Non-occupational Pesticide Exposure Pathways for North American Women Living in Agricultural Areas

Nicole C. Deziel[1,2], Melissa C. Friesen[1], Jane A. Hoppin[3], Cynthia J. Hines[4], Kent Thomas[5], Laura E. Beane Freeman[1]

[1]Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Bethesda, MD

[2]Yale School of Public Health, Yale University, New Haven, CT

[3]Department of Biological Sciences, North Carolina State University, Raleigh, NC

[4]Division of Surveillance, Hazard Evaluation and Field Studies, National Institute for Occupational Safety and Health, Cincinnati, OH

[5]National Exposure Research Laboratory, U.S. Environmental Protection Agency, RTP, NC

Address correspondence to: Nicole Deziel, Yale School of Public Health, 60 College St., New Haven, CT 06510, nicole.deziel@yale.edu, 203-785-6062

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Abstract:

Background: Women living in agricultural areas may experience high pesticide exposures compared to women in urban or suburban areas due to their proximity to farm activities. Objective: Our objective was to review the evidence in the published literature for the contribution of non-occupational pathways of pesticide exposure in women living in North American agricultural areas. Methods: We evaluated the following non-occupational exposure pathways: para-occupational (i.e., take-home or bystander exposure), agricultural drift, residential pesticide use, and dietary ingestion. We also evaluated the role of hygiene factors (e.g., house cleaning; shoe removal). Results: Among 35 publications identified (published 1995-2013), several reported significant or suggestive ($p<0.1$) associations between para-occupational (n=19) and agricultural drift (n=10) pathways and pesticide dust or biomarker levels, while three observed that residential use was associated with pesticide concentrations in dust. The four studies related to ingestion reported low detection rates of most pesticides in water; additional studies are needed to draw conclusions about this pathway's importance. Hygiene factors were not consistently linked to exposure among the 18 relevant publications identified. Conclusions: Evidence supported the importance of para-occupational, drift, and residential use pathways. Disentangling exposure pathways was difficult because agricultural populations are concurrently exposed to pesticides via multiple pathways. Most evidence was based on measurements of pesticides in residential dust, which are applicable to any household member and are not specific to women. An improved understanding of non-occupational pesticide exposure pathways in women living in agricultural areas is critical for studying health effects in women and for designing effective exposure-reduction strategies.

INTRODUCTION

Most evidence for health effects of pesticides in adults comes from studies of occupationally-exposed men (McDuffie 1994, 2005). Relatively less is known about pesticide-related health effects in women, and there may be sex-specific risk differences with respect to reproductive toxicity and hormonally-driven cancers (Ward et al. 2010; Caserta et al. 2008). In addition, comparatively little is known about non-occupational pesticide exposure pathways. Though these pathways may contribute less than occupational exposures in occupationally-exposed individuals, these pathways are expected to be important in non-occupationally exposed populations, particularly for those living in regions of intense crop production. Some studies have observed that pesticide exposures in women living in agricultural areas are consistent with the high end of the exposure distribution for the general population (Castorina et al. 2010; Bradman et al. 2005; Bradman et al. 2007; Arbuckle and Ritter 2005; Curwin et al. 2007). However, the contribution of non-occupational exposure pathways to pesticide exposure in agricultural women is not well-characterized. Understanding their pesticide exposure pathways is integral to a more comprehensive evaluation of health risks of pesticides among women.

The objective of this review was to identify the important pathways and gaps in the literature through consideration of all published reports of non-occupational pesticide exposure in women living in agricultural areas in North America. Women in agricultural areas may be exposed to pesticides if they are farmers or farmworkers, live with a farmer or farmworker (*i.e.*, in a "farm home"), or live in a home in an agricultural area without any farmer or farmworker residents (*i.e.*, a "non-farm home"). We excluded the "occupational pathway", defined here as personal mixing and applying of pesticides on a farm. Non-occupational pathways include para-occupational, agricultural drift (primary and secondary), residential pesticide use, and dietary ingestion. We define para-occupational exposures as those occurring through the introduction of pesticides into the home by household members who use or contact pesticides at work or from bystander exposure during pesticide applications (e.g., a wife engaging in outdoor farm tasks not involving contact with pesticides, such as driving a tractor). We define primary agricultural drift as that which occurs from the transport of pesticides to non-treatment sites at the time of application, while secondary drift involves the volatilization and movement of pesticide residues from soil and plants or the movement of pesticide-laden dust or soil by wind after the time of application (Ward et al. 2006). We consider the residential pesticide use exposure pathway to be that which occurs from the application of pesticides to the home, lawn, or garden. Dietary ingestion occurs from drinking water or eating food with pesticide residues. Exposures experienced via these pathways may be modified by hygienic practices undertaken to reduce pesticide exposures, such as separate laundering of pesticide-contaminated clothing or changing work clothes/shoes prior to entering the home. We review the evidence for the contribution of each exposure pathway individually.

METHODS

We identified relevant pesticide exposure studies published in the English language through September 2013. We searched PubMed, Scopus, Web of Science, and Google Scholar, and checked reference lists of pertinent articles. Most studies were obtained from a PubMed search using the following terms: "environmental exposure"[MeSH] AND "pesticides"[MeSH] AND (home OR household OR indoor). To be included in this review, publications had to meet the following criteria: 1) be conducted in North America; 2) focus on exposure as the outcome measure; 3) include biological and/or environmental measurements of women living in agricultural areas or environmental measurements from homes in agricultural areas; and 4) address at least one of the exposure pathways of interest or hygiene factors. We focused on studies conducted in North America because of international variability in agricultural and household practices due to differences in climate, types of pests, types of crops, and pesticide regulations. We used inclusive criteria and report on the findings from all studies with at least five samples. We excluded papers that presented pilot/preliminary data if the data were included in a subsequent, more comprehensive publication. For studies with environmental measures, we focused on pesticide levels in residential dust (including bulk dust and surface wipe samples) and assumed they would be representative of women's exposures, although they would be applicable to all household members. Dust measurements may represent chronic residential pesticide exposure because chemicals in indoor dust resist degradation due to limited sunlight, microbial activity, and moisture (Simcox et al. 1995; Lewis et al. 1994). Publications reported dust measurements as concentrations (mass of pesticide per mass of dust) and/or loadings (mass of chemical per surface area). We excluded results from air sampling because only three studies included it, and these measurements were predominantly below the detection limit (Curwin et al. 2005; Lu et al. 2004; Weppner et al. 2006). We excluded results from food samples because only one pilot study measured pesticides in food (Melnyk et al. 1997).

RESULTS

Characteristics of the 35 publications (published 1995-2013) meeting our search criteria are presented in Table 1. The majority (29 out of 35) were attributed to 10 larger studies or research groups. Fourteen out of thirty-five (40%) publications were conducted in the Northwestern

United States in Washington or Oregon, six (17%) included populations in Iowa, five (14%) in California (CA), five (14%) in North (NC) or South Carolina (SC), four (11%) in Canada, and three (9%) in Minnesota (MN). These geographic regions reflect differences in crop types and application methods, with orchard farms dominating the studies in the Northwestern United States, corn and soybean farms found commonly in the Iowa studies, and varied crops (vineyards, fruits, vegetables) in California. Sample sizes ranged from 6 to 800 participants or households (residences and/or occupants). Some studies focused on women specifically, including those from the Farm Family Exposure Study (MN and SC), the Iowa Farm Family Exposure Study, and the Ontario Pesticide Exposure Assessment Study. The Center for Health Assessment of Mothers and Children of Salinas (CHAMACOS) Study (CA) included more than 600 pregnant women, but the target population was the children. Twenty-eight publications included environmental samples from the home (26 dust, 4 water, 2 both). Eleven publications had biological samples, including 4 with both biological and environmental samples. The publications predominantly covered organophosphate insecticides, such as chlorpyrifos (n=19), azinphos-methyl (n=14), phosmet (n=13), and diazinon (n=12), as well as common agricultural herbicides such as 2,4-dichlorophenoxyacetic acid (2,4-D) (n=10) and atrazine (n=9) (Supplemental Material Table S.1).

We describe the evidence related to each pathway separately by environmental and biological monitoring. There was insufficient information to evaluate pathways separately by pesticide. We classified the studies by whether they observed an association that was suggestive ($0.05<p<0.1$), statistically significant ($p<0.05$), null ($p>0.1$), or descriptive (no comparison groups or no p-values or confidence intervals provided). Some studies exhibited a combination of categories if a relationship differed by pesticide or exposure metric. We considered studies reporting a suggestive or statistically significant association to provide evidence for a particular pathway.

Para-occupational Exposure

Twenty-two publications investigated the para-occupational exposure pathway, thirteen with residential dust samples only, six with biological samples only, and three with both.

Residential Dust

Nine publications evaluated the para-occupational pathway by comparing pesticide concentrations in residential dust in farm homes to non-farm homes, and two studies compared pesticide concentrations in residential dust in farm homes during planting and non-planting seasons. Because most farm homes were also located near treated fields, it was difficult to disentangle the para-occupational and agricultural drift pathways. Several publications accounted for drift by adjusting for proximity to farmland in multivariable regression models or by restricting the analysis to all homes beyond a specified distance from treated fields. After adjustment for nearby agricultural applications, Gunier et al. (2011) observed that farm homes had higher levels of chlorpyrifos and simazine (but not five other pesticides evaluated) in residential dust compared to non-farm homes. In a University of Washington study (Simcox et al. 1995), dust levels of azinphos-methyl, chlorpyrifos, parathion, and phosmet were 3-15 times higher in farm homes compared to non-farm homes. Simcox et al. (1995) observed interactions for some pesticides between farm vs. non-farm homes and proximity to treated crops, making it difficult to assess the independent contribution of each of these factors. In another University of Washington publication, levels of chlorpyrifos, azinphos-methyl and phosmet, commonly used insecticides in the region, were significantly higher in farm homes compared to non-farm homes, all located >400 m from treated fields (Lu et al. 2000; Fenske et al. 2002). They found no association for parathion, the use of which had been discontinued in the area prior to the study, suggesting the observed differences were due to more recent usage. In CHAMACOS (Harnly et al. 2009), farm homes compared to non-farm homes had higher dust levels of iprodione, but not chlorpyrifos, trans-permethrin, diazinon, or dacthal after adjustment for agricultural pesticide use near the home (15 other pesticides were not evaluated due to detection rates <5%).

Three Iowa studies found that adjustment for drift had no impact on the para-occupational relationships. In the Iowa Farm Family Pesticide Exposure Study (Curwin et al. 2005), concentrations of atrazine, metolachlor, chlorpyrifos, acetochlor, alachlor, glyphosate, and 2,4-D were higher in farm homes compared to non-farm homes, but the differences were only significant for atrazine and metolachlor. Homes of farmers who had applied atrazine, metolachlor, chlorpyrifos, and glyphosate within seven days prior to sampling had higher levels of the respective chemicals in dust compared to non-farm homes and farm homes that did not apply the chemical (Curwin et al. 2005). Golla et al. (2012) found that atrazine concentrations in residential dust in Iowa farm homes were an order of magnitude higher during the planting season when atrazine is widely applied than during the non-planting season. Lozier et al. (2012) also observed higher atrazine loadings in the application season compared to the off-season in same-room samples in Iowa homes of agricultural commercial pesticide applicators.

Four publications, which did not present comparisons specifically accounting for drift, also observed higher detection rates and concentrations of at least one pesticide in residential dust in farm homes compared to non-farm homes. Ward et al. (2006) found that both detection rates and concentrations of six agricultural herbicides in residential dust were approximately four times higher in Iowa farm homes compared to non-farm homes. In a study of organophosphates commonly used in agriculture in Washington state (Lu et al. 2000), diazinon and azinphos-methyl were more frequently detected in farm homes compared to non-farm homes, but chlorpyrifos and phosmet were not quantifiable in any homes. In For Healthy Kids, residential dust concentrations of azinphos-methyl and phosmet were significantly five times and three times higher in Washington state farm homes than non-farm homes, respectively (Coronado et al. 2011); both pesticides were commonly used in the study time period. Within the farm homes in For Healthy Kids, researchers observed a significant correlation (r=0.52) between azinphos-methyl concentrations in house dust and dust from the commuter vehicle, providing additional support for the para-occupational pathway (Curl et al. 2002; Coronado et al. 2006). Results for other organophosphates measured in the study (malathion, diazinon, methyl parathion, and chlorpyrifos) were not reported due to low detection rates or limited use in the study region.

Six publications evaluated the impact of specific tasks on the para-occupational exposure pathway. In the For Healthy Kids Study, farmworkers who reported working with pome versus non-pome fruit (Coronado et al. 2006), thinning orchards versus no thinning (Coronado et al. 2004), or pruning versus no pruning (Coronado et al. 2004) had significantly higher levels or greater percent detection of azinphos-methyl in the dust in their homes and/or the vehicles they used to commute. No associations with residential or commuter vehicle dust levels were observed for farmworkers who reported mixing/loading/applying pesticides; harvesting or picking; loading plants, fruits, or vegetables; sorting plants, fruits or vegetables; planting or transplanting; or irrigating (Coronado et al. 2004). McCauley et al. (2003) reported that median levels of the summed concentrations of four organophosphate pesticides (azinphos-methyl, chlorpyrifos, malathion, and phosmet) were higher in Oregon farmworker homes if at least one person was involved in tree thinning, compared to homes with no one reporting that task. In a University of Washington study (Fenske et al. 2002), median residential dust concentrations and loadings of chlorpyrifos and parathion were statistically significantly higher in homes of farmers who applied pesticides versus those who did not. In the Golla et al. (2012) Iowa study, atrazine concentrations were higher in homes where the farmer personally mixed and applied atrazine compared to homes where the farmer did not. Lozier et al. (2012) in Iowa did not observe differences in atrazine loadings among homes of applicators, mixers, or applicator/mixers in samples collected during peak application season.

Pesticide Biomarkers

Six publications reported results from urinary pesticide biomarker measurements in women the day before, day of, and one or more days after their husbands applied the pesticides of interest. Comparisons of pre- and post-application biomarker levels in these women did not suggest increased exposure as a result of a specific pesticide application event. In the Iowa Farm Family Exposure Study (Curwin et al. 2007), the estimated geometric mean concentration of the urinary metabolite of metolachlor was elevated 4-fold (not statistically significant) over the sampling period in women whose husbands applied the chemical compared to those whose husbands did not. No differences were observed for urinary biomarkers of atrazine, chlorpyrifos, and glyphosate. However, the correlations between urinary pesticide concentrations between husband and wife across the pre-, during-, and post-application periods combined were moderate to high for metolachlor (0.66), atrazine (0.43), chlorpyrifos (0.61), and glyphosate (0.59) (Curwin et al. 2007). In the same study, the urinary biomarkers of atrazine and chlorpyrifos in women in farm homes at the application event were significantly or suggestively higher than the levels in women in non-farm homes; no differences were observed for biomarkers of metolachlor or glyphosate (Curwin et al. 2007). In the Ontario Pesticide Exposure Assessment Study (Arbuckle and Ritter 2005; Arbuckle et al. 2006), in which husbands applied at least one of the two herbicides 2-methyl-4-chlorophenoxyacetic acid (MCPA) and 2,4-D, the percentage of detectable urinary biomarkers of these chemicals did not differ in women in the days before, during, and after their husbands applied the respective chemical(s). The percentage of non-detects among the women was 78% throughout; in contrast, the husbands' urinary biomarker concentrations increased 4-fold. In the same study, no correlation in urinary 2,4-D concentrations was observed between wives and husbands at the time of application (Arbuckle et al. 2006). Higher correlations between spouses and applicators were observed for several additional herbicides, including dichlorprop (r=0.57), mecoprop (0.52), and 4-(4-chloro-2-methylphenoxy)butyric acid (r=0.70), though it was not clear if any were applied at the time of sampling (Arbuckle and Ritter 2005). In the Farm Family Exposure Study, there were negligible changes in urinary biomarker concentrations of glyphosate, 2,4-D, and chlorpyrifos on the day of application or three days following application in spouses whose husbands applied the chemical, even when the applicator's exposure increased over that same time period (Alexander et al. 2007; Acquavella et al. 2004; Alexander et al. 2006). Correlations between applicator and spouse biomarker levels were not reported in these publications.

There was modest evidence that spouses who were "present" while their husbands applied the pesticide(s), had higher urinary pesticide levels, though it was not clear how "presence" was defined. For example, in the Farm Family Exposure Study, spouses who were present at some time while their husbands applied 2,4-D (Alexander et al. 2007) or chlorpyrifos (Alexander et al. 2006), as documented by a trained observer, had approximately 1.5-fold higher urinary concentrations of the respective pesticide biomarkers compared to women who were not present at any time during the application; differences were not statistically significant. The percent detection (2-4%) of glyphosate in spouses whose husbands had applied it was too low to evaluate the impact of spouse presence during application (Acquavella et al. 2004). In the Ontario Pesticide Exposure Assessment study, median urinary levels of 2,4-D, but not MCPA, of women who were "outside" while their husband applied the specific herbicide were statistically significantly higher compared to all other women (Arbuckle and Ritter 2005).

Two publications compared pesticide biomarkers in women living in farm homes to non-farm homes independent of a specific application event. No differences were observed in percent of detectable blood organophosphate levels (Huen et al. 2012). The odds of detection of bromoxynil phenol in plasma of women living with a grain farmer were elevated (not statistically significantly) compared to women who did not live with a grain farmer (Semchuk et al. 2003).

Agricultural Drift

Twenty-two publications addressed agricultural drift, seventeen using residential dust and five with biomarkers (one with both).

Residential Dust

Six publications reported associations between concentrations of pesticides in residential dust and proximity to treated farmland, a commonly used surrogate for drift. A University of Washington study observed significantly higher levels of azinphos-methyl, chlorpyrifos, and parathion in residential dust in farm and non-farm homes within 50 ft of treated land compared to homes located farther away (Simcox et al. 1995). When restricted to farm homes only, levels of azinphos-methyl and parathion (but not chlorpyrifos) remained significantly elevated within 50 ft of treated land (Simcox et al. 1995). In another University of Washington study, concentrations of azinphos-methyl (Lu et al. 2000) and chlorpyrifos (Fenske et al. 2002) were significantly higher in farm homes within 200 ft of treated orchards compared to homes farther away. No such associations were observed for phosmet (Lu et al. 2000), which was also commonly used, or parathion (Fenske et al. 2002), which was historically, but not currently used. McCauley et al. (2001) reported that concentrations of azinphos-methyl in farm homes decreased significantly by 18% when the distance from agricultural field doubled. Quandt et al. (2004) observed that surface wipes inside farm homes in Virginia and North Carolina yielded higher odds of detection, but not odds of higher concentrations, of at least one of six agricultural-use pesticides (disulfoton, esfenvalerate, lindane, oxyfluorfen, pendimethalin, simazine) in homes that were "within a short walk" of farmland. Richards et al. (2001) reported that 3 of 8 homes within 125 m of a treated rice field had detectable levels of the commonly used propanil, while none of the homes located further away did.

Seven publications did not observe an association between distance to agricultural land and pesticide exposures. In two study populations of farm homes in the For Healthy Kids Study, proximity to farmland was not associated with increased residential dust concentrations of azinphos-methyl (Coronado et al. 2011, Curl et al. 2002) or phosmet (Coronado et al. 2011). In the Iowa Farm Family Pesticide Exposure Study, Curwin et al. (2005) found no association between distance to treated farmland and concentrations of atrazine in residential dust in non-farm homes. Two studies of Iowa farm homes (Lozier et al. 2012; Golla et al. 2012) reported no relationship between distance from home to crop fields and atrazine levels in dust. Similarly, in a study of Oregon farm homes, no association was seen between total organophosphate levels and distance to the nearest active orchard (McCauley et al. 2003). Weppner et al. (2006) studied 6 homes in central Washington State located within 200 m of potato fields and found no increase in indoor methamidophos surface residues following aerial applications of methamidophos to the fields.

Four studies incorporated additional information to the distance metrics, such as crop acreage, amount of pesticide applied, and wind direction, to assess the relationship between drift and levels of pesticides in the dust. Ward et al. (2006) found that the frequency of detection of at least one of six agricultural herbicides studied (acetochlor, alachlor, atrazine, benazon, fluazifop-*p*-butyl, and metolachlor) increased 6% with each 10-acre increase in crop acreage up to the maximum buffer radius of 750 m, even after adjusting for presence of a farmworker resident. In addition, the total concentration of these agricultural herbicides increased 1.05-fold for each 10 acres of crop acreage within 750 m. There was no clear pattern when using the simpler metric of distance to treated land. Gunier et al. (2011) observed that concentrations of five (chlorpyrifos, dacthal, iprodione, simazine, and phosmet) out of seven (not carbaryl or diazinon) pesticides that were applied agriculturally within 1250 m of a home during the prior year were present at higher concentrations in the residential dust compared to homes without application of the respective pesticide. Associations remained after adjusting for the presence of farmworkers. In CHAMACOS (Harnly et al. 2009), each kg/day increase in application near the home (up to 9-square-mile area or ~2,800 m radius) of chlorpyrifos, dacthal, and iprodione was associated with increased pesticide dust concentrations after adjustment for farmworker resident. Conversely, no relationship was seen for permethrin or diazinon. Also in CHAMACOS, no increase in residential dust loadings or concentrations was observed when using a simpler distance metric, *i.e.*, comparing homes within 60 m of a field to those located farther away. In the Fresno Pesticide Exposure Study, application of trifluralin (but not eight other pesticides evaluated) within a 1,250 m buffer around a home was significantly associated with concentrations in the dust after adjusting for other factors, such as residential pesticide use (Deziel et al. 2013).

Pesticide Biomarkers

Five biomonitoring publications examining the influence of agricultural drift on pesticide biomarker levels in women observed no associations. The For Healthy Kids study observed a 23% reduction in the non-specific organophosphate urinary metabolite dimethylthiophosphate with each mile from farmland in non-farmworkers, who were 81% women, but the relationship was not suggestive or statistically significant (95% confidence interval: -45% to 11%) (Coronado et al. 2011). In the Farm Family Exposure Study, proximity to treated farmland was not associated with increased urinary 2,4-D (Alexander et al. 2007), 3,5,6-trichloro-2-pyridinol (a chlorpyrifos metabolite) (Alexander et al. 2006), or glyphosate (Acquavella et al. 2004). In CHAMACOS, living within 200 ft of a field was not associated with higher detection of blood levels of organophosphates (Huen et al. 2012). Also in CHAMACOS, living within 60 m of an agricultural field was not associated with higher serum levels of the organochlorines dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethene (DDE), hexachlorocyclohexane (HCH), and hexachlorobenzene (HCB) (Bradman et al. 2007), but these pesticides had been banned or restricted in the United States prior to the study period, and serum levels were mainly related to birth in Mexico, where the organochlorines have had more recent use.

Residential Pesticide Use

Nine publications examined the relationship between personal or professional pesticide applications in homes and residential dust measurements of pesticides in farm homes or homes in agricultural areas. No biomonitoring studies evaluated this pathway.

Three publications observed associations between pesticide applications in homes in agricultural areas and residential dust measurements for at least one pesticide. These studies asked specific questions about pest treatment practices and focused on homes located in agricultural areas, not specifically farm homes. In the California Childhood Leukemia Study (Gunier et al. 2011), households reporting treatments for fleas/ticks or outdoor professional pest treatments had significantly two times higher concentrations of chlorpyrifos and diazinon, respectively in carpet dust after adjustment for density of agricultural pesticide use within a 1250 m buffer around the home. No relationships between pest treatments and carpet dust concentrations were seen for carbaryl, dacthal, phosmet, simazine, or iprodione, although residential uses for iprodione were phased out in 1998. In the Fresno Pesticide Exposure Study (Deziel et al. 2013), treatment for bees/wasps/hornets was associated with significantly higher concentrations of chlorpyrifos and treatment for lawn/garden pests was associated with higher concentrations of diazinon and piperonyl butoxide in analyses adjusted for agricultural pesticide applications. Treatment for ants/flies/roaches was associated with significantly higher concentrations of carbaryl, but lower concentrations of piperonyl butoxide and simazine. Homes with professional outdoor treatments versus those with no professional treatments had significantly higher concentrations of permethrin, cypermethrin, cyfluthrin, and diazinon. In an agricultural area of the mid-Rio Grande Valley in Texas on the U.S./Mexico border (Freeman et al. 2004), loadings of demeton-O were marginally correlated (Spearman r=0.24, p=0.08) with the number of locations within a home pesticides were applied; no significant or suggestive correlations with use were observed for demeton-S, fonofos, diazinon, disulfoton, methyl parathion, fenitrothion, or malathion. Because of reports of potential misuse of agricultural pesticides in the community, the investigators included pesticides with and without approval for residential use. Associations between residential pesticide use and dust levels of pesticides would only be expected if the pesticide active ingredients were present in products used; however, the studies did not generally collect that information.

Six publications observed null or mostly null associations between residential pesticide use and pesticide concentrations in dust. These were predominantly in farm homes, did not always account for agricultural use, and also included some pesticides not permitted or commonly used residentially. McCauley et al. (2001) observed no association between family use of pest control products and levels of azinphos-methyl in farm homes; azinphos-methyl is not registered for residential use. In another study (McCauley et al. 2003) pesticide use in homes compared to no use, was not associated with levels of total organophosphate residues. Lu et al. (2000) did not observe any association between residential use of organophosphates in homes, including uses specifically on pets or lawns and gardens and levels of pesticides in residential dust. In farm and non-farm homes in the Iowa Farm Family Pesticide Exposure Study (Curwin et al. 2005), none of the three self-reported residential use variables (use of an insecticide, treating a lawn with pesticides, and spraying a garden with pesticides) were associated with concentrations of chlorpyrifos, glyphosate, and 2,4-D, pesticides with both agricultural and residential uses. Self-reported use of an insecticide was associated with atrazine concentrations in the residential dust of farm homes, but atrazine is not an insecticide and is not commonly used residentially in Iowa so the reason for this association is unknown. Golla et al. (2012) and Lozier et al. (2012) observed no association between application of pesticides in the home or to the lawn and dust levels of atrazine.

Ingestion

Four studies measured pesticides in drinking water in farm homes. In the Ontario Pesticide Exposure Assessment Study (Arbuckle et al. 2006), 20% of the 122 farm homes had drinking water with measurable levels of at least one pesticide, most commonly atrazine. Only 1% had detectable levels of 2,4-D and 3% had detectable levels of MCPA, though in each home a farmer had used at least one of the two chemicals at the time of study. In a study of 816 farm homes using well water in Alberta, Canada (Fitzgerald et al. 2001), 3% had measurable levels of at least one of eight herbicides in their tap water, with 2% positive for MCPA and 1% for 2,4-D. The six other herbicides (dicamba, bromoxynil, fenozaprop, diclofop-methyl, trifluralin, triallate) were not detected. In a study of 6 farm homes in Washington state, none of the commonly used organophosphate pesticides analyzed (azinphos-methyl, chlorpyrifos, diazinon, dichlorovos, or phosmet) were detected in drinking water (Lu et al. 2004). Similarly, in a pilot study within the Agricultural Health Study (Melnyk et al. 1997), none of the 30 target pesticides analyzed were detected in drinking water samples from 6 farm homes.

Hygiene Factors

Eighteen studies evaluated the impact of various hygiene factors on levels of pesticides in environmental or biological samples, including strategies recommended in EPA Worker Protection Standard pesticide safety educational materials (U.S.EPA 2008) (Supplemental Material, Table S2).

Composite Hygiene Factors

Three publications looked broadly at multiple hygiene factors. The study with the strongest design was the For Healthy Kids community intervention trial of 571 farmworkers (Thompson et al. 2008). This 2-year educational intervention about hygiene factors had no impact on house and vehicle dust levels of three organophosphates studied (phosmet, azinphos-methyl, or malathion). Within a subset of 95 homes in this population, azinphos-methyl levels in house and vehicle dust were unrelated to the number of home hygiene practices undertaken (shoe removal, work clothing removal, laundering work clothes separately, vacuum and mopping frequency) (Coronado et al. 2012). In an Oregon study of 24 farm homes (McCauley et al. 2003), no association was seen with levels of total organophosphates or azinphos-methyl in dust and a score that incorporated work clothes removal, shoe removal, time between arriving home and washing, time between arriving home and changing.

Laundering Clothes

None of the nine publications evaluating the impact of laundry practices observed an association with concentrations of pesticides in residential dust (Fenske et al. 2002; Lu et al. 2000; Coronado et al. 2012; Lozier et al. 2012) or biological samples from women (Alexander et al. 2007; Acquavella et al. 2004; Alexander et al. 2006; Semchuk et al. 2003). In CHAMACOS, women who personally laundered agricultural work clothes had 2 to 42% significantly higher serum levels of DDT and HCH than women who did not, but this association was not significant after adjusting for living in Mexico, where DDT had been widely used (Bradman et al. 2007).

Changing Shoes/Clothes and Washing after Agricultural Work

Three studies observed that shoe or clothing removal was associated with pesticide concentrations in residential dust. In CHAMACOS (Harnly et al. 2009), homes of farmworkers who stored work shoes in the home had higher residential dust concentrations/loadings of chlorpyrifos, diazinon, and permethrin, but not iprodione. McCauley et al. (2003) observed that levels of azinphos-methyl and total organophosphates in residential dust were significantly lower in homes of farmworkers who changed out of their work clothes within 2 hours of arriving home from work compared to those who waited longer. No relationships with azinphos-methyl or total organophosphate levels in dust were observed in homes where workers showered within 30 min of coming home versus longer or in homes where workers reported removing shoes. Households where the farmworkers changed their work shoes inside the home had significantly higher loadings of atrazine (Lozier et al. 2012). Curwin et al. (2005) and Lozier et al. (2012) found evidence (suggestive and statistically significant) of elevated levels of pesticides in rooms where the farmer changed, compared to other rooms in the home. Five publications observed that shoe or clothing removal was unrelated to pesticide concentrations in residential dust (Fenske et al. 2002; Lu et al. 2000; Golla et al. 2012; Coronado et al. 2012) or biomarkers (Bradman et al. 2007).

House Cleaning

Five studies provided some evidence that cleaning practices may influence levels of pesticides in residential dust. An Oregon study observed an association between total organophosphate concentration and number of days since last cleaning of the sampled area (McCauley et al. 2003). An Oregon cleaning intervention study in 10 homes (McCauley et al. 2006) found that cleaning windowsills significantly reduced the loadings of total organophosphates, but cleaning linoleum floors was ineffective. The effectiveness of commercially steam cleaning the carpets was inconclusive because the baseline concentrations were low. In CHAMACOS (Harnly et al. 2009), lower cleanliness as rated by an observer considering “household organization, overflowing trash, and presence of dust” was associated with higher loadings of chlorpyrifos and dacthal, but not diazinon, iprodione, or trans-permethrin. Quandt et al. (2004) observed that the odds of detecting a higher number of pesticides in surface wipe samples were four times higher in homes rated as difficult to clean based on age, type of dwelling, general state of repair, and crowding of occupants, furniture, and possessions; frequency of vacuuming was not associated with odds of pesticide detection. Vacuuming at least once per week was linked to reduced loadings of atrazine in residential dust in homes of pesticide handlers (not statistically significant) (Lozier et al. 2012). Five publications did not observe associations between vacuuming and cleaning practices and pesticide concentrations in residential dust (Fenske et al. 2002; Lu et al. 2000; Simcox et al. 1995; Curwin et al. 2005; Coronado et al. 2012).

Pets

Two publications observed an association between presence of pets and concentrations of pesticides in dust. Having a dog spending time inside and outside the house was associated with a suggestive 2-fold increase in atrazine levels in residential dust, compared to having no dog or a dog that stayed outside (Golla et al. 2012). Compared to having no pets, having a dog was associated with higher concentrations of chlorpyrifos and dacthal, but not 11 other pesticides measured (Deziel et al. 2013). Presence of pets was not associated with concentrations of pesticides in residential dust in four studies in agricultural areas (Lozier et al. 2012; McCauley et al. 2003; Curwin et al. 2005; Simcox et al. 1995). The impact of pets may have been related to the relative time spent indoors/outdoors, which varied by study and was asked differently across the studies.

DISCUSSION

This literature review summarizes the evidence for the contribution of non-occupational pathways to pesticide exposures in women living in agricultural areas, who may be exposed to a greater number of pesticides and at higher concentrations than women in the general population. A better understanding of non-occupational pesticide exposure pathways in these women is critical to studying pesticide-related health effects and reducing exposures. Though we were focused on women's pesticide exposures, the strongest evidence came from studies with residential dust measurements, which were not specific to women. Of the 35 publications described here, 19 reported relationships between para-occupational exposure and pesticide measurements in house dust or pesticide biomarkers. Ten observed a relationship between agricultural drift and pesticide dust concentrations. Three observed associations between self-reported residential use and concentrations of pesticides in dust. The relationships with hygiene factors were inconsistent across the 18 relevant studies. A large, community intervention trial observed no impact of pesticide-safety training or hygiene factors on pesticide levels. The four drinking water studies generally reported poor detection rates of pesticides, providing limited information to understand the role of ingestion.

Evidence for the para-occupational exposure pathway came primarily from residential dust monitoring that compared farm and non-farm homes, or homes of farmers who performed tasks that involved contact with pesticides and homes of farmers not doing those tasks. In contrast, biomonitoring studies conducted at the time of a pesticide application event did not demonstrate increases in urinary pesticide biomarkers in women whose husbands applied the chemicals compared to those who did not, even when the husbands' exposures increased. Although these biomonitoring studies were generally well-designed, interpretation was difficult because of low percent detection and limited variability in exposures. The discrepancies between environmental and biological monitoring may be because assessment of whether the farmer-husband applied the chemical (yes/no) is not sufficiently specific to predict a concurrent increase in exposure in the spouses. For example, women observed to be present or outside during the pesticide application event exhibited modest increases in concentrations of pesticide biomarkers compared to women who were not present or outside (Alexander et al. 2007; Alexander et al. 2006). Future studies should collect more detailed information about the activity and location of women when their husbands apply pesticides, as well as information on amount of pesticides applied, duration of pesticide application, hygiene factors and use of personal protective equipment, to evaluate whether specific para-occupational exposures increase exposure.

Agricultural drift, as measured by proximity to treated farmland, was generally associated with higher detection rates and concentrations of common agricultural pesticides in residential dust. Some studies using simple Euclidian distance did not observe an association unless additional information, such as amount of pesticides applied or acres treated was incorporated into the exposure metrics. This is supported by results from epidemiologic studies which have demonstrated attenuation of effect estimates when proximity to fields was used as a surrogate for more refined metrics of pesticide exposure (Ritz and Rull 2008). In contrast, there was little evidence that proximity alone was linked to levels of pesticide biomarkers. Because many pesticide biomarkers reflect recent, high-exposure events (Barr et al. 2002), associations between concentrations of pesticide biomarkers and primary agricultural drift may be expected, but not necessarily secondary drift. The relationship between biomarkers and drift are likely dependent on a variety of factors, such as timing of sample collection, application method, physicochemical properties of the pesticide, and meteorology (Ward et al. 2006). More information is needed to understand how primary and secondary components of drift contribute to residential exposure.

Moderate evidence suggested that residential pesticide use is associated with pesticide concentrations in dust in farm homes and homes in agricultural areas. Inconsistencies in relationships by pesticide may reflect whether the specific active ingredients were in the residential pest control products used, the timing of sample collection relative to when pesticides were used in the home or garden, or differences in wording of questions about residential use across studies. Additionally, the dual use of several pesticides in residential and agricultural products makes it is difficult to separate out the residential use contribution. These studies were generally small and questions about residential use were generally non-specific because that was not typically the study focus. More specific questions about residential pest treatments in larger study populations may improve our understanding of this relationship.

Women in agricultural areas may have different dietary patterns than the general population, *e.g.*, they may be more likely to consume fruits and vegetables directly from the field, which could contain higher pesticide residues (Goldman et al. 2004). Data related to pesticide concentrations in the diets of women living in agricultural areas were extremely limited, making conclusions difficult. We identified only one study, of 6 households, that provided duplicate diet measurements (Melnyk et al. 1997). Similarly, farm families often rely on private wells, which may be susceptible to pesticide contamination (Gilliom 2007). For instance, in a subset of the Agricultural Health Study cohort, 75% of participants reported using private wells as their primary source of drinking water and 16% had wells within 50 yards of where pesticides were mixed (Gladen et al. 1998). However, the publications included in this review reported low detection rates or concentrations of pesticides in drinking water. The presence of pesticides in well water is related to many factors such as intensity of pesticide use, solubility of the pesticide, and permeability of the soil (e.g., permeability) (Stackelberg et al., 2012). More studies on food and drinking water-based exposures in agricultural populations would help inform the role of the ingestion pathway.

Although hygiene factors are a potential exposure pathway modifier, our review identified limited support for relationships between shoe/clothing removal, laundry practices, and presence of pets and pesticide levels in dust. Five studies did suggest that house cleaning practices may be related to pesticides in the dust. However, many studies were not focused on hygiene factors, had limited power to evaluate these practices, and incorporated questions that were subjective or were asked differently across the studies. One exception was the For Healthy Kids Study (Thompson et al. 2008; Coronado et al. 2012), a relatively large, community-based intervention study specifically evaluating whether safety and hygiene factors were associated with pesticide exposures. This study found that neither recommended practices, such as removing shoes and laundering work clothes separately, nor an educational intervention were linked to pesticide levels in homes or commuter vehicles. These findings suggest that more work is needed to investigate the effectiveness of recommended practices.

Some challenges warrant consideration in interpretation of this review. Disentangling the exposure pathways remains difficult because agricultural populations are exposed to pesticides via multiple pathways concurrently. Additionally, pesticide levels in residential dust and biomarkers aggregate over multiple pathways; therefore independent contributions from each pathway are not easy to discern. We observed some inconsistent relationships between environmental and biological measurements which may reflect different windows of exposure, with dust capturing the accumulation of many sources over time (Simcox et al. 1995) and biomarkers for most current-use pesticides reflecting recent exposures due to their relatively short half-lives (Barr et al. 2002). Agreement may only be expected if daily exposures were fairly stable within an individual. Additionally, pesticide dust levels, though a potentially useful exposure indicator in children (Bradman et al. 1997), may not be a good proxy for exposure in adults. People may be exposed to pesticides in dust via incidental ingestion, dermal absorption, and inhalation, but the extent of these exposures in adults and their dependence on individual-specific activity factors is not well understood (U.S.EPA 2011). While both dust and biomarkers aggregate over multiple pathways, only biomarkers include the dietary or occupational pathways and thus differences may occur when the dietary pathway or occupational pathways contribute substantially to total exposure. In addition, few studies had dust and biological samples in the same population, thus inconsistencies could be attributable to any of the many factors that differed among the studies (e.g., geographical location, study time period, diet). Curwin et al. (2007) measured both dust and biomarkers and found that for farm women urinary levels of all pesticides were not associated with house dust levels; in non-farm women the pesticide urinary levels of metolachlor were associated with dust levels but not atrazine, chlorpyrifos, or glyphosate. Ultimately, dust and biomarker measurements may provide complementary information. Methodological studies to better understand the relationship between these two metrics are needed to interpret this body of literature.

Studies that attempted to isolate a pathway through stratification or adjustment in multivariable models and/or studies with both biological and environmental measurements, such as CHAMACOS, For Healthy Kids, the University of Washington studies, and the Iowa Farm Family Exposure Study, provided the most information on relative importance of pathways. Apparent inconsistencies across studies that used the same exposure measures may be due to differences in study population and sample size, pesticides measured, regional or temporal differences in pesticide use patterns, differences in sampling and laboratory and statistical methods, differences in the way the non-occupational pathways were assessed, product formulations, or the physicochemical properties of the pesticides. For example, although farmers and farmworkers could perform different tasks, leading to different para-occupational exposures, our review combined these two occupational groups due to lack of standardization in definitions in the literature. There was insufficient evidence in the literature to examine pathways for individual pesticides.

Other gaps in understanding warrant consideration. Most studies measured only a few pesticides and many active ingredients currently in common use are not covered by the literature reviewed here. The studied populations were concentrated in certain geographical areas (e.g., Northwestern United States) with distinct crop types and therefore this body of literature may not be generalizable to all agricultural areas in North America or to other parts of the world. Finally, this review did not focus on the occupational pathway, but as women living on farms may personally handle pesticides, there is a need in future research to place the non-occupational exposure pathways into context with the occupational pathway. Finally, publication bias could be a potential source of error in this review, if the published research we surveyed is not representative of all completed studies.

CONCLUSION

Pesticides have been linked to numerous adverse health effects; effects could be different in women compared to men. Though the potential for relatively high exposure to pesticides in agricultural women compared to the general population has been documented, exposure characterization has been limited. An extensive review was undertaken to better understand the contribution of non-occupational pathways to pesticide exposure in women living in agricultural areas. Relative to the body of literature on male farmers and farm children, women living in farm homes or in agricultural areas remain largely understudied. Most of the evidence came from studies of residential dust, which is not specific to women. The results from biomonitoring studies specifically of women were often difficult to interpret due to low detection rates or limited variability in pesticide biomarkers. Future research should include women with a greater variability in pesticide contact and should include more detailed information about the extent of their contact with pesticides, either on the farm or in the home. Though disentangling exposure pathways was challenging, overall we found reasonably consistent evidence that para-occupational and agricultural drift pathways contributed to pesticide exposure in women, moderate consistency for the contribution of residential pesticide use, and limited evidence for hygiene factors as an exposure modifier. Insufficient evidence was available to assess dietary exposures. An improved understanding of the important pathways of pesticide exposure in women is critical for future epidemiologic and exposure studies as well as for designing effective risk mitigation strategies.

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Table 1. Evidence for non-occupational pesticide exposure pathways in reviewed literature.

Study/ Rearch Group	Sources	State/ Country	Time Period	Population	Crops	Environ-mental Sample[c]	Biological Sample[d]	At Application Event	Para-occupational	Agricultural Drift	Residential Use	Ingestion	Hygiene	Statistical Analyses
Agricultural Health Pilot Study														
	Melnyk et al. 1997	IA, NC	1994	6 households	cattle, grains, soybeans, fruit, vegetables	W	N	N	N	N	N	d	N	summary statistics
California Childhood Leukemia Study/Fresno Pesticide Exposure Study														
	Gunier et al. 2011	CA	2001-2006	89 households	NA	D	N	N	++/o	++/o	++/o	N	N	multivariable regression
	Deziel et al. 2013	CA	2003-2005	21 households	NA	D	N	N	N	++/o	++/o	N	++/o	multivariable regression
CHAMACOS														
	Bradman et al. 2007	CA	1999-2000	426 pregnant women	vegetables, vineyards, orchards	N	Y	N	N	o	N	N	o	multivariable regression
	Harnly et al. 2009	CA	1999-2000	197 households	vegetables, vineyards, orchards	D	N	N	++/o	++/o	N	N	++/o	multivariable regression
	Huen et al. 2012	CA	1999-2000	234 mothers	vegetables, vineyards, orchards	N	Y	N	o	o	N	N	N	NA
Farm Family Exposure Study														
	Acquavella et al. 2004	MN, SC	2000-2001	48 households	NA	N	Y	Y	o	o	N	N	o	summary statistics
	Alexander et al. 2006	MN, SC	2000-2001	34 households	NA	N	Y	Y	+/o	o	N	N	o	non-parametric tests; multivariable regression
	Alexander et al. 2007	MN, SC	2000-2001	34 households	NA	N	Y	Y	+/o	o	N	N	o	summary statistics, multivariable regression, non-parametric tests
For Healthy Kids Study														
	Coronado et al. 2004	WA	1999	156 households	orchards, berries, grapes, hops	D	N	N	++/o	N	N	N	N	chi-square test
	Coronado et al. 2006	WA	1999	156 households	orchards, berries, grapes, hops	D	N	N	++	N	N	N	N	summary statistics
	Curl et al. 2002	WA	1999	156 households	tree fruit, berries, grapes, hops	D	N	N	++	o	N	N	N	ANOVA, correlations

Coronado et al. 2011	WA	2005-2006	109 households	orchards, berries, grapes, hops	D	Y	N	++	o	N	N	N	summary statistics
Coronado et al. 2012	WA	2005	95 households	orchards, berries, grapes, hops	D	Y	N	N	N	N	N	o	chi-square, non-parametric tests
Thompson et al. 2008	WA	1999-2003	210/203 basesline/follow-up households	orchards, berries, grapes, hops	D	N	N	N	N	N	N	o	summary statistics
Iowa Farm Family Pesticide Exposure Study													
Curwin et al. 2005	IA	2001	50 households	corn, soybeans	D	N	Y	++/+/o	o	o	N	o	mixed effects models
Curwin et al. 2007	IA	2001	50 households	corn, soybeans	D	Y	Y	++/+/o	N	N	N	N	mixed effects models
Iowa Pesticide Exposure Studies													
Golla et al. 2012	IA	2005	32 households	corn	D	N	Y	++	o	o	N	+/o	ANOVA
Lozier et al. 2012	IA	2007-2009	30 households	corn	D	N	Y	++/o	o	o	N	+	ANOVA, single and multivariable regression
Ontario Pesticide Exposure Assessment Study													
Arbuckle et al. 2006	Canada	1996	32 households	livestock, grains, oilseeds, fruits, vegetables	D, W	Y	Y	o	N	N	d	N	non-parametric tests; correlation
Arbuckle and Ritter 2005	Canada	1996	126 households	livestock, grains, oilseeds, fruits, vegetables	N	Y	Y	++/o	N	N	N	N	non-parametric tests; correlation
Oregon Pesticide Exposure Studies													
McCauley et al. 2001	OR	1997	96 households	orchards, vegetables, berries	D	N	N	N	++/o	o	N	d	NA
McCauley et al. 2003	OR	1998	24 households	orchards	D	N	N	+	o	o	N	++/o	t-test, non-parametric test, ANOVA, correlations
McCauley et al. 2006	OR	NA	10 households	orchards	D	N	N	N	N	N	N	++/+/o	non-parametric test
University of Washington Studies													
Fenske et al. 2002	WA	1995	75 households	orchards	D	N	N	++/o	++/o	N	N	o	non-parametric tests
Lu et al. 2000	WA	1995	76 households	orchards	D	N	N	++	++/o	o	N	o	non-parametric tests

	Lu et al. 2004	WA	1998	6 households	orchards	D, W	N	N	N	N	N	d	N	summary statistics
	Simcox et al. 1995	WA	1992	59 households	orchards	D	N	N	++/+/o	++/o	N	N	o	non-parametric tests; correlation
	Weppner et al. 2006	WA	NA	6 households	potatoes	D	N	Y	N	o	N	N	N	summary statistics
Other														
	Freeman et al. 2004	TX	2000-2001	27 households	NA	D	N	Y	N	N	+/o	N	N	non-parametric tests
	Fitzgerald et al. 2001	Canada	1995-1996	816 households	NA	W	N	N	N	N	N	d	N	descriptive
	Quandt et al. 2004	VA, NC	2001	41 households	NA	D	N	N	N	++/o	N	N	++/o	multivariable regression
	Richards et al. 2001	AK	NA	11 households	rice	D	N	Y	N	+	N	N	N	descriptive
	Semchuk et al. 2003	Canada	1996	154 women	grain/wheat	N	Y	N	+	N	N	N	+	multivariable regression
	Ward et al. 2006	IA	1998- 2000	112 households		D	N	N	++	++	N	N	N	multivariable regression; summary statistics

[a] Key for Exposure Pathways
N, not evaluated
+, relationship between pesticide levels and exposure pathway 0.1<p<0.05
++, relationship between pesticide levels and exposure pathway p<0.05
o, no association between pesticide levels and exposure pathway p>0.1
d, descriptive only; no comparison group
/, slash indicates some combination of above, depending on pesticide or sample type e.g., environmental vs. biological or metric
[b] D, bulk dust or dust wipe; W, water sample
[c] sample collected from women living in farm homes or non-farm homes (not men or children)
NA, information not available

Supplemental Material

Non-occupational Pesticide Exposure Pathways for North American Women Living in Agricultural Areas

Nicole C. Deziel, Melissa C. Friesen, Jane A. Hoppin, Cynthia J. Hines, Kent Thomas, Laura E. Beane Freeman

Table of Contents	Page

Table S1. Pesticides evaluated in each reviewed publication.

Study Name	Source	Herbicides	Insecticides	Fungicides
Agricultural Health Pilot Study	Melnyk et al. 1997	2,4-D, alachlor, atrazine, dacthal, dicamba, metolachlor, trifluralin	a-chlordane, aldicarb, aldrin, carbaryl, carbofuran, chlorpyrifos, DDD, DDE, DDT, dieldrin, fonofos, g-chlordane, heptachlor, lindane, malathion, permethrin, phorate, propoxur, pyrethrins, terbufos	captan, chlorothalonil, dicloran, folpet, metalaxyl
California Childhood Leukemia Study	Gunier et al. 2011	dacthal, simazine	carbaryl, chlorpyrifos, diazinon, phosmet	iprodione
CHAMACOS	Bradman et al. 2007		DDE, DDT, HCB, HCH	
CHAMACOS	Harnly et al. 2009	dacthal	acephate, azinphos-methyl, bensulide, chlorpyrifos, cis-permethrin, DCPA, DDE, DDT, diazinon, dimethoate, fenamiphos, fonofos, iprodione, malathion, methamidiphos, methidathion, methomyl, oxydemeton-methyl, phosmet, trans-permethrin	iprodione, vinclozoline
CHAMACOS	Huen et al. 2012		chlorpyrifos, diazinon	
Farm Family Exposure Study	Acquavella et al. 2004	glyphosate		
Farm Family Exposure Study	Alexander et al. 2006		chlorpyrifos	
Farm Family Exposure Study	Alexander et al. 2007	2,4-D		
For Healthy Kids Study	Coronado et al. 2006		azinphos-methyl (low detection rates: chlorpyrifos, diazinon, malathion, methyl parathion, phosmet)	
For Healthy Kids Study	Coronado et al. 2011		azinphos-methyl (low detection rates: DMPT, phosmet)	

For Healthy Kids Study	Coronado et al. 2004		azinphos-methyl (low detection rates: chlorpyrifos, diazinon, malthion, methyl parathion, phosmet)	
For Healthy Kids Study	Curl et al. 2002		azinphos-methyl, chlorpyrifos, diazinon, malathion, methyl parathion, phosmet	
For Healthy Kids Study	Thompson et al. 2008		azinphos-methyl, malathion, phosmet	
For Healthy Kids Study	Coronado et al. 2012		azinphos-methyl	
Fresno Pesticide Exposure Study	Deziel et al. 2013	dacthal, simazine, trifluralin	carbaryl, chlordane, chlorpyrifos, cyfluthrin, cypermethrin, diazinon, methoxychlor, permethrin, piperonyl butoxide, propoxur	
Iowa Farm Family Pesticide Exposure Study	Curwin et al. 2007	2,4-D, acetochlor, alachlor, atrazine, glyphosate, metolachlor	chlorpyrifos	
Iowa Farm Family Pesticide Exposure Study	Curwin et al. 2005	2,4-D, acetochlor, alachlor, atrazine, glyphosate, metolachlor	chlorpyrifos	
Iowa Pesticide Exposure Studies	Lozier et al. 2012	atrazine		
Iowa Pesticide Exposure Studies	Golla et al. 2012	atrazine		
Non-Hodgkin Lymphoma Study	Ward et al. 2006	2,4-D, acetochlor, alachlor, atrazine, bentazon, dicamba, fluazifop-p-butyl, metolachlor, pendimethalin, trifluralin		
Ontario Pesticide Exposure Assessment Study	Arbuckle et al. 2006	2,4-D		

Ontario Pesticide Exposure Assessment Study	Arbuckle et al. 2005	2,4-D, MCPA	
Oregon Exposure Studies	McCauley et al. 2001		azinphos-methyl (low detection rates: captan, carbaryl, chlorpyrifos, DDE, DDT, malathion, pentachlorophenol, phosmet, pipernoyl butoxide)
Oregon Exposure Studies	McCauley et al. 2003		azinphos-methyl, chlorpyrifos, diazinon, malathion, parathion, phosmet
Oregon Exposure Studies	McCauley et al. 2006		azinphos-methyl, chlorpyrifos, diazinon, ethyl parathion, malathion, methyl parathion, phosmet
University of Washington Studies	Fenske et al. 2002		chlorpyrifos, ethyl parathion
University of Washington Studies	Lu et al. 2000		azinphos-methyl, phosmet
University of Washington Studies	Lu et al. 2004		azinphos-methyl, chlorpyrifos, diazinon, phosmet
University of Washington Studies	Simcox et al. 1995		azinphos-methyl, phosmet, chlorpyrifos, ethyl parathion
University of Washington Studies	Weppner et al. 2006		methamidophos
--	Freeman et al. 2004	atrazine, simazine	azinphos-methyl, chlorpyrifos, demeton-O, ethion, demeton-S, diazinon, disulfoton, ethyl parathion, fenithrothion, fonofos, malathion, methyl parathion

--	Quandt et al. 2004	atrazine, metolachlor, oxyfluorfen, pendimethalin, simazine	a-chlordane, carbaryl, chlorpyrifos, cis-permethrin, DDE, DDT, diazinon, esfenvalerate, g-chlordane, heptachlor, lindane, methoxychlor, propoxur, total disulfoton, trans-permethrin	ortho-phenylphenol
--	Richardset al. 2001	propanil		
--	Semchuk et al. 2003	2,4-D, bromoxynil, dicamba, ethalfluralin, fenoxaprop, triallate, trifluralin, MCPA		
--	Fitzgerald et al. 2001	2,4-D, bromoxynil, dicamba, diclofop-methyl, fenoxyprop, MCPA, triallate, trifluralin		

2,4-D, 2,4-dichlorophenoxyacetic acid; DDE, dichlorodiphenyldichloroethylene; DDT, dichloro-diphenyl-trichloroethane; DMPT, dimethylphosphorothidate, DDD, dichlorodiphenyldichloroethane; HCB, hexachlorobenzene, HCH, hexachlorocyclohexane; MCPA, 2-methyl-4-chlorophenoxyacetic acid

Table S2. Evidence for the relationship between pesticide levels in biological or environmental samples and hygiene factors in the reviewed literature.[a]

Study Name	Source	Overall	Laundry	Changing Clothes/ Shoes	House Cleaning	Pets
CHAMACOS	Bradman et al. 2007		o	o		
CHAMACOS	Harnly et al. 2009			++/o	++/o	
Farm Family Exposure Study	Acquavella et al. 2004		o			
Farm Family Exposure Study	Alexander et al. 2006		o			
Farm Family Exposure Study	Alexander et al. 2007		o			
For Healthy Kids Study	Coronado et al. 2012	o	o	o	o	
For Healthy Kids Study	Thompson et al. 2008	o				
Fresno Pesticide Exposure Study	Deziel et al. 2013					++/o
Iowa	Lozier et al. 2012		o	+	+	o
Iowa Farm Family Pesticide Exposure Study	Curwin et al. 2005			++/+/o	o	o
Iowa Planting Study	Golla et al. 2012			o		+
Oregon Exposure Studies	McCauley et al. 2003	o		++/o	+	o
Oregon Exposure Studies	McCauley et al. 2006				+/o	
University of Washington Exposure Studies	Fenske et al. 2002		o	o	o	
University of Washington Exposure Studies	Lu et al. 2000		o	o	o	
University of Washington Exposure Studies	Simcox et al. 1995				o	o
--	Quandt et al. 2004				++/o	
--	Semchuk et al. 2003		o			

[a] Key for Exposure Pathways

+, relationship between pesticide levels and exposure pathway 0.1<p<0.05

++, relationship between pesticide levels and exposure pathway p<0.05

o, no association between pesticide levels and exposure pathway p>0.1

d, descriptive only; no comparison group

/, slash indicates some combination of above, depending on pesticide or sample type e.g., environmental vs. biological or metric

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