Fungicide Application Practices and Personal Protective Equipment Use among Orchard Farmers in the Agricultural Health Study

C. J. Hines, J. A. Deddens, J. Coble, M. C. R. Alavanja

ABSTRACT. *Fungicides are routinely applied to deciduous tree fruits for disease management. Seventy-four private orchard applicators enrolled in the Agricultural Health Study participated in the Orchard Fungicide Exposure Study in 2002-2003. During 144 days of observation, information was obtained on chemicals applied and applicator mixing, application, personal protective, and hygiene practices. At least half of the applicators had orchards with ≤100 trees. Air blast was the most frequent application method used (55%), followed by hand spray (44%). Rubber gloves were the most frequently worn protective equipment (68% mix; 59% apply), followed by respirators (45% mix; 49% apply), protective outerwear (36% mix; 37% apply), and rubber boots (35% mix; 36% apply). Eye protection was worn while mixing and applying on only 35% and 41% of the days, respectively. Bivariate analyses were performed using repeated logistic or repeated linear regression. Mean duration of mixing, pounds of captan applied, total acres sprayed, and number of tank mixes sprayed were greater for air blast than for hand spray ($p < 0.05$). Spraying from a tractor/vehicle without an enclosed cab was associated with wearing some type of coverall ($p < 0.05$). Applicators often did not wash their hands after mixing (77%), a finding not explained by glove use. Glove use during mixing was associated with younger age, while wearing long-sleeve shirts was associated with older age ($p < 0.05$ each). Self-reported unusually high fungicide exposures were more likely on days applicators performed repairs ($p < 0.05$). These data will be useful for evaluating fungicide exposure determinants among orchard applicators.*

Keywords. *Agriculture, Apple, Fungicide, Orchard, Peach, Personal protective equipment, Pesticide, Work practices.*

Fungicides are routinely applied to apple, peach, and other deciduous tree fruits in private and commercial orchards for the control of fungal diseases that can substantially impact crop yield as well as fruit appearance and quality. Fungicides were applied to 90% and 80%, respectively, of the apple and peach acreage in USDA-surveyed states in 2003 (USDA-NASS, 2004). In 2003, commercial apple production in the U.S. ranked third (4.4 million tons) after oranges and grapes (11.5 and 6.6 million tons,

Submitted for review in August 2006 as manuscript number JASH 6642; approved for publication by the Journal of Agricultural Safety and Health of ASABE in November 2006.

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

The authors are **Cynthia J. Hines,** MS, CIH, Research Health Scientist, National Institute for Occupational Safety and Health, Cincinnati, Ohio; **James A. Deddens,** Professor of Mathematical Sciences, National Institute for Occupational Safety and Health, Cincinnati, Ohio, and Department of Mathematical Sciences, University of Cincinnati, Cincinnati, Ohio; **Joseph Coble,** Staff Scientist, and **Michael C. R. Alavanja,** Captain USPHS, National Cancer Institute, Rockville, Maryland. **Corresponding author:** Cynthia J. Hines, National Institute for Occupational Safety and Health, 4676 Columbia Pkwy, R-14, Cincinnati, OH 45226; phone: 513-841-4453; fax: 513-841-4486; e-mail: chines@cdc.gov.

  ISSN 1074-7583

respectively), and peach production ranked fifth (1.3 million tons) after grapefruit (2.1 million tons; USDA-NASS, 2005).

Fungicides commonly used on apples and peaches in the U.S. include sulfur, captan, calcium polysulfide, mancozeb, and copper sulfate (USDA-NASS, 2004). Fungicides are typically applied to orchards during the spring and summer using either air blast or hand spray application methods. An air blast sprayer has nozzles mounted in a semicircular pattern on a manifold over a radial fan at the rear of the sprayer. The sprayer is towed behind a tractor or other vehicle, which may or may not have an enclosed cab, at typically 0.5 to 3 mph. Hand spraying is done using a wand or gun with a single nozzle, and the applicator either sits on a tractor or stands on the ground while spraying.

Fungicide use in the U.S. is regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This act requires pesticide manufacturers to provide toxicity and exposure information to the U.S. Environmental Protection Agency (USEPA) to ensure that the intended use of their products does not cause unreasonable adverse effects on the environment. Many fungicides in current use have low acute toxicity in mammals but may cause skin and mucous membrane irritation, as well as dermal sensitization (USEPA, 1999).

The Agricultural Health Study (AHS) is a large cohort study of 57,311 licensed pesticide applicators in Iowa (IA) and North Carolina (NC) and 32,347 spouses of the private applicators. The AHS has been described elsewhere (Alavanja et al., 1996), and questionnaires may be accessed at www.aghealth.org. Fungicide use has been associated with increased risk of retinal degeneration among farmers who applied pesticides and the wives of farmer applicators enrolled in the AHS (Kamel et al., 2000; Kirrane et al., 2005). Among farmers, risk of retinal degeneration increased with total lifetime days of fungicide use (Kamel et al., 2000). For both applicators and wives, retinal degeneration was reported more frequently among persons who grew orchard fruit as compared to those who did not grow orchard fruit. As both studies were cross-sectional in design, and disease status and pesticide use were self-reported, these findings are considered exploratory. However, the findings led us to an interest in understanding fungicide application practices and exposure determinants among applicators in the AHS orchards. We were also interested in evaluating an algorithm developed for estimating pesticide exposure intensity in the AHS (Dosemeci et al., 2002).

In 2002 and 2003, the National Institute for Occupational Safety and Health (NIOSH) conducted the Orchard Fungicide Exposure Study (OFES) among 74 orchard fungicide applicators enrolled in the AHS. The goal of the OFES was to describe applicator practices during mixing and application, to monitor applicator fungicide exposures, and to identify major fungicide exposure determinants. The OFES focused on three target fungicides typically used in apple and peach orchards at the time (captan, thiophanate--methyl (TPM), and benomyl) and for which environmental and/or biological monitoring methods were available. These fungicides were intended to serve as model compounds for evaluating fungicide exposure determinants in orchards. Benomyl was voluntarily withdrawn from the market in 2001; however, it was anticipated that applicators would use existing supplies during the study period. To ensure an adequate sample size, all applicators applied captan.

In this article, we report on the overall design of the OFES and on the observed fungicide use, personal protective equipment, and hygiene practices of the applicators. We compare OFES participants to non-participating AHS applicators and examine the relationship between applicator characteristics and certain application and mixing practices. Exposure monitoring and algorithm evaluation results will be reported elsewhere.

Methods

Participant Recruitment

Applicators in the AHS had previously completed an enrollment questionnaire (1993-1997, phase 1) and a follow-up questionnaire (1999-2003, phase 2) in which they provided information about crops and pesticide use. All private applicators in NC and IA who reported growing apples or peaches during the AHS phase 2 interview were administered a telephone screening questionnaire to determine OFES eligibility. To be eligible, applicators had to plan to grow apples or peaches during the coming season, respond that they were either "certain," "probable," or "not sure" about personally applying captan to apples or peaches, and agree to be contacted about the study. An in-person recruitment visit was scheduled with eligible applicators. During the in-person visit, study procedures were explained and informed consent was obtained. This study was approved by all relevant Institutional Review Boards.

A total of 290 AHS private applicators reported growing apples or peaches in phase 2. Of these, 263 (91%) completed the screening interview, and 139 (53%) of those screened met the eligibility criteria for recruitment. Due to changes in either crop or fungicide plans, another 31 applicators were determined to be ineligible during the in-person visits, and six more became ineligible before monitoring could be conducted. The final number of eligible applicators was 102, of which 76 consented to participate in the OFES. Observational data collection and exposure monitoring was conducted on 74, for a participation rate of 73%.

Data Collection

Two sampling visits, at least seven days apart, were scheduled per applicator on days the applicator planned to spray captan from March to August in 2002 and 2003 in NC (usually in the same year) and in 2003 in IA. During the first visit, demographic data including age, gender, and county of residence were confirmed, and information on total years the participant had applied fungicides to orchards and current pesticide certification status was obtained. Questions from the phase 1 and phase 2 AHS questionnaires pertaining to mixing and application methods, personal protective equipment (PPE) worn during mixing and application (asked separately), presence of enclosed cabs, repairing and cleaning of equipment, cleaning nozzles, timing of changing into clean work clothes after spraying, timing of bathing, showering, or washing hands and arms after spraying, frequency of glove replacement, and self-reported unusual fungicide exposure (e.g., spills, leaks) were asked on both visits. Other information suggested by extension agents (e.g., number of trees, tree density, location of mixing, re-using disposable chemical-resistant (CR) suits, spray pattern, and tractor speed) was also collected. Those who reported a perceived unusually high fungicide exposure event were asked about the body part exposed, task and application method associated with the exposure, and the elapsed time to wash the body or change clothes after exposure.

OFES staff, who were on site during each monitored application, collected data by direct observation whenever possible, otherwise by interview when the applicator could not be observed (e.g., out of sight while spraying or activity took place in the home). Mixing method, product formulation, product container, application method, presence or absence of an enclosed cab, dust filter or charcoal filter in cab, windows or doors open during spraying, spray pattern, PPE and clothing during mixing and during application were recorded for each tank mix. Information on frequency of hand washing after mixing and wearing clothes from previous sprayings without laundering was also obtained. Participants were asked if they had smoked cigarettes or chewed tobacco during the monitored period.

The concentration and amount of active ingredient (a.i.) applied per tank was computed for each target fungicide by recording the amount of product added to the tank along with the product's EPA registration number and the volume of liquid in the tank before and after spraying. The total amount of a.i. applied per day was summed across all tanks, and the mean a.i. concentration was averaged across all tanks. Start and stop times of application and of mixing were recorded separately for each tank, and the duration of spraying and of mixing was determined by subtraction. The total duration of spraying and of mixing was summed across tanks.

Data Analysis

Demographic characteristics of the OFES participants were summarized. OFES participants were compared to non-participating AHS applicators on selected characteristics using previously collected data available in the AHS Phase 1 and Phase 2 Private Applicator files (Release Nos. P1REL0310.02 and P2REL0312.02, respectively) and the Phase 2 Private Applicator Supplemental file (Release No. P2REL0312.01). Education level and farm size in acres were collapsed into three categories each. A chi-squared test was used on categorical variables, and a t-test was used on continuous variables. Mixing, application, PPE, and hygiene practices were described by computing frequencies or summary statistics.

Bivariate analyses were performed to investigate relationships between application methods, use of enclosed cabs, PPE use, hygiene activities, equipment cleaning, equipment repair, age, and outdoor temperature. Application method (air blast vs. hand spray), use of an enclosed cab (yes/no), use of an enclosed cab during air blast application (yes/no), and age were tested one at a time as predictor variables against each type of PPE used (yes/no). Age as a predictor of hygiene activities, e.g., bathing/showering (yes/no) and hand washing (yes/no), was similarly examined. Application method was examined as a predictor of mixing duration (min), application duration (min), number of tank mixes applied, tank size used (gal), pounds of captan a.i. applied, number acres sprayed, doing a repair (yes/no), tank rinsing (yes/no), hosing down the sprayer (yes/no), and hosing down the tractor (yes/no). Doing a repair was tested as a predictor of self-reported unusually high fungicide exposure (yes/no). Mean outdoor temperature during application was tested as a predictor of wearing long-sleeve shirts (yes/no).

To account for repeated measurements on participants, bivariate analyses were modeled using either repeated logistic regression for dichotomous dependent variables (PROC GENMOD) or repeated linear regression for continuous dependent variables (PROC MIXED) using applicator as the subject effect. A natural log transformation was applied to continuous dependent variables that were skewed to the right. Repeated logistic models used the generalized estimating equation (GEE) method with an exchangeable covariance structure. When PROC GENMOD could not be used due to a cell having 0 observations (and hence having to divide by 0), the analysis was run separately for each monitoring event with Fisher's exact test and the more conservative of the two p-values reported. Repeated linear models used the restricted maximum likelihood estimation method and a compound symmetric covariance structure. A t-test was used for the analysis of age by application method as each participant had only one age observation, and a Kruskal-Wallis rank sum test was used for analyses involving number of tank mixes, as its distribution did not appear to be normal (or lognormal). Statistical significance was set at 0.05 with no adjustment for multiple comparisons. All analyses were done in either SAS v. 9.13 (SAS Institute, Inc., Cary, N.C.) or S-Plus v. 6.2 (Insightful, Seattle, Wash.).

Results

Demographic and Farm Characteristics of OFES Participants

More OFES participants were from NC (53) than from IA (21) (table 1).All applicators, except one, were male. NC applicators were slightly older than IA applicators (mean (±SD) 63.7 ±12.4 vs. 61.6 ±12.2 years, respectively). NC applicators resided in 32 counties, mostly in western and central NC, while IA applicators resided in 17 counties, mostly in eastern and central IA. Most OFES applicators (93%) reported current pesticide certification, with the proportion in IA (81%) lower than in NC (98%). Certification is only required to purchase and apply restricted-use pesticides (e.g., azinphos-methyl), not general-use pesticides (e.g., captan, TPM, and benomyl). Mean (±SD) number of years the applicators had applied fungicides to orchards was 26.7 ±14.3 (range 5 to 70), with 28.7 ±14.2 years in IA and 25.9 ±14.4 years in NC. Apples were grown by 64 applicators, and peaches were grown by 50 applicators. Applicators were more likely to have apple orchards with >100 trees in IA (71%) than in NC (42%), while they were more likely to have peach orchards with >100 trees in NC (32%) than in IA (0%). IA applicators did not have any apple orchards with less than 10 trees, compared to 28% in NC. About half (54%) of the applicators had both apple and peach orchards.

Table 1. Demographic and farm characteristics of Orchard Fungicide Exposure Study (OFES) participants at time of observation in 2002 and 2003.

		Iowa	North Carolina	Total
Number of participants		21	53	74
Women		0	1	1
Race = white		21	53	74
Age (years) at first sampling event				
Mean (±SD)		61.6 (±12.2)	63.7 (±12.4)	63.1 (±12.3)
Median (range)		60 (40-86)	63 (37-90)	62.5 (37-90)
By category:	30-49	3 (14%)	8 (15%)	11 (15%)
	50-69	12 (57%)	26 (49%)	38 (51%)
	70+	6 (29%)	19 (36%)	25 (34%)
No. of participant days		42 (29%)	102 (71%)	144 (100%)
No. of counties of residence		17	32	49
No. of years applied fungicides to orchards				
Mean (±SD)		28.7 (±14.2)	25.9 (±14.4)	26.7 (±14.3)
Median (range)		30 (7-59)	20 (5-70)	22 (5-70)
Certified applicators		17 (81%)	52 (98%)	69 (93%)
No. of apple trees in orchard				
0		0	10 (19%)	10 (14%)
1-9		0	5 (9%)	5 (7%)
10-100		6 (29%)	16 (30%)	22 (30%)
>100		15 (71%)	22 (42%)	37 (50%)
No. of peach trees in orchard				
0		11 (52%)	13 (25%)	24 (32%)
1-9		6 (29%)	11 (21%)	17 (23%)
10-100		4 (19%)	12 (23%)	16 (22%)
>100		0	17 (32%)	17 (23%)

Comparison of OFES Participants to Non-Participating AHS Applicators

The 74 OFES participants were similar to the 216 non-participants with respect to gender, race, education level, farm size, and proportion growing apples or peaches at phases 1 and 2 (table 2). However, participants were, on average, four years older (mean ±SD; 62.6 ±12.3 years) than non-participants (58.2 ±12.8 years) ($p < 0.05$). The proportion of applicators from IA was significantly higher among participants (28%) than non-participants (15%, $p < 0.05$; table 2). Participants had significantly fewer acres of apples at phase 2 (mean ±SD; 16.5 ±28.6) than non-participants (34.8 ±56.3; table 2). However, no difference was found for acres of peaches at phase 2 between the two groups. OFES participants and non-participants were also similar with respect to having ever personally mixed or applied captan, the decade they first personally applied captan, the number of years they had mixed or applied captan (phase 1), the number of days per year they used captan (phase 1), and using a tractor to apply captan to apples and peaches (phase 2) (data not shown).

Table 2. Comparison of Orchard Fungicide Exposure Study (OFES) participants to non-participants for characteristics selected from the phase 1 (enrollment, 1993-1997) and phase 2 (follow up, 1999-2003) private applicator questionnaires.

	Characteristic	OFES Participants % or Measure (*n* = 74)	Non-Participants[a] % or Measure (*n* = 216)
Phase 1	Gender		
	Male	99	96
	Female	1	4
	Race		
	White	99	94
	Black	0	2
	Missing	1	3
	Age, years (as of 1 Jan. 2002)		
	Mean (±SD)[b]	62.6* (±12.3)	58.2* (±12.8)
	Median (range)	62.6 (35.5-88.6)	58.2 (28-86.9)
	State		
	Iowa[b]	28*	15*
	North Carolina	72	85
	Highest level of schooling		
	Less than high school	8.1	11.1
	High school	27.0	34.3
	More than high school	59.5	48.6
	Something else	0	0.9
	Missing	5.4	5.1
	Acres planted on farm		
	Did not work on a farm	1.4	2.3
	None	2.7	6.0
	Less than 5 acres	18.9	14.4
	5 to 49 acres	32.4	35.2
	50 or more acres	36	24.5
	Missing	8.1	17.6
	Apples as a crop (phase 1)[c]	73	67
	Peaches as a crop (phase 1)[c]	36	28

(continued)

Table 2 (cont'd). Comparison of Orchard Fungicide Exposure Study (OFES) participants to non-participants for characteristics selected from the phase 1 (enrollment, 1993-1997) and phase 2 (follow up, 1999-2003) private applicator questionnaires.

Phase 2	Apples as a crop (phase 2)[c]	73	80
	Peaches as a crop (phase 2)[c]	43	34
	Acres of apples (phase 2)	(*n* = 54)	(*n* = 170)
	Mean (±SD)[b]	16.5* (±28.6)	34.8* (±56.3)
	Median (range)	8.0 (1-180)	14.0 (1-444)
	Acres of peaches (phase 2)	(*n* = 31)	(*n* = 72)
	Mean (±SD)	4.8 (±6.1)	12.2 (±37.2)
	Median (range)	2.0 (1-30)	3.0 (1-300)

[a] All applicators from the selected sample of 290 who did not participate in the OFES.
[b] * indicates that values are significantly different ($p < 0.05$).
[c] Applicators could have grown more than one crop; hence, percentages may sum to more than 100.

Table 3. Pesticides and other ingredients sprayed by Orchard Fungicide Exposure Study (OFES) applicators on observed days.

Pesticide Type	Pesticide Common Name or Ingredient	% of Days (*n* = 144)	% of Applicators (*n* = 74)
Fungicide	Captan	100	100
	Thiophanate-methyl	19	22
	Benomyl	12	15
	Fenarimol	7	9
	Ziram	6	8
	Myclobutanil	6	9
	Sulfur	5	5
	Triadimefon	3	4
	Ferbam	3	4
	Mancozeb	2	4
	Metiram	2	3
	Chlorothalonil, dodine, kresoxim-methyl, lime sulfur	<1 each	1 each
Insecticide	Phosmet	28	39
	Azinphos-methyl	27	36
	Malathion	13	15
	Carbaryl	8	11
	Methoxychlor	4	7
	Permethrin	3	5
	Dimethoate	2	3
	Esfenvalerate	2	4
	Dicofol	1	3
	Endosulfan	1	3
	Methomyl	1	3
	Methyl parathion	1	1
	Bifenzate, chlorpyrifos, diazinon, fenpropathrin	<1 each	1 each
Bactericide	Streptomycin	6	11
Other ingredients	Spreader or sticker	22	28
	Calcium/calcium nitrate	12	16
	Surfactant	10	11
	Defoamer	6	7
	Fertilizer, nitrogen, 1-napthaleneacetic acid, sodium bisulfate, citric acid, micronutrients, potassium	≤2 each	≤4 each

Chemicals Used

The 74 OFES applicators were observed on 144 days (102 in NC; 42 in IA). Seventy applicators participated on two days and the remaining four on only one day. Recruitment was based on the intention to apply captan; thus, captan was applied on all 144 days. As a group, applicators used 14 other fungicides, 16 insecticides, and a number of spray additives, nutrients, and plant growth regulators during the 144 days (table 3). The five most frequently applied pesticides after captan were phosmet, azinphos-methyl, TPM, malathion, and benomyl (28%, 27%, 19%, 13%, and 12% of the days, respectively). Applicators added a spreader or sticker to the tank mix on 22% of the days.

Information on formulation, mixing methods, concentration, and amount of active ingredient applied for captan, TPM, and benomyl is given in table 4. Captan was usually formulated as a wettable powder (84%) and occasionally as a liquid flowable (16%).

Table 4. Characteristics of captan, thiophanate-methyl, and benomyl use by Orchard Fungicide Exposure Study (OFES) applicators on observed days.

Characteristic	Captan (% of days)	Thiophanate-methyl (% of days)	Benomyl (% of days)
Mixing	(n = 139)	(n = 27)	(n = 16)
Formulation			
Liquid flowable	16	0	0
Wettable powder (WP)	84	7	12
WP in water-soluble packet	0	93	75
Dry flowable	0	0	12
Product container			
Jug	15	0	0
Bag	79	7	12
Water-soluble packet	0	93	75
Not original container	6[a]	0	12[b]
Mixing method			
Poured a liquid	16	0	0
Poured a solid	84	33	44
Water-soluble packet	0	67	56
Opened water-soluble packet	NA	39	33
Application	(n = 144)	(n = 27)	(n = 17)
Amount of a.i. applied (lbs)			
AM (±SD)	8.2 (±14.4)	2.6 (±2.4)	0.24 (±0.27)
Median	2.2	2.1	0.12
Range	0.01-100	0.05-8.4	0.002-1
Conc. of a.i. applied (lbs/gal)			
AM (±SD)	0.018 (±0.013)	0.004 (±0.003)	0.0022 (±0.0017)
Median	0.013[c]	0.0028[d]	0.0017[e]
Range	0.0024-0.076	0.0005-0.014	0.0004-0.0076

[a] Canister, metal can, plastic bag, or plastic jar.
[b] Plastic jar.
[c] Equivalent to 2.7 lbs Captan 50 WP per 100 gal water. Captan 50 WP contains 48.9% captan a.i.
[d] Equivalent to 0.4 lbs of Topsin-M 70 WP per 100 gal water. Topsin-M WP contains 70% thiophanate--methyl a.i.
[e] Equivalent to 5.4 oz. of Benlate WP per 100 gal water. Benlate WP contains 50% benomyl a.i.
Abbreviations: a.i. = active ingredient, AM = arithmetic mean, NA = not applicable, SD = arithmetic standard deviation.

Table 5. Orchard Fungicide Exposure Study (OFES) applicator mixing, application, repair, and equipment cleaning practices on observed days.

Practice			% of Days or Measure (*n* = 144, except where noted)
Mixing	Applicator did mixing		97
	Mixing location (*n* = 139)		
	Shed[a]		17
	Outdoors		83
	Duration of mixing per tank, min (*n* = 317)[b]		
	Mean (±SD)		12.9 (±10.3)
	Median (range)		11 (2-80)
Application	Applicator did spraying		100
	Crop sprayed		
	Apple only		57
	Peach only		28
	Apple and peach		12
	Other orchard fruit combinations		3
	Application method		
	Air blast, high volume (>100 gal/acre)		13
	Air blast, low volume (≤100 gal/acre)		42
	Hand spray		44
	Mist blower/fogger		1
	No. of acres sprayed by tree density, median (range)		
	Low density (≤200 trees per acre; *n* = 136)		2.6 (0.1-50)
	High density (>200 trees per acre; *n* = 11)		6 (1-14)
	No. of tank mixes sprayed in a day	1	48
		2	22
		3	16
		4 or 5	8
		6 or 7	3
		8, 9, or 12	3
	Spray additive used[c]		33
	Spray pattern	Each row	92
		Alternate rows	3
		Other (e.g., isolated trees)	6
	Time started spraying	Earliest	4:10 a.m.
		50th percentile	9:08 a.m.
		75th percentile	10:40 a.m.
		Latest	7:00 p.m.
	Time stopped spraying	Earliest	06:40 a.m.
		50th percentile	11:20 a.m.
		75th percentile	1:43 p.m.
		Latest	11:35 p.m.
	Use of a tractor or other vehicle while spraying[d]		76
	Fully enclosed cab on tractor/vehicle[e]		17
	Dust filter in cab[f]		67
	Charcoal filter in cab[f]		39
	Cab windows and/or door open when spraying[f]		22
	Tractor speed, mph, mean (±SD), range (*n* = 99)		3.0 (±1.3), 1.5-9.3

Table 5 (cont'd). Orchard Fungicide Exposure Study (OFES) applicator mixing, application, repair, and equipment cleaning practices on observed days.

Practice	% of Days or Measure
Repair and cleaning	
Repair spray or mixing equipment	18
Rinse pesticide tank	38
Hose down/rinse off sprayer	38
Hose down tractor or towing vehicle	24
Clean nozzles	33
Ambient weather conditions during exposure monitoring[g]	
Temperature, °F, mean (±SD), range	73.4 (±11.7), 39.4-95.7
Relative humidity, %, mean (±SD), range	54.3 (±16.4), 12.5-88.0
Wind speed, mph, mean (±SD), range	1.8 (±1.9), 0-10.5

[a] A shed was defined as a structure having at least two opposing sides and a roof.
[b] Includes filling tank with water.
[c] Includes spreaders, stickers, surfactants, and defoamers.
[d] Includes hand spraying from a tractor or other vehicle.
[e] Denominator = 109.
[f] Denominator = 18. A cab may have one or more of the filter/window conditions indicated.
[g] n = 142 for temperature; n = 141 for relative humidity and wind speed. Temperature and relative humidity were measured using either an Oaktron thermohygrometer (model WD-35612-00, Davis Instruments, Hayward, Cal.) or a TH-CALC (model 8722, TSI, Inc., Shoreview, Minn.). Wind speed was measured using an Extech digital thermometer/anemometer (model 407112, Davis Instruments, Hayward, Cal.). All instruments were factory calibrated within a year of field measurements.

TPM and benomyl were usually formulated as wettable powders in water-soluble packets (93% and 75%, respectively). Captan was usually stored in its original container, either a bag (79%) or jug (15%), but was occasionally transferred to other containers (6%). Captan was always poured as a solid (84%) or liquid (16%) using an open (no enclosure) mixing method. Applicators opened water-soluble packets to pour out the powder on about one-third of the days the packets were used, thus negating the packet's protective feature. The median amount of captan a.i., TPM a.i., and benomyl a.i. applied per day was 2.2 (range 0.01 to 100), 2.1(range 0.05 to 8.4), and 0.12 (range 0.002 to 1) lbs, respectively. The median applied concentration of captan a.i., TPM a.i., and benomyl a.i. was 0.013, 0.0028, and 0.0017 lbs/gal, respectively.

Mixing, Application, Repair, and Equipment Cleaning Practices

Mixing, application, repair, and equipment cleaning practices are summarized in table 5. Applicators personally mixed chemicals on 139 days (97%). Mixing was usually done outdoors (83%), otherwise in a shed (17%). Applicators sprayed apples on 82 days (57%), peaches on 40 days (28%), apples and peaches on 17 days (12%), and other combinations of tree fruit on the remaining 5 days (3%). Air blast application was slightly more frequent (55%) than hand spray (44%). Low-volume (≤100 gal/acre) air blast application was more frequent (42%) than high-volume (>100 gal/acre) application (13%). On 11 days (6%), "high-density" trees (i.e., >200 trees/acre) were sprayed. On 69 days (48%), the applicator sprayed only one tank mix. One, two, or three tank mixes were sprayed on 124 days (86%), while four or more tank mixes were sprayed on 20 days (14%). The maximum number of tank mixes sprayed in a single day was 12.

Applicators typically sprayed each row (92%), but occasionally sprayed alternate rows (3%) or used other strategies (e.g., sprayed isolated trees, 6%). The median time applicators started spraying was 9:08 a.m., with 75% of the spraying started by 10:40 a.m. (range 4:10 a.m. to 7:00 p.m.). The median time applicators stopped spraying was

11:20 a.m., with 75% of the spraying completed by 1:43 p.m. (range 6:40 a.m. to 11:35 p.m.). A tractor or other vehicle was used for spraying on 109 (76%) days. On 18 of these days (17%), the tractor had an enclosed cab. Cabs had dust filters on 12 days (67%), charcoal filters on 7 days (39%), and either the cab window(s) or door was open while spraying on 4 days (22%). On most days when a tractor was used, applicators sprayed while driving (n = 99, 91%). Their mean (±SD) speed was 3.0 ±1.3 mph (range 1.5 to 9.3). On the other 10 days, applicators drove to each tree, stopped, and then sprayed. The median number of nozzles on the air blasters was 12 (range 4 to 28). Hand sprayers had only one nozzle. Large variations in mean temperature and mean relative humidity (39°F to 96°F and 12% to 88%, respectively) were measured during the observed period. Mean (±SD) wind speed was less variable (1.8 ±1.9 mph), as applicators typically sprayed in low wind conditions to prevent drift.

Equipment cleaning was more frequent than repair. Applicators rinsed pesticide-containing tanks on 55 days (38%), hosed down or rinsed off the sprayer on 54 days (38%), hosed down a tractor (or other towing vehicle) on 34 of the 109 days tractors/towing vehicles were used (24%), and cleaned nozzles on 47 days (33%). Applicators reported repairing equipment on 26 days (18%). Application method was not related to repairing equipment ($p > 0.05$).

Mean duration of mixing, pounds of captan a.i. applied, concentration of captan a.i. applied, total acres sprayed, number of tank mixes sprayed, and tank size used were significantly greater for air blast than for hand spray (table 6). Mean duration of application was higher for air blast than for hand spray (93 vs. 66.8 min), but the difference was not statistically significant ($p = 0.083$). Long mixing durations were typically related to slow methods of filling the tank with water.

Hygiene Practices

The frequency of applicator hygiene practices is given in table 7. Applicators did not wash their hands after mixing on 77% of the days. Hand washing right after mixing or

Table 6. Exposure covariates for Orchard Fungicide Exposure Study (OFES) applicators stratified by application method.

	Air Blast (n = 79 days)		Hand Spray (n = 63 days)		
Exposure covariate[a]	GM (GSD)	Range	GM (GSD)	Range	p-value
Duration of mixing (min)	26.7 (2.5)	0-230	12.9 (2.1)	2-102	0.0009
Duration of applying (min)	93.0 (2.2)	17-426	66.8 (2.1)	5-417	0.083
Captan a.i. applied (lbs)	7.9 (3.4)	0.16-100	0.4 (3.6)	0.01-9.8	<0.0001
Conc. captan a.i. applied (lbs/gal)	0.019 (1.9)	0.004-0.076	0.0096 (2.1)	0.0024-0.041	0.0003
No. of acres sprayed	5.3 (3.1)	0.25-50	1.2 (3.0)	0.1-10	<0.0001
No. of tank mixes[b]	Median = 2	1-12	Median = 1	1-9	0.0007
Tank size (gal)	241 (2.0)	50-500	43 (4.4)	2.5-400	<0.0001
No. of nozzles	Median = 12	4-28	Median = 1	1	NE
Age, years, AM (SD)[c]	60.3 (10.6)	40-80	66.9 (13.3)	36-90	0.0174

[a] A repeated linear regression model was run for each covariate, except number of tank mixes and age.
[b] A Kruskal-Wallis rank sum test was used for number of tank mixes by application method, as the distribution did not appear normal (or lognormal).
[c] A t-test was used for age by application method, as each participant had only one age observation (n = 42 applicators for air blast, n = 31 for hand spray, and one applicator used a mist blower/fogger).
Abbreviations: a.i. = active ingredient, AM = arithmetic mean, GSD = geometric standard deviation, GM = geometric mean, NE = not estimated (no variability in the number of nozzles for hand spray,) and SD = arithmetic standard deviation.

Table 7. Orchard Fungicide Exposure Study (OFES) applicator hygiene practices on observed days.

Practice	% of Days (*n* = 144, except where noted)
Wash hands after each mixing or loading event (*n* = 139)	
Always	18
Sometimes	4
Never	77
Used disposable/removable protective clothing	36
Changed clothes after application (and did not wear disposable or removable clothing) (*n* = 92)	
Right away	58
At lunch	7
At end of day	36
Wore unwashed work clothes from prior pesticide application	10
Bathing and showering (without regard to when spraying ended)[a]	
Wash hands/arms only right away	33
Bathe/shower right away	50
Bathe/shower at lunch	4
Wash/hands arms only at end of day	<1
Bathe/shower at end of day	12
Smoked cigarettes on monitored day	4
Chewed tobacco on monitored day	7

[a] On 90 of the 144 days (62%), spraying was completed before lunch (12:00 p.m.).

applying was not associated with wearing rubber gloves ($p > 0.05$). On the 92 days when applicators did not wear disposable or removable spray suits, applicators changed their clothes immediately after application on 53 days (58%) and at the end of the day on 33 days (36%). Wearing unwashed work clothes from pesticide application on prior days was infrequent (15 days, 10%). Applicators bathed or showered right after application on 50% of the days, while on 33% of the days, applicators washed only their hands or arms right away. Applicators waited until later in the day to wash hands, bathe, or shower on only 17% of the days. Cigarette smoking and tobacco chewing while handling pesticides was infrequent (4% and 7% of the days, respectively). The low frequency of smoking during pesticide handling was consistent with the low frequency of current smoking (15.2%) found among AHS farmer applicators (Alavanja et al., 1996).

Personal Protective Equipment Use

Only small differences were observed in PPE worn during mixing and applying (table 8). Rubber gloves were the most frequently worn PPE, and they were worn more frequently during mixing (68%) than applying (59%). Respirators (of any type) were worn on about half the days during mixing (45%) and applying (49%). Eye protection (safety glasses, chemical goggles, or face shields) was worn during mixing and applying on 35% and 41% of the days, respectively. Rubber boots were worn on about one-third of the days during mixing (35%) and applying (36%). Aprons were rarely worn during mixing (2%) and applying (3%). Applicators wore either a disposable CR coverall (e.g., Tyvek) or a spray suit (e.g., waterproof "rain suit") during mixing and applying on 36% and 37% of the days, respectively. Disposable CR coveralls were not new on approximately 30% of the days they were worn. Applicators wore short-sleeve shirts on 38% of the days for both mixing and applying. A small number (4%) wore short pants while applying and mixing.

Table 8. Personal protective equipment and clothing use by Orchard Fungicide Exposure Study (OFES) applicators during mixing and applying on monitored days.[a]

Personal Protective Equipment		Mixing % of Days (n = 139)	Applying % of Days (n = 144)
Head cover, including hats		75	81
Face shield		12	15
Safety glasses		15	16
Chemical goggles		8	10
Apron		2	3
Rubber boots		35	36
Spray suit		14	15
Disposable chemical-resistant coveralls (e.g., Tyvek)		22	22
	Coverall was new	71	69
	Coverall was used	29	31
Fabric coverall		16	14
Gloves	None	28	35
	Cloth or leather	4	6
	Rubber[b]	68	59
Glove age[c]	New	31	30
	Used - new within past week	6	4
	Used - new within past month	12	11
	Used - older than one month	50	35
	Used - age unknown	1	1
Respirator	None	55	51
	Negative pressure, 1/2-face disposable dust/mist	13	10
	Negative pressure, 1/2-face disposable HEPA	1	2
	Negative pressure, 1/2-face cartridge dust/mist	1	<1
	Negative pressure, 1/2-face cartridge HEPA	0	<1
	Negative pressure, 1/2-face cartridge OV	13	17
	Negative pressure, 1/2-face cartridge OV/pesticide	9	8
	Negative pressure, full-face cartridge OV/pesticide	1	2
	Positive pressure, full-face OV	0	1
	Positive pressure, full-face OV/pesticide	6	7
Shirt	Long sleeves	60	61
	Short sleeves	38	38
	No sleeves	<1	<1
	No shirt	<1	<1
Pants	Long pants	94	94
	Short pants	4	4
	No pants (wore coverall only)	1	1

[a] An item of personal protective equipment was counted only if applicator used or wore the item on 50% or more of the tank mixes applied during the day.
[b] Includes natural rubber unlined, natural rubber flock-lined, heavy nitrile rubber, thin nitrile rubber, neoprene rubber, heavy latex, thin latex, polyvinyl chloride, and butyl rubber gloves.
[c] n = 100 for mixing; n = 93 for applying.
Abbreviations: HEPA = high-efficiency particulate air; OV = organic vapor.

Some PPE use was related to application equipment. Applicators were significantly more likely to wear a spray suit during air blasting than during hand spraying (22.8% vs. 6.4%, p = 0.043; table 9). Spraying from a vehicle without an enclosed cab (by either method) was significantly associated with wearing some type of coverall (i.e., either a

Table 9. Significant associations among covariates related to age, application, personal protective equipment, hygiene practices, repairs, and unusually high self-reported exposure among Orchard Fungicide Exposure Study (OFES) applicators.

Outcome	Covariate	Categories (*n*)	Result	p-value
Wore spray suit during application	Application method	Air blast (79) Hand spray (63)	18 (22.8%) 4 (6.4%)	0.043
Wore long-sleeve shirt during application	Application method	Air blast (77) Hand spray (63)	39 (50.6%) 47 (74.6%)	0.017
Wore any outer coverall[a] during application with tractor	Cab enclosure	Enclosed cab (18) No enclosed cab (91)	1 (5.6%) 57 (62.6%)	0.012
Used respirator during air blast application	Cab enclosure	Enclosed cab (18) No enclosed cab (91)	1 (5.6%) 37 (60.7%)	0.0002
Self-reported unusually high fungicide exposure	Repair	Did a repair (26) No repair (118)	6 (23.1%) 2 (1.7%)	0.0016
Wore rubber gloves during mixing	Age	Yes (94) No (45)	60.9 years 67.7 years	0.045
Wore long-sleeve shirt during mixing	Age	Long-sleeve (84) Short-sleeve (53)	66.8 years 57.0 years	0.0011
Applied by air blast	Age	Air blast (79) Hand spray (63)	60.3 years 65.2 years	0.031
Wore long-sleeve shirt during application	Age	Long-sleeve shirt (88) Short-sleeve shirt (54)	67.2 years 57.0 years	0.0007
Washed hands after mixing	Age	Always/sometimes (32) Never (107)	58.1 years 64.6 years	0.022
Wore long-sleeve shirt during application	Mean outdoor temp. during application	Long-sleeve shirt (82) Short-sleeve shirt (53)	69.6°F 79.4°F	<0.0001

[a] Either a spray suit, disposable chemical-resistant coverall, or fabric coverall.

spray suit, a disposable CR suit, or a cloth coverall) as compared to spraying from a vehicle with an enclosed cab (61.8% vs. 5.6%, p = 0.012; table 9). Among applicators who air blasted, those without an enclosed cab were significantly more likely to wear a respirator (60.7%) and rubber gloves (65.6%) than those with an enclosed cab (5.6%, p = 0.0002; and 0%, p = 0.0031, respectively). Applicators were more likely to wear short--sleeve shirts while air blasting as compared to hand spraying (49% vs. 25%, p = 0.017). Wearing short pants and short-sleeve shirts was not related to air blasting with an enclosed cab (p > 0.05). When long-sleeve shirts were worn, outdoor temperatures during application averaged 10°F cooler than when short-sleeve shirts were worn (p < 0.0001).

High Self-Reported Exposure Events

Six different applicators reported an unusually high fungicide exposure event on 8 days (6% of days). These reports included exposure to the hands (all 8 days), the chest/back/arms/legs and feet (3 days each), and the lungs from breathing (1 day). Exposure to the head and digestive tract (from swallowing) was not reported. When exposed, applicators reported doing mixing (3 days), applying (3 days), and cleaning or maintenance (2 days). All three instances of self-reported high exposure during application occurred while hand spraying. Applicators washed up within 30 min after three of the eight exposure events and waited more than 9 h after two events. On the remaining three events, they washed up between 0.5 and 3 h after exposure. Reporting an unusually high fungicide exposure event was significantly more likely on days that applicators reported doing repairs compared to days with no repairs (23.1% vs. 1.7%, p = 0.0016; table 9).

Applicator Age

A few characteristics differed significantly by applicator age (table 9). Applicators who air blasted were, on average, five years younger than those who hand sprayed (60.3 vs. 65.2 years, p = 0.031). Those who wore rubber gloves during mixing were, on average, seven years younger than those who did not (60.9 vs. 67.7 years, p = 0.045). In contrast, applicators who wore long-sleeve shirts during mixing and applying were, on average, 10 years older than those who did not (~67 vs. 57 years, each, p = 0.0011 and p = 0.0007, respectively). Applicators who washed hands after mixing were also significantly younger than those who did not (58.1 vs. 64.6 years, p = 0.022). Bathing or showering right after applying was marginally associated with younger age (61.0 vs. 65.8 years, p = 0.06).

Discussion

To our knowledge, the OFES is the largest and most comprehensive study of fungicide mixing, application, and work practices of apple and peach orchard applicators in the U.S. Understanding how fungicides are mixed and applied under real-world conditions is essential to the training and education of pesticide applicators. The large number of orchard applicators in this study using hand sprayers provides a rare opportunity to compare their exposures to those using air blast sprayers. In addition, the nesting of the OFES participants within the AHS cohort will allow for follow-up of the applicators on their health and exposure status.

OFES participants were representative of all AHS participants with respect to most characteristics examined; however, compared to non-participants, they were slightly older (4 years on average), were somewhat overrepresented by participants from IA, and reported growing, on average, 18 fewer acres of apples. This suggests possible under--sampling of younger applicators, applicators from NC, and applicators with larger orchards. Overall, OFES applicators had small orchards, with approximately 50% of the applicators having 100 or less apple trees and 77% having 100 or less peach trees. The higher percentage of applicators from NC (72%) than IA (28%) is likely related to greater apple production in NC (67,500 tons) than in IA (3000 tons; USDA-NASS, 2005). The extensive use of hand spraying (44% of the days) is related to the small scale of the OFES orchards in that the number of acres sprayed by hand was 4-fold lower than by air blast. While the OFES was not intended to represent all U.S. apple and peach production, the study likely captured mixing and application practices common to farmers with small orchards.

Large variability was observed in several parameters that could impact exposure when applying fungicides. Duration of application varied from 5 to 426 min (85-fold difference), amount of captan a.i. applied varied from 0.01 to 100 lbs (10,000-fold difference), and number of acres sprayed varied from 0.1 to 50 (500-fold difference). Duration of mixing, duration of application, amount of captan a.i. applied, total acres sprayed, and number of tank mixes were highly correlated (Pearson r: range 0.24 to 0.76; p-value:

range 0.004 to <0.0001). Exposures related to opening water-soluble packets may be of most concern among applicators with small orchards. Although all U.S. registrations of benomyl were cancelled by 15 January 2002 (USEPA, 2005), 15% of the applicators sprayed benomyl in 2002 and/or in 2003.

Applicators generally wore the same PPE for mixing and for applying. Rubber gloves were the most frequently worn PPE (both mixing and applying), followed by respirators, protective outerwear (spray suit or disposable CR coverall), and rubber boots. Protective outerwear was worn on about a third of the days, and applicators wore some type of outer clothing (disposal CR coverall, spray suit, or fabric coverall) on at least half of the days. Applicators using tractors or vehicles without an enclosed cab to spray were more likely to wear additional outer clothing. Given that disposable CR-resistant coveralls, which cannot be decontaminated, were re-used for mixing and applying 30% of the time, additional training may be needed on proper use of these suits. Glove use did not explain infrequent hand washing after mixing. Applicators may not consider mixing and application as separate exposure tasks but rather as one continuous task. Evidence for the latter notion is that applicators washed their hands, bathed, or showered immediately after completing their applications on 83% of the days.

Reports of PPE use specific to fungicide application in orchards are limited. Keeble et al. (1987) described self-reported clothing and personal equipment use among 175 fruit growers and workers using captan (primarily in Virginia) who were similar in age and education level to the OFES applicators. While some PPE descriptions did not overlap with our study, use of goggles (12.6%) and use of long water-repellant coats (17.1%) were similar to our study (10% for goggles and 15% for spray suit), whereas waterproof glove use (36%) and respirator use (26.9%) were less than in our study (59% and 49%, respectively). In both studies, gloves were the most frequently reported PPE used for captan.

In a study of PPE use among over 800 California fruit and nut farm operators in 1993, Nieuwenhuijsen et al. (1996) found a higher percentage of operators who reported using gloves (type not specified) half the time or more while mixing, loading, and applying pesticides (81%) than in our study for rubber glove use (68% for mixing; 59% for applying). In a small group of IA farmers using fungicides (n = 10), Reynolds et al. (1998) found minimal use of PPE during mixing and applying, with farmers never wearing gloves, rubber boots, respirators, goggles, and disposable clothing 60% to 70%, 70%, 90%, 80%, and 90% of the time, respectively.

DeJonge et al. (1983-1984) found that among licensed pesticide applicators in Michigan, fruit growers had stronger beliefs regarding protection from pesticides, wore protective apparel more frequently, and chose protection over comfort more frequently than non-fruit growers. The authors suggested that air blast spray methods made the risk of exposure more obvious to fruit growers, and this influenced wearing protective apparel. Differences in the above-cited studies may be partly related to data collection methods (self or telephone-administered questionnaires vs. direct observation) or to the presence of other, more toxic pesticides in the tank mix that may have influenced PPE use.

When applying captan 50WP, applicators are required to wear long-sleeve shirts, long pants, waterproof gloves, shoes plus socks, and protective eyewear (Vance, 2005). In addition to the above items, a CR apron and a dust/mist filtering respirator are required during mixing. Only (18%) of OFES applicators fully complied with PPE requirements during application, and none during mixing. Lack of PPE compliance during mixing is partly due to infrequent apron use (2%); however, respirators were worn during mixing only 45% of the time. Without the apron requirement for mixing, compliance was 11%. Substituting a disposable CR coverall or a spray suit for the apron requirement during mixing increased compliance only slightly (from 0% to 6%). The relatively low use of protective eyewear during mixing (35%) and applying (41%) is a concern, as captan can cause eye damage ranging from minor to severe (Gordon, 2001). Applicators frequently mixed and applied relatively small quantities of captan (e.g., those doing hand spray used, on average, only 0.4 lbs of captan a.i.). Small quantity pesticide use may lead to reduced risk perception and less tendency to wear PPE.

Glove use during mixing was associated with younger age in our study. Wearing long-sleeve shirts, however, was associated with older age. These findings on glove use and long-sleeve shirts are consistent with a survey of California farmers in which use of "better" PPE (at least three types of PPE worn more than half the time) was associated with younger age and use of "better" sun protection (wearing long-sleeve shirts and using sunscreen more than half the time) was associated with older age (Schenker et al., 2002). We found that wearing a long-sleeve shirt during either mixing or applying was associated with older age and, not surprisingly, with lower mean outdoor temperature during application. Perhaps older applicators wear long-sleeve shirts because they are less tolerant of colder temperatures than younger applicators and thereby receive additional sun protection benefits. The EPA typically requires long-sleeve shirts during mixing and applying of pesticides, but observers have long speculated that non-compliance is related to thermal comfort.

Self-reports of unusually high fungicide exposures were more likely on days applicators performed repairs, although applicators only reported high exposure events while actually doing a repair 25% of the time. Alavanja et al. (1999) also found that self-repair of pesticide equipment was associated with self-reported high pesticide exposure events in the AHS. Cleaning equipment was reported more frequently than repairing equipment. Cleaning tasks, which are intended to reduce pesticide surface contamination as a possible contact exposure route, may contribute to exposure (e.g., due to splashes) if adequate PPE is not worn. Arbuckle et al. (2002) found that washing spraying equipment was one of the factors associated with increased urinary 2,4-dichlorophenoxyacetic acid (2,4-D) levels in farmer applicators. The EPA also requires applicators using captan and other pesticides to wash the outside of gloves before removing them, a practice observed during our study but not systematically recorded. Washing the outside of gloves is intended to prevent applicator contamination with pesticides when removing or re-using gloves. Whether this cleaning practice results in pesticide-contaminated splashes on the arms or body is not clear.

Strengths of this study include a high participation rate, a relatively large number of applicators and days monitored, the use of field observers to record actual work practices, observer-verified estimates of product amount used, and detailed information about mixing and application practices at the tank mix level. A limitation common to this type of study is that some applicator work practices or behaviors may have been influenced by the presence of an observer. Findings from this study pertaining to limited PPE use, age-related PPE and hygiene practices, opening of water soluble packets, infrequent hand washing after mixing, and repair-related self-reported exposure suggest the need for focus groups to better understand the motivational and resource factors behind these behaviors so that appropriate intervention studies or training and education initiatives to improve work practices can be developed.

Conclusions

At least half of the fungicide applicators in the OFES had relatively small apple or peach orchards (≤100 trees). Since OFES applicators were more likely to use hand spray than air blast on smaller acreage, the amount of hand spraying observed in this study was substantial (44% of the days). Rubber gloves were the most frequently worn PPE, followed by respirators, protective outerwear, and rubber boots. The limited use of eye protection is a particular concern given that some fungicides like captan can be serious eye irritants. Although the hands are typically an important exposure route for pesticides, applicators often did not wash their hands after mixing, whether they wore gloves or not. Only 17% of applicators had an enclosed cab when they sprayed fungicides using a tractor or other vehicle. In the absence of an enclosed cab, applicators placed more reliance on PPE (coveralls, respirators, and rubber gloves) for protection. Practices such as opening water-soluble packets and re-using disposable clothing were observed in this study and deserve further attention with respect to exposure risk. The detailed field observations made during actual fungicide applications will provide a valuable source of information for evaluating exposure determinants among orchard applicators, for assessing exposure strategies used in the AHS, and for identifying intervention studies and pesticide safety training needs, especially for applicators with small orchards.

Acknowledgements

We gratefully acknowledge the contributions of the AHS Coordinating Center, the North Carolina and Iowa AHS Field Stations, the field team (Tamara Carlson, Martha Ryals, Christopher Lyu, John Masters, Frances Patterson, Elizabeth Schroeder, Sean Smith, and Leslie Wilson), and the industrial hygiene technicians (Kevin L. Dunn and Belinda Johnson) to this study. Most importantly, we would like to thank the AHS applicators for their participation.

This work was supported by intramural research funds from the National Institute for Occupational Safety and Health and the National Institutes of Health (National Cancer Institute and the National Institute of Environmental Health Sciences).

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