventral surface of each thigh, midway between hip and knee; one on the ventral surface of each shin, slightly below the knee. This configuration is identical, with the exception of the upper arm patches, to the traditional patch method employed in another greenhouse handgunner study<sup>(25)</sup> and recommended by the U.S. EPA,<sup>(38)</sup> and resulted in a total of 12 patches per worker. Head exposure was estimated by taking the mean of the chest, back, and shoulder patch values. Upper front torso/chest exposure was estimated from a single patch located on the front of the chest just below the jugular notch. Upper back torso/back exposure was estimated from a single patch located on the upper back just below the base of the neck. All other body regions were represented by the mean of the left and right patches covering them. Prior to chemical extraction, all patch samples were examined under longwave ultraviolet light. This procedure was used for the first time as a screening technique to determine whether patches had become contaminated from sources other than the aerosol mist (e.g., patches contacted by the wet spray hose exhibited a distinct pattern and high tracer deposition). Of the total number of patch samples collected (252), six exhibited such a pattern and were excluded from analysis. The six excluded patches were located below the waist of the applicator and were due to contact with either a wet bench or spray hose. The mean values for patches from other workers covering specific body regions were substituted for patches removed from analysis by the screening method. The total body deposition rates were generated for each worker by summing the seven mean patch deposition rates of the body regions analyzed.

After each application the subject was escorted to an on-site laboratory, where the patches were carefully removed by staff wearing surgical gloves who handled the patches at the edges. Each patch was center-cut into 5 × 5 cm squares with a tabletop paper cutter and immediately placed in a 118-ml (4-oz) glass sample jar and stored in an ice chest pending

TABLE 1. Geometric Mean Fluorescent Tracer Deposition Rates Over Five Body Regions Under Different Application Pressures and Ventilation Conditions ( $\text{ng} \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$ )

Patch Location	n	284 kPa			841 kPa		
		Uni	Multi	None	Uni	Multi	None
Head	6	25.4 <sup>a</sup> (1.4)	290.9 <sup>e</sup> (1.7)	59.4 <sup>bc</sup> (1.8)	39.3 <sup>ab</sup> (1.5)	173.0 <sup>d</sup> (1.2)	63.5 <sup>c</sup> (1.2)
Back	6	9.4 <sup>a</sup> (1.6)	118.3 <sup>d</sup> (1.9)	47.1 <sup>c</sup> (1.7)	18.5 <sup>b</sup> (2.3)	67.8 <sup>cd</sup> (1.5)	43.3 <sup>c</sup> (1.4)
Upper arms	6	25.3 <sup>a</sup> (1.6)	285.0 <sup>d</sup> (1.8)	49.3 <sup>b</sup> (1.8)	51.1 <sup>b</sup> (1.5)	165.4 <sup>c</sup> (1.2)	52.6 <sup>b</sup> (1.4)
Forearms	6	16.5 <sup>a</sup> (1.6)	370.1 <sup>d</sup> (1.6)	58.5 <sup>b</sup> (2.1)	46.3 <sup>b</sup> (1.5)	153.6 <sup>c</sup> (1.4)	70.2 <sup>b</sup> (1.4)
Total body	6	140.6 <sup>a</sup> (1.4)	1550.0 <sup>d</sup> (1.6)	339.7 <sup>b</sup> (1.6)	220.4 <sup>b</sup> (1.5)	859.1 <sup>c</sup> (1.2)	311.1 <sup>b</sup> (1.3)

Uni = unidirectional ventilation; Multi = multidirectional ventilation; None = no ventilation. Statistical analysis was performed on log-transformed data. For a given patch location, values followed by like letters are not significantly different ( $p < 0.05$  level; Duncan's multiple range test). Geometric standard deviation values are in parentheses.

transport to the Environmental Sciences laboratory. To avoid cross-contamination of patches, the cutting blade was rinsed with pesticide-grade acetone before each patch was cut.

Breathing zone contamination was measured with a battery-powered personal air sampling pump attached to an MS&T PM-10 personal impactor (Harriman Associates, Auburn, Maine) containing a 25-mm glass fiber filter. The monitor, which collects aerosol particles of 10  $\mu\text{m}$  or less (aerodynamic diameter), was clipped to the lapel of the worker's shirt. The sampling pump operated at 4 L/min, per manufacturer's recommendation, and was calibrated before and after each application. Each air-sampling filter was removed by tweezers and placed in a 59 ml (2 oz) sample jar and stored along with the patches.

All patch and air sample values were normalized by the amount of tracer applied, allowing direct comparison across workers. Patches served as indicators of tracer deposition over their respective body regions, whereas the PM-10 air sampler served as an indicator of breathing zone contamination.

### Analysis

Extraction of patch samples involved opening the sample jar, adding 25.0 ml pesticide-grade toluene, and placing it on an oscillating shaker table for 30 minutes at high speed (100 cycles/min). Each 25-mm glass fiber air filter was extracted in the same manner, but with a 10-ml solvent volume. Each patch/air filter was then removed from the sample jar using clean tweezers, and a 1-ml aliquot was analyzed for fluorescence with a Turner 430 spectrofluorometer set at the following operating conditions: excitation = 376 nm, emission = 430 nm, and bandwidth = 15 nm. Quantitation of samples was accomplished by a standard curve which ranged from 1.9 to 373 ng/ml. Samples that were too concentrated were diluted to fall within the linear range of the instrument. The lowest standard solution was employed as the analytical limit of detection. The limit of quantitation for each sample matrix was found to be 1.8  $\text{ng}/\text{cm}^2$  for the patches and 18.7  $\text{ng}/\text{m}^3$  for the air samples. Laboratory extraction efficiency studies resulted in a mean recovery of  $96 \pm 3.9$  percent for the patches and  $99 \pm 3$  percent for the air filters.

Field blank and field spike samples were collected for each applicator before each application and resulted in a total of 36 field blanks and 36 field spikes. All field blank samples had no detectable levels of tracer. Patch field spike recoveries averaged  $98 \pm 2$  percent, while air filter spikes averaged  $99 \pm 1$  percent.

### Results

In general, data collected during this study exhibited little variability, which is undoubtedly due to the controlled nature of the study. Patches were extracted and analyzed separately to determine if one side of the body received more deposition than the other. This was found not to be the case. This finding is probably due to the applicators switching hands when spraying benches on either side of the aisle.

### Greenhouse Environment Characterization

The mean temperatures measured before and after the applications (20° and 18°C, respectively) while the ventilation system was operating were not significantly different. The same trend was observed for the relative humidity measurements (49 and 61%, respectively). However, under no ventilation conditions, the mean relative humidity after the application was found to be significantly greater than humidity levels prior to the applications (58 and 79%, respectively) ( $p < 0.05$ ). In general, a consistent pattern of temperature depression was noted as relative humidity increased. As water is added to the greenhouse air during an application, the increase in humidity results in an evaporative cooling process. Overall, maximum relative humidity values occurred when no ventilation was provided.

Under unidirectional ventilation both intake louvers had relatively high air velocities (10.0 m/s), which were found to decrease rapidly to approximately 1.5 m/s in the application area. Center aisle velocities were slightly lower than in those aisles that were directly aligned with the intake louvers. However, these values increased slightly as the exhaust fan was approached.

Patch data for the different ventilation conditions and application pressures are presented in Tables 1 and 2. Since the data sets appeared to have a consistent lognormal distribution, a logarithmic transformation was applied and the geometric mean utilized when making comparisons. First, the interaction of application pressure and ventilation type was evaluated. Mean values for total body and each specific body region were compared by analysis of variance using a Duncan's multiple range test ( $p < 0.05$ ).

Results clearly indicate that an interaction between application pressure and ventilation condition occurs during greenhouse handgunning applications. Mean total body, back, upper arm, and forearm dermal deposition rates increased significantly when application pressure was increased under unidi-

TABLE 2. Geometric Mean Fluorescent Tracer Deposition Rates on Patches Under Different Ventilation Conditions ( $\text{ng} \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$ )

Patch Location	n	Uni	Multi	None
Chest	12	18.8 <sup>a</sup> (1.9)	125.5 <sup>b</sup> (1.9)	46.9 <sup>c</sup> (1.6)
Upper legs	12	13.7 <sup>a</sup> (2.1)	85.4 <sup>b</sup> (1.9)	20.9 <sup>a</sup> (1.6)
Lower legs	12	16.4 <sup>a</sup> (2.5)	115.3 <sup>b</sup> (1.9)	23.3 <sup>a</sup> (1.7)

Uni = unidirectional ventilation; Multi = multidirectional ventilation; None = no ventilation.

Patch data were pooled for low and high pressure applications. Statistical analysis was performed on log-transformed data. For a given patch location, values followed by like letters are not significantly different ( $p < 0.05$  level; Duncan's multiple range test). Geometric standard deviation values are in parentheses.

rectional ventilation conditions. However, under multidirectional ventilation conditions, the total body rate decreased significantly when application pressure was increased. In the absence of ventilation, no significant difference was observed.

Tracer deposition rates during low pressure, unidirectional applications were found to be significantly less than low pressure, no ventilation applications for all regions except the chest, upper legs, and lower legs. Deposition rates observed under multidirectional ventilation conditions were found to be significantly greater than the other ventilation conditions at either pressure except for the back at high pressure, where multidirectional ventilation and no ventilation were not significantly different. At either application pressure, total body deposition rates under both unidirectional ventilation and no ventilation conditions were significantly less than the multidirectional condition ( $p < 0.05$ ). At the lower application pressure, the geometric mean multidirectional deposition rate was elevenfold higher than the deposition rate under unidirectional ventilation and fivefold higher than the no ventilation condition. At the higher application pressure, the same trend was exhibited, but to a lesser degree. The mean deposition rate under multidirectional ventilation was found to be fourfold higher than the unidirectional rate, and threefold higher than with no ventilation.

Another consistent pattern emerged for body regions where the interaction of application pressure and ventilation did not result in significant differences (Table 2). When comparing geometric means for the chest, upper legs, and lower legs under different ventilation conditions, significantly more deposition occurred under multidirectional ventilation when data

from high and low pressure applications were pooled ( $p < 0.05$ ).

When comparing patch deposition rates obtained for low pressure applications with high pressure applications under the same ventilation condition, two comparisons were found to be significantly different ( $p < 0.05$ ). Mean values for low pressure applications under unidirectional ventilation were significantly less than high pressure applications for all regions except the head. This pattern was reversed for multidirectional ventilation, where high pressure applications resulted in significantly less deposition for all regions except the back.

### Air Sampling

Summary statistics for air samples collected in the breathing zone of the worker are presented in Table 3. The data collected closely approximated a normal distribution. Therefore, it was not necessary to logarithmically transform the data. The precision of this sampling method is reflected in the consistently low coefficients of variation. Differences in mean values for all ventilation conditions and application pressures were compared by analysis of variance using Duncan's multiple range test ( $p < 0.05$ ). Breathing zone contamination under unidirectional and multidirectional ventilation was significantly lower than under the no ventilation condition at either application pressure. The no ventilation value at low pressure was threefold and fourfold greater than multidirectional and unidirectional values, respectively. For high pressure applications, the no ventilation value was threefold and fivefold greater than multidirectional and unidirectional values, respectively. When comparing application pressures under the same ventilation conditions, the low pressure application rate was significantly less than the rates for multidirectional and no ventilation conditions.

### Discussion

In general, temperature and relative humidity data exhibited little variability and serve as indicators of the overall stability of the greenhouse environment. Therefore, these environmental variables are not expected to affect the exposure data in any significant manner. The effect of ventilation type and application pressure on dermal and breathing zone exposure during this study was evaluated by two distinctly different methods. The patch technique (dermal) is a passive sampling method which relies on the impaction of different-sized aerosol droplets onto each patch. The air sampling technique employed

TABLE 3. Fluorescent Tracer Deposition Rate on Air Filters During Applications Under Different Hydraulic Pressures and Ventilation Conditions ( $\mu\text{g} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$ )

Application Pressure (kPa)	Ventilation Type	n	Mean	Median	Coefficient of Variation (%)
284	Unidirectional	6	12.2 <sup>a</sup>	13.5	30.3
284	Multidirectional	6	16.3 <sup>a</sup>	16.1	33.4
284	None	6	50.3 <sup>c</sup>	46.7	27.3
841	Unidirectional	6	21.9 <sup>ab</sup>	21.8	18.7
841	Multidirectional	6	31.9 <sup>b</sup>	31.0	8.0
841	None	6	104.0 <sup>d</sup>	96.4	20.6

Values followed by like letters are not significantly different ( $p < 0.05$  level; Duncan's multiple range test).

here is a method that actively collects aerosol droplets which are 10  $\mu\text{m}$  or less in aerodynamic diameter in the breathing zone of the applicator. A potential limitation of the study may center on the use of a tracer instead of an actual pesticide. It is unclear whether the tracer behaves differently than an actual pesticide, but earlier pesticide studies have demonstrated a good correlation between the two.<sup>(17,33,34)</sup> Since this study was designed to examine some of the physical factors that may affect applicator exposure, the issue of whether a surrogate or actual pesticide was used does not appear to detract from the validity of this study. The justification for the use of a surrogate compound is based on the presumption that physical factors such as ventilation and application pressure will remain unaffected by the chemistry of a given compound.

It is clear that the upper body regions receive the majority of aerosol deposition. This finding is confirmed by a recent study conducted under similar conditions<sup>(17)</sup> and may be attributed to the application technique, which involves turning the spray wand so that the underside of the leaves receive complete spray coverage. This method of application directs the spray upward and, in turn, increases the potential for contact with the head, back, and arms. Conversely, the torso of the applicator may redirect air movement due to its size relative to the other body regions, which may reduce deposition on the chest.

Under unidirectional ventilation, exposure during low pressure applications was significantly lower than during high pressure applications for all regions except the head. Under multidirectional ventilation, however, the low pressure application resulted in significantly greater dermal deposition than the high pressure application. This difference appears to be due to droplet size distribution created by the nozzle. Under unidirectional ventilation conditions, low pressure applications resulted in larger droplets, which settle out of the airspace quickly. However, as application pressure increases, smaller droplets, which may remain buoyant longer than the low pressure droplets, are formed, resulting in an increase in the incidence of contact with the applicator. For multidirectional ventilation, where the corkscrew air pattern is directed upward toward the ceiling the scenario is quite different. Even though the low pressure application produces a range of droplets that are larger than the high pressure application, the range of droplet sizes may include those that can travel upward with the rising air currents and remain suspended in the greenhouse air and impact on the patches. Also, large droplets presumably carry more tracer, which could account for the larger deposition values noted during low pressure applications. Conversely, under multidirectional ventilation conditions, the droplets in the high pressure range are smaller and may become more widely dispersed, thereby reducing the potential for contact with the patches. It appears that for multidirectional ventilation, as droplet size decreases, the incidence of contact with the patches also decreases.

The MS&T PM-10 Cascade impactor proved to be a precise and reliable unit that was easily handled in the field. Patterns for breathing zone contamination were different than the patterns exhibited for total dermal deposition under different ventilation conditions and application pressures. It appears that low pressure applications produced significantly less breathing zone contamination when compared with high pressure applications under multidirectional and no ventilation conditions.

Low pressure applications conducted under unidirectional ventilation also produced lower deposition rates than high pressure applications, but the difference was not statistically significant. Low pressure applications conducted under unidirectional ventilation conditions resulted in the least contamination, while high pressure applications under no ventilation conditions resulted in the most contamination. In general, high application pressures always resulted in greater breathing zone contamination when compared with low pressure applications.

The effect of ventilation type on breathing zone contamination was found to be the same for either application pressure. Unidirectional ventilation was found to produce values that were significantly lower than those for no ventilation. It appears that unidirectional ventilation produces a constant, predictable air flow pattern that is capable of carrying aerosol droplets away from the applicator, regardless of application spray pressure. Multidirectional ventilation was found to significantly reduce breathing zone contamination when compared with no ventilation. This finding appears to be due to the small number of droplets measuring 10  $\mu\text{m}$  or less which become randomly dispersed by multidirectional ventilation.

## Conclusions

- (1) Both sampling techniques indicated that unidirectional ventilation clearly reduced dermal and breathing zone contamination when compared with the other ventilation conditions examined, confirming previous findings.<sup>(26)</sup> Unidirectional air flow patterns are both consistent and predictable, thereby allowing an experienced applicator to minimize dermal and breathing zone contamination.
- (2) Multidirectional ventilation increased dermal exposure when compared with no ventilation, but did not increase breathing zone contamination.
- (3) Higher application pressure increased breathing zone contamination substantially.
- (4) Exposure variables such as ventilation and application pressure do not necessarily affect dermal and breathing zone contamination in the same manner. This finding supports the need for careful characterization of both dermal and respiratory exposure during greenhouse handgunning applications.

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