Int Arch Occup Environ Health (2013) 86:479–488
DOI 10.1007/s00420-012-0776-2

ORIGINAL ARTICLE

Personal air sampling and risks of inhalation exposure during atrazine application in Honduras

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Received: 6 December 2011 / Accepted: 18 April 2012 / Published online: 22 May 2012

Abstract
Purpose To assess occupational inhalation exposure to the herbicide atrazine during pesticide application in a developing country.
Methods Personal air samples were collected during atrazine application using a personal sampling pump equipped with an OSHA Versatile Sampler (OVS-2) sorbent tube. Samples were collected from 24 pesticide applicators in Honduras. Application was observed during sampling, and a survey was completed in the home.
Results Fourteen of the 24 participants used pump backpack sprayers to apply atrazine and 10 used tractor/boom systems. Despite applying about 15 times as much atrazine, the tractor/boom participants (11.5 μg/m^3) had only slightly higher (not statistically significant) time-weighted averages (TWA) than participants using backpack sprayers (9.6 μg/m^3). Within the backpack sprayer group, those that used a cone spray nozzle (11.54 μg/m^3) had nearly double the TWA than applicators using a flat spray nozzle (5.98 μg/m^3; $P = 0.04$). In the tractor/boom group, the participants that rode on the boom or the back of the tractor monitoring nozzles (15.0 μg/m^3) had almost double the average TWA than tractor drivers (8.0 μg/m^3; $P = 0.097$).
Conclusions Since tractor/boom pesticide application decreases the number of man-hours required to apply pesticides, and does not increase inhalation exposure significantly, it decreases the overall population occupational exposure. Monitoring nozzles on booms from a distance rather than on the back of a tractor or boom may decrease or eliminate inhalation exposure. Use of flat spray nozzles for herbicide application among pump backpack sprayers may reduce their inhalation exposure.

Keywords Pesticide exposure · Honduras · Central America · Herbicide · Inhalation exposure · Atrazine · Pesticide exposure assessment

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Introduction

From 1994 to 2000, the quantity of pesticides imported into the Central American isthmus increased steadily from 34 to 45 million kilograms, due to increased herbicide use throughout Central America (Henao and Arbelaez 2002). In 1992, little or no triazine derivates were imported into Central America. However, by 1998, nearly 600,000 kilograms of triazine derivates were being imported into the Central American isthmus annually (Galvao et al. 2002).

Most studies of pesticide exposure and related health effects in Central America have focused on highly toxic pesticides and acute pesticide poisonings, while few have assessed chronic exposure and inhalation exposure during application. Also, most research on health effects of pesticides has taken place in Costa Rica and Nicaragua, and little is known about the rest of Central America (Wesseling et al. 2001). Dowling et al. (2005) and Rodríguez et al. (2006) used urine samples from farmers and family members in Nicaragua to assess exposure to the insecticide chlorpyrifos among small-scale farmers and banana plantation workers.

Dermal exposure to chlorpyrifos and methamidophos of 32 farmers in Nicaragua using motorized or manual backpack sprayers was most frequently observed on the front and back of the hands (>87 %), the front side of the left forearm (75 %), and the back of the trunk (75 %; Aragón et al. 2006). In this study, concerns were raised about drift of pesticide mist and inhalation exposure, but personal air sampling during pesticide application was not done.

In Honduras, Steinberg et al. (1989) used serum pesticide concentrations to show that mean DDT and DDE blood levels were higher in the exposed group, but not statistically significantly so. These levels were within the range found in the general population in the United States at the time (Steinberg et al. 1989). Keifer et al. (1996) studied pesticide drift and environmental exposure among general populations not involved in pesticide application in Nicaragua where aerial application was common. Mean cholinesterase activity levels were significantly lower (indicating more exposure) in residents living near cotton fields than in the control community. The cotton field exposure group also reported more chronic and acute symptoms. No exposure studies have focused on the widely used herbicide atrazine in Central America (Wesseling et al. 2005).

Multiple studies have shown associations between atrazine and deleterious human health effects such as preterm delivery (Savitz et al. 1997), spontaneous abortion (Arbuckle et al. 2001), prostate cancer in black males (Mills 1998), non-Hodgkin's lymphoma (Weisenburger 1990; Zahm et al. 1993), ovarian neoplasms (Donna et al. 1989), birth defects (Winchester et al. 2009), and abdominal wall defects (Mattix et al. 2007). Atrazine has also been shown to act as an endocrine disrupting compound in various animal studies (Cooper et al. 2000; Hayes et al. 2003; Kniewald et al. 2000; Rodriguez et al. 2005; Wetzel et al. 1994).

Dermal exposure to atrazine (and other pesticides) during handling and application is of particular concern. Ikonen et al. (1988) showed that while atrazine metabolites in urine samples correlated with the dust dose in breathing zone samples among railway weed operators, urine metabolite concentrations indicated that a major part of atrazine had been absorbed by another route, likely dermal. Subsequently, Ademola et al. (1993) demonstrated that roughly 16 % of applied atrazine doses were absorbed by human skin in vitro.

There are typically two agricultural seasons in Honduras and these seasons vary by region, crop, and land characteristics. Corn production during 'Primera' runs from May to October and produces about 80 % of the corn in Honduras (personal communication, Aug. 13, 2008). 'Postrera' lasts from November to March, producing about 20 % of the total corn, and yield is approximately 30 % lower due to poorer weather conditions (personal communication, Aug. 13, 2008).

In 2007, approximately 95,000 acres of corn were planted in the Department of Olancho, Honduras (personal communication, August 13, 2008). According to staff at the Regional Secretary of Agriculture and Livestock (SAG—from its initials in Spanish), corn producers in Olancho typically apply 0.9–1.3 pounds of atrazine per acre (personal communication, August 13, 2008); atrazine is the most commonly used corn herbicide, and this is the application rate recommended by SAG technicians in the field.

In developed countries, most agricultural pesticide application is done in tractors with enclosed cabs with closed windows. Frequently, pesticides are mixed in enclosed systems with little direct contact. Commercial applicators in Iowa (Lozier et al. 2011) reported that they were only exposed to pesticides when a nozzle clogged on their sprayer or when they were mixing pesticides in the shop. Consequently, it is believed that the primary route of exposure for these applicators was dermal. In Honduras conversely, with the extensive use of backpack sprayers and very few tractors with enclosed cabs, it is likely that dermal and inhalation routes of exposure are both significant. This study aims to quantify the inhalation exposure of Honduran farmers and farm workers to atrazine during the application process. The study identified determinants of inhalation exposure among pesticide applicators and offers strategies to reduce airborne exposures. While atrazine is the central focus of this study, it can be used as a surrogate for other pesticides routinely applied using similar application methods.

Materials and methods

This study took place in the department of Olancho, Honduras, during the first agricultural season (Primera), from May to July 2009. The study population was a convenience sample. The pesticide applicators were recruited using nine agrochemical vendors in Juticalpa and the assistance of staff of the regional Secretary of Agriculture and Livestock (SAG for its name in Spanish) office, also located in Juticalpa. People who purchased atrazine products from one of the nine agrochemical vendors were compiled into lists and contacted. In addition to the lists from the atrazine vendors, a SAG agronomist helped identify areas where corn was produced and introduced study personnel to corn farmers in the region and participants were recruited by word of mouth. To be eligible for the study, the pesticide applicator had to plan to apply atrazine during the Primera agricultural season. The participant could be either a landowner/corn producer or a hired farm-worker. For logistical reasons, the study population came from approximately a 30-mile radius around Juticalpa, the departmental capital.

Once a participant was enrolled in the study, a field surveyor accompanied the participant on the day that atrazine was applied. Atrazine application methods were observed and a personal air sample was collected. Each participant was equipped with an OSHA Versatile Sampler (OVS-2) sorbent tube (SKC, Eighty-Four, PA) containing XAD-2 resin with an 11-mm quartz fiber filter and polyurethane foam (PUF). A personal sampling pump, calibrated to 1 L/min, was attached to the sampling tube and the belt of the applicator. The amount of atrazine applied, number of acres sprayed with atrazine, duration of spraying, equipment used, type of spray nozzle used, and clothing worn were recorded. Field blanks were collected for quality control purposes. Samples were transported from the field in coolers with ice packs and transferred to a refrigerator for storage. Samples were shipped to Battelle Northwest Laboratory in Columbus, Ohio, for analysis.

A questionnaire was completed with the pesticide applicator and his family during a different visit to the participant's home. The questionnaire contained questions related to pesticides used, quantities used, frequency used, which members of the household worked directly with the pesticides, the type of spray equipment used to apply pesticides, personal protective equipment used, laundering practices of work clothes, and other general information about the house and agricultural practices. During the visit to the home, urine samples were collected from the atrazine applicator, spouse, and up to 3 children. These biological monitoring results and a more in-depth investigation of potential dermal exposure will be presented in a different article.

This research protocol and all English and Spanish documents associated with it were approved by the IRB committee at the University of Iowa as well as the Ethics Committee at the Honduran National University in Tegucigalpa, Honduras. All pesticide applicators and their spouses that participated in this study provided written informed consent prior to participation.

The personal air sample sorbent tubes were analyzed by Bureau Veritas North America, Inc. using high performance liquid chromatography according to a modified OSHA Stop-gap procedure (OSHA 2005). The individual sections of the OVS-2 tube were removed and placed into separate test tubes. The glass fiber filter was included with the front sorbent section of the tube. The foam plugs that separated the sections were discarded. The individual sections were then chemically desorbed using 2 mL of acetonitrile. The samples were capped and placed on a mechanical shaker for 30 min. After desorption, the samples were transferred to auto-sampler vials and analyzed by high performance liquid chromatography. Three field blanks were tested and atrazine was not detected in them. Three sets of laboratory control spike (LCSILCSD) pairs were prepared and analyzed with this subsequence. The recoveries were all within the default limits of 80–120 %. The average recovery was 89.69 %. The sample results and blind spikes were recovery-corrected with the average recovery of the LCS pairs. Two blind spikes were prepared and analyzed in replicate with this subsequence. The recoveries were all within the default limits of 80–120 %. The replicate analyses were all within the 20 % relative percent difference limit. The results were reported in micrograms (μg), per sample. The limit of detection (LOD) was 0.1 μg/sample, and results that were reported as less than the LOD were given the value 0.05 μg/sample (LOD/2).

Time-weighted averages (TWA) were calculated for each sample using the average of the before and after flow rates and the total minutes during which each sample was taken. Descriptive summary statistics were used to describe the central tendency and variance of each variable measured. Linear regression and analysis of variance (ANOVA) were used to determine whether atrazine handling and other personal practices influenced the levels of atrazine found in personal air samples. All statistical analyses were performed using SAS system software, version 9.2 (SAS Institute, Inc., Cary, NC). All significance testing was performed at the 0.05 level of significance.

Results

Twenty-four pesticide applicators participated in this study. All of the pesticide applicators that participated in the study were male with an average age of 36.5 years (SD = 11). The average years of formal education among the pesticide applicators was 5.1 (SD = 4), and 58 % of the pesticide applicators reported that they could read and write.

Farming practices

Manual backpack sprayers were used by 14 (58 %) of the participants to apply atrazine and other pesticides, while 10 (42 %) applied pesticides using a tractor and boom (Fig. 1). Five of the participants who applied with tractor/

Fig. 1 *Left*: Study participants applying atrazine to corn using backpack sprayers. *Right*: Study participants applying atrazine to corn using tractor and boom

boom worked as tractor drivers and five worked on the side of the boom or on top of the tractor wheel cover to observe the nozzles and raise and lower the boom arms. Table 1 compares general farming information between the backpack sprayers and the tractor/boom sprayers.

Pesticide use and application

About a third of the participants reported checking the direction of the wind before beginning the application. However, this practice had no effect on the application method. Atrazine and other pesticides were always applied walking or driving in the direction of the corn rows while spraying in both directions. They would never stop spraying in one direction due to the wind because it would be too costly and time inefficient. Backpack sprayers reported lowering the height of the spray apparatus when they were spraying into the wind in an effort to reduce spray from getting on their clothing or in their face.

Field observations and personal air samples

During the in-home surveys, backpack sprayers reported using long-sleeved shirts more often than tractor/boom applicators. However, this was not observed in the field where no significant difference was seen (Table 2). In the case of wearing rubber boots, the field observations coincided with the survey results (Table 2).

One personal air sample was taken from each of the 24 participants while they applied atrazine. All of the field blanks were below the analytical limit of detection. There were 14 participants who applied atrazine with a backpack sprayer while 10 applied with a tractor/boom. Of the 14 using backpack sprayers, 9 were observed using cone spray nozzles for application, while the other 5 used flat spray nozzles (Fig. 2). Five of the participants on the tractor/boom were tractor drivers, another five were observers who rode on the back of the tractor or on the boom.

Atrazine was always mixed in the field while some other pesticides were mixed before going to the field. In some cases, other pesticides were added to the tank and applied simultaneously with atrazine. During air sampling and field observations, the following pesticides were mixed with atrazine for some of the participants: glyphosate (herbicide), picloran + 2,4,D (herbicides), deltamethrin + triazophos (insecticides), nicosulfuron (herbicide), and pendimethalin (herbicide). Participants also reported applying paraquat, organophosphate insecticides, and pyrethroids using the same methods observed in this study. Water was most often hauled to the field on a tractor or truck from between 500 m and 2 km away. There were a

Table 1 Mean general demographic and farming data compared between backpack sprayers and tractor/boom applicators

Parameter	Backpack sprayers ($n = 14$)	Tractor/boom applicators ($n = 10$)	P value[a]
Years living in current town	31.8	25.9	0.38
Age (years)	37.3	35.4	0.69
Years of formal education	3.3	7.7	0.005
Years farming corn	13.6	10.7	0.56
Acres of corn planted last year	2.6	56.2	0.08
Corn yield last year (bushels/acre)	54	84	0.31
Corn used for household consumption (bushels)	27	28	0.95
Corn sold (bushels)	177	9,630	0.11
Price of corn sold (dollars/bushel)	$2.84	$2.22	0.42
Number of years that you have been applying pesticides to your corn	13	14	0.75
Acres of corn planted during Primera	1.3	53.7	0.01
Acres of corn planted during Postrera	0.43	5.1	0.13
Daily work duration when working in corn field (hours)	5.6	10	0.0002

[a] P value was calculated in SAS using PROC TTEST

Table 2 Observed clothing in the field during atrazine application

Pesticide application clothing	Percent backpack sprayers ($n = 14$)	Percent boom sprayers ($n = 6$)	P value[a]
Footwear			
Rubber boots	79	17	0.02
Other boots or shoes	21	83	
Leg wear			
Pants	100	83	0.30
Coveralls	0	17	
Shirt			
Short sleeve	71	50	0.61
Long sleeve	29	50	
Head wear			
Wide brim hat	29	17	0.48
Baseball cap	71	66	
None	0	17	

[a] P values were calculated in SAS using Fisher's Exact Test

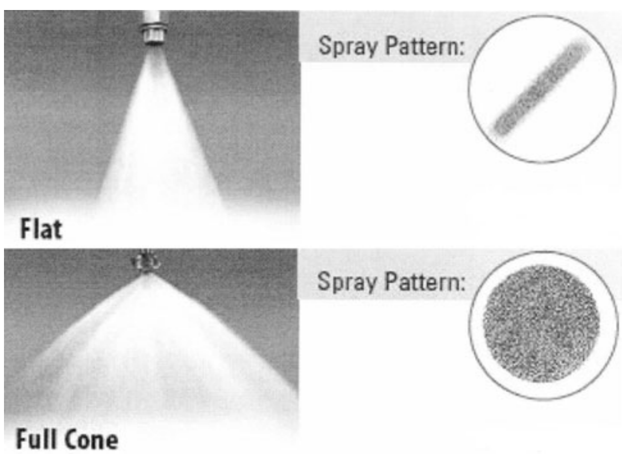

Fig. 2 Flat-spray nozzles and cone spray nozzles apply pesticides in a different pattern (*Source*: Spraying Systems Co.)

few fields where water was available nearby in the form of small streams or wells. Atrazine was manually mixed with water in a 5-gallon bucket and then added to either the backpack sprayer or boom tank (Fig. 3). No one was observed using gloves during pesticide mixing. All mixers except one were observed using a stick to mix the atrazine solution in a 5-gallon bucket, the other used his bare hand. When the atrazine solution was added to the boom tank and then water was added to fill the rest of the tank and dilute the solution, large amounts of foam were produced. Many participants were seen removing this foam with their bare hands (Fig. 3). Frequently, a cloth or piece of fabric was used to filter the atrazine solution as it was poured into the

Fig. 3 *Top left*: A sardine can was the most common unit of measurement for atrazine mixing for backpack sprayers. *Top right*: Mixing atrazine in a 5-gallon bucket for tractor/boom application. *Bottom*: Applicator using his bare hand to remove foam formed from an atrazine solution; water hauled to the field in pickup truck; a 14-year-old boy hauled the water in the truck and helped mix atrazine

tanks. This cloth was usually wrung out and handled with bare hands.

Table 3 compares atrazine handling and time-weighted average (TWA), inhalation exposure between backpack sprayers and tractor/boom applicators. During the sampling period, the backpack sprayers applied atrazine to about one-tenth the number of acres, applied approximately one-fifteenth the amount of atrazine by weight, and applied about 35 % less atrazine per acre than tractor/boom applicators. Despite using only one-fifteenth of atrazine by weight, the average TWA for backpack sprayers (9.6 µg/m^3) was slightly less than the average TWA for tractor/boom applicators (11.5 µg/m^3; $P = 0.42$).

While there was not a significant difference in the TWA of backpack sprayers and tractor/boom applicators, there were associations between TWAs and work practices within each group (Fig. 4). Among backpack sprayers, those who applied atrazine with a cone spray nozzle had nearly double the mean TWA ($\bar{x} = 11.54$ µg/m^3) compared to applicators using flat spray nozzles ($\bar{x} = 5.98$ µg/m^3; $P = 0.04$). Within the group of applicators who used tractor/boom application systems, workers who were either on the boom or on the back of the tractor ($\bar{x} = 15.00$ µg/m^3) had almost twice the exposure of the tractor drivers ($\bar{x} = 8.01$ µg/m^3; $P = 0.097$).

Table 3 Personal air sampling done during atrazine application to corn fields

Variable	Central tendency	Backpack sprayers ($n = 14$)	Tractor/boom applicators ($n = 10$)	P value
Acres applied during air sampling	Mean	2.3	24.4	<0.0001
	SD	0.73	15.5	
	(Range)	(1.4–3.4)	(5.2–48.2)	
Atrazine applied during air sampling (grams)	Mean	947	13,805	<0.0001
	SD	354	10,173	
	(Range)	(459–1,606)	(2,850–30,000)	
Pounds of atrazine applied per acre	Mean	0.926	1.29	0.047
	SD	0.33	0.52	
	(Range)	(0.64–1.49)	(0.88–2.10)	
Mean atrazine exposure (μg/m^3)	Mean	9.6	11.5	0.42
	SD	5	6.7	
	(Range)	(4.3–18.4)	(3.5–23.8)	

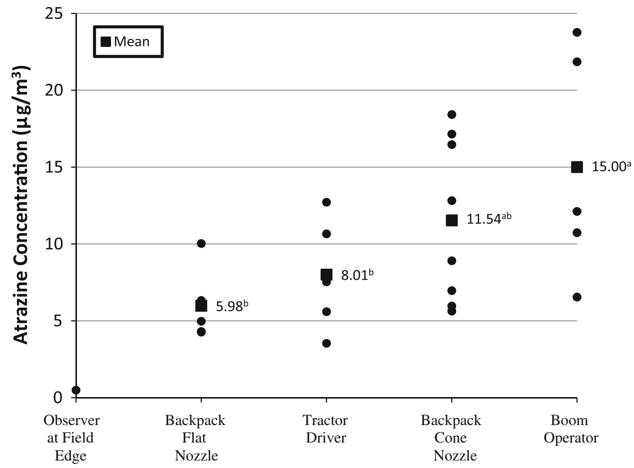

Fig. 4 Personal air sampling atrazine concentrations by category of pesticide application. Mean atrazine concentrations with the *same superscript letter* are not significantly different at $P = 0.05$ (PROC GLM in SAS)

Personal air samples were obtained from two other workers and were not included in the analysis due to not meeting the criteria. However, their TWA levels are important. One was a backpack sprayer who did not apply atrazine, but was in a field with four other backpack sprayers that were applying atrazine. This worker was approximately 1–30 m away from the atrazine applicators at all times. Despite not actually spraying atrazine, this applicator's TWA was 1.41 μg/m^3. Being in the field during atrazine application resulted in inhalation exposure to atrazine. The other personal air sample that was not included in the analysis came from a boom observer who stayed at the edge of the field (>50 m from the tractor) during atrazine application. The TWA for this worker was the only sample that was below the limit of detection (Fig. 4).

Regression analysis showed that there was no significant association between atrazine TWAs and atrazine handling variables such as acres applied with atrazine, pounds of atrazine applied, and number of tanks of atrazine applied.

Seasonal atrazine application

Tractor/boom participants reported applying atrazine an average of 3.3 days during the 2009 "Primera" corn production cycle, compared to 5.2 days for those using backpack sprayers (Table 4). However, three of the 14 backpack sprayers averaged 18.3 days of application, while the other 11 applied atrazine an average of 1.6 days. The three backpack sprayers averaging 18.3 days worked for a farmer whose tractor needed repair. The replacement piece had not been imported yet, and the farmer could wait no longer so they applied atrazine to 100 acres using backpack sprayers. Assuming these three workers would apply atrazine at the average rate of the tractor/boom applicators of this study (20 acres/day), it would have taken them approximately 5 days of tractor/boom application to cover the 100 acres they sprayed in 18 days. It is also likely that only two workers would be needed to operate the tractor and boom, rather than the three that applied with backpack sprayers. A functioning tractor would have reduced total exposure days from 54 (18 days × 3 workers) to 10 (5 days × 2 workers).

Discussion

This study shows that the time-weighted average (TWA) inhalation exposure risk of atrazine applicators depended more on worker duties and nozzle type than the quantity of atrazine applied. Atrazine handling variables such as kilograms of atrazine applied or acres applied with atrazine were not associated with TWA inhalation exposures, but nozzle type for backpack sprayers and job duties for tractor/boom applicators did affect exposure.

Flat spray nozzles spray pesticide mixtures in droplets in a 2-dimensional curtain and are designed to help create a film over the entire soil surface. According to an agronomist that worked with the regional SAG office, flat spray

Table 4 Average atrazine usage of participants over the entire "primera" production season

Workers	Days atrazine applied (SD)	Hours atrazine applied (SD)	Kilograms of atrazine applied (SD)	Acres applied	Acres/day (SD)
Backpack sprayers (14)	5.2 (7.4)	24.9 (37.7)	4.4 (5.4)	10.1 (12.3)	2.4 (0.6)
Malfunctioning tractor (3)	18.3[a] (4.6)	92.2[c] (23.1)	14.1[f] (3.1)	31.5[h] (7.7)	1.7[j] (0.0)
Regular backpack sprayers (11)	1.6[b] (0.9)	6.5[d] (3)	1.8[f] (0.9)	4.3[h] (3.1)	2.5[j] (0.6)
Tractor and boom applicators (7)	3.3[b] (1.4)	19.4[d] (10.3)	67.6[e] (35.4)	65.1[g] (43.3)	19.8[i] (12.1)
P value[a]	<0.0001	<0.0001	<0.0001	0.0004	0.0002

P value was calculated using PROC GLM in SAS comparing "malfunctioning tractor," "regular backpack sprayers," and "tractor and boom applicators." In columns, values with different letters differ significantly

nozzles are recommended for herbicide application because they are more effective at creating a film of herbicide over the entire ground surface (personal communication, June 2009). Cone spray nozzles spray pesticide mixtures in a cone-shaped, 3-dimensional form and are not recommended for herbicide application. They create more of a pesticide mist and are designed for targeted spraying, which is more ideal for insecticides and fungicides. Despite these recommendations, two-thirds of the backpack sprayer participants were observed using cone spray nozzles to apply the herbicide atrazine. During field observations, pesticide applicators with cone spray nozzles were seen swinging their arm and spray apparatus back and forth in order to create the desired herbicide film causing their inhalation exposure to increase. This practice also likely increased dermal exposure by dousing the skin and clothes of these applicators. Backpack sprayers using flat spray nozzles were observed holding their spray apparatus and nozzle steady at a fixed height in order to get the best results.

Boom operators had the highest exposure as a group because they worked in close proximity to pesticide application booms where large quantities of pesticides were sprayed. Efforts to reduce boom operator exposure are clearly needed. It is recommended that the boom operators observe the boom spraying apparatus from a distance whenever conditions allow. One of the boom monitors observed the atrazine application from the edge of the corn field rather than mounted on the boom or the back of the tractor. While this was only one participant, his TWA was the only one below the analytical limit of detection.

While it is intuitive that removing the worker from the boom area is the most effective way to reduce inhalation exposure, observing from a distance is not always possible. The one participant who did observe from the edge of the corn field could do so for three following reasons: (1) The corn had not germinated in the field, allowing an unobstructed view of the boom and nozzles, (2) Prowl, a yellowed-colored herbicide, was mixed with atrazine, making it easier to notice a malfunctioning nozzle from far away, and (3) The boom arms had hydraulic levers and the tractor driver could raise and lower them with a switch. Other tractor and boom application systems that were observed required that the worker be mounted on the boom for one of two following reasons: (1) The corn plants were too tall and a malfunctioning nozzle could not be spotted from a distance or (2) The systems did not have hydraulics so the boom arms were manually raised and lowered using a pulley system. Therefore, when a worker must be mounted on the boom, it is recommended that the worker use long pants and long shirts at all times, and also use a handkerchief or mask to reduce inhalation exposure. Also, when possible, the worker should sit on the tractor wheel cover or the back of the tractor to be further away from the spray apparatus. Other studies in the past have recommended more effective personal protective equipment (PPE) such as chemical protective clothing or respirators. However, these items are usually prohibitively expensive (Clarke et al. 1997) in developing countries, and there is evidence that in Central America PPE is ineffective due to heat, perspiration, and work practices (van Wendel de Joode et al. 1996; Wesseling et al. 2001; Aragón et al. 2001).

Backpack spraying will continue to be a very large part of pesticide application in developing countries for many years due to the high cost of tractor/boom application and terrain. Therefore, it is necessary that backpack sprayers use the correct nozzle for the pesticide being sprayed. Workers often do not own their own backpack sprayers and can rarely control which kind of nozzle is in place. They also do not have enough money to purchase the recommended nozzle for each pesticide application. Nozzles are typically only available at agronomy stores in larger towns or cities that can be up to 2 h away by bus (more for other regions of the country). The Honduras Secretary of Agriculture and Livestock operates many agricultural extension programs to education farmers and provide seeds. Programs to educate farmers regarding proper nozzle usage and providing nozzles to pesticide applicators could greatly decrease airborne (both inhalation and dermal) exposure to hazardous pesticides. Using the correct nozzle would also increase the pesticide efficiency and possibly the crop yield.

Aragón et al. (2001) reported that the educational level of independent farmers in the Northern Pacific Plain of Nicaragua is typically not higher than primary school and their illiteracy rate is 40.3 %. This is similar to the participants in this study whose average formal education was 5.1 years and 42 % self-reported that they cannot read or write.

In both Aragón et al. (2001) and this study, pesticides were mostly purchased in retail chemical stores, and pesticide applicators were observed repairing backpack sprayers and touching the nozzles with their bare hands in the field (Fig. 5). Similarly, farmers in Nicaragua and Honduras stated that they were aware of the risks involved with pesticide exposure, but that was not demonstrated by their practices. The belief that pesticides are a necessary ingredient to successful farming was prominent in both studies.

A study assessing exposure to herbicides among pesticide applicators along electric power transmission line right-of-ways observed that using hand-held application equipment is more liable to result in exposure than other application methods (Libich et al. 1984). The current study showed that despite using much less atrazine, backpack sprayers were exposed to almost the same amount of airborne atrazine and most likely have an increased risk of dermal exposure due to their proximity to the pesticide mist during application. Some boom operators also reported their clothes being soaked in pesticide after applying all day, indicating high risk of dermal exposure. We also observed significant dermal exposure during atrazine mixing and repairing clogged nozzles.

Fig. 5 Dismantling and repairing the nozzle of a backpack sprayer that had become clogged, most likely because of debris in the water. Gloves were not used, nor available

Despite there being a clear pattern of inhalation exposure among these categories of atrazine applicators, the TWA of the highest exposure group (boom operators) is still relatively low. The threshold limit value (TLV) for atrazine is 5 mg/m^3; about 500 times higher than the study-wide TWA (ACGIH 2001). However, Baharuddin et al. (2011) demonstrated that while inhalation exposure to 2,4-D and paraquat (both herbicides) was below the permissible exposure limits, dermal exposure assessment among those using manual sprayers ranged from moderate to high using the Dermal Exposure Assessment Method (DREAM). This indicates that participants in the current study may have experienced high dermal exposure, despite such low TWAs.

While this paper focused primarily on inhalation exposure, further discussion of dermal exposure and prevention is warranted. While the use of rubber boots is seen as a protective measure, this type of boot can actually increase dermal exposure in some cases. If atrazine solution enters into the boot, it will stay in that boot, and in contact with the applicator's skin, until the boot and sock are removed. Consequently, the rubber boot can serve as a reservoir of pesticide solution and greatly increase the dermal absorption of pesticide (Spiller et al. 2003). Workers must be cautious to keep pesticides from entering the boot and if they do, remove the boot immediately and rinse thoroughly. Changing socks at this time would also reduce the potential for dermal exposure of this kind.

Dermal exposure can be reduced or prevented entirely by adapting work habits and using cost-effective personal protective equipment. During mixing and loading, pesticide solutions should never be mixed with a bare hand. Observed practices in this study of using a stick or broom handle work well at accomplishing this. Many times workers were seen removing pesticide solution foam from the mouth of the boom tank. This is unnecessary. When boom tanks overflow with foam and solution, efforts should be made to avoid contact with the overflow. Frequently, when the atrazine solution was added to backpack sprayer tanks, a cloth filter was used to keep debris out of the tank to avoid clogging the nozzle. When this type of filtration is used, the cloth filter or rag should not be handled with bare hands. If pesticide solution does need to be touched, disposable gloves should be used.

During pesticide application, there are various ways to reduce dermal and inhalation exposure alike. Using appropriate nozzles correctly was been shown to reduce inhalation exposure and could go a long way to reduce the potential for dermal exposure. Whenever possible, the worker should observe the boom from a distance. It is very important to use gloves when unblocking nozzles when they do get clogged by debris. Lastly, bring a change of clothes to the field is a good way to reduce dermal exposure. That way, when a worker is doused with pesticide spray, they can change into clean clothes so that their skin is not in constant contact with contaminated clothing.

Atrazine may serve as a surrogate for other, more acutely toxic pesticides. For example, work practices and hygienic factors found to be associated with atrazine in personal air samples are likely to also be associated with exposure to other similarly handled and applied pesticides. It is likely that workers are exposed to a wide variety of pesticides that are handled and applied using methods similar to those observed in this study. Consequently, they are almost certainly exposure to more acutely toxic pesticide mixtures. Interventions developed from the results of this study to control exposure to atrazine could also control exposure to other, more toxic pesticides.

Wesseling et al. (2001) recommended that strategies to control pesticide exposure should focus on eliminating or reducing the use of highly toxic pesticides rather than training and supplying personal protective equipment. This is consistent with the findings in Aragón et al. (2001), and this study, which showed that despite knowledge of the risks of pesticide exposure, pesticide applicators rarely change their behaviors. However, this study showed that there are differences in exposure depending on the equipment used and as long as pesticides are part of agriculture, training applicators to use appropriate equipment and modify their work practices may reduce exposure.

Conclusion

The introduction of tractor/boom pesticide application in the last few decades could reduce inhalation exposure to applicators because they can apply pesticides to more acres in fewer hours and are further removed from the spraying apparatus. However, boom operators had the highest measured time-weighted averages (and likely dermal exposure), and interventions should target this population accordingly. Tractor/boom technologies are only available to wealthier farmers in Honduras. The working poor who apply pesticides are disproportionally exposed to greater quantities of pesticides due to the continued use of backpack sprayers and the fact that it takes more man-hours to spray the same number of acres with a backpack sprayer than with a tractor and boom. An intervention to train backpack sprayers and SAG extension workers about the correct nozzle choice for different pesticides has the potential to reduce pesticide exposure among this population. This type of intervention must make nozzles more affordable and available in rural areas at the point of use in order to be effective.

Acknowledgments We are thankful to the Honduran Secretary of Agriculture and Livestock (Secretaria de Agricultura y Ganaderia—SAG) regional office in Juticalpa, Olancho, especially, the regional director, Ing. Gustavo Gomez Amador. We also extend our sincerest gratitude to SAG Ing. Jose Francisco Lopez Montoya. Without his assistance, this study would not have been possible. We are thankful to Dr. Jackeline Alger of the Antonio Vidal Institute of Infectious Diseases and Parasitology in Tegucigalpa, Honduras, for her assistance in navigating the research infrastructure in Honduras, Dr. Denis Padgett Moncada and the other members of the Ethics Committee at the Honduran National University, and Leda Lozier for her work in the field and the laboratory. We also thank Bureau Veritas North America for their work in sample analysis. This research was supported by a pilot project research training grant from the Environmental Health Sciences Research Center at the University of Iowa. The Heartland Center, an Education and Research Center, is supported by Training Grant No. T42OH008491 from the Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health.

Conflict of interest The authors declare that they have no conflict of interest.

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