

Farmer Exposure to Organic Solvents During the Maintenance and Repair of Farm Machinery: A Pilot Study

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Background *The maintenance/repair of farm machinery is a common farming activity. Dermal exposure to organic solvents has not been well documented. A pilot study was conducted to characterize exposure to organic solvents.*

Methods *A survey questionnaire was administered to 31 Kentucky farmers in 2008. Dermal exposure assessment was conducted in 10 farmers while farmers performed farm machinery maintenance/repair tasks using a solvent sampling patch. Benzene, toluene, xylene, and n-hexane were analyzed.*

Results *All four organic solvents were identified from the samples with toluene (<0.5–36,000 µg/patch) and xylene (15–5,700 µg/patch) at significantly higher levels. Twenty-six farmers reported the use of personal protective equipment <50% of their time repairing/maintaining farm machinery on the questionnaire; only two farmers wore gloves during the exposure assessment.*

Conclusions *Farmers routinely use solvent products for farm machinery maintenance/repair. Dermal exposure to organic solvents is a potential hazard. Further studies to characterize and evaluate exposure in larger samples of farmers are needed.* Am. J. Ind. Med. 52:973–981, 2009. © 2009 Wiley-Liss, Inc.

KEY WORDS: *farm machinery maintenance and repair; dermal exposure; organic solvents; personal protective equipment*

INTRODUCTION

Farming is one of the most dangerous occupations and industries in the United States. Currently, the agricultural

industry fatality rate is 30 deaths/100,000 full-time workers, which is the highest in the nation [Bureau of Labor Statistics, 2008a]. The nonfatal agricultural worker injury rate is 3.2 injuries and illnesses per 100 workers [Bureau of Labor Statistics, 2008b]. Elevated injury rates have been observed in the repair of field machinery and equipment [Rasmussen et al., 2000], and 12% of all agricultural work-related fatalities in Australia were due to farm machinery [Franklin et al., 2001].

Farmers and agricultural workers are exposed to a variety of respiratory and dermal hazards, including dust, pesticides, and organic solvents. Exposure to organic solvents by farmers during the maintenance and/or repair of farm machinery may be particularly important to the overall exposure of farmers to chemicals since the maintenance and repair of farm machinery are primary tasks performed by farmers [Wu et al., 2003; Amshoff and Reed, 2005]. Personal protective equipment (PPE) is not routinely

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used during these activities to prevent exposure to solvents and other agricultural hazards [Schenker et al., 2002], which further increases the risk of exposure.

Recent evidence suggests that exposure to organic solvents while maintaining and repairing agricultural machinery occurs frequently in the agriculture sector and may be associated with some adverse health effects. Farmers frequently clean machinery with gasoline [Coble et al., 2002] and use gasoline- or diesel-powered tractors. These exposures have resulted in elevated odds of wheezing [Hoppin et al., 2004]. Additionally, exposure to organic solvents during sugarcane farming has been associated with an increased risk for oral cancer [Coble et al., 2003].

The repair and maintenance of farm machinery is a common task performed frequently on the farm and was a primary task performed by 77% of surveyed farmers aged 50 and older in Kentucky and South Carolina [Amshoff and Reed, 2005]. Farm machinery maintenance and repair was performed more often than other typical farm tasks such as tilling ground and feeding animals. Engine repair was performed monthly by approximately 31% of Iowa and North Carolina farmers [Coble et al., 2002] and was a common farm task in California [Wu et al., 2003] and other states. However, little research has been conducted to quantify task-based exposures, particularly through the dermal route to organic solvents, and to identify factors that affect the exposures.

We conducted a pilot study among Kentucky farmers during their routine maintenance and repair of farm machinery. The objectives were to (1) identify and characterize farm machinery maintenance and repair tasks through an administered survey; (2) assess farmer exposure to organic solvents during these tasks using a survey questionnaire; (3) quantify dermal exposure to various organic solvents and evaluate exposure factors; and (4) determine the use of PPE and the perceived risk of exposure and related health outcomes.

MATERIALS AND METHODS

Study Population and Recruitment

This pilot study recruited 31 Kentucky farmers who actively farmed and who were 18 years of age and older. The recruitment was conducted at the Kentucky Farm Bureau Show and through a snowball sampling technique ($n = 21$ for the completion of the survey alone and $n = 10$ for the completion of the survey and the dermal exposure assessment). Each farmer was given the information on study objectives and potential risks and benefits. Those who agreed to participate in either the questionnaire survey and/or dermal exposure sampling gave informed consent. The study was approved by the University of Kentucky Institutional Review Board. Field data collection began in October 2007 and was completed in April 2008.

Questionnaire Survey on Tasks and Exposures

Before the questionnaire was administered to farmers, telephone interviews were conducted with a focus group of five agriculture extension agents. The purpose of these interviews was to gain preliminary information on the nature of farm machinery maintenance and repair tasks, type of fuel solvent products commonly used, the nature of farm crops, and their distribution across the state of Kentucky. This information was used to design the survey questionnaire which was modified based on the California Farmer Health Study (University of California, Davis) that focused on farm tasks and exposures to pesticides among farmers. Questions on solvent exposure were derived primarily from preliminary case studies (Mel Myers, University of Kentucky, personal communication).

The survey questionnaire included the following information: (1) demographics including name, age and contact information; (2) tasks performed during routine farm machinery maintenance and repair activities including the frequency of contact with organic solvents; (3) PPE used during job tasks; and (4) perceived potential risk of exposure and health outcomes (Table I). General exposure to gases/fumes and pesticides was characterized on a 0–10 scale where “0” means no exposure and “10” indicates regular long-term exposure.

Dermal Exposure Assessment

Assessment of dermal exposure to fuel solvents was conducted with samples collected by workers themselves using a commercial solvent sampling pad (CLI Laboratories, Inc., Des Plaines, IL) which was a band-aid type of solvent patch with a sticky backing material and a charcoal pad adhered to the front. See Figure 1 for details. When a farmer was recruited and willing to participate in both the questionnaire survey and dermal exposure assessment, he (she) was trained by the field technician on patch sample collection, and storage. A standard protocol was used for the training and provided to the farmers upon consent to participate in the dermal exposure sampling.

After being explained the purpose of the study, giving informed consent, and completing the questionnaire, the farmers who agreed to dermal exposure assessment were given and explained a solvent sampling form. The solvent sampling form requested the collection date, weather on collection day, an explanation of job tasks performed using solvents, location where job task was performed, solvent used, total task time, dominant hand, and PPE used (gloves, respirator, or coveralls). The farmers were given opportunities to ask questions about the solvent sampling form. The field technician then opened an example Ziploc bag that contained the solvent sampling pads, vials, parafilm, and

TABLE I. Kentucky Farming Characteristics and Job Tasks, 2008* (n = 31 Farmers Surveyed)

Characteristic	Number of participants	Percentage of participants
Primary commodity produced in the last 12 months		
Livestock	17	55
Field crops	16	52
Row crops	3	10
Other	2	6
Primary commodity worked with over career		
Livestock	28	90
Field crops	28	90
Row crops	22	71
Fruit trees	4	13
Type of off-farm job		
Construction	7	23
Professional	4	13
Percent time wearing gloves during service/repair of farm machinery		
0	15	48
1–49	11	35
≥50	3	10
Off-farm job?	11	35
Concerned about potential farm exposure-related illness in family	20	65

*Numbers may not add up to 31 respondents for each variable since multiple answers could be chosen by the respondent.

aluminum foil and gave farmers their own sample Ziploc bag. The field technician removed the contents of the example Ziploc bag that corresponded to the farmer sample bag and explained how many patches to use for each task and which fingers or the palm to place the patches on, the use of the aluminum foil to wrap the solvent sample pads after sampling, the deposition of the foil-wrapped solvent sampling pads into their respective vials, and the use of

parafilm to wrap the vials. The vials used to store the solvent sampling pads were labeled with “left” or “right” (indicating the hand sampled) and labeled with an ID number. The farmers were instructed to store the vials with the solvent sampling pads in a Ziploc baggie in their refrigerator. The farmers were then instructed to contact the field technician to pick up the vials immediately after collection along with the completed solvent sampling form.

Farmers were told to perform their job tasks as they normally do and to not change their normal routine. They were told that the only thing they could change in their normal routine was to wear the solvent pad. They were also told that if gloves were routinely used to repair/maintain farm machinery, then they should wear the gloves over the solvent sampling patches. After the solvent sampling collection procedure was fully explained to the farmer, the farmer was asked to repeat the instructions back to the field technician. The farmers were also given another opportunity to ask questions related to the sampling procedures and the solvent sampling form. The farmers were given phone numbers to call either the field technician or other study personnel so that any questions related to the exposure assessment could be answered immediately. The instructions on how to perform the solvent sampling were well received by the farmers and there were no difficulties understanding the instructions.

Before performing the maintenance or repair tasks in which the solvent products were used, the farmer



FIGURE 1. Photo of solvent sampling pad. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

was instructed to place the pad on the thumb, index or middle finger and the palm center. Both left and right hands were sampled during the tasks. The farmer then performed the repair/maintenance tasks on the farm machinery as he (she) routinely did on the farm (barn, shop, or field). After a repair task was completed, the farmer removed the solvent sampling pads from one hand (or gloves first), wrapped them together in aluminum foil (to prevent loss and contamination of solvents) and placed the wrapped pads in a clean vial. The vial cap was screwed on tight and then wrapped tightly in parafilm. Pads from left and right hands were placed in separate wrappings and vials. The two glass vials were placed in the farmer's refrigerator. The farmer then called the field technician to pick up the sample vials from the refrigerator and the sample vials were placed in a sample cooler for transport to the laboratory. Once the samples were transported to the laboratory, samples were stored in the laboratory refrigerator before being cold-shipped to the analytical service (Bureau Veritas, North America, Inc., Novi, MI) within 48 hr for solvent analysis. One pad from unused field patches was also wrapped in a separate vial and shipped for analysis as a field blank.

Solvent Laboratory Analysis

Laboratory analysis of the solvent sampling pads was performed by Bureau Veritas North America, Inc. The analytical method was modified based on NIOSH Analytical Method 1501. The charcoal absorbent on the pad measured $2 \times 2 \text{ cm}^{-2}$ in size and 0.2 mm in thickness. The loading capacity of solvents was between 0.5 and 1 g cm^{-2} . This high loading capacity provided sufficient ability to absorb high concentrations of any solvent that would be encountered through skin exposure in the workplace. Received samples were stored in the refrigerator before analysis. Charcoal absorbents were removed from original shipped pads and placed into 15 ml French squares. A 5 ml aliquot of carbon disulfide was added to each sample bottle using a Brinkman Dispensette III. The samples were then placed on a mechanical shaker for 30 min to dissolve the solvents collected on the charcoal absorbent. After shaking, an aliquot of each sample extract was transferred to an auto sampler vial for analysis by gas chromatography equipped with flame ionization detection. A Phenomenex ZB-1 column (60 m $\times$ 0.32 mm ID 1 μm film thickness) was used for separation with a column flow rate of 1.5 ml helium min^{-1} , a split flow rate of 14.63 ml helium min^{-1} , and a purge flow rate of 3.09 ml helium min^{-1} . The detector flow rate was 30 ml min^{-1} for hydrogen; 400 ml min^{-1} for air and 25 ml min^{-1} for make-up gas (helium). The injection port temperature was maintained at 250°C and detector temperature at 280°C. The oven temperature was initially maintained at 50°C for 3.00 min and then programmed to

increase at a rate of 10°C min^{-1} . The final oven temperature was 280°C. The injection volume was 1 μl .

In order to quantify the solvents contained in the samples, a five-point calibration curve was prepared by first preparing a stock standard consisting of 5 μl of each individual analyte prepared from neat (pure) chemicals purchased from Sigma-Aldrich (St. Louis, MO) with purities of 99.5+% which was diluted to a volume of 10 ml with carbon disulfide. The remaining four individual analytical standards were prepared by diluting the working stock standard as follows: 2 μl of working stock in 1 ml carbon disulfide for Standard 1; 5 μl of working stock in 1 ml carbon disulfide for Standard 2; 20 μl of working stock in 1 ml carbon disulfide for Standard 3; and 1 ml of working stock in 10 ml carbon disulfide for Standard 4. The calibration curve ranged from 5 to 2,000 $\mu\text{g}/\text{sample}$ diluted with carbon disulfide for each of the solvents and was constructed using linear regression with a 1/year weighting for each solvent. All of the curves met an R^2 requirement of 0.995 or better. The sample concentrations were determined by comparing the sample values with the calibration curve using peak area.

Field blanks were analyzed in the same way as samples. For each batch of sample analysis, five laboratory (method) blanks were analyzed at the same time. The results showed no detectable values. Five laboratory controlled spike samples were also analyzed with each batch of field samples. Average quality control recovery rate was 97.1% for benzene, 103% for *n*-hexane, 99.0% for toluene, and 99.9% for total xylene. The reported analytical limit is 5 μg for all the solvents.

Statistical Analysis

Statistical analysis was performed using Statistical Analysis Software (SAS, Inc., Cary, NC). Laboratory solvent data were reported as the total amount of each solvent (μg) per sample which was subtracted by the field blank value. For solvents found as non-detectable, a $\frac{1}{2}$ LOD value was used in statistical analysis. Descriptive statistics were provided for the tasks performed, and type and quantities of solvent products used. The number of samples, geometric mean and geometric standard deviation, minimum and maximum and percentage of samples below the LOD were calculated for all solvents. Data were tabulated by PPE use (use vs. no use), PPE type (gloves vs. protective clothing), sampling location (left vs. right hand) and exposure time (≤ 30 min vs. > 30 min). Since the data were skewed and there was a very small sample size, parametric *t*-tests might not be relevant due to possible assumption violations. Therefore, a Wilcoxon signed-rank test, a non-parametric method analog to the paired *t*-test, was performed to determine the difference between dermal exposures to toluene and xylene, and those to benzene or *n*-hexane. A Wilcoxon–Mann–Whitney test was also used to compare dermal exposure by exposure time and use of PPE.

RESULTS

Farming Activities, Tasks, and Solvent Exposure

The median age of the farmers was 60 years (ranging from 33 to 80 years of age) and median farm size was 185 acres (ranging from 10 to 2,200 acres). Table I shows that the primary commodities produced were livestock ($n = 17$) and field crops ($n = 16$). Eleven farmers also worked an off-farm job. In addition to the maintenance and repair of farm machinery, farmers performed a variety of tasks: feeding animals (approximately 20 times per month), mechanical harvesting of farm crops (approximately 5 times per month averaged over the year), and some shop work (approximately 8 times per month) (data not shown). Potential farm exposure-related illness in their family was of concern to 20 farmers, but 26 farmers did not use gloves (50% of the time or more) while servicing and/or repairing their farm machinery.

All of the participants drove tractors (Table II); 17 drove both diesel and gasoline tractors and 13 drove diesel tractors alone. Almost all of the farmers repaired their own tractors, balers, mowers, hay rakes, and farm trucks. Ten respondents performed service/repair activities <1 time per month, seven respondents performed service/repair activities 1–5 times per month, and ten more than 5 times per month. Service/repair locations included sheds/shops ($n = 13$), barns ($n = 12$), and garages ($n = 10$). The primary solvents used by most farmers for the service/repair of farm machinery were diesel fuel, grease, WD40, oil, and hydraulic fluid. Other products less frequently used included gasoline, mineral spirits, and kerosene. Almost half of respondents used less than 1 quart of fuel for service/repair activities. After servicing/repairing farm machinery, seven respondents used gasoline to clean their hands, four used diesel fuel, and two used mineral spirits (data not shown). The mean exposure to gases and fumes by farmers was self-reported to be “6.” Exposure to pesticides was self-reported to be “5.”

Dermal Exposure to Organic Solvents

Ten farmers agreed to participate in the dermal exposure assessment out of the 31 farmers who completed the survey questionnaire (convenience sample). Of the ten farmers who participated in the dermal exposure assessment, five were cleaning/maintaining an engine, four were repairing an engine, and one was preparing a tractor to paint. Most of the maintenance/repair tasks were performed inside in the barn ($n = 6$), or in the garage ($n = 3$). Four participants used gasoline or diesel fuel, two used mineral spirits, one used WD40, one used oil, one used carburetor cleaner, and one used kerosene for farm machinery repair activities. Most of

TABLE II. Kentucky Farmer Exposure to Organic Solvents by Exposure Location and Solvent Type* ($n = 31$ Farmers Surveyed)

Characteristic	Number of participants	Percentage of participants
Fuel type used for tractor driving		
Gasoline and diesel	17	57
Diesel only	13	43
Self-service/repair of farm equipment	29	94
Type of farm equipment serviced/repared		
Tractor	31	100
Mower	30	97
Hay rake	29	94
Farm truck	28	90
Baler	28	90
Wagon	26	84
Combine	10	32
Frequency (times per month) of service		
<1	10	37
1–5	7	26
>5	10	37
Service location		
Shed/shop	13	42
Barn	12	39
Garage	10	32
Field	9	29
Driveway	8	26
Types of solvents used		
WD40	26	84
Oil	26	84
Diesel fuel	25	81
Grease	25	81
Hydraulic fluid	25	81
Gasoline	16	52
Mineral spirits	14	45
Kerosene	8	26
Quantity (gallon) of solvents used		
≤ 1/4	13	42
1	9	29
>1	7	23

*Numbers may not add up to 31 respondents for each variable since multiple answers could be chosen by the respondent.

the farm machinery maintenance/repair activities took longer than 30 min and only two participants wore protective gloves.

Table III shows dermal exposure to the four organic solvents (*n*-hexane, benzene, toluene, and xylene) in different sampling hands according to the type of products used. All four solvents were detected in all solvent sampling pads. Regardless of the solvent product used, elevated levels of xylene were detected in the solvent sampling pads of all 10

TABLE III. Farmer Dermal Exposure to Organic Solvents by Sampling Hand, Product Type, and Solvent Type

Worker	Sampling hand	Product used	Solvent quantity used	Total task time (min)	Personal protective equipment used	Benzene (μg)	<i>n</i> -hexane (μg)	Toluene (μg)	Xylene (μg)
1	Left	Kerosene	0.5 gallon	30	None	<5	6	11	86
	Right ^a					<5	6	9	70
2	Left	Carburetor cleaner	0.25 gallon		None	<5	<5	22,000	540
	Right ^a			30		<5	<5	36,000	270
3	Left	Motor oil	1 gallon	40	None	<5	<5	52	140
	Right ^a					9	<5	110	310
4	Left	Mineral spirits	0.125 gallon		Coveralls	<5	<5	<5	650
	Right ^a			60		7	<5	<5	630
5	Left ^a	Mineral spirits	0.75 gallon	180	Gloves	19	48	220	5,700
	Right					51	80	47	5,300
6	Left	WD40	Unknown	45	Coveralls	<5	<5	38	230
	Right ^a					<5	<5	22	170
7	Left	Gasoline, diesel fuel	Unknown	90	Coveralls	<5	<5	13	17
	Right ^a					<5	<5	7	15
8	Left	Gasoline	0.05 gallon	75	None	360	61	560	39
	Right ^a					87	180	220	160
9	Left	Diesel fuel	3 gallons	10	None	13	37	320	1,600
	Right ^a					7	18	200	1,000
10	Left	Gasoline, diesel fuel	Unknown	90	Gloves, Coveralls	31	36	290	920
	Right ^a					55	82	530	1,800

^aDominant hand.

participants, and high levels of toluene were detected in the solvent sampling pads of 9 participants. Very little benzene and *n*-hexane were detected with any of the solvent products. Six participants had low levels of detectable benzene in the solvent sampling pads and five participants had low detectable *n*-hexane. The concentrations of all four organic solvents were highly correlated between hands on an individual. The associated *P* values for spearman's correlation coefficients are listed as follows: benzene ($P = 0.003$), *n*-hexane ($P < 0.0001$), toluene ($P = 0.0007$), and xylene ($P < 0.0001$). The donning of gloves did not provide sufficient protection of the hands from exposure to the solvents. Only two participants wore gloves and they both wore latex gloves.

The use of carburetor cleaner resulted in a very high exposure to toluene and the use of small quantities of mineral spirits resulted in elevated concentrations of xylene. Elevated benzene and *n*-hexane concentrations were detected in three out of the four participants using gasoline/diesel fuel and increased toluene and xylene levels were observed in all four participants using gasoline/diesel fuel.

We compared the possible differences in dermal exposure to four organic solvents (*n*-hexane, benzene,

toluene, and xylene) by exposure time ($<$ or $= 30$ min vs. > 30 min) and usage of PPE (gloves + coveralls) (yes vs. no). Only the laboratory results on the dominant hands were used for the comparison. The results from the Wilcoxon–Mann–Whitney test indicated there were no significant differences between the use of gloves and/or coveralls and exposure to *n*-hexane, benzene, toluene, and xylene, and whether the task took less than 30 min or more than 30 min.

DISCUSSION

Although farming is one of the most dangerous occupations in the United States with elevated rates of injuries and illnesses, research to characterize exposure to organic solvents through the dermal route is very limited. Farming is an important industry in Kentucky, and crops (i.e., tobacco and corn), and livestock (i.e., horses and beef cattle) are the primary commodities produced (National Agricultural Statistics Service). Frequently, farm commodities such as tobacco and beef cattle are both grown and raised together in Kentucky. In order to evaluate farmers' exposure to organic solvents during their farming activities and to assess the risk of potential health outcomes, we conducted this pilot

study. Consistent with other published studies [Coble et al., 2002, 2003; Wu et al., 2003; Amshoff and Reed, 2005], we found that farm machinery maintenance and repair was a primary task performed by Kentucky farmers. Many farmers used solvent-containing products as primary agents for the maintenance and repair of their farm machinery which allowed them to have direct contact with organic solvents.

Although pilot in nature, this study has several strengths. First, the study used both a survey questionnaire to characterize the solvent exposure frequency and a dermal patch sampling technique to evaluate task-based solvent exposures. Farmers in this study reported exposure to solvents while performing at least two types of farm tasks: (1) the maintenance/repair of farm machinery; and (2) hand cleaning after a farm task was performed. Most farmers in this study had repeated short-term exposures to solvents since greater than one-third of the farmers performed maintenance/repair tasks on farm machinery at least five times per month for less than 1 hr at a time. Repeated short-term exposures to organic solvents may be just as important as long-term exposures to organic solvents in producing detrimental effects on occupational health [Hery et al., 1996; Leung et al., 2005], particularly when large quantities of solvents are used. Over 50% of the time, the product used for maintenance and repair service among surveyed farmers was ≥ 1 quart. These large quantities used in farm machinery maintenance and repair plus the practice of hand washing with solvents after tasks were performed resulted in elevated dermal exposures among farmers.

To the best of our knowledge, this is the first study to quantitatively assess dermal exposure of farmers to organic solvents from solvent products. Although previous studies reported that solvent exposure in farmers can occur when performing a variety of different farm tasks [Blair and Zahm, 1995; Coble et al., 2002, 2003; Hoppin et al., 2004; Perry and May, 2005; van Balen et al., 2006], we focused our quantitative dermal exposure assessment on farm machinery maintenance and repair tasks because these are the main tasks performed by farmers in Kentucky. The results revealed that significant amounts of solvents were detected on both hands when farmers performed maintenance and repair tasks. Although currently there are no standards or recommended exposure limits for dermal exposure to these solvents, exposure through the dermal route may be as significant as the inhalation route.

Exposure among workers and solvent types was quite variable, possibly related to various exposure factors such as the quantities of solvent products used, task duration, weather conditions, task location, and other exposure factors. Exposures to toluene and xylene were particularly high. This was seen in Worker 2 (Table III) who used carburetor cleaner which resulted in a high exposure to toluene. Carburetor cleaner contains a high content of toluene. For example, Champion carburetor cleaner manufactured by Chase

Products Co. (Broadview, IL) contained 30–35% of toluene (US Department of Health and Human Services, 2008). Other exposures might have contributed to the exposure variation as well, such as the lack of indoor ventilation (inside a barn or garage) where the maintenance and repair were performed, since fumes released in the air by the solvents could have been deposited onto the skin and onto the solvent sampling pad while working in enclosed areas.

We characterized dermal exposure both with and without the use of gloves. Although there were only two workers who used gloves during the maintenance and repair activities, the exposure was at a similar magnitude as that when no gloves were used. This may suggest that the gloves used were not the right type for protection against solvents, and allowed permeation to occur. PPE, such as respirators, gloves and coveralls are an important and necessary tool to protect workers against solvent exposures. Chang et al. [2007 a] found that urinary concentrations of mandelic acid and methyl hippuric acid, biomarkers for xylene and benzene, respectively, were reduced by 69% and 49% when nitrile gloves and protective suits were worn by spray painters. Previous studies indicate that farmers do not regularly wear gloves or use other PPE types during farm tasks [Branson and Sweeney, 1991; McDuffie et al., 2002; Struttman and Reed, 2002]. Only two out of the ten dermal exposure assessment participants in this study wore gloves (latex). For each solvent, NIOSH and manufacturers recommend specific type of gloves to use. Using the wrong type of gloves will not adequately protect workers from dermal exposures. Education by cooperative extension agents is encouraged to educate farmers on both the use of gloves to prevent exposure to organic solvents and to provide advice on the specific type of gloves recommended for the types of solvents routinely used on the farm.

Nine out of the ten farmers who participated in the exposure assessment performed their farm machinery repair/maintenance tasks in an enclosed area. Even though inhalation exposure assessment of solvents was not performed in this study, inhalation exposure to solvents should also be of concern to farmers. Occupational exposure limits have been established for airborne concentrations of chemicals such as benzene, toluene, *n*-hexane, and xylene which are present in products such as gasoline, carburetor cleaner, mineral spirits, diesel fuel, etc. Also, fumes from chemicals within enclosed areas can be deposited on the skin. Farmers should be made aware of the exposure hazards of organic solvents when utilized in enclosed areas.

In this pilot study we applied a novel approach to quantify dermal exposure to solvents—a small, easy to use, charcoal-based sampling patch. This type of patch is less expensive, and can be used for both qualitative and quantitative assessments. The white strip in the mid section of the charcoal piece changes to gray color when direct contact with organic solvents occurs for qualitative assessment. If

quantitative analysis is desired, the patch can be sent to a laboratory for solvent quantification. If no color change is observed, quantification analysis is not necessary. This will save time and money in conducting dermal exposure assessments.

Dermal patches have been validated and utilized for dermal exposure assessment in a number of worker populations [Mäkinen and Linnainmaa, 2004; McClean et al., 2004; Rajan-Sithamparanadarajah et al., 2004; Chang et al., 2007 b]. Vermeulen et al. [2006] used carbon patches to detect benzene and toluene in shoe manufacturing workers and concluded that skin patches are useful to “quantify the probability of dermal exposure” and to “provide estimates of the potential contribution of the dermal pathway to systemic exposure.” In a study by McClean et al. [2007] of dermal exposure among asphalt roofing workers, the authors thought that dermal exposure was closely associated with absorbed dose. In addition, the authors reported that wind speed and humidity could affect dermal exposure concentrations: wind was negatively associated with exposure and humidity was positively associated with exposure.

Exposure to organic solvents has been associated with neurological effects [Ritchie et al., 2001; Yu et al., 2004], genotoxic effects [Roma-Torres et al., 2006], multiple system health effects [Kaukiainen et al., 2004], cancer [Guo et al., 2004; Strom et al., 2005; Clapp et al., 2008], and liver and kidney damage. In this study, although we did not measure the health effects of solvent exposure, we did survey farmers on their perceived risk of exposure and related illness in the family. A large percentage of farmers ($n = 20$, 65%) were concerned with the potential health damage associated with exposure to organic solvents. However, in practice they did not use adequate personal protection as necessary to reduce the exposures. There is a need to train farmers to modify work practices and to improve their safety knowledge and behavior.

This pilot study design (self-collection of dermal exposure data) was successful in terms of recruitment, and the representation of solvent exposures among Kentucky farmers. Ten of the 31 farmers who completed the survey questionnaire, agreed to participate in the dermal exposure assessment. Since the farmer had to learn about the self-collection procedure, and to self-collect the specimens and complete forms, a considerable amount of valuable time was expended by the farmer (at least 1–2 hr total) so we think that the response rate was very good. While all of the farmers who participated in the dermal exposure assessment were from central Kentucky, we think that this pilot study represents average Kentucky farmers since the average farm size in Kentucky is 162 acres (USDA:Economic Research Service) and our survey questionnaire results determined that the median farm size of the respondents was 185 acres.

There are a number of limitations of the pilot study. First, because of the pilot nature of this study, only a limited

number of workers were surveyed and participated in the dermal exposure assessment. Second, the limited number of patch samples did not allow us enough power to detect significant differences between various exposure factors and to identify exposure determinants. However, the samples we took did provide us a range of exposures and also showed some general trends which are useful to us in designing a large study to assess dermal exposures and exposure-related health risks. Third, since only dermal patches were analyzed, dermal patch concentrations do not represent total dermal exposure; therefore, the concentration results only reflect exposure in a limited area of skin. Fourth, other factors, such as how soon the samples were wrapped and placed in the vial, and if samples were contaminated by workers during sampling, may have also affected the content of solvents analyzed.

Despite these limitations, this pilot study showed that farmers continue to maintain and repair their own farm machinery, and that solvents are being used routinely by farmers for the repair and maintenance of farm machinery and hand cleaning. PPE is not routinely used and dermal exposure of farmers to toluene and xylene during these maintenance/repair activities may be of concern. A comprehensive dermal exposure assessment study of solvent exposure should be performed on farmers. Worker safety practices, including the use of PPE such as nitrile gloves and coveralls, and working in well-ventilated areas when maintaining and repairing farm machinery should be encouraged in farming communities.

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