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Organophosphorus pesticide residue levels in homes located near orchards

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ABSTRACT

Organophosphorus pesticides (OPs) are commonly applied to agricultural crops. Families living in these communities may have higher exposure to OPs due to take home exposures and close proximity to agricultural fields. The objectives of this study were to measure OP concentrations in home carpet dust in agricultural and non-agricultural households and examine factors that may impact OP concentrations such as occupation, housing characteristics, and resident behaviors. Agricultural households had at least one parent who worked in agriculture during the previous 5 years. Carpet dust samples were collected at two time points from 278 households in an agricultural community located in the Pacific Northwest from 2008–2011. Samples were analyzed for four types of OPs: azinphos-methyl, phosmet, malathion, and chlorpyrifos. Overall, OP detection frequencies and concentrations were higher in agricultural households compared to non-agricultural households.

Factors associated with higher OP concentrations in home carpet dust were identified and included: (1) homes with two or more agricultural workers living in the home, (2) homes located in close proximity to an agricultural field or orchard, (3) having an entry floor mat, and (4) frequently vacuuming the house. Having air conditioning in the home had a protective effect with OP concentrations. While the use of these four OPs is restricted or limited for residential use in the United States, results show that they were still found in the indoor environment. The understanding of the impact of agricultural work and other factors that elevate levels of OPs in the home is crucial to mitigating pesticide exposure in agricultural communities.

KEYWORDS
Agriculture; exposure; household

Introduction

Due to their toxicity and widespread use, organophosphorus pesticides (OPs) are a concern to populations living in rural communities where there is increased potential for OP exposure from agricultural activities. Children's exposure is a particular concern since adverse health outcomes that have been related to OP exposure including cognitive and behavioral deficits and reduced lung function.[1–6] Children can have higher exposures because of their behavior, such as increased contact with the floor and hand-to-mouth contact in younger children, which may lead to inadvertent ingestion.[7,8]

In the United States, several OPs have been banned for residential use because of these concerns, although they may still be used on agricultural crops and remain in the environment.[9] In spite of the bans, OPs are still detected in indoor home environments. Detectable levels in the home may be due to OP residues being transferred into homes when agricultural workers have residues on their skin and clothes (i.e., para-occupational pathway) and from environmental sources such as air, soil and dust. The drift of spray from pesticide applications could also enter the home.[10,11]

In studies examining the impact of OP exposure on health, the assessment of home OP contamination is essential since it can lead to greater precision in characterizing potential exposure which in turn can lead to more accurate relationships between exposure and health outcomes. Prior studies have reported that OP concentrations in home dust were higher in agricultural households compared to non-agricultural households, as well as in homes that were located in close proximity to agricultural fields treated with pesticides compared to homes that were farther away.[12–16] These higher dust concentrations in agricultural households are associated with increased pesticide metabolites in children's urine.[14,15,17] However, the

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contribution of pathways to home OP contamination is not well-characterized, including contaminant transport and behaviors, specifically worker behaviors. Understanding these contributions is necessary in order to mitigate OP concentrations in homes and reduce exposures of agricultural workers, their families and families that live in agricultural regions.

The first objective of this study was to measure the concentration of four pesticide residue levels in home carpet dust. These four OPs, azinphos-methyl, phosmet, malathion, and chlorpyrifos, were used in the tree fruit orchards of the area at the time of the study. A second objective was to identify determinants of contamination such as housing characteristics and resident behaviors associated with OP concentrations in the home. Identifying these determinants may help guide future research and interventions designed to reduce exposure, specifically in the home environment.

Methods

Study population and design

Families living in an agricultural community for at least 3 years and with a child between the ages of 5 and 12 were recruited through schools and community events to participate in a longitudinal study. Families were recruited between 2008 and 2010 and were categorized as non-agricultural or agricultural depending on parents' occupations (i.e., at least one parent worked in agriculture during the previous five years). Questionnaire data and home carpet dust samples were collected from each family at two time points, approximately one year apart. The first data collection time point, defined as Time 1, took place when the family was recruited, between 2008–2010. The second time point, Time 2, occurred approximately one year after Time 1, during 2009–2011. For example, if a family was recruited in 2009, their Time 1 is 2009 and their Time 2 is 2010. Data collection occurred each year in the fall, which was after the peak application season (May–August) in the orchards in the study region.

Carpet dust sample collection and analysis

Carpet dust samples were collected from carpets in the participants' homes based on standard protocols.[14,18] Families without carpet in their homes were excluded from sample collection. Each dust sample was collected from a 122 cm square area of carpet in the main entrance or living room area of the home with a small high-volume surface sampler (HVS4) (CS_3, Inc., Venice, FL). Dust fines from each sample were obtained by sieving the bulk material with a 150 um sieve (No. 100 USA Standard Testing Sieve, ASTME-11 specification; VWR, West Chester, PA) and shaking for 10 min with a sieve shaker (Model RX-24; WS Tyler, Inc., Mentor, OH). Approximately 1 g of dust fines were extracted with 4.0 mL of acetonitrile containing internal standards, sonicated at 60°C for 40 min, and centrifuged at 2,500 rpm for 10 min. Samples were analyzed by liquid chromatography–mass spectrometry (Agilent 6410, Santa Clara, CA) for four OPs, azinphos-methyl, phosmet, malathion, and chlorpyrifos, used in the local orchards during the study years based on previous studies.[14,15,18] The limits of detection (LOD) levels for each year were: 2008: 4.0 ng/g dust (all four OPs); 2009: 2.0 ng/g dust (all four OPs); 2010: 2.0 ng/g dust (phosmet, malathion, and chlorpyrifos) and 5.0 ng/g dust (azinphos-methyl); and 2011: 4.0 ng/g dust (azinphos-methyl and chlorpyrifos) and 2.0 ng/g dust (phosmet and malathion). Non-detectable concentrations of pesticides were replaced by one-half the relevant LOD.[19] OP concentrations were reported as nanograms of pesticide per gram dust (ng/g) for each specific OP.

Questionnaires

Questionnaires were administered by a bilingual research assistant to collect information from the parent(s). Questionnaires included: a Demographics questionnaire which collected information on family members' ages, education levels and ethnicities, type of housing, housing ownership, information on parents' job types and duties, proximity to nearby fields or orchards (lives within 25 m of a field or orchard, yes/no), practices while handling pesticides at work, and after-work hygiene practices; the Pesticide Inventory and Pesticide Use Survey[13,20] which collected information on residential chemical storage and use in and around the home and garden for pests and information on housing characteristics (e.g. ventilation and cleaning habits); and a Life History Calendar which used a visual calendar and a semi-structured interview to collect a detailed history of pesticide exposure opportunities during a child's life as well as a history describing the parents' pesticide use at work and at home. This method can help to improve recall by increasing the participant's ability to recollect different activities during specific times.[21] The calendar was used in conjunction with the demographic questionnaire to verify parents' job types, work duties, and work history as well as how long they have lived in their current home. A shortened follow-up questionnaire and abbreviated life history calendar were administered at the second visit.

Data analysis

OP concentrations were not normally nor log-normally distributed, as determined by the Shapiro-Wilk test. Frequencies of OP detection and median OP concentrations were compared between samples from non-agricultural and agricultural households at both time points by using Chi-Square and Wilcoxon Mann-Whitney tests. Within-household OP concentrations were compared for households that had home carpet dust samples from both time points using the Wilcoxon signed-rank test to examine changes over time.

To examine the relationships between OP concentrations in the home and determinates of contamination, OP concentrations were categorized into low, medium, and high groups based on tertiles at both time points. Multinomial logistic regression models were used to examine the relationships between the low, medium, and high OP concentration groups and determinants of contamination that have been associated with high or low OP concentrations in previous research. Potential determinants identified from prior studies included: (1) type of agricultural work (i.e. fieldwork, fruit sorter or packer in a fruit-packing house, or no agricultural work),[14–16] (2) number of agricultural persons in the household,[13] (3) specific home characteristics (i.e., housing type, house ownership, proximity of house to an agricultural field, presence of an entry floor mat, open windows and doors, frequency of cleaning carpeted floors, air cooling systems),[12,22] and (4) hygiene practices after handling pesticides (i.e., wearing work clothes in the home after work, removing shoes prior to entering the home, time before washing off after arriving home).[23,24] We report only on the relationships between the low and high OP concentration groups from the multinomial regression models. The regression models were stratified by agricultural and non-agricultural households and by time point to control for non-independence among the repeated observations for each individual. Separate models were constructed for all four OPs at Time 1 and Time 2. Due to the strong association between mother's job type and number of agricultural persons in the household, we only included number of agricultural persons in the household in the models. Housing type and entry floor mat were not included in the non-agricultural household models since almost all of the participants reported yes to having an entry floor mat and having the housing type: house/apartment/duplex. Use of personal protective equipment and after-work hygiene practices after working with pesticides were not included in the agricultural models since only 55 participants reported working with pesticides. Odds ratios (ORs) were calculated with 95% confidence interval (95% CI) for determinants of high OP concentrations. The OR represents the odds of having high OP concentrations given the presence of a determinant, compared to the odds of having low OP concentration given the absence of a determinant. A p-value of <0.05 was considered statistically significant. All analyses were conducted using SAS statistical software version 9.4 (SAS Institute, Inc., Cary, NC).

Results

Demographics

Initially, 328 families were enrolled in the study. Fifty homes (15%) were ineligible for pesticide residue sampling due to the absence of carpets in the homes. Families with at least one dust sample were included ($n = 278$ out of 328, 85%). The education level for both parents was significantly lower in the agricultural families (8.5 years of education for mothers and 7.3 years for fathers) compared to the non-agricultural families (12 years for mothers and 11.8 years for fathers; Table 1). A significantly greater proportion of agricultural families were Hispanic. More agricultural families reported living within 25 m to an agricultural field or orchard and lived in cabins or trailers. A significantly greater number of non-agricultural families reported using pesticides in or around the home compared to agricultural families.

Among the agricultural families, the majority of fathers worked in an agricultural field or orchard (68%), 9% of fathers worked in fruit-packing houses, and 23% of fathers did not work in agriculture. Twenty-six percent of the mothers worked in an agricultural field or orchard, 35% of mothers worked in fruit-packing houses, and 40% of mothers did not work in agriculture. Most of the participants who worked with pesticides reported that they did not change out of their work clothes or remove their shoes/boots before entering their home (82%). The majority of agricultural workers reported wearing protective clothing and equipment at work including face protection (64%), overalls (47%), and/or boots (65%).

Table 1. Demographic, housing characteristics, and behaviors of the non-agricultural and agricultural families.

	Non-agricultural (n = 140)		Agricultural (n = 138)		
Characteristics (Time 1)	Mean (SD)	Range	Mean (SD)	Range	*p*-Value
Demographics					
Mother's education, years	12.0 (4.5)	0–23	8.5 (3.7)	0–20	**<0.01****
Father's education, years	11.8 (4.7)	0–23	7.3 (3.8)	0–21	**<0.01****
Number of persons in home	4.7 (1.1)	2–9	4.6 (1.4)	1–11	0.20
	N (%)		**N** (%)		
Hispanic ethnicity	53 (38)		130 (94)		**<0.01***
Housing Characteristics					
Housing type					**<0.01***
House/Apartment/ Duplex	133 (95)		95 (69)		
Cabin/Trailer	7 (5)		43 (31)		
House ownership					**<0.01***
Own	97 (69)		46 (34)		
Rent	42 (30)		51 (37)		
Employer provided	1 (1)		40 (29)		
Lives within 25 m to a field or within a field	49 (35)		76 (55)		**<0.01***
Entry floor mat	131 (94)		113 (88)		0.08
Leaves doors and windows open	126 (91)		114 (88)		0.54
Has air conditioning[A]	75 (55)		67 (52)		0.65
Owns a vacuum cleaner	137 (99)		116 (91)		**<0.01***
Frequency of cleaning carpeted floors among families with a vacuum[B]					**<0.01***
> 1 per week	67 (50)		90 (78)		
≤ 1 per week	68 (50)		25 (22)		
Residential pesticide use					
Used pesticides in home or yard	97 (62)		32 (31)		**<0.01***
Agricultural-related questions			**Agricultural (n = 138), N** (%)		
Father works in fields[C]			87 (68)		
Mother works in fields[C]			35 (26)		
Household agricultural persons, ≤ 3 months[D]					
1 person			82 (59)		
≥ 2 persons (range 2–7)			53 (38)		
After-work hygiene practices (after working with pesticides) (n = 56)					
Enters home after work with work clothes on[E] (n = 55)			33 (60)		
Does not take shoes/boots off before entering the home[F] (n = 50)			41 (82)		
Washes off ≥30 min after arriving home[G] (n = 56)			15 (27)		
Uses personal protective equipment or clothing at work[H]					
Face protection[I] (n = 122)			78 (64)		
Gloves[J] (n = 121)			116 (96)		
Overalls (n = 123)			58 (47)		
Boots (n = 124)			80 (65)		

*Chi-square, $p < 0.05$;
**Wilcoxon Mann-Whitney, $p < 0.05$.
[A]Air conditioning includes central air conditioning, window units, or an evaporative cooler.
[B]Missing responses to the question.
[C]Included fieldwork and pesticide mixing/applying (reference is working as a sorter/packer in fruit packing house or not working in agriculture).
[D]Number of residence members that worked in agriculture in last 3 months.
[E]Reference category: never enters home with work clothes on.
[F]Reference category: always takes shoes/boots off before entering the home.
[G]Reference category: right away.
[H]Always or sometimes used clothing or protective equipment at work (reference category: never).
[I]Face protection: wears glasses, goggles, paper mask, and/or respirator.
[J]Gloves: includes wearing rubber, cloth, and/or leather gloves.

OP detection frequencies and concentrations in home dust

Ninety-nine percent (n = 276) of all households had at least one detectable OP in their home carpet dust at one time point. The percent detected for all OPs was significantly higher for agricultural households compared to non-agricultural households (p < 0.01) except for malathion at Time 2 (p = 0.13); see Figure 1. Malathion and chlorpyrifos were most frequently detected (86% and 82%, respectively), phosmet was detected in 64% of the households, and only 50% of the azinphos-methyl residue levels were above the LOD.

All OP concentrations were significantly higher for agricultural households compared to non-agricultural households (Figure 2). Malathion and chlorpyrifos had the highest median concentrations, with medians

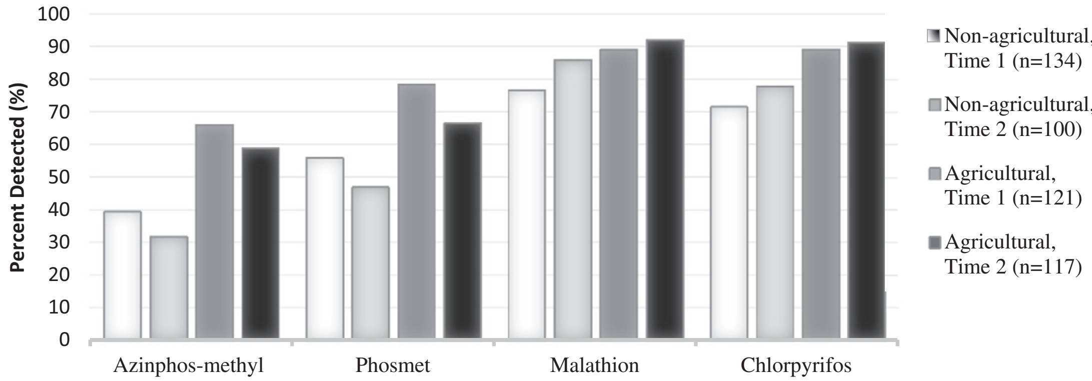

Figure 1. Percent of organophosphates detected in carpet dust samples from non-agricultural and agricultural households at Time 1 and Time 2 (2008–2011).

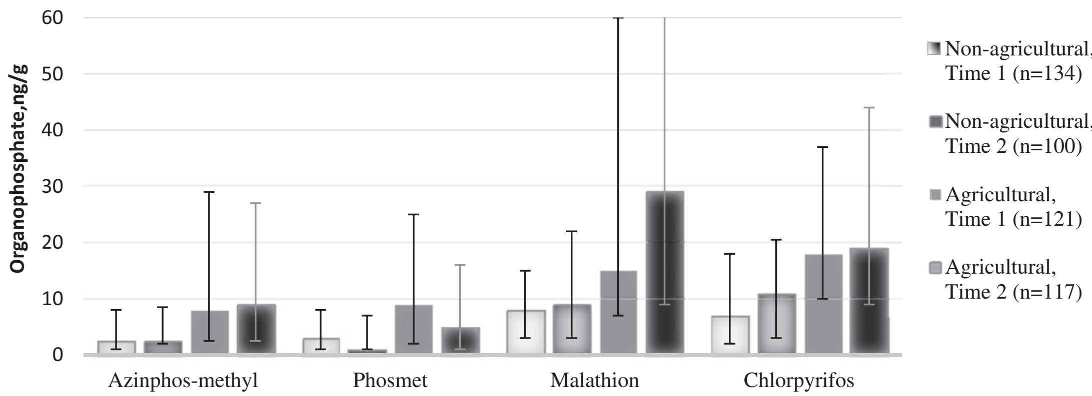

Figure 2. Median organophosphate concentrations and interquartile ranges in carpet dust samples from non-agricultural and agricultural households at Time 1 and Time 2 (2008–2011). Note: 75^{th} percentile for malathion in agricultural households at Time $2 = 110$ ng/g dust.

of 99.0 ng/g for malathion at Time 2 in 2011 and 19.5 ng/g for chlorpyrifos at Time 1 in 2008 (Table 2).

The within-household OP concentrations between the two sample collection time points were not significantly different except that both groups had significant increases in malathion concentrations from Time 1 in 2010 to Time 2 in 2011 ($p < 0.01$) and the agricultural group had significant decreases in phosmet concentrations from Time 1 in 2009 to Time 2 in 2010 and Time 1 in 2010 to Time 2 in 2011 ($p < 0.01$) (data not shown).

Factors associated with OP concentrations in home dust in multivariable models

Several factors were examined for their effect on the concentrations of the four OPs in agricultural and non-agricultural households. Among agricultural households, the odds of having high azinphos-methyl concentrations at Time 1 were 6.25 times more likely compared to low azinphos-methyl concentrations in homes that had two or more agricultural persons in the home in the past 3 months compared to having one agricultural person in the home (Table 3). The odds of having high phosmet and malathion concentrations in homes at Time 2 that had two or more agricultural persons in the home compared to having one agricultural person in the home both approached statistical significance (OR: 3.14, $p < 0.10$ and OR: 4.07, $p < 0.10$, respectively). Cleaning the home less frequently was protective for azinphos-methyl at Time 1 and Time 2, the odds of having high azinphos-methyl was less likely in households that were cleaned once or less per week compared to households that were cleaned greater than once per week or daily (OR: 0.23 and 0.11, respectively). The odds of having high phosmet concentrations were 3.75 times more likely in homes located within 25 m of an agricultural field or orchard at Time 1. In addition, the odds of having high phosmet concentrations were 4.24 times more likely in homes that did not having air conditioning at home compared to homes that did have air

Table 2. Comparison of organophosphate detection frequencies and concentrations in home dust between non-agricultural and agricultural households (2008–2011).

Year and pesticide type	Non-agricultural Percent detected[A]	Non-agricultural Median[B] (IQR) (ng/g)	Agricultural Percent detected[A]	Agricultural Median[B] (IQR) (ng/g)	Percent detected *p*-value[C]	Median *p*-value[C]
2008	***n* = 20**		***n* = 28**			
AZM	25%	2.0[E] (2–5)	54%	6.5 (2–41)	0.052	**0.041**
Phosmet	50%	3.5 (2–23)	61%	9.5 (2–37)	0.473	0.438
Malathion	50%	4.0 (2–15)	71%	10.5 (2–59)	0.138	0.096
Chlorpyrifos	40%	2.0 (2–21)	68%	19.5 (2–42)	0.059	0.067
2009	***n* = 93**[D]		***n* = 83**[D]			
AZM	49%	1.0[E] (1–8)	72%	7.0 (1–22)	**0.002**	**<0.001**
Phosmet	63%	4.0 (1–10)	88%	9.0 (4–22)	**<0.001**	**<0.001**
Malathion	86%	9.0 (5–18)	95%	20.0 (8–72)	**0.041**	**<0.001**
Chlorpyrifos	69%	8.0 (1–24)	94%	18.0 (9–54)	**<0.001**	**<0.001**
2010	***n* = 94**[D]		***n* = 88**[D]			
AZM	28%	2.5[E] (2.5–7)	57%	9.5 (2.5–29)	**<0.001**	**<0.001**
Phosmet	51%	2.0[E] (1–6)	69%	6.0 (1–16)	**0.012**	**0.0012**
Malathion	79%	6.0 (3–18)	91%	15.0 (6–65)	**0.023**	**<0.001**
Chlorpyrifos	94%	8.0 (5–17)	99%	19.0 (10–36)	0.067	**<0.001**
2011	***n* = 27**		***n* = 39**			
AZM	30%	2.0[E] (2–13)	62%	10.0 (2–35)	**0.012**	**0.010**
Phosmet	19%	1.0[E] (1–1)	59%	7.0 (1–17)	**0.001**	**<0.001**
Malathion	93%	17.0 (8–45)	95%	99.0 (29–239)	0.717	**<0.001**
Chlorpyrifos	52%	11.0 (2–18)	79%	19.0 (12–38)	**0.019**	**0.008**

Abbreviations: IQR, interquartile range; AZM, Azinphos-methyl; OP, organophosphorus pesticides.
[A]Percentage of frequency of detection (%) for each organophosphate measured above the limit of detection (LOD). LOD levels in ng/g dust by year: 2008 - 4.0 for 4 OPs; 2009 - 2.0 for 4 OPs; 2010 - 2.0 for phosmet, malathion, and chlorpyrifos and 5.0 for azinphos-methyl; and 2011 - 4.0 for azinphos-methyl and chlorpyrifos and 2.0 for phosmet and malathion.
[B]Median dust levels were calculated with imputed values (limit of detection (LOD)/2) for values below the LOD.
[C]Wilcoxon Mann-Whitney test.
[D]Sample sizes for 2009 and 2010 are larger due to the fact we had participants with Time 1 or Time 2 samples.
[E]Imputed value (limit of detection (LOD)/2).

conditioning at Time 2. The odds of having high chlorpyrifos concentrations compared to low concentrations were 4.82 times more likely in homes where there was an entry floor mat.

Among the non-agricultural families, the only factor associated with high OP concentrations was living within 25 m of an agricultural field or orchard (OR: 10.02 for azinphos-methyl at Time 1 and OR: 7.51 and 4.45 for phosmet at Time 1 and Time 2, respectively) (Table 4). The association between high azinphos-methyl concentrations and increasing frequency of open windows or doors per week approached significance (OR: 4.82, $p < 0.10$). Carpet cleaning frequency and having No A/C at the home, were also included in the non-agricultural models but none of these factors were significant.

Discussion

Overall, carpet dust samples from agricultural households had fewer samples below the LOD, and higher OP concentrations for samples above the LOD compared to non-agricultural households. These results replicate previous findings that homes with agricultural workers have elevated residential concentrations of OPs.[12,14,15] This indicates that families of agricultural workers have an increased potential for pesticide exposure in the home. These findings support the concept that pesticides are inadvertently brought from the workplace to the home environment. While we did not analyze the use of personal protective equipment and after-work hygiene practices after working with pesticides as determinants of contamination, the majority of agricultural workers reported wearing protective equipment at work. In addition, over half of the participants reported entering the home after work with work clothes on and reported not taking shoes/boots off before entering the home. Fenske et al. reported that work type among Washington tree fruit orchard workers was a significant predictor of pesticide concentration in the homes of azinphos-methyl, chlorpyrifos, and malathion.[18] Authors suggest that understanding job task may be an indicator for OP contamination in the homes and that targeted interventions should be focused at the workplace and not at the home in order to minimize pesticide exposure in the home. Lozier et al. suggested several interventions in the workplace of agricultural workers such as providing changing and storage areas for non-work clothes.[25]

The carpet dust OP concentrations measured in our study were generally lower than those previously reported for households in similar rural communities (e.g., chlorpyrifos median of 130 ng/g in 1999[26]; azinphos-methyl medians between 220-570 ng/g in

Table 3. Adjusted ORs (95% CIs) from logistic regression models for factors of highest tertile organophosphate concentrations (versus lowest tertile) in agricultural home dust samples at both time points, n = 138.

Factors	Azinphos-methyl		Phosmet		Malathion		Chlorpyrifos	
	Time 1 (n = 115)	Time 2 (n = 90)	Time 1 (n = 114)	Time 2 (n = 104)	Time 1 (n = 114)	Time 2 (n = 113)	Time 1 (n = 102)	Time 2 (n = 113)
≥ two agricultural persons in home[A]	**6.25 (1.3, 29.9)***	1.93 (0.41, 9.04)	3.14 (0.9, 10.96)**	0.84 (0.22, 3.16)	1.02 (0.31, 3.32)	4.07 (0.79, 20.95)**	1.73 (0.29, 10.24)	0.33 (0.06, 1.8)
Father works in fields and/or orchards[B]	1.00 (0.28, 3.61)	0.58 (0.12, 2.9)	0.52 (0.15, 1.81)	1.18 (0.33, 4.18)	1.81 (0.58, 5.6)	1.42 (0.35, 5.76)	1.81 (0.41, 7.92)	3.82 (0.75, 19.47)
Lives within 25 m of an agricultural field or orchard[C]	2.42 (0.73, 8.02)	4.09 (0.97, 17.26)**	**3.57 (1.27, 9.99)***	1.79 (0.55, 5.84)	0.86 (0.31, 2.33)	0.35 (0.08, 1.53)	2.24 (0.65, 7.75)	1.12 (0.32, 3.93)
Housing is an apartment, duplex, or house[D]	2.28 (0.65, 8.03)	1.67 (0.42, 6.69)	1 (0.33, 2.96)	1.69 (0.51, 5.6)	0.97 (0.34, 2.76)	0.81 (0.20, 3.3)	0.90 (0.21, 3.93)	0.47 (0.12, 1.82)
Floor mat is present	0.33 (0.03, 3.29)	2.52 (0.32, 19.75)	0.91 (0.22, 3.77)	0.46 (0.07, 3.12)	1.74 (0.48, 6.4)	0.38 (0.04, 3.85)	**4.82 (1.01, 23.16)***	2.45 (0.33, 18.06)
Increasing frequency of open windows/doors[E]	1.54 (0.63, 3.75)	1.2 (0.45, 3.19)	1.09 (0.47, 2.54)	1.53 (0.62, 3.77)	0.88 (0.40, 1.95)	1.1 (0.35, 3.45)	1.3 (0.51, 3.33)	2.34 (0.82, 6.69)
No A/C at home[F]	1.16 (0.36, 3.77)	1.49 (0.47, 4.73)	2.37 (0.86, 6.48)**	**4.24 (1.38, 13.09)***	0.98 (0.37, 2.56)	0.56 (0.15, 2.06)	0.59 (0.16, 2.14)	1.40 (0.42, 4.72)
Cleans home ≤1/week[G]	**0.23 (0.06, 0.93)***	**0.11 (0.02, 0.59)***	0.46 (0.12, 1.8)	0.79 (0.21, 3.08)	1.33 (0.40, 4.36)	2.63 (0.39, 17.77)	0.33 (0.07, 1.5)	1.0 (0.22, 4.65)

Abbreviations: OR, odds ratio; CI, confidence interval.
Significant OR and 95% CI are bolded at $p < 0.05$.
*< 0.05.
**$p < 0.1$.
[A]Number of residence members that worked in agriculture in last 3 months (reference is 0 or 1 members).
[B]Includes fieldwork and pesticide mixing and applying (reference is working as a sorter/packer in fruit packing house).
[C]House is next to or within an agricultural field or orchard (reference category is no).
[D]Lives in an apartment, duplex or house (reference category is lives in a cabin or trailer).
[E]Frequency the windows/doors left open for ventilation (per one category increase): categories include <1 per week, >1 per week, and every day.
[F]A/C at home includes central air conditioning, window units, or an evaporative cooler.
[G]Includes only those that own a vacuum (reference category: "more than once per week").

Table 4. Adjusted ORs (95% CIs) from logistic regression models for factors of highest tertile organophosphate concentrations (versus lowest tertile) in non-agricultural home dust samples at Time 1*, n = 140.

Factors	Azinphos-methyl		Phosmet		Malathion		Chlorpyrifos	
	Time 1 (n = 126)	Time 2 (n = 89)	Time 1 (n = 126)	Time 2 (n = 89)	Time 1 (n = 126)	Time 2 (n = 89)	Time 1 (n = 126)	Time 2 (n = 89)
Lives within 25 m of an agricultural field or orchard[A]	**10.02 (3.08, 32.56)***	3.16 (0.82, 12.17)**	**7.51 (2.68, 21.06)***	**4.45 (1.43, 13.84)***	0.91 (0.34, 2.45)	1.32 (0.38, 4.56)	1.77 (0.68, 4.62)	1.98 (0.65, 6.01)
Increasing frequency of open windows/doors[B]	1.52 (0.42, 5.58)	4.82 (0.82, 28.45)**	0.7 (0.25, 2.0)	2.28 (0.51, 10.21)	0.58 (0.23, 1.47)	0.96 (0.26, 3.55)	1.02 (0.42, 2.48)	0.73 (0.21, 2.5)
No A/C at home[C]	1.12 (0.33, 3.72)	1.47 (0.4, 5.45)	1.38 (0.48, 3.97)	1.96 (0.62, 6.15)	0.83 (0.31, 2.23)	1.01 (0.3, 3.44)	1.39 (0.55, 3.57)	1.33 (0.43, 4.1)
Cleans home ≤1/week[D]	0.76 (0.24, 2.37)	1.21 (0.31, 4.73)	0.84 (0.31, 2.33)	0.96 (0.31, 3.01)	1.19 (0.44, 3.19)	0.53 (0.16, 1.76)	1.21 (0.46, 3.19)	0.85 (0.29, 2.53)

Abbreviations: OR, odds ratio; CI, confidence interval.
Significant OR and 95% CI are bolded at $p < 0.05$.
*< 0.05.
**$p < 0.1$.
[A]House is next to or within an agricultural field or orchard (reference category is no).
[B]Frequency the windows/doors left open for ventilation (per one category increase); categories include <1 per week, >1 per week, and every day.
[C]A/C at home includes central air conditioning, window units, or an evaporative cooler.
[D]Includes only those that own a vacuum (reference category: "more than once per week").

2002[27]). These lower concentrations are likely due to the U.S. Environmental Protection Agency (EPA) ban of residential use of chlorpyrifos and initiating restrictions on the agricultural use of phosmet and azinphos-methyl put into place in 2000.[28]

There is one factor indicating that para-occupational pathways may contributed to pesticide residues found in the homes. Homes where two or more persons worked in agricultural during the prior three months were more likely to have higher azinphos-methyl OP concentrations (highest tertile vs. lowest tertile concentrations) compared to homes where only one person worked in agricultural and there was a similar trend in significance with phosmet and malathion. Similarly, McCauley et al. found a positive correlation between home azinphos-methyl levels in house dust and the number of persons in each house who specifically worked in agriculture.[13]

Homes located within 25 m to an agricultural field or orchard had higher OP concentrations than homes located farther away for both agricultural households and non-agricultural households. Several studies found higher levels of azinphos-methyl or chlorpyrifos in dust from homes that were located near agricultural fields.[12–16] Having an air conditioner was found to be protective and associated with lower phosmet concentrations at one time point. Harnly et al. also found that having an air conditioner in the home was strongly associated with reduced OP concentrations.[22] Investigators reported that this result is likely because windows may be closed during pesticide application for homes with air conditioners compared to homes with open windows. Higher OP concentrations in homes next to a field or orchard indicates that pesticide spray drift may have contributed to pesticide residues found in the home. It is important to note, that application methods of OPs in the orchards may have affected pesticide spray drift.[18,29] There is likely less drift when pesticides are applied with ground airblast spraying than when they are applied aerially.[17] Keeping windows closed may help prevent residues from entering the home. We also found that for azinphos-methyl, homes that were cleaned more than once per week were more likely to have high concentrations compared to homes that cleaned once or less per week. In addition, having a floor mat was a risk factor for higher concentrations of chlorpyrifos in the home. It is unclear why these behaviors increased pesticide concentrations in the home, however we did observe that home that were cleaned more were slightly more likely to also be homes in close proximity to the fields. Cleaning methods may be ineffective and floor mats may become repositories for pesticide residues. More information is needed to understand how these behaviors impact exposure.

The findings in this study suggest that agricultural use of OPs is a source of OP contamination in the home. While associations between several significant factors and OP concentrations varied between the models, having a home with 25 m to a field or orchard was a significant risk factor among households for azinophos-methyl and phosmet. Para-occupational pathways and pesticide spray drift are two likely sources of contamination. Families with agricultural workers and families that live in close proximity to agricultural activities may have increased exposures due to higher levels of OPs in the home environment. Previous finding with this population have reported changes in pesticide levels over time.[1] A large increase in malathion concentrations was measured in home dust from 2010–2011 (15–99 ng/g in agricultural homes). This increase coincided with a local infestation of the spotted wing drosophila in the orchards and recommendations from local extension agents included the use of malathion applied through aerial application.[29,30]

The chief strength of this study was the detailed information from the questionnaires about several housing characteristics and resident behaviors. In addition, the repeated home dust samples, which allowed us to determine the variability in concentrations between the two time points. We also were able to demonstrate similar results with a few factors, which adds to the strength of the results. A limitation was the self-reported proximity of homes to a field or orchard, however since proximity is categorized into within 25 m or not within 25 m, this may reduce misclassification. In addition, dust samples were not collected from households without carpet. These households may be systematically different from those with carpet. However, dust sample collection of households without carpet would have used different methods; therefore, these data would not be comparable. Another limitation was that azinphos-methyl was infrequently detected in dust samples and values below the LOD were substituted with one-half of the LOD. OP concentrations were classified into tertiles to limit the potential bias from the substituted measures.

Conclusion

In summary, home dust samples were collected from homes at two time points and analyzed for four OPs. Although OP concentrations in carpet dust is not a measure of direct exposure, they are useful indicators of OP contamination in the home. This study indicates that OPs are found in the home even after restrictions have been placed on the use of these OPs in the residential environment. The findings indicate that para-occupational pathways and pesticide spray drift contributed to increased concentrations of OPs in the homes.

Many adverse health effects have been linked to OP exposure. As mentioned above, studies have found that OP exposure may be associated with deficits in learning in school-aged children.[1,3] Due to the importance of limiting OP exposure in rural communities, it is essential to understand factors that may increase indoor OP exposure in agricultural communities. Results of this study can be used in subsequent exposure assessment studies.

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