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Pesticides Present in Migrant Farmworker Housing in North Carolina

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Abstract

Background—Migrant farmworkers are exposed to pesticides at work. Housing provided to migrant farmworkers may also expose them to pesticides, increasing their health risks. This analysis (1) describes the presence of organophosphorous (OP) and pyrethroid pesticides in North Carolina migrant farmworker houses, and (2) delineates associations of farmworker camp characteristics with pesticide detection and concentration.

Methods—In 2010, 186 migrant farmworkers camps in NC were recruited (participation rate of 82.3%); pesticide wipe samples for 176 houses were analyzed. Tobacco is the predominant hand-harvested crop in this region. Two farmworkers per camp completed interviews; a third assisted with a housing inspection. Gas chromatography–mass spectrometry was used to detect OP and pyrethroid pesticides. Covariates of pesticide detection and concentration were determined with ANOVA and Tobit regression.

Results—OPs were found in 166 of 176 houses (average of 2.4/house); pyrethroids were found in 171 houses (average of 4.3/house). The number of different OPs detected in each camp and concentrations of these OPs were not associated with camp and housing characteristics. The number of different pyrethroids detected in each camp and concentrations of these pyrethroids were associated with camps having residents with H2-A visas, a posted North Carolina Department of Labor Certificate of Inspection, no barracks, fewer residents, no bedroom weather protection or floor violations, and no roaches.

Conclusions—Farmworkers are exposed to pesticides where they live. Policy on removing pesticides from farmworker houses is needed. Reducing pesticides in farmworker houses will reduce one health risk confronted by this vulnerable population.

Keywords

health disparities; vulnerable population; occupational exposures; environmental exposures; agricultural workers; immigrant workers

INTRODUCTION

Farmworkers are exposed to a broad range of pesticides. High levels of pesticide biomarkers have been measured for farmworkers [Arcury et al., 2010] and for members of their families [Coronado et al., 2004; Bradman et al., 2011; Huen et al., 2012]. Exposure to these pesticides can affect the immediate and long-term health of migrant farmworkers [Reigart and Roberts, 1999]. Long-term health effects include increased risks for cancer [Alavanja et al., 2004], respiratory disease [Valcin et al., 2007], neurological disease [Starks et al., 2012], and reproductive problems [Swan, 2006; Perry et al., 2011]. Farmworkers experience pesticide exposure in their houses as well as at work, adding to the potential health effects. Pesticides have been measured in the houses of farmworker families in California [Harnly et al., 2009; Quirós-Alcalá et al., 2011], Oregon [McCauley et al., 2006], Washington [Lu et al., 2000; Curl et al., 2002; Coronado et al., 2010], and western North Carolina (NC) [Quandt et al., 2004]. The specific pesticides in farmworker family houses have changed as the number of organophosphorous (OP) pesticides registered for use has declined and the use of pyrethroid pesticides has increased.

Pesticide exposure in migrant farmworker housing in the eastern US has not been examined. Migrant farmworkers differ from seasonal farmworkers in that migrant farm-workers move to temporary houses at least 75 miles from their permanent houses to work seasonally in agriculture [Carroll et al., 2005]. Migrant farmworkers have little control of their housing; therefore, it deserves special consideration. Housing provided for migrant farmworkers by their employers is often in extremely poor condition [Ziebarth, 2006; Vallejos et al., 2011]. NC migrant farmworker housing generally violates current regulations establishing minimum quality standards [Arcury et al., 2012a], and often does not provide farmworkers conditions conducive to basic safety, hygiene, or privacy [Arcury et al., 2012b]. NC migrant farmworker camps have an average of 11.4 housing violations, with a range of 4–22 violations. Kitchens in these camps often have pest infestation; refrigerators in two-thirds do not maintain an appropriate temperature [Quandt et al., 2013]. Drinking water in one-third of the camps is contaminated [Bischoff et al., 2012].

Documenting the extent to which environmental pesticides are present in migrant farmworker housing is important. Clinically, residential as well as occupational exposure should be considered when evaluating migrant farmworker health. Pesticide exposure among the members of vulnerable populations, such as farmworkers, is a matter of environmental justice. Farmworkers have no control of the pesticides applied at their work [Arcury et al., 2002]. Migrant farmworkers are not provided with information about

pesticides applied in housing supplied by their employers. Although they face considerable risk from exposure, farmworkers receive relatively low rewards for the pesticide hazards they experience [Robinson et al., 2011].

This analysis has two aims. First, it describes the presence of OP and pyrethroid pesticides in NC migrant farmworker houses. Second, it delineates the associations of migrant farmworker camp and housing characteristics with the presence of these pesticides.

METHODS AND MATERIALS

Participants

This study was conducted in 16 counties in east-central NC where a large number of farmworkers are employed. Tobacco is the predominant hand-harvested crop in this region, with farmworkers also employed for planting and harvesting cucumbers, sweet potatoes, and other vegetable and fruit crops. The counties are served by the organizations that participated in the research: NC Farmworkers Project, Carolina Family Health Center, Kinston Community Health Center, and Piedmont Health Services. The study focused on employer-provided housing occupied by migrant farm-workers referred to as camps. Lists of camps were obtained from partner organizations. These lists were expanded as new camps were encountered during data collection. All identified camps were asked to participate in the study. A total of 186 camps was enrolled in the study, with a participation rate of 82.3% (186/226). Residents in 36 camps declined to participate, and the grower or contractor refused to permit participation in four other camps. Camps that participated in the study were given a volley ball as a token of appreciation. Residential pesticide data could not be collected in 10 of the 186 camps, so the final sample included 176 camps.

The project was described to the residents of each camp, and the data collectors asked that three camp residents volunteer to participate. Two farmworkers completed interviews that provided information on potential health characteristics associated with housing quality, as well as their perceptions of the housing in which they lived. One farmworker was needed to guide the data collectors in conducting an inspection of the camp housing; this included an inspection of the general camp grounds, kitchen and dining facilities, bathing facilities, laundry facilities, and bedrooms [Arcury et al., 2012a,b]. The number of buildings inspected varied with the size of the camp, with most camps (61.1%) having only one building, 20.0% having two buildings, and 18.9% having three or more buildings. All the participants spoke Spanish; 68 (18.3%) also spoke an indigenous language. The final sample included 371 men who completed interviews and 182 men who assisted in the housing assessments; 231 men refused to participate when asked. The participation rate of 70.5% (553/784) could have been lower as individuals who did not want to participate could avoid the recruiters. Farmworkers who completed the interviews and who helped with the assessment were each given a \$30 cash incentive. This research was approved by the Wake Forest School of Medicine IRB. All study participants provided written informed consent.

Data Collection

Data were collected from June through October 2010. Data are from three study components: (1) interviewer administered questionnaires; (2) housing assessments; and (3) wipe samples to assess residential pesticide exposure. Data collection forms were developed in English and translated into Spanish by a native Spanish speaker. The forms were reviewed by staff members of the community partners who were native Spanish speakers. Revised forms were field tested.

Interviews and housing assessments were completed by trained staff members who were fluent Spanish speakers [Arcury et al., 2012a]. Interviews assessed demographic information, housing features, and perceptions of housing quality; they took approximately 90 min to complete. Housing assessments were completed with the assistance of a farmworker. The housing assessment form assessed compliance with standards summarized in the NC Department of Labor (NCDOL) Introduction to Migrant Housing Inspections [NCDOL, 2008].

Up to three wipe samples were collected in each camp: one each in uncarpeted floor areas in the entry way of the bedrooms of the two interviewed farmworkers and one in a camp common area. These areas were selected as they were areas commonly used by the farmworkers. Wipe samples are a standard method for documenting the presence of dislodgeable environmental toxicants on surfaces [Quandt et al., 2004; Deziel et al., 2011; Lu et al., 2013]. A 50 cm × 50 cm template was placed in each area, and each area was wiped with two sterile 4" × 4" dressing gauze laced with 2 ml of pesticide grade isopropanol. All gauze pads were placed into the same sterile amber glass bottle to which 4 ml of pesticide grade toluene was added. Bottles were placed in a cooler with blue-ice until they were placed in a freezer at -20°C. All the containers were packaged in insulated shipping containers with dry-ice and shipped to the laboratory for analysis. In addition, 30 field blanks and 30 matrix spikes were made. Field blanks and matrix spikes were prepared by placing clean gauze pads in sample jars on the selected days of sampling. These were brought to the field, and, for matrix spikes, known amounts of pesticides were added. These were then brought back to the lab along with field samples.

Laboratory Procedures

Sample preparation—Established procedures were used for the analysis [Lu et al., 2013]. Known amounts of mixed internal standards including D₆-dichlorvos, D₁₀-diazinon, and D₆-*trans*-permethrin were spiked into sample bottles. 80 ml of ethyl acetate was added into each bottle and it was shaken for 30 min on a shaker table. The extraction solvent was then poured into to a centrifuge tube. Another 80 ml of ethyl acetate was added to each sample bottle for a second extraction for 30 min on a shaker table. The extraction solvents were combined (approximately 160 ml) and evaporated to near dryness at 40°C under gentle nitrogen in a TurboVap evaporator. The extract was reconstituted with 0.8 ml ethyl acetate and toluene (3:1 by volume). The dissolved sample extract was then transferred to a 2-ml dispersive-SPE centrifuge tube (Agilent Technologies, Santa Clara, CA), which contained 150 mg of MgSO₄, 50 mg of PSA, 50 mg of C₁₈, and 7.5 mg of graphite carbon for cleanup. The d-SPE tube was vortexed for 1 min, and centrifuged at 7,500 rpm for 5 min. Four

hundred microliter of supernatant was transferred into an auto sampler vial for GC–MS analysis.

GC–MS analysis—Pesticides were separated and identified using an Agilent 6890 gas chromatograph coupled with an Agilent 5973 mass selective detector (MSD). One microliter of sample was injected in splitless. The injection inlet temperature was kept at 270°C. Pesticides were separated through a 30 m × 0.25 mm DB-5 ms column. The oven temperature program was started and held at 60°C for 2 min, ramped to 180°C at 25°C/min and held at 180°C for 4 min, then ramped to 250°C at 10° C/min and held for 4 min, then to 270°C at 3°C/min and held for 4 min, and finally to 300°C at 20°C/min, plus 3 min post-run at 300°C. The carrier gas was helium, and the flow rate was constantly at 1.2 ml/min. The MSD was kept at 230°C for source, 150°C for quad, and 280°C for Aux-2 temperature. One quantitation ion and two to three confirmation ions were monitored for each chemical using the SIM model. The SIM masses and retention times of measured pesticides are listed in Table AI.

Sample analysis—Field blank wipes were prepared by spiking internal standards into brand new grade gauze pads and then following the extraction steps described above. Blanks contained trace level (<1 ng per analysis) of bifenthrin, allethrin, tefluthrin, and chlorpyrifos, and 19 ng of resmethrin per analysis. Target compounds were identified based on the quantitation ion, confirmation ions and retention time, while the concentrations were quantified based on the quantitation ion only. Target compounds were calculated using linear regression generated from a 10-point external calibration curve prepared in solvent. Reported results were corrected by blank levels and the recoveries generated from matrix spiked calibration standards (n = 7).

Measures

Eleven OP and 14 pyrethroid pesticides were detected in laboratory analysis at greater than the limit of quantification (LOQ). LOQ is the lowest concentration for each analyte that can be accurately measured with great confidence, as defined by the noise (the background) to signal ratio greater than 3. LOQ was calculated using three times the standard deviation of the Limit of Detection. In general, the impact of using LOQ versus LOD only matters to a very small fraction of data that falls into this range, but not the overall distribution of the data set. Three sets of pesticide measures were created: (1) the concentration of each pesticide was reported in $\mu\text{g}/\text{m}^2$ for standardization as all samples from a camp were analyzed together; (2) a dichotomous indicator for the presence of each individual pesticide in each camp; and (3) the total number of OPs found in a camp, the total number of pyrethroids found in a camp (where total-permethrin was included in the total but *cis*-permethrin and *trans*-permethrin were not counted), and the total number of any pesticides found in a camp.

Camp characteristics included the presence of any workers with H-2A visas in the camp; housing type (no barracks present, barracks present); number of residents in camp (1–10; 11–20; 21 or more); the presence of female residents in the camp; whether the camp violated the regulation on crowding; and data collection period (early season of June through mid-

July; mid season of mid-July through August; late season of September or October). Additional characteristics were included in the analysis that could affect the presence of pesticides in the houses. These included whether a NCDOL Certificate of Inspection was posted; a weather protection violation was present in either bedroom; a floor violation was present in either bedroom; roaches were present in either bedroom; and roaches were present in the camp included [Arcury et al., 2012a]. The method described by Bradman et al. [2005] was used to determine the presence of roaches; this method relies on the observation of living or dead roaches, of roach egg cases, or of roach feces in an area.

Statistical Analysis

Frequencies and percentages were used to summarize camp and housing characteristics as well as the prevalence of a pesticide (defined as greater than LOQ) in the wipe samples. For each pesticide that had at least 20% values above the LOQ, geometric means (GMs), geometric standard deviations (GSD), and quartiles were estimated using maximum likelihood methods based on the proportion of values below the LOQ as well as the actual values above the LOQ. The association of camp and housing characteristics with the number of OP, pyrethroid and total pesticides were assessed using analysis of variance (ANOVA) models. We selected pesticides that had at least 20% values above the LOQ and evaluated the effect of the camp and housing characteristics on the concentration of these pesticides using Tobit regression models to account for the left-censoring of the data. Models were fit on the natural log scale to assess bivariate associations and the regression coefficients were back-transformed to the original scale for ease of interpretation of results. The reported regression coefficients (beta) represent the fold change in pesticide concentrations for one unit increase in a predictor. The standard errors (SE) of the back-transformed regression coefficients were obtained using the Delta method [Oehlert, 1992; Rice, 1994]. All analyses were performed by SAS 9.3 (Cary, NC) and *P*-values less than 0.05 were considered significant.

RESULTS

Camp and Housing Quality Characteristics

Over two-thirds of the camps had workers with H-2A visas present (Table I). The housing in 70.5% of the camps included barracks. Almost half (48.3%) of the camps had 10 or fewer residents, 26.7% had 11–20 residents, and a quarter had 21 or more residents. About a quarter had a crowding violation, and a quarter had female residents. Data were collected in 27.8% of the camps in early season, 45.5% in mid-season, and 26.7% in late season. One-third of the camps had a NCDOL Certificate of Inspection posted. Over half (55.6%) were found to have a bedroom weather protection violation, and 48.3% had a bedroom floor violation. Roaches were present in 54.3% of the bedrooms and 72.6% of the camps.

Pesticides in Farmworker Houses

OP pesticides and pyrethroid pesticides were found in a large number of houses (Table II). Among the OPs, chlorpyrifos was present in almost three-quarters of the migrant farmworker houses (GM 0.11 $\mu\text{g}/\text{m}^2$), and malathion was present in 64.2% of the houses (GM 0.12 $\mu\text{g}/\text{m}^2$). Phosmet was present in 18.8% of the houses. Registration for use in the US

has been discontinued for fenthion (43.8%), diazinon (16.5%), and mevinphos (14.2%); however, each was present in a substantial number of houses, although their concentrations were relatively low. Dichlorvos was present in 7.4% of the houses. Phosalone was present in 5.7% of the houses; this pesticide is not registered for use in NC. Telfuthrin, coumaphos, and fonophos had limited occurrences.

Many pyrethroid pesticides were found. *Cis*-permethrin, *trans*-permethrin, and total-permethrin were each present in about 90% of houses (GMs 1.05 μm^2 , 1.50 μm^2 , 2.41 μm^2 , respectively). Tetramethrin was found in 80.0% of the houses (GM 0.19 μm^2), with bifenthrin present in 72.0% (GM 0.11 μm^2), cypermethrin in 59.1% (GM 0.70 μm^2), allethrin in 36.4% (GM 0.02 μm^2), resmethrin in 32.4% (GM <0.01 μm^2), and cyhalothrin in 19.3%. Two pyrethroids not registered for use in NC were found in the samples: cypermethrin was common, being present in 59.1% of the houses; fenvalinate was found in 8.5% of the houses.

No OPs were detected in 10 houses, and no pyrethroids were detected in five houses, but only one house was devoid of any pesticide (Table III). As many as six different OPs were found in the houses (mean = 2.4). As many as nine different pyrethroids were found in the houses (mean = 4.3). Up to 15 total pesticides were found in these houses (mean = 6.6). None of the camp or housing characteristics was significantly associated with the number of OPs found. Four characteristics were associated with the number of pyrethroids. Camps with H2-A workers had fewer pyrethroids (mean = 4.0, SE = 0.16) than those without H-2A workers (mean = 4.5, SE = 0.24; $P = 0.04$). Camps with barracks had more pyrethroids (4.8, SE = 0.24) than those without barracks (3.9, SE = 0.16; $P < 0.01$). Camps with fewer residents had a smaller number of pyrethroids present; those with 1–10 residents had an average of 3.7 pyrethroids (SE = 0.10), those with 11–20 residents had an average of 4.3 pyrethroids (SE = 0.25), and those with 21 or more residents had an average of 4.8 pyrethroids (SE = 0.26; $P < 0.01$). Finally, camps with bedroom floor violations had more pyrethroids (4.6, SE = 0.19) than those without such violations (3.8, SE = 0.19; $P < 0.01$). Multivariate analysis that included H2-A visa status, barracks presence or absence, number of residents, and floor violations resulted in only floor violations having a significant association with number of pyrethroids: houses with no bedroom floor violations had a mean of 4.0 different pyrethroids, and those with violations had a mean of 4.9 different pyrethroids ($P < 0.01$).

Camp and Housing Quality Characteristics Associated With Pesticides

Four OPs (chlorpyrifos, malathion, fenthion, phosmet) with a sufficient number of detections greater than the LOQ were included in the bivariate analysis comparing camp characteristics differences in concentrations of pesticides detected. Three of these 44 comparisons attained statistical significance ($P < 0.05$). Concentrations of chlorpyrifos for camps with no crowding were 60% less than camps with crowding ($\beta = 0.40$, SE = 0.17). Concentrations of fenthion for camps with no barracks were 49% higher than in camps with barracks ($\beta = 1.49$, SE = 0.31). Concentrations of phosmet were 79% lower in camps measured at mid season than in camps at which samples were collected in late season ($\beta = 0.21$, SE = 0.13).

Nine pyrethroids (*cis*-permethrin, *trans*-permethrin, total-permethrin, tetramethrin, bifenthrin, cypermethrin, allethrin, resmethrin, cyhalothrin) had values greater than the LOQ for at least 20% of the wipe samples. Bivariate comparisons of the associations of the concentrations of these nine pyrethroids with camp characteristics were calculated (Table IV). Three of the covariates, crowding violation, female residents and no camp roaches present, had no significant associations with any of the pyrethroid concentrations.

Camps with no H-2A workers had concentrations of bifenthrin that were 140% higher ($\beta = 2.40$, SE = 0.98) and of resmethrin that were 521% higher ($\beta = 6.21$, SE = 4.81) than those with H-2A workers. Those camps with no barracks present had concentrations of bifenthrin that were 72% lower ($\beta = 0.28$, SE = 0.11) and of resmethrin that were 80% lower ($\beta = 0.20$, SE = 0.16) than those with barracks. Camps with 1–10 residents had concentrations of bifenthrin that were 65% lower ($\beta = 0.35$, SE = 0.16) than those with 21 or more residents. Camps at which data were collected in mid-season had concentrations of bifenthrin that were 154% greater ($\beta = 2.54$, SE = 1.19) than those with data collection in the late season. Camps with the NCDOL Certificate of Inspection posted had concentrations of *cis*-permethrin that were 58% lower ($\beta = 0.42$, SE = 0.13), of *trans*-permethrin that were 59% lower ($\beta = 0.41$, SE = 0.13), and of total-permethrin that were 62% lower ($\beta = 0.38$, SE = 0.11), but concentrations of allethrin that were 354% greater ($\beta = 4.54$, SE = 3.50) than camps with an NCDOL Certificate of Inspection posted.

Camps with no weather protection violations had concentrations of *cis*-permethrin that were 50% lower ($\beta = 0.50$, SE = 0.14), of *trans*-permethrin that were 53% lower ($\beta = 0.47$, SE = 0.14), of total-permethrin that were 55% lower ($\beta = 0.45$, SE = 0.14), and of tetramethrin that were 55% lower ($\beta = 0.45$, SE = 0.15). Camps with no floor violations had concentrations of tetramethrin that were 53% lower ($\beta = 0.47$, SE = 0.16), of bifenthrin that were 52% lower ($\beta = 0.48$, SE = 0.18), and of resmethrin that were 85% lower ($\beta = 0.15$, SE = 0.11). Houses without roaches present in the bedroom had concentrations of *cis*-permethrin that were 43% lower ($\beta = 0.57$, SE = 0.16), of *trans*-permethrin that were 48% lower ($\beta = 0.52$, SE = 0.15), of total-permethrin that were 47% lower ($\beta = 0.53$, SE = 0.17), of cypermethrin that were 70% lower ($\beta = 0.30$, SE = 0.15), and of cyhalothrin that were 77% lower ($\beta = 0.23$, SE = 0.15) than those with roaches present.

DISCUSSION

Migrant farmworkers in NC face environmental exposure to a substantial number of OP and pyrethroid insecticides in their housing. OPs are limited for use in agricultural production. The number of OPs found in these migrant farmworker houses and the concentrations of specific OPs are not associated with camp characteristics. Pyrethroids are labeled for residential and agricultural use. The number and concentrations of pyrethroids present in the migrant farmworker houses are associated with specific camp characteristics. Camps having workers with H-2A visas, a posted NCDOL Certificate of Inspection, no barracks, fewer residents, and no bedroom weather protection or floor violations, and no roaches had lower levels of pyrethroids.

Comparison of these results with other research needs to be undertaken with caution. Earlier studies of agricultural worker housing were limited largely to analyses of a few specific OPs, such as azinphos-methyl, diazinon and chlorpyrifos; and several completed sample collection over a decade ago [Lu et al., 2000; Harnly et al., 2009]. Azinphos-methyl has not been widely used in the eastern US. Diazinon was withdrawn from use at the end of 2004. Chlorpyrifos was withdrawn from non-agricultural use in 2001. Therefore, these pesticides should be present in farmworker houses less often and at lower concentrations in 2010 (when our data were collected) than in studies in which data were collected in the 1990s and early 2000s. Many earlier analyses used different methods to collect environmental samples, with many collecting dust samples rather than the wipe samples used for this research. Finally, most of the published research has focused on houses inhabited by farmworker families with children. This analysis focused on migrant men in camps; only a few camps had women or children present.

However, comparison of these results to other research documents the relatively high levels of residential pesticides to which migrant farmworkers are exposed. Based on dust samples collected in 2006 in Salinas, California, Quirós-Alcalá et al. [2011] report that 55% of the 29 samples collected in 15 farmworker homes and 36% of the 25 samples collected in 13 Oakland urban homes contained chlorpyrifos, compared to 72.7% of the samples collected for this study. They also report that 7% of their farmworker samples and 12% of their urban samples contained malathion, compared to 64.2% of the samples collected in this study. They did find that 79% of the samples from farmworker houses and 52% of the samples from urban houses contained diazinon, compared to 16.5% of the migrant farmworker houses in this study; however, their samples were collected closer to the time when diazinon was still registered. Similar to this study, Quirós-Alcalá et al. [2011] report the presence of pyrethroid pesticides in all of the samples they collected in farmworker and urban houses.

Quandt et al. [2004] collected wipe samples from 41 farmworker family houses located in western NC and Virginia in 2001. Seventy-eight percent of their wipe samples contained chlorpyrifos (compared to 72.7% in this study), and 34% contained diazinon (compared to 16.5%). Detections of *cis*-permethrin (66%) and *trans*-permethrin (93%) were about the same as for the migrant farmworker houses in this study (90.3% and 89.8%, respectively). Finally, Harnly et al. [2009], based on dust samples collected in 1999–2000, reported that 91% of 197 agricultural worker family houses in California had chlorpyrifos in their homes (compared to 72.7% for this study), 86% had diazinon (compared to 16.5%), 7.2% had phosmet (compared to 18.8%), 98% had *cis*-permethrin (compared to 90.3%), and 98% had *trans*-permethrin (compared to 89.8%).

Most studies examining the presence of pesticides in farmworker houses measured covariates of exposure that are not comparable to those relevant in this analysis. For example, measures of proximity to agricultural fields and variation in socioeconomic status have been relevant in other studies [Lu et al., 2000; Quandt et al., 2004; Coronado et al., 2011], but are not relevant to this analysis, as all migrant farmworker camps in NC are adjacent to fields and all migrant farmworkers have similar incomes. Residents with H2-A visas and NCDOL certificates of inspection were relevant to this study, but have not been relevant to other studies. However, several analyses of farmworker family houses found

indicators of cleanliness related to pesticide presence and concentrations. Houses that were difficult to clean or that were less clean had greater levels of pesticides [Quandt et al., 2004; Harnly et al., 2009]. Similarly, recent use of pesticides in the home [Quirós-Alcalá et al., 2011], as well as storing pesticides and work shoes in the home [Harnly et al., 2009], were related to greater levels of pesticides. Several housing measures in this study reflect this association; houses with more weather and floor violations had greater levels of pesticides, and those with no roaches had lower levels of pesticides.

OP and pyrethroid insecticides are toxic chemicals with known health effects. In addition to the number and concentrations of OP and pyrethroid insecticides found in the migrant farmworker houses, specific characteristics of several of these pesticides raise larger concerns for ongoing pesticide exposure of farmworkers. For example, the OP fenthion was found in samples from 48.1% of the migrant farmworker houses. This OP is no longer registered for use in the US. Two other OPs, diazinon and mevinphos, which also are no longer legal to use in the US, are each found in about 15% of the migrant farmworker houses. Therefore, while migrant farmworkers may no longer be exposed to these pesticides while working, they are exposed to them where they sleep. The same is true for the pyrethroids cypermethrin (found in 59.1% of the samples) and fenvalinate (found in 8.5% of the samples); neither is registered for use in NC, but NC migrant farmworkers are exposed to both in their houses.

The substantial prevalence of three OP and pyrethroid pesticides not registered for use is an important concern. It is doubtful that these pesticides are being purchased and applied illegally. The cause of the continued presence of these pesticides in the residential environment is likely more insidious. It results from their persistence in indoor environments even years after they are no longer used in agriculture. Totally removing them from the migrant farmworker houses (and the houses of others in rural communities) may require a concerted effort over years. We can expect that the remnants of other pesticides, such as chlorpyrifos and malathion, will be in rural houses for years after these pesticides are removed from commercial use. The public health community needs to consider methods that can be implemented to significantly reduce residential pesticide exposure in farmworker housing.

Residential exposure to these pesticides compounds workplace exposure. Rather than having a safe refuge from occupational pesticide exposure, these farmworkers continue to be exposed in their houses. The specific health implications of this residential pesticide exposure have not been delineated. The Agricultural Health Study indicates that chronic exposure to even small amounts of pesticides increases risk for significant health outcomes, including cancer and neurological deficient [Starks et al., 2012; Koutros et al., 2013]. Current policy does not address the types and levels of pesticides to which farmworkers are exposed in their houses. The US Environmental Protection Agency [1992] Work Protection Standard addresses work place pesticide use and storage; required training includes discussion of take home routes of pesticide exposure. However, no requirements for testing farmworker houses for pesticide exposure are included in this policy. Understanding the individual and synergistic components of occupational and residential pesticide exposure for

farmworkers and other worker populations will require an integrated research program with access to individual participants at work and at home.

The results of this study should be evaluated in terms of its limitations. The data come from one region of one state in 1 year. Only grower-owned migrant farmworker camps are included in the study. Generalizations of results to other regions should be made with caution. This study uses a cross-sectional design; therefore, the causal relationships can only be inferred. Although all identified migrant farmworker camps were asked to participate in the study, not all migrant farmworker camps may have been identified; the conditions in unidentified camps may differ from those in the camps identified for the study. Data collectors were not allowed into a number of camps; the conditions in these camps may differ from the camps that participated in the study. The limit of detection for pesticides measured by this study is limited to current limits on technology. However, the study has a number of strengths, including its large sample size and high participation rate, extensive collection of information, and use of state-of-the-art technology in measuring pesticides.

Migrant farmworkers are exposed to substantial numbers of pesticides when they work. This analysis shows that they continue to be exposed to pesticides in the houses in which they live. Some of the pesticides to which workers are exposed in their houses are pesticides that are no longer legal to use in the workplace. Indicators of housing conditions are related to the number and concentrations of pyrethroid pesticides found in migrant farmworker houses. Exposure to these pesticides increases risks for immediate and long-term health effects for these migrant farmworkers. Efforts to reduce pesticides in farmworker houses will reduce one health risk that the members of this vulnerable population confront. Policy on removing pesticides from migrant farmworker houses is needed. Further research on the number and concentrations of pesticides to which migrant farmworkers are exposed in their houses and the potential health effects of this exposure is also needed.

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Appendix

TABLE AI

Pesticide Name, GC–MS Retention Times, Quantitation Ion (Q ion) and Confirmation Ions (C Ion)

Pesticide	Retention time (min)	Q ion	C1 ion (%Q1/T)	C2 ion (%Q2/T)	C3 ion (%Q3/T)
Organophosphorous pesticides					
Bromophos	15.42	331	329	333	125
Chlorpyrifos	14.88	314	258	286	208
Coumaphos	24.62	362	226	210	334
Diazinon	12.31	304	227	276	248
Dichlorvos	6.63	109	185	145	220
Fenthion	15.00	278	279	169	125
Fonophos	12.28	246	109	137	110
Mevinphos	7.81	127	192	109	164

Pesticide	Retention time (min)	Q ion	C1 ion (%Q1/T)	C2 ion (%Q2/T)	C3 ion (%Q3/T)
Phosmet	20.42	160	161	133	317
Phosalone	21.69	182	184	367	154
Pirimphos-ethyl	15.41	318	333	304	290
Pirimphos-methyl	14.40	290	276	305	233
Resmethrin	19.72	123	143	171	128
Tefluthrin	12.70	177	178	197	199
Tetramethrin	20.56	164	123	165	107
Pyrethroid pesticides					
Allethrin	16.04	136	123	107	168
Bifenthrin	20.45	181	166	165	182
Cyfluthrin	25.79–26.35	226	127	163	199
Cyhalothrin	22.1–22.48	181	197	208	199
Cypermethrin	26.64–27.2	163	165	181	209
Fenpropathrin	20.78	181	265	125	
Fenvalinate	29.09–29.75	419	181	225	167
Flucythrinate	27.14–27.7	199	225	209	181
Fluvalinate	29.55–29.81	250	252	181	251
<i>cis</i> -permethrin	24.36	183	127	163	165
<i>trans</i> -permethrin	24.71	183	127	163	165
Phenothrin	21.34–21.55	123	183	184	124
Resmethrin	19.72	123	143	171	128
Tefluthrin	12.70	177	178	197	199
Tetramethrin	20.56	164	123	165	107

TABLE I

Migrant Farmworker Camp Characteristics, Eastern North Carolina, 2010 (n = 176)

Camp characteristics	n	%
Workers with H-2A visas present	120	68.2
Housing type		
Barracks present	124	70.5
No barracks present	52	29.6
Number of residents in camp		
1–10	85	48.3
11–20	47	26.7
21 or more	44	25.0
Crowding violations	38	22.1
Female residents	45	25.6
Data collection period		
Early season (June – mid-July)	49	27.8
Mid season (mid-July – August)	80	45.5
Late season (September – October)	47	26.7
NCDOL certificate of inspections posted	57	33.1
Bedroom weather protection violation	95	55.6
Bedroom floor violation	84	48.3
Bedroom roaches present	95	54.3
Camp roaches present	127	72.6

TABLE II

Organophosphorous and Pyrethroid Pesticides Prevalence Greater Than the Limit of Quantification (LOQ) and Concentrations ($\mu\text{g}/\text{m}^2$), Migrant Farmworker Housing, Eastern North Carolina, 2010 (n = 176)

Pesticides	Uses and current registration for pesticides							Prevalence greater than LOQ	Concentrations (µg/m²) total sample					Geometric mean for samples greater than LOQ		
	Lice	Crops	Livestock	Commercial	Turf	Residential	Registration		n	%	Geometric mean	Geometric SD	Percentiles			
													25th		Median	75th
Organophosphorous pesticides																
Chlorpyrifos		x						128	72.7	0.11	8.12	0.03	0.11	0.47	3.56	0.30
Malathion		x						113	64.2	0.12	9.18	0.03	0.12	0.54	4.64	0.55
Fenthion	x		x				D ^a	77	43.8	0.01	3.13	0.01	0.02	0.04	0.12	0.04
Phosmet		x						33	18.8							0.65
Diazinon		x				x	D	29	16.5							0.11
Mevinphos		x					D	25	14.2							0.03
Dichlorvos		x			x			13	7.4							0.05
Phosalone		x					N ^b , I ^c	10	5.7							0.50
Tefluthrin		x						6	3.4							0.06
Coumaphos		x						1	0.6							1.72
Fonophos					x		D	1	0.6							0.11
Pyrethroid pesticides																
cis-permethrin		x				x		159	90.3	1.05	6.91	0.28	1.05	3.85	25.14	1.64
trans-permethrin		x				x		158	89.8	1.50	7.49	0.39	1.50	5.85	41.24	2.54
Total-permethrin		x				x		159	90.3	2.41	8.37	0.58	2.41	10.12	79.47	4.16
Tetramethrin		x				x		140	79.6	0.19	9.20	0.04	0.19	0.84	7.26	0.43
Bifenthrin		x				x		126	71.6	0.11	11.80	0.02	0.11	0.57	6.25	0.33
Cypermethrin		x				x	N	104	59.1	0.70	22.88	0.09	0.76	6.31	131.62	7.55
Allethrin				x		x		64	36.4	0.02	62.17	0.00	0.02	0.37	20.60	2.14
Resmethrin					x	x		57	32.4	0.00	58.95	0.00	0.00	0.07	3.72	0.55
Cyhalothrin		x				x		34	19.3							2.00

Pesticides	Uses and current registration for pesticides							Prevalance greater than LOQ		Concentrations (µg/m ²) total sample					Geometric mean for samples greater than LOQ
	Lice	Crops	Livestock	Commercial	Turf	Residential	Registration	n	%	Geometric mean	Geometric SD	Percentiles			
												25th	Median	75th	
Phenothrin		x				x		16	9.1					0.81	
Fenvalinate		x				x	N	15	8.5					6.48	
Fenpropathrin		x				x		5	2.8					0.41	
Cyfluthrin		x				x		5	2.8					1.22	
Fluvalinate-tau		x				x		1	0.6					1.11	

^aD = registration discontinued for use in the United States.

^bN = not registered for use in North Carolina.

^cI = allowed only on imported crops.

TABLE III

Number of Organophosphorous, Pyrethroid, and Total Pesticides Above the Limit of Quantification Found in Each Camp (n = 176)

Number of pesticides	n	%
Organophosphorous pesticides		
0	10	5.7
1	34	19.3
2	50	28.4
3	47	26.7
4	24	13.6
5	7	4.0
6	4	2.3
Pyrethroid pesticides		
0	5	2.8
1	7	4.0
2	20	11.4
3	26	14.8
4	45	25.6
5	35	19.9
6	18	10.3
7	17	9.7
8	2	1.1
9	1	0.6
Total pesticides		
0	1	0.6
1	2	1.1
2	5	2.8
3	10	5.7
4	17	9.7
5	20	11.4
6	32	18.2
7	30	17.0
8	18	10.2
9	20	11.4
10	11	6.2
11	7	4.0
12	2	1.1
15	1	0.6

TABLE IV

Significant Associations of Migrant Farmworker Camp Characteristics With Concentrations ($\mu\text{g}/\text{m}^2$) of Pyrethroid Pesticides Found in Each Camp (n = 176)

Farmworker camp characteristics	Permethrin		Total	Tetramethrin	Bifenthrin	Cypermethrin	Allethrin	Resmethrin	Cyhalothrin
	cis	trans							
No workers with H-2A visas									
Beta ^a	1.43	1.41	1.52	1.29	2.40	2.38	0.37	6.21	0.65
Standard error	0.45	0.46	0.52	0.47	0.98	1.27	0.29	4.81	0.44
P-value	0.25	0.28	0.22	0.49	0.03	0.10	0.21	0.01	0.52
Housing type: no barracks present									
Beta	0.87	0.90	0.83	0.84	0.28	0.56	0.33	0.20	1.18
Standard error	0.28	0.30	0.30	0.31	0.11	0.30	0.26	0.16	0.80
P-value	0.65	0.75	0.62	0.64	<0.01	0.28	0.16	0.04	0.80
Number of residents in camp									
1–10 versus 21 or more									
Beta	0.70	0.80	0.69	0.80	0.35	0.47	0.31	0.32	1.14
Standard error	0.25	0.30	0.27	0.34	0.16	0.29	0.27	0.28	0.86
P-value	0.32	0.55	0.34	0.60	0.02	0.22	0.18	0.19	0.86
11–20 versus 21 or more									
Beta	0.88	0.96	0.89	0.67	0.77	1.33	0.16	0.22	0.96
Standard error	0.36	0.41	0.39	0.32	0.41	0.90	0.16	0.22	0.81
P-value	0.74	0.92	0.79	0.40	0.62	0.67	0.06	0.13	0.96
Data collection period									
Early season versus late season									
Beta	0.56	0.56	0.59	1.22	0.98	0.29	0.41	2.00	0.72
Standard error	0.22	0.25	0.26	0.56	0.51	0.20	0.40	2.03	0.63
P-value	0.14	0.16	0.22	0.66	0.96	0.06	0.36	0.49	0.71
Mid season versus late season									
Beta	1.06	1.11	1.16	1.11	2.54	1.71	0.32	1.75	1.63
Standard error	0.38	0.41	0.45	0.46	1.19	1.01	0.28	1.61	1.23
P-value	0.86	0.78	0.69	0.81	0.04	0.36	0.20	0.54	0.51

Farmworker camp characteristics	Permethrin			Total	Tetramethrin	Bifenthrin	Cypermethrin	Allethrin	Resmethrin	Cyhalothrin
	cis	trans								
NCIOL certificate of inspections posted										
Beta	0.42	0.41	0.38	1.20	1.02	0.76	4.54	1.00	2.24	
Standard error	0.13	0.13	0.11	0.44	0.43	0.41	3.50	0.80	1.42	
P-value	<0.01	<0.01	<0.01	0.62	0.05	0.61	0.04	0.99	0.20	
No bedroom weather protection violation										
Beta	0.50	0.47	0.45	0.45	1.01	0.59	1.04	0.50	0.37	
Standard error	0.14	0.14	0.14	0.15	0.39	0.30	0.77	0.38	0.23	
P-value	0.02	0.01	0.01	0.02	0.97	0.30	0.96	0.36	0.11	
No bedroom floor violation										
Beta	0.65	0.57	0.56	0.47	0.48	0.58	0.32	0.15	0.32	
Standard error	0.19	0.17	0.18	0.16	0.18	0.29	0.24	0.11	0.20	
P-value	0.13	0.06	0.07	0.02	0.05	0.28	0.12	0.01	0.06	
No bedroom roaches present										
Beta	0.57	0.52	0.53	0.67	0.55	0.30	2.51	2.89	0.23	
Standard error	0.16	0.15	0.17	0.23	0.21	0.15	1.84	2.15	0.15	
P-value	0.05	0.03	0.04	0.23	0.12	0.01	0.21	0.15	0.02	

^a Betas were estimated from Tobit regression models and represented the fold change in the pesticide concentration with one unit increase in a predictor and were therefore unitless.