ORIGINAL ARTICLE

Variability in the take-home pathway: Farmworkers and non-farmworkers and their children

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Organophosphate pesticides (OPs) are related to ill health among adults, including farmworkers who are exposed to OPs as part of their regular work. Children of both farmworkers and non-farmworkers in agricultural communities may also be affected by pesticide exposure. Study groups of 100 farmworkers with a referent child (aged 2–6 years) and 100 non-farmworkers with a referent child were recruited to participate in three data collection periods over the course of a year. At each collection, participants provided three urine samples within 5 days, and homes and vehicles were vacuumed to collect pesticide residues in dust. In thinning and harvest seasons, farmworkers and their children had higher dimethyl urinary metabolites than non-farmworkers and their children. During the non-spray season, the urinary metabolites levels decreased among farmworkers to a level comparable to that of non-farmworkers. Farmworkers consistently had higher pesticide residues in their home and vehicle dust. Differences exist between farmworkers and non-farmworkers in urinary metabolites, and the differences extended throughout the agricultural seasons.OP metabolites are seen at much higher levels for farmworkers and their children than for non-farmworkers and their children during agricultural seasons when OPs are in use. These metabolite levels were significantly higher than the nationwide NHANES IV survey and up to 10-fold higher than other rural agricultural studies.

INTRODUCTION

Organophosphate pesticides (OP) are among the most widely used class of insecticides in agricultural settings, with an estimated 33 million pounds applied in the United States every year. Although their use has been decreasing overall, OPs still account for an estimated 40% of all insecticides applied in the United States.[1,2] Pesticides used throughout the Yakima Valley, the site of this study, include OP insecticides such as azinphosmethyl (AZM), phosmet (PH), diazinon (DZ), malathion (ML), and chlorpyrifos (CP) among others. Data for Washington from the Agricultural Chemical Use Database show that in 2005 >196,000 pounds of AZM and >87,000 pounds of PH were used on apple crops alone.[3] The US Environmental Protection Agency mandated the nation-wide elimination of AZM by 30 September 2012.[4] Although general residential uses of OP insecticides have declined following the respective phase-outs of CP, DZ, and AZM, their uses are still permitted for defined agricultural purposes in the Yakima Valley.[5–7]

Although the short-term health effects of exposure to OPs are widely known, the health effects of chronic exposures are less well understood and are hampered by challenges faced when studying farmworkers who are often seasonal and migratory.[8–10] There is little doubt that OPs can be related to ill health among adults, especially farmworkers who are exposed to OPs as part of their regular work.[11–17] Even more disturbing, however, is that farmworkers' families, including children, are exposed to pesticides through the occupational take-home pathway.[18–23]

Children are a particularly susceptible population to pesticides due to their exposure-prone behaviors as well as physiologically based differences between adults.[24,25] Because children have greater surface area to body weight ratios and higher circulatory flow rates than adults, they may accumulate more pesticides and distribute them throughout the body more rapidly than adults in the same environment.[26–29] Children's immature metabolism and elimination systems may be less effective than adults for clearing pesticides from the body.[30] Changes in the production of liver enzymes during early developmental stages may increase or decrease the toxicity of pesticides in children's bodies, thereby producing a greater proportional impact than adults.[31] In addition, young children have lower activities of key OP-detoxifying enzymes, including paraoxonase, that may further increase children's susceptibility to exposure.[32–36]

For the past 10 years, we have followed a community-based participatory research strategy in the Lower Yakima Valley of Washington State to reduce pesticide exposure among children of Hispanic farmworkers.[18,37] Our previous studies indicated that young children aged 2–6 years were exposed through a take-home pathway[18] and that farmworkers who worked in pome fruit crops (apples and pears), as well as their children, were more heavily exposed to pesticides than farmworkers working in non-pome crops (cherries and peaches).[20,38] In response to our previous work, our Community Advisory Board (CAB) encouraged a new project that examined potential seasonal differences in exposure pathways important for children of agricultural workers compared with children of non-agricultural workers. Specifically, the CAB wanted to know if farmworkers and their children had higher levels of OP exposure than those of non-farmworkers and their children living in the same communities; in

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addition, the CAB wanted to examine multiple pathways of exposure, including the take-home pathway, a dietary pathway, an environmental pathway, and a lifestyle pathway. To do this, we jointly designed, with the CAB, a cohort study to be conducted in the Lower Yakima Valley. The overall goal of the study was to assess the urinary metabolites of OPs in adult farmworkers and their children and in adult non-farmworkers and their children. The purpose of this report is twofold: (1) to examine seasonal OP exposure of farmworkers and their children compared with non-farmworkers and their children; and (2) to examine the OP take-home pathway based on occupation and season.

The study was conducted to correspond to major pesticide applications at the specific questionnaire times, for example, dimethyl (DM) pesticides such as azinphosmethyl and phosmet were applied during the thinning and harvest seasons. During the non-spray season, crops are dormant and no sprays are used. The identification of respondents, surveying, and sample collection were done when the DM sprays were most likely. Understandably, the spray patterns vary by year and the prevalence of specific pests.

MATERIALS AND METHODS

Setting

This cohort study took place in the Lower Yakima Valley of eastern Washington State. The Valley is a rich agricultural region and is known for its fruit and vegetable production. Orchard crops, such as apples, pears, cherries, and peaches are predominant, as are hops and grapes. The Yakima Valley is the primary area for raising fruit in the state. Azinophosmethyl has the highest use among OPs (196.2 thousands of pounds in 2005 in the State) and is applied during thinning and harvest times in the Valley. Phosmet is also applied (102 thousands of pounds for apples and pears in 2005 in the State). Most of the agricultural work in the Valley is done by farmworkers who are of Hispanic origin. The Hispanic population has burgeoned in recent years with the Yakima County 2000 census reflecting 35% of the population as Hispanic or Latino in origin, increasing to 45.8% in the 2010 census.[39] Further, census data indicate that in the communities in the Lower Yakima Valley, the percentage of Hispanic is approximately 67%.[39]

Study Groups

We recruited two study groups: a cohort of 100 farmworkers along with a referent child aged 2–6 years in the farmworker household; and a cohort of 100 non-farmworkers along with a referent child aged 2–6 years in the non-farmworker household. The study groups were contacted three times during a year: During the "thinning" season when OPs are in heavy use among orchard crops; during the harvest season, when OPs are used less frequently on orchard crops; and in the non-spray season, when crops are dormant. Because we were primarily interested in orchard crops that received OP applications, we limited our farmworker cohort to those who worked in pome fruit crops.[38]

Recruitment. Participants were recruited through flyers distributed by multiple means. Flyers were created for both farmworkers and non-farmworkers. The flyers specified the inclusion criteria and provided information on the samples that would be taken. The flyers were distributed throughout the Valley; project staff distributed them at grocery stores, community organizations, churches, worksites, health fairs, and other activities in the Valley. Individuals who were interested in participating in the project left their name, address, and telephone number (if they had a telephone) with the project staff, and they were re-contacted later by telephone or in person and asked if they were still interested in participating. If the response was affirmative, the project was explained in more depth and, for those who continued to be interested, informed consent was reviewed and signed. All participants who joined the study groups were given a household total of $160 for participation in all the phases of data collection in the study, which lasted for a total of 1 year.

Inclusion Criteria. All farmworker participants needed to be aged ≥18 years, have a child in the household aged 2–6 years who could participate in the study, plan to be in the Valley for an entire year, and work as a thinner or harvester in apple or pear crops. For non-farmworkers, the inclusion criteria required that the participant be ≥18 years, have a child aged 2–6 years who could participate in the study, plan to be in the Valley for an entire year, and have an occupation other than farmworker. Occupations of non-farmworkers included positions in factories, dairies, stores, schools, and daycares.

Data Collection. All data collection procedures were reviewed and approved by the Institutional Review Board (File IR 5946) at the Fred Hutchinson Cancer Research Center. Interview information and samples were collected from farmworkers and their children and non-farmworkers and their children during each of the three agricultural seasons. Sampling began in the thinning season (May through July, 2005), followed by the harvest season (September through October, 2005) and the non-spray season (December 2005 through February 2006). Each adult completed two interviews each season, one on the first day of data collection that included questions about the adult, and one on the fifth day of data collection that focused on child activities. Topics included self-reported level of general pesticide exposure, job tasks, worker self-protective practices, employer practices, family protective practices, family pesticide use, proximity to fields, eating behaviors, child behavioral practices, child eating behaviors, contact information, and sociodemographics.

In addition to the questionnaire data, we collected a number of biological samples from each adult farmworker and non-farmworker during each of the seasons, including three urine samples, one venous blood sample, one fingerstick blood sample, and buccal cells. For farmworkers only, we also collected saliva samples. For all children, we collected three urine samples, a fingerstick blood sample, and buccal cells. Environmental samples were also collected and included a dust sample from the homes of both farmworkers and non-farmworkers as well as a dust sample from their vehicles (see Table 1). For this paper, we focus on the urine samples and the dust samples collected during the three agricultural seasons and for the dust samples collected during the thinning season from both farmworker and non-farmworker households.

Collection Procedures. Data were collected three times throughout the year, reflecting the three agricultural seasons present in the Valley. The first data were collected during the thinning season (Spring, 2005) with average monthly high temperatures of 75–90 degrees Fahrenheit at Sunnyside, WA, USA, a central location in the Valley. During the thinning season, farmworkers remove, by hand, small buds, shoots, and undersized fruit from the branches of apple and pear trees to allow the remaining buds to produce larger fruit. During this season, pesticides are used to control the coddling moth and other insects. The primary pesticides used during this season are DMs, such as azinphosmethyl and phosmet. The second survey period took place between September and October 2005 (Fall), which was the harvest season for several of the Lower Yakima Valley's largest orchard crops, which include apples and pears and had average monthly high temperatures of 80 degrees Fahrenheit and 67 degrees Fahrenheit, respectively. Again, the primary pesticides used during this season were azinphosmethyl and phosmet. The third survey was conducted between December 2005 and February 2006 (Winter) with average monthly high temperatures of 39–47 degrees Fahrenheit. This period occurred when the crops were dormant; thus, this was considered the non-spray period in which no pesticides were applied to the fields.

Surveys. Six bilingual (Spanish and English) project staff were trained in survey interviewing. During a 3-day training session, staff were familiarized with the survey, learned how to do tracking, and practiced obtaining informed consent from potential participants. Each staff member received a Handbook summarizing the importance of confidentiality, the informed consent process, the surveys, tips on interviewing, a Question-by-Question explanation of the questionnaires, and tracking forms. During the 3-day training, staff went through the Handbook and practiced interviewing each other and completing tracking forms. At the end of the training, staff were tested and certified in interview and consent procedures.

Urine Collection. For urine, we collected three independent morning voids separated by 2 days each; thus, each participant, adult and child, provided a urine sample on the first day of data collection, another one on the third day, and yet another on the fifth day. We repeated this sampling during the harvest and non-spray seasons. Urine samples, collected in plastic cups, were placed in a plastic bag and then put on frozen ice packs in a cooler immediately after collection. Samples were then transported to the field office where 10 ml were pipetted into 15-ml bottles, and samples

Table 1. Samples collected in the three agricultural seasons and those presented in this paper.

Samples	Thinning season May–July 2005	Harvest season September–October 2005	Non-spray season December 2005–February 2006	Presented in this paper
Urine of adults and children, days 1, 3, and 5	X[a]	X[a]	X[a]	X
Household survey, days 1 and 5	X	X	X	Sociodemographic data
House dust, day 5	X[a]	X	X	Thinning season
Vehicle dust, day 5	X[a]		X	
Buccal cells of adults and children, days 1 and 5	X		X	
Fingerstick blood of adults and children, day 1	X[a]		X[a]	
Venous blood of adults only, day 1	X[a]		X[a]	
Saliva from adult farmworkers only, day 1	X[a]		X[a]	

[a]Samples with analytical laboratory results available.

were frozen and stored in freezers at $-10\,^\circ$C before being sent on dry ice to the laboratory at the Centers for Disease Control for analysis. Measurements were made via high-performance liquid chromatography-linked tandem mass spectrometry (HPLC-MS/MS).[40]

Dust Samples. Using a Nilfisk vacuum cleaner, house dust was collected from the residences of the participants. A cleaned vacuum and fresh polyliner bag, along with a clean vacuum hose and wand, were used for each household. Procedures for house and vehicle dust sampling were developed by the University of Washington.[41] Areas were vacuumed in a standardized manner. A square half meter by half meter template was used as a guide. Depending on flooring type, 4–8 templates were vacuumed. The area vacuumed was where the parent reported "the child played most frequently." After dust collection, the vacuum bag and polyliner were removed and placed in a plastic bag and stored at $-10\,^\circ$C for transfer to the laboratory at the University of Washington for analysis. Vehicle dust was collected in a similar manner. The footwells, front and rear (except in the case of trucks without rear footwells), of the vehicle were thoroughly vacuumed. After dust collection, the vacuum bag and polyliner were removed and placed in a plastic bag and stored at $-10\,^\circ$C for transfer to the laboratory at the University of Washington for analysis. The most heavily used OPs on Washington apple and pear crops were analyzed in home and vehicle dust—azinphosmethyl, malathion, phosmet, chlorpyrifos, and diazinon (NASS, 2005).

Laboratory Analysis of Urine. Each urine sample was analyzed for three DM metabolites: dimethyl-phosphate (DMP), dimethyl-thiophosphate (DMTP), and dimethyl-dithiophosphate (DMDTP) and three diethyl (DE) metabolites: diethyl-phosphate (DEP), diethyl-thiophosphate (DETP), and diethyl-dithiophosphate (DEDTP). Urine samples were analyzed for all six of these metabolites using the method of Odetokun et al.[40] Metabolite levels were reported without measure of creatinine.[1] Briefly, 2-ml aliquots of urine were spiked with isotopically labeled analogs of the target analytes, mixed thoroughly and then lyophilized to remove residual water. The residue was reconstituted in solvent and derivatized to form the chloropropyl phosphate esters of each metabolite. The concentrated extract was analyzed using HPLC-MS/MS with both quantification and confirmation precursor–product ion pairs being measured. Each run consisted of a full 8-point calibration plot, 3 quality-control materials spiked at concentrations spanning the entire calibration range, 2 blank samples, and 36 unknown urine samples. Analytes were quantified using isotope dilution calibration to provide data in ng/ml units. Data were converted to molar units (SI units) using the general equation concentration (ng/ml) $\times$ molecular weight (nmol/ng) $\times$ 1000 (ml/l) to produce nM (nmol/l) concentrations. Data were considered valid only if the quality control materials were deemed acceptable according to Westgard's multirules.[42] A target analyte was considered quantifiable if it coeluted chromatographically with its isotopically labeled analog, had a signal-to-noise ratio >3, possessed the correct quantification and confirmation precursor–product ion pairs, and the quantification and confirmation ion paired were present in an approximate 3:1 ratio. The accuracy of the

method ranged from 98% to 103% with relative SDs of $<15\%$. The limits of detection (LODs) for each of the metabolites were: DMP 4.8 nmol/l (0.6 ug/l), DMTP 1.4 nmol/l (0.2 ug/l), DMDTP 0.6 nmol/l (0.1 ug/l), DEP 1.3 nmol/l (0.2 ug/l), DETP 0.6 nmol/l (0.1 ug/l), and DEDTP 0.5 nmol/l(0.1 ug/l). When a metabolite's value was below the LOD, one-half of the LOD was used for the value of the metabolite.

Statistical Analysis of Urine Data. To examine how the patterns of metabolite concentrations changed with seasons, we first summarized the collection of the three times in each season as a median of the three voids over a 5-day period for each person by season. We summed the three DM metabolites for each person to estimate the total moles of DM metabolites and similarly for the DE metabolites. The same individuals were followed longitudinally across all three seasons. We were able to collect urine from 92% of the individuals across the three seasons.

We compared distributions of metabolites using non-parametric tests in order to understand how concentrations of OP metabolites in urine changed across seasons for farmworkers and non-farmworkers and their children. We show median molar concentrations of DM and DE metabolites and 95% confidence intervals for the medians for each season. Confidence intervals are non-parametric estimates that contain the median at least 95% of the time and are based on the binomial distribution.[43] The median concentrations are compared in two ways—farmworkers with non-farmworkers and across seasons. To compare farmworkers with non-farmworkers, the differences between the medians of the distributions are tested using a two-sided two-sample Wilcox test. The results are shown in the three median comparison column; if there was no significant difference between the medians (adjusted $P>0.05$), the result is shown as "F,N" and for adjusted $P<0.05$ either "F$>$N" or F$<$N" (where F represents farmworker and N represents non-farmworker) is shown depending upon which median was significantly larger. To compare across seasons, a paired Wilcox test was used for each pair of seasons. Paired tests are used, because the same individuals were measured across seasons; the test is based on taking the difference between seasons for each person and testing whether the median of these values is significantly different from zero. The results between seasons are shown for each pair of thinning (T), harvest (H), and non-spray (O) seasons, and the direction of the trend ("$<$" or "$>$") for significant trends (adjusted $P<0.05$) is based on whether the median of the differences is positive or negative. The P-values from these tests were adjusted to control for false discovery using the method of Benjamini and Hochberg for the 27 significance tests performed for differences between farmworkers and non-farmworkers and between seasons.[44] Significance was determined based on the adjusted P-value being <0.05. Comparisons of urinary pesticide metabolite data were present for NHANES and displayed as cumulative percentile of normal distribution *vs* the DMTP concentration (ug/l) (Figure 3).

Analysis of Dust Data. Concentrations of OP residues in dust are displayed for the thinning season. Empirical probability plots show the observed distributions of values in farmworkers and non-farmworkers for
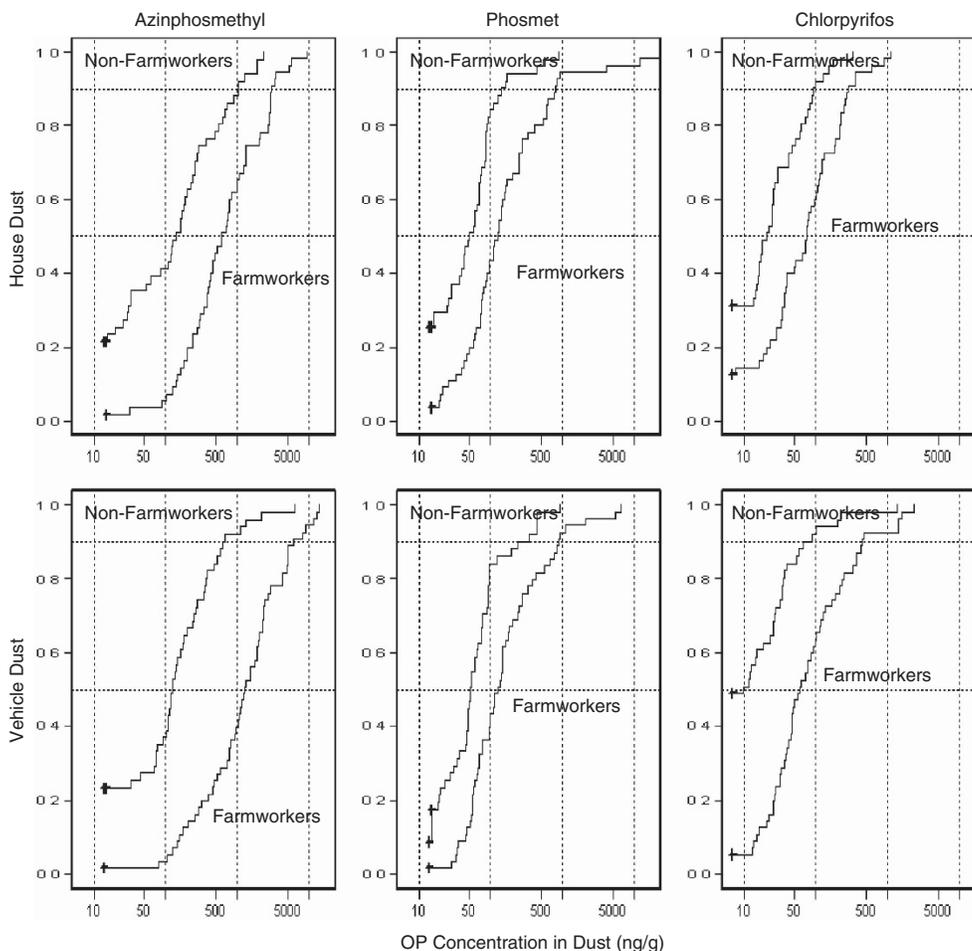
Figure 1. Empirical cumulative distribution plots of six house and vehicle OP residue concentrations for farmworkers and non-farmworkers during the thinning season. Horizontal dashed lines are at 50% (median) and 90% empirical probabilities. Vertical lines are at 10,100, and 1000 ng OP/g dust. OP pesticides are classified as either dimethyl (DM) or diethyl (DE) pesticides. The lowest concentrations shown on the plots are at the limits of detection and empirical probability at the limit of detection is the percentage of the samples below the limit of detection. Comparisons of the medians between the farmworker and non-farmworker distributions for each pesticide are based on two-sided two-sample Wilcox test with P-values adjusted for false discovery.[44]

azinphos-methyl, malathion, phosmet, methyl-parathion, chlorpyrifos, and diazinon, as these are the most common pesticides used in the Valley. Distributions with higher concentrations are shifted to the right. The lowest concentrations shown on the plots are at the LODs, and the empirical probability at the LOD is the percentage of the samples below the LOD. Horizontal dotted lines are shown for the 50th (median concentration) and the 90th percentiles of the empirical distributions and vertical lines at concentrations of 10, 100, and 1000 ng OP/g dust (Figures 1 and 2). Differences in the medians between the farmworkers and non-farmworkers for each of the pesticides are tested using the same methods as for the urinary analysis described above. Spearman correlations were calculated between dust and urine values for the thinning season.

RESULTS

Table 1 lists the types of samples collected for this study, including biospecimens from blood, urine, and buccal cells as well as environmental samples, such as house and vehicle dust. These data were collected in coordination with data collection on occupation, diet, and proximity. In this paper, we discuss the analysis of the urine and dust samples with an emphasis on the thinning season of the agricultural calendar. Table 1 delineates what samples were taken and which ones have analytical laboratory results available. All samples are stored in a biorepository for future analysis.

Characteristics of the Sample

The total number of survey respondents in the farmworker cohort was 100 and 100 in the non-farmworker cohort. Table 2 summarizes the basic characteristics of the two cohorts. As can be seen, there are some differences between farmworker families and non-farmworker families. More farmworkers were in the 30–34-year range compared with non-farmworkers. More farmworkers were married or living as married than non-farmworkers. The non-farmworkers had higher incomes than the farmworkers. More farmworkers were born in Mexico compared with non-farmworkers, and they were also less likely to live in a single family home compared with non-farmworkers. Differences between farmworkers and non-farmworkers for the demographic variables were tested using the Fisher's exact test for each category. We found that the age structure ($P=0.83$), gender ($P=0.9$), and number of children ($P=0.5$) were not significantly different, whereas marriage rates ($P=0.011$), place of birth ($P<0.001$), and type of dwelling ($P<0.001$) were significantly different.

Pesticide Urinary Metabolites

We see in Table 3 that median concentrations of DMs are higher for farmworkers and their children in the thinning and harvest seasons and decrease significantly in the non-spray season. For
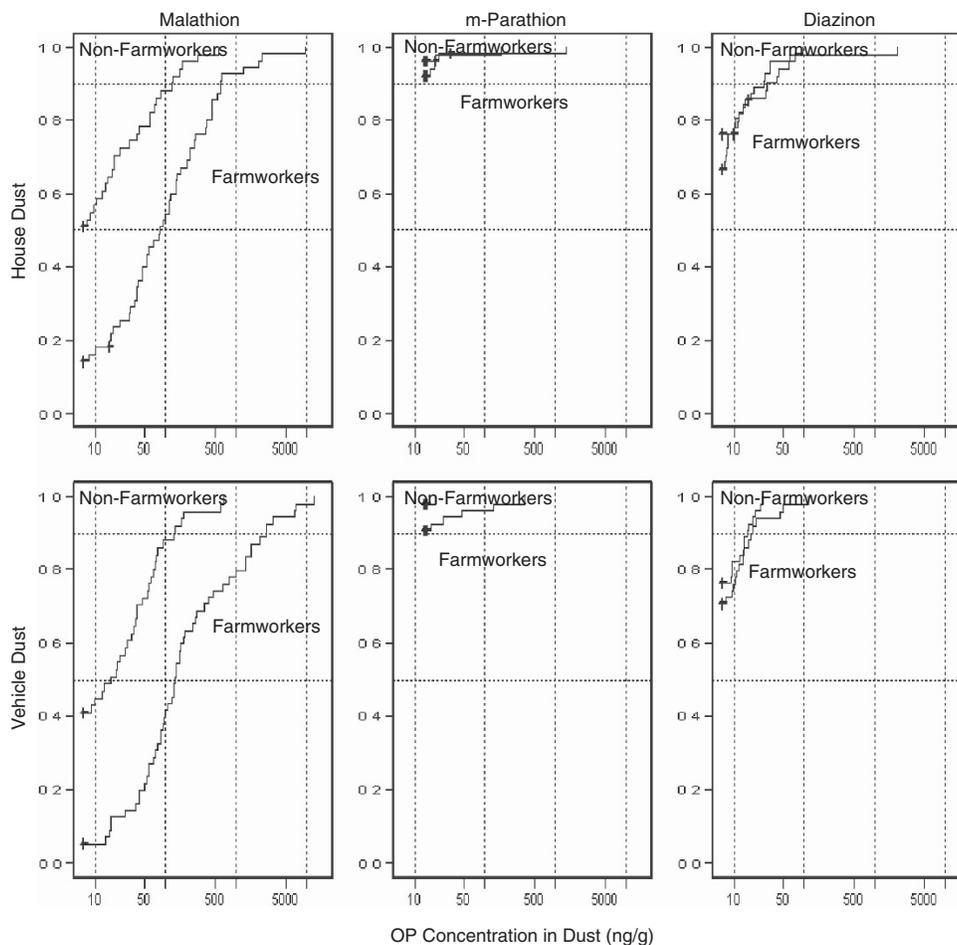
Figure 2. Empirical cumulative distribution plots of six house and vehicle OP residue concentrations for farmworkers and non-farmworkers during the thinning season. Horizontal dashed lines are at 50% (median) and 90% empirical probabilities. Vertical lines are at 10, 100, and 1000 ng OP/g dust. OP pesticides are classified as either dimethyl (DM) or diethyl (DE) pesticides. The lowest concentrations shown on the plots are at the limits of detection and empirical probability at the limit of detection is the percentage of the samples below the limit of detection. Comparisons of the medians between the farmworker and non-farmworker distributions for each pesticide are based on two-sided two sample Wilcox test with *P*-values adjusted for false discovery.[44]

DM metabolites, the farmworker adults have significantly higher levels than the non-farmworker adults in both the thinning and harvest seasons and the farmworker children are higher than the non-farmworker children in the thinning season but not the harvest or the off season. In contrast, non-farmworkers and their children have a significant rise in DM metabolites during the harvest season compared with their values in the thinning and non-spray seasons.

The only significant changes in DE metabolites between seasons is that there is a significant drop for the adult farmworkers in the non-spray season to a level that is significantly lower than the adult non-farmworkers. Although we cannot see significant changes in DE values for children across the seasons, the values for farmworker children do drop enough in the harvest and non-spray seasons so that they are less than the non-farmworker children.

The results in Table 4 provide a statistical analysis to compare metabolites across seasons and between farmworkers and non-farmworkers. Significant differences in metabolite levels are seen. The levels in thinning season are significantly higher than the non-spray season for DM metabolites in farmworker adults and children and for DE metabolites in farmworker adults. When the thinning and harvest seasons are compared, significant differences are seen in levels for the thinning season, and it is lower

than the harvest season for DM metabolites in non-farmworkers and their children. The levels in harvest season are higher than the non-spray season for all comparisons of DM metabolites, but no differences were significant for comparisons between DE metabolites. When levels in farmworkers and non-farmworkers are compared for DM metabolites, the adult farmworkers have significantly higher concentrations than the adult non-farmworkers in the thinning and harvest seasons, and the farmworker children had significantly higher concentrations in the thinning season compared with non-farmworker children. For the DE metabolites, the levels in farmworker adults are significantly lower in the non-spray season. The levels in farmworker children are significantly lower in the harvest and no-spray seasons. All other comparisons between farmworkers and non-farmworkers were not significant.

Pesticide Residues in Dust
In Figures 1 and 2, pesticide residues in house and vehicle dust of both farmworkers and non-farmworkers during the thinning season are shown. As shown in the plots, farmworkers consistently have higher residue concentrations in both house dust and vehicle dust compared with their non-farmworker counterparts. The differences are most striking for azinphos-methyl, phosmet,

Table 2. Characteristics of the sample ($N = 200$) by occupation.		
Characteristic	Occupation	
	Farmworker (n = 100)	Non-farmworker (n = 100)
Age (mean), years	31.6	31.3
<25	11	15
25–29	20	27
30–34	46	28
≥35	23	29
Gender		
Female	79	81
Marital status		
Married/living as married	92	76
Widowed/divorced	6	15
Never married	2	8
Income		
<15,000	39	31
15,000–25,000	40	32
>25,000	21	36
Number of children		
1	11	14
2	25	32
3	30	23
≥4	34	30
Birthplace		
Mexico	97	64
US	2	36
Type of dwelling		
Single family home	52	80
Apartment	28	15
Trailer	20	5

chlorpyrifos, and malathion, many of which are heavily used in the Valley. For methyl-parathion and diazinon, there are only a small percentage of the samples above the LOD with similar concentrations for farmworkers and non-farmworkers with concentrations above the LOD. During the thinning season, we found a correlation of 0.47 ($P = 0.005$) for total DM OP concentrations in vehicle dust and total DM metabolite concentration in urine for adult farmworkers and 0.17 ($P = 0.023$) for house dust and urine, whereas for non-farmworker adults we found a correlation of 0.19 ($P = 0.1$) between vehicle dust and urine and 0.01 ($P = 0.9$) between house dust and urine. This reveals support for the occupational take-home pathway for farmworkers as the correlation was highest between vehicle dust and urinary metabolites, and a correlation between house dust and urine metabolites was also present during this time of high pesticide use. Non-farmworkers showed a similar pattern of higher correlation for vehicle dust vs house dust but at a lower correlation and with concurrent absolute lower urinary metabolite concentrations and lower OP residue concentrations in dust.

A comparison of our adult and child study populations to a national survey, NHANES IV, a previous study in the Valley [19,38] and the CHAMACOS study in the Salinas valley of California, [45] is shown in Figure 3 for the urinary metabolite DMTP. The NHANES IV survey was conducted in 2003–2004, the years closest in time to our study population in late spring, early summer of 2005 during the thinning season. The figure shows the cumulative distribution for each group plotted on a normal distribution scale. Lines to the right indicate populations that have higher concentrations in the urine. We see in the comparison for adults that the farmworkers

have higher concentrations than non-farmworkers in the present study and that both are higher than that for the adults measured in the NHANES IV survey except at the upper end of the distribution (above 90%) where that for non-farmworkers and adults in NHANES IV are similar. The figure also shows that farmworker children have higher concentrations of DMTP in their urine than non-farmworkers and both are higher than the 6–11 year olds in NHANES IV. We compared our child concentrations with the 6–11-year olds in NHANES IV as this was the group closest in age to our 2–6-year olds. We used one-sample Wilcoxon tests to compare the medians for DMTP in the current study to NHANES IV. For each of the four comparisons, the P-value was <0.0001 (farmworker adult vs NHANES adult, non-farmworker adult vs NHANES adult, farmworker child vs NHANES child 6–11 years, and non-farmworker child vs NHANES child 6–11 years), indicating significantly higher levels in our farmworker children. Also shown are the youth population of 12–19-year olds from NHANES IV. The levels of metabolites shown in Figure 3 were also compared with other studies. Farmworkers and their children aged 2–6 years were sampled in the thinning season in the Valley in 1999 and 2002. Those studies showed considerable differences between different years. For comparison, we looked at non-intervention communities' children and adults for those two previous studies in the valley and the results are presented in Figure 3.[19,38] The 1999 season had lower concentrations of DMTP in urine for both the adults and the children and the 2002 thinning season had slightly higher concentrations than did the farmworkers in the present study during thinning season. Year-to-year fluctuation of urinary DMTP was also seen in a longitudinal study in the Valley from 1998 to 1999.[46,47] To provide a comparison to a different agricultural region, we also show the DMTP levels for a group of women residing in the Salinas Valley of California between 1999 and 2001 reported in the CHAMACOS study,[45] which was significantly different ($P<0.01$) from the thinning season adults in this study. The CHAMACOS group is 10-fold lower than the farmworker groups in Yakima Valley for 1999, 2002, and 2005 but higher than the non-farmworker group measured in the Yakima Valley in 2005.

DISCUSSION

In this study, we report on the urinary pesticide metabolites in families of farmworkers and non-farmworkers living in agricultural communities and pesticide residues in the dust of their households and their vehicles. Data collected during three seasons when pesticides are thought to be used most heavily (thinning season), not as heavily (harvest season), and not at all (non-spray season) indicated that adult farmworkers and their children had higher levels of OP urinary metabolites in the seasons with higher pesticide use (thinning and the harvest seasons). During the non-spray season, there were few differences between farmworker families and non-farmworker families in terms of DM and DE metabolites. Similarly, during the thinning season, there were higher OP concentrations among farmworkers in both house and vehicle dust compared with non-farmworkers.

In both the thinning and harvest seasons, farmworkers had higher DM metabolite concentrations in urine than those of non-farmworkers; however, the DM concentrations for farmworkers' children were only higher in the thinning season. This is somewhat confusing as the adult farmworkers continued to have higher concentrations of DM metabolites in the harvest season. The children of farmworkers had approximately the same median levels in the thinning and harvest season but that of the non-farmworkers' children had more than double their median levels during the harvest season. This suggests that there may be another pathway by which OP pesticides enter the body, especially during the harvest season. It may be that consumption of fruits treated with OP pesticides is contributing to the urinary

Table 3. Median urinary metabolite (DAP) concentrations (μg/l) and 95% CI in adult and child samples by sampling season.

Time of collection and metabolite type	Adults			Children		
	Percentage > LOD	Farmworker	Non-farmworker	Percentage > LOD	Farmworker	Non-farmworker
Thinning		(n = 99)	(n = 95)		(n = 99)	(n = 94)
DMP	86	13.80 (10.68–17.80)	2.31 (1.88–2.82)	86	5.76 (4.65–7.11)	3.74 (3.06–4.57)
DMTP	99	62.87 (47.82–82.41)	5.05 (4.23–6.03)	99	16.79 (13.78–20.39)	7.16 (5.74–8.90)
DMDTP	93	5.93 (4.56–7.69)	0.77 (0.63–0.92)	91	2.43 (1.95–3.04)	0.89 (0.71–1.09)
DEP	74	1.69 (1.24–2.29)	1.55 (1.15–2.09)	77	1.83 (1.37–2.46)	1.96 (1.45–2.63)
DETP	88	0.84 (0.68–1.05)	0.61 (0.51–0.73	87	0.62 (0.50–0.76)	0.64 (0.53–0.77)
DEDTP	64	0.14 (0.11–0.18)	0.17 (0.14–0.21)	61	0.12 (<LOD–0.15)	0.15 (0.12–0.18)
Harvest		(n = 97)	(n = 94)		(n = 97)	(n = 94)
DMP	82	9.38 (6.61–13.15)	5.79 (4.24–7.93)	77	3.29 (2.45–4.39)	5.29 (3.94–7.16)
DMTP	98	69.11 (52.19–91.41)	18.02 (13.06–24.89)	98	21.87 (17.48–27.35)	16.35 (12.66–21.20)
DMDTP	85	2.82 (1.74–4.51)	3.02 (2.15–4.26)	80	0.84 (0.54–1.29)	2.54 (1.86–3.49)
DEP	52	0.20 (<LOD–0.39)	0.62 (0.34–1.07)	53	0.12 (<LOD–0.26)	0.85 (0.55–1.29)
DETP	68	0.16 (<LOD–0.27)	0.87 (0.65–1.16)	67	0.11 (<LOD–0.18)	0.95 (0.76–1.18)
DEDTP	42	<LOD	0.12 (<LOD–0.18)	39	<LOD	0.11 (<LOD–0.16)
Non-spray		(n = 91)	(n = 87)		(n = 91)	(n = 86)
DMP	67	1.06 (0.70–1.56)	2.91 (2.29–3.70)	70	1.50 (1.05–2.11)	3.91 (3.00–5.07)
DMTP	99	6.71 (5.60–8.05)	6.07 (5.00–7.37)	97	6.21 (5.02–7.67)	7.58 (6.06–9.48)
DMDTP	81	0.51 (0.39–0.67)	0.66 (0.54–0.80)	82	0.58 (0.44–0.77)	0.91 (0.74–1.13)
DEP	60	0.16 (<LOD–0.31)	1.45 (1.00–2.08)	63	0.25 (0.13–0.46)	1.85 (1.31–2.55)
DETP	85	0.60 (0.45–0.78)	0.76 (0.62–0.92)	85	0.68 (0.51–0.91)	0.78 (0.63–0.95)
DEDTP	52	<LOD	0.17 (0.13–0.22)	49	<LOD	0.16 (0.12–0.21)

Table 4. Comparison of median concentrations of DM and DE metabolites (nmoles/l) of organophosphate pesticides for farmworkers (F in Group column) and non-farmworkers (N in Group column) and their children across the thinning (T), harvest (H) and off (O) seasons.

Age and Metabolite	Group	Thinning season		Harvest season		Non-spray season		Median comparisons across seasons		
		Median (95% CI)	Median comparison	Median (95% CI)	Median comparison	Median (95% CI)	Median comparison	Thinning/ harvest	Harvest/ non-spray	Thinning/ non-spray
Adult DM	F	672 (403,909)	F>N <0.001	658 (402,1035)	F>N <0.001	56 (42, 72)	F,N0.4	T,H 0.8	H>O <0.001	T>O <0.001
	N	60 (44, 70)		174 (98, 231)		66 (53, 82)		T<H <0.001	H>O <0.001	T,O 0.4
Child DM	F	198 (145,258)	F>N <0.001	186 (118, 234)	F,N 0.8	76 (41, 95)	F,N0.1	T,H 0.9	H>O <0.001	T>O <0.001
	N	75 (54, 99)		191 (106, 245)		92 (74, 116)		T<H 0.001	H>O <0.001	T,O 0.7
Adult DE	F	30 (23, 38)	F,N 0.2	21 (9, 30)	F,N 0.2	14 (7, 17)	F<N<0.001	T,H 0.09	H,O 0.2	T>O <0.001
	N	27 (17, 28)		24 (14, 28)		32 (23, 36)		T,H 0.5	H,O 0.9	T,O 0.4
Child DE	F	29 (23, 34)	F,N 0.8	9 (<LOD, 22)	F<N 0.001	18 (9, 23)	F<N0.002	T,H 0.06	H,O 0.3	T,O 0.2
	N	31 (23, 35)		25 (18, 29)		32 (23, 40)		T,H 0.8	H,O 0.4	T,O 0.7

Significant differences at the 0.05 level for median comparisons between farmworkers and non-farmworkers or across seasons are shown by "<" or ">" based on non-parametric Wilcox tests (P-values are shown below each comparison) with P-values adjusted for false discovery[42] across all tests in the table, and "," indicates that there was no detectable difference.

metabolite levels. Further analyses of these data and including dietary data will help us address that question. Alternatively, overspray or drift may contribute to urinary metabolites in children, whether they live in farmworker or non-farmworker households. Preliminary analyses of our drift data indicate that this is not the case[48]

Comparison of our data with NHANES (2003–2004) shows that farmworkers and non-farmworkers, as well as their children, had up to 10-fold higher levels of OP metabolites than a nationally representative sample.[49] This was particularly true of the DMs during all three seasons of data collection. For DEs, the NHANES data were similar to our values during the non-spray season. Our values are also higher than the values observed in similar studies.[23,45] The values in our study reflect the OP metabolite concentrations found in urine during different agricultural seasons, including the thinning season, a time of peak AZM use. The implication of these observations is that examination of the three agricultural season cohort allows for an opportunity to
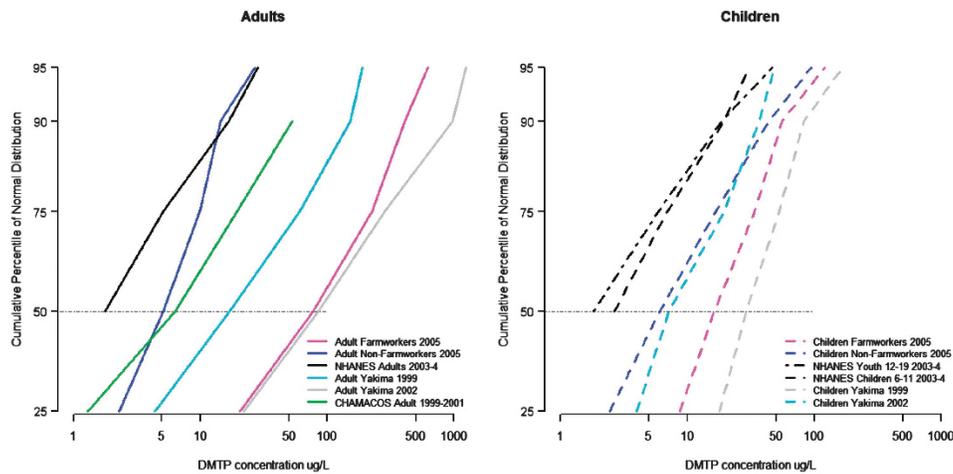
Figure 3. Comparison of urinary DMTP distribution in study populations in thinning season of 2005, NHANES IV national survey values in 2003–4 (closest available year to study populations), an earlier study in the Yakima valley in the thinning seasons of 1999, and 2002, and in the CHAMACOS study in the Salinas valley of California in 1999–2000. The children in the study populations were 2–6 years of age, whereas the closest age group in NHANES IV was 6–11 years of age.

examine essential data to characterize variation in exposure. This type of data reflects the novel aspects of our study with the sampling protocol reflecting practices of farmworkers and non-farmworkers.

As we have discussed previously, the take-home pathway appears to be a way for pesticide residues to get into the home and thereby affect children.[19] Figures 1 and 2 indicate that uniformly there are more pesticide residues in the dust found in the homes and vehicles of farmworkers compared with non-farmworkers during the thinning season. As these residues adhere to clothing, shoes, and skin, it is not surprising that they are off-loaded into vehicles and ultimately into homes. Potential confounders for our dust observations could include home pesticide use. Questionnaire data in our study indicated that 28% of the farmworkers and 44% of the non-farmworkers reported the use of pesticides, bug killers, or weed killers in their home, yard, or garden. However, these levels are moderate compared with a recent report. Further, it is congruent with the take-home pathway that the differences between farmworkers and non-farmworkers are more pronounced in the vehicles than in home. Other factors to consider in future analyses include proximity to orchards and fruit consumption patterns.

These data add to the growing body of literature[26,50,51] that indicates that farmworkers and their children are at higher risk for the sequelae of pesticide exposure than non-farmworkers and their children. McCauley et al.,[50] for example, found that pesticide residues in house dust in a specific area of Oregon were higher than that for both agricultural and non-agricultural households in other parts of Oregon.[50] Similarly, Lu et al. found higher levels of pesticide residues in house dust of farmworkers compared with house dust of non-farmworkers.[52] They also noted that OP concentrations in hand wipes of children's toys were higher in agricultural families compared with that in non-agricultural families.

The present study adds to the understanding of pesticide exposure by following matched groups of farmworkers and non-farmworkers across three agricultural seasons showing that significant exposures occur in the harvest season as well as the thinning season. Previous studies had not shown continuing exposure into the harvest season of pre-school children living in the Yakima Valley based upon urine concentrations of metabolites.[46,47] Also, our group of farmworkers did not include indivi-

duals who mixed or handled or applied pesticides but focused on those who worked in orchards doing other tasks.

Note should be taken of the increased pesticide metabolites in the urine of non-farmworker children during the harvest season. These rates were twofold higher for DMTP in the harvest season than in the thinning season. The levels for farmworker children also increased during the harvest season but not to the same extent. More research is needed to understand how and why non-farmworkers' children increase their metabolites during the harvest season.

Few studies have examined differences in OP urinary metabolites across seasons of farmwork practice. These data indicate that metabolites stay high from thinning through harvest, but that they drop dramatically during the non-spray season. For children, however, the drop-off in the non-spray season is less pronounced than it is for adults.

CONCLUSIONS

There are definite differences in the urinary OP metabolites of farmworkers and non-farmworkers. OP DM metabolites are seen at much higher levels for farmworkers and their children than non-farmworkers and their children during agricultural seasons when OP persticides are in use. These metabolite levels were significantly higher than the nationwide NHANES IV survey and up to 10-fold higher than other rural agricultural studies. Pesticide residues in the dust in vehicles and homes of farmworkers are higher compared with that of non-farmworkers during the thinning season. In the present study, we focused on seasonal differences in OP pesticide urinary metabolites and concurrent occupational practices across three agricultural seasons to evaluate OP pesticide exposure pathways. We have characterized changes in metabolites by comparing the median urinary metabolite concentrations between farmworkers and non-farmworkers and across seasons. Of importance for further analysis is the fact that we have collected biospecimen samples several days apart and, with ongoing analysis, are identifying the episodic nature of the exposures.

In summary, this study provides a significant new addition to the literature in that it looked at episodic pesticide use and evaluated potential for exposure by household within farmworkers and non-farmworkers and their children across three seasons where the agricultural practices led to very different

agricultural applications. We have been able to characterize these differences and seasonal dynamics to inform other longitudinal cohorts, such as the National Children's Study.[53]

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