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Abbreviations:

DDT = dichlorodiphenyltrichloroethane

GAO = Government Accounting Office

OCP = organochlorine pesticide

OP = organophosphorus pesticide

NORA = National Occupational Research Agenda

PPE = personal protective equipment

US-EPA = United States Environmental Protection Agency

WPS = Worker Protection Standard

Outline

Abstract

Objective: To identify of factors potentially associated with pesticide exposure among farmworkers; to grade the evidence in the peer-reviewed literature for such associations; and to propose a minimum set of measures necessary to understand farmworker risk for pesticide exposure.

Data Sources: Review of Medline, Science Citation Index, Social Science Citation Index, PsycInfo, and AGRICOLA data bases.

Data Extraction: Articles restricted to those reporting primary data collection and analysis published in 1990 or later. Authors read and summarized evidence for pesticide exposure associations.

Data Synthesis: Articles were graded by type of evidence for association of risk factor with pesticide exposure: 1=Association demonstrated in farmworkers; 2=Association demonstrated in non-farmworker sample; 3=Plausible association proposed for farmworkers; or 4=Association is plausible, but not published for farmworkers. Of over 80 studies identified, only a third used environmental or biomarker evidence to document farmworker exposure to pesticides. Summaries of articles were compiled by level of evidence in tables and summarized. A minimum list of data to be collected in farmworker pesticide studies was derived from these evidence tables.

Conclusions: Despite ongoing concern about pesticide exposure of farmworkers and their families, relatively few studies have tried to directly test the association of behavioral and environmental factors with pesticide exposure in this population. Future studies should attempt to use similar behavioral, environmental, and psychosocial measures to build a body of evidence with which to better understand the risk factors for pesticide exposure among farmworkers.

Introduction

Human exposure to the pesticides that exist in the home, workplace and community is regulated by a variety of behaviors and environmental factors. While many of these are commonly accepted in research on farmworker health and form the basis of pesticide safety education, there has been no comprehensive review of the empirical evidence linking these factors to exposure or to the relationship of exposure and health. We focus on the measurement of behavioral and environmental factors important at two points in the pesticide and health relationship: (1) those that predict pesticide exposure, including who is exposed and how s/he is exposed; and (2) those that modify the absorbed dose of pesticides.

This review is based on the premise that such a compilation of data will allow scientists to identify factors that have been found associated with pesticide exposure and, perhaps more importantly, to identify the gaps in current knowledge of the pesticide and health relationship. To the extent that determinants of exposure can be assessed with comparable measures across studies, results of such studies can be then compared to provide better-grounded answers to questions on the health effects of pesticides.

In this paper we present a model of the relationship between predictors of pesticide exposure among farmworkers and pesticide exposure or health outcomes. We identify comprehensively the range of factors that may be associated with pesticide exposure, and distinguish those for which a firm relationship for farmworker exposure has been identified in the scientific literature and those for which the association can only be inferred from other data. We also suggest a minimum set of measures that are necessary to understand farmworker pesticide exposure.

Conceptual Model

This paper is guided by a model that contrasts proximal and distal determinants of pesticide exposure (Figure 1). Those proximal to pesticide exposure—that is, the immediate determinants of exposure—are generally behaviors practiced either by farmworkers in the workplace or by farmworkers or their co-resident household members at home. These include (in the workplace) use of personal protective equipment (PPE) and field sanitation, as well as (at home) laundry practices and child activity patterns. These proximal factors are themselves determined by predictors considered more distal to the exposure. These include environmental conditions at work (e.g., safety training), at home (e.g., number of farmworkers in residence), and in the larger community (e.g., total farmland treated with pesticides). These environmental factors affect exposure through behavior; the association of environmental and behavioral factors is moderated by psychosocial factors, including the attitudes, values, beliefs and knowledge held by farmworkers. For example, farmworker residences with a high residential density might be expected to store soiled work clothing that would present an exposure risk to household residents. This relationship could be positively influenced by beliefs that pesticides are harmless, or negatively influenced by knowledge of recommended laundry practices.

A portion of pesticides to which an individual is exposed is absorbed as the pesticide dose, and this can have health effects. According to the model, the amount absorbed is moderated by some of the workplace and household behaviors (e.g., handwashing by workers or household residents) as well as other moderators. The latter include genetic factors, body size, and developmental status; these are not covered in this review.

Methods

This review focused on the conceptual model (Figure 1) developed by the authors. Components of the model were expanded to produce a list of factors potentially related to pesticide exposure in farmworkers. These formed the search terms for a review of the literature that searched Medline, Science Citation Index, Social Science Citation Index, PsycInfo, and AGRICOLA databases. Reviews were restricted to peer-reviewed publications from studies involving primary data collection and published 1990 or later. A few earlier studies were included for topics with little research coverage. Articles were graded by the type of evidence for the association of a particular risk factor with pesticide exposure: 1=Association demonstrated in farmworkers; 2=Association demonstrated in non-farmworker sample; 3=Plausible association proposed for farmworkers; or 4=Association is plausible, but not published for farmworkers. To be classified as "1", the study participants had to be described as migrant or seasonal farmworkers. In most other cases the study participants were described as "growers," "farmers," or members of their families and were classified as non-farmworkers. Study participants described as "applicators" were classified as non-farmworkers. Summaries of articles were compiled by level of evidence and summarized in tables. Due to space restrictions, only those articles graded "1" or "2" are presented here (Table 1). A minimum list of data to be collected in farmworker pesticide studies was derived from these evidence tables (Table 2).

Workplace Behaviors

Wearing PPE is one of the behaviors most widely assumed to protect workers from pesticide exposure. The label PPE can apply to everything from long-sleeve shirts to protective coveralls and respirators. Studies in the US and abroad show that wearing PPE appropriate to the task results in lower exposure to pesticides (Table 1). Although the studies vary in the types of chemicals, PPE tested (gloves, overalls), and type of exposure measure (cholinesterase activity, skin wipes, organochlorine [OCP] pesticide serum levels) they indicate that PPE is effective in reducing worker exposure to pesticides (Fenske et al. 1990; Gomes et al. 1999; Hernández-Valero et al. 2001; Lander et al. 1991; Ohayo-Mitoko et al. 1999). Studies in farmers (Arbuckle et al. 2002) and applicators (Fenske et al. 2002a; Nigg et al. 1993) lend further support for the effectiveness of PPE, though indicate variations due to fabrics and clothing design. In general, fabric less capable of penetration and designs that cover the largest amount of skin provide the greatest protection from pesticide exposure for workers. Despite the indications of efficacy, studies (particularly of farmers and applicators) show that PPE is frequently not used (e.g., Perry et al. 2002)

Other worker behaviors have been suggested as ways to reduce pesticide exposure and are included as recommended practices in the US-EPA Worker Protection Standard (WPS) training (US-EPA 1992). These include washing hands in the field before eating and after mixing pesticides. The importance of such behavior is demonstrated by studies showing that pesticides can be transferred to the home via automobile (e.g., Curl et al. 2002; Thompson et al. 2003). Curwin et al. (2003) showed that farmworker hand levels of the OP acephate could be reduced 96% by handwashing.

Additional practices have been suggested to reduce exposure. These include wearing grower-provided uniforms and showering at the worksite before returning home. There have been no tests to determine if such workplace behaviors would reduce exposure of the farmworker or the farmworker family.

Farmworker children are sometimes taken to the fields either to work or because adequate child care is lacking (Cooper et al. 2001). Such practices are likely to be predictors of pesticide exposure. Hernández-Valero et al. (2003) investigated the possible pathways of organochlorine pesticide (OCP) exposure among 36 migrant farmworker children whose home base was Baytown, Texas. One-third of the children had previously conducted farmwork, and the farmwork duration significantly increased their exposure levels. Mandel et al. (2005) found that children of Minnesota growers often helped apply chemicals and therefore had levels of pesticide exposure closer to their parent who applied chemicals than to the other parents.

Household Behaviors

The application of residential pesticides in the home and yard has been investigated as a source of pesticide exposure among farmworkers and non-farmworkers (Table 1). The collection of wipe (Quandt et al. 2004) or vacuum samples (Bradman et al. 1997), which allow direct identification of the type of pesticide found, have been used to link pesticides applied to worker dwellings to those pesticides detected. However, not all studies have had positive results (McCauley et al. 2001). Urinary metabolites of OP pesticides have also supported the link between residential pesticide application and worker exposure (Arcury et al. 2005).

Similar results have been found in non-farmworker populations. Yard and garden pesticides were found to be transferred into homes by residents and by dogs (Lewis et al. 2001, Morgan et al. 2001; Nishioka et al 2001). Use of OP pesticides in gardens is associated with metabolite levels in children (Fenske 2002b; Lu et al. 2001)

Several household sanitation behaviors are associated with farmworker pesticide exposure. Bradman et al. (1997) found that more frequent mopping and vacuuming was associated with lower pesticide recoveries in dust wipes. Arcury et al. (2004) suggested that having a vacuum cleaner was associated with lower levels of urinary OP metabolites.

A number of studies have documented the high potential for personal exposure to pesticides due to waiting for extended periods before showering after work, not changing clothes immediately after work, and failure to separate work from household laundry (Alavanja et al. 1999; Curwin et al. 2002; Goldman et al. 2004). However, with the exception of McCauley et al. (2003), there is little direct evidence to support this association.

Work Environment

The organization of work is a sub-field of occupational health that is concerned with the way that work processes are structured and managed. Organization of work investigators attend to such factors as the nature of the employment relationship (e.g., permanent versus contingent labor), job design (e.g., complexity of tasks, level of worker control), interpersonal elements of jobs (e.g., worker-supervisor relations), as well as such things as work schedules, job security, and communication with an employing organization. Although it has not been explicitly used in farmworker research, evidence suggests that several aspects of the way farm work is organized contribute to pesticide exposure (Marquart et al. 2003).

Several inter-related processes underlying the nature of the employment relationship suggest that pesticide exposure is likely to be greater among farmworkers in seasonal (e.g., workers with H2A visas) or day labor relationships in contrast to those in more "permanent" positions. Farmworkers in employment relationships that are more permanent may receive more effective safety training and more consistent reinforcement of safety behaviors than seasonal farmworkers or day-laborers. Researchers contend that workers in non-standard employment relationships, such as seasonal workers or day-laborers, may be given tasks that place them in greater risk of becoming exposed to pesticides in contrast to permanent workers (Quinlan et al. 2001). Moreover, farmworkers in seasonal and day-labor arrangements may be less likely to request safety equipment or report potential hazards to owners/operators out of fear that it may jeopardize future opportunities for work (Aronsson 1999; Aronsson et al. 2002; Quinlan et al. 2001). Despite the plausibility of several of these linkages, differences in pesticide exposure among farmworkers in different types of employment relationships have not been explicitly studied.

Different aspects of job design, or the tasks performed on a job and how they are performed, have been linked to pesticide exposure (Table 1). Tasks that are not regulated by the WPS can result in elevated pesticide exposure (Coronado et al. 2004). A greater number of tasks or duties that put individuals in contact with pesticides or pesticide residues, such as self-service and repair of application equipment among applicators and greater number of field activities among workers, is associated with greater exposure (Alavanja et al. 1999; Hernández-Valero et al. 2001). Environments that provide farmworkers with little control over how pesticides are applied (e.g., high exposure application methods), when pesticides are applied (e.g., avoiding windy days), and frequency of application are all associated with increased pesticide exposure among farmworkers (Mage et al. 2000; Martin et al. 2002; Mekonnen & Agonafir 2002). Likewise environments that provide little personal control over protective behaviors, such as the absence of well-maintained PPE or being unable to wash or change clothes during the workday, contribute to elevated pesticide exposure (Alavanja et al. 1999; Arcury et al. 2002; Austin et al. 2001; Mekonnen & Agonafir 2002; Parrott et al. 1999).

Although there have been no explicit comparison studies, it is likely that different crops are associated with different levels of pesticide exposure because of the differences in task associated with crops. For example, some will involve greater hand labor for cultivation and harvest than others. It is likely that those requiring more hand labor will result in greater exposure.

Interpersonal elements of farmwork also contribute to pesticide exposure. Better quality relationships between workers and farmers/growers are important for identifying potential sources of pesticide exposure as well as for designing and implementing effective strategies for minimizing exposure (Grieshop et al. 1996). Communication difficulties due to language differences between workers and farmers/growers contribute to greater pesticide exposure through less effective training (McCauley et al. 2002; Rao et al. 2004). Similarly, differences in belief systems about the risks of pesticide exposure and appropriate behaviors for minimizing risk can contribute to elevated exposure by undermining the effectiveness of training and safety programs (Arcury et al. 2001; Quandt et al. 1998; Rao et al. 2004). The psychological demands of the work environment can contribute to lower adherence to safety regulations (Kidd et al. 1996; Thu 1998; Walter et al. 2002). Despite the strong suggested connection of these work environmental factors to pesticides, no studies have examined pesticide exposure and the organization of work, either in farmworkers or in other populations.

One of the major aspects of the work environment directly related to pesticide exposure is safety training for workers. Minimum content and standards for pesticide safety training are part of the WPS, which mandates training for field workers as well as for applicators. A number of studies have examined safety training in farmworkers, but none of these has examined the association of safety training with pesticide exposure. This work shows that many farmworkers fail to receive training as mandated (Arcury et al. 1999; Elmore & Arcury 2001; GAO 2000), but that the rates vary over time (Arcury et al. 2001). Salazar et al. (2004) found that even when safety training is presented, it sometimes is poorly understood due to language barriers. Research with applicators (Martinez et al. 2004) and farmers (Perry and Layde 2003) shows that safety training produces increased knowledge, but does not necessarily result in appropriate safety behaviors.

Household Environment: Physical and Social

Proximity of dwellings to agricultural fields treated with pesticides has been suggested as a dwelling characteristic associated with exposure (Fenske et al. 2000). Studies of dust samples from farmworker residences support this suggestion both in terms of concentrations of pesticides (McCauley et al. 2001) and numbers of pesticides found in the home (Quandt et al. 2002, 2004). Curl et al. (2003) found no association between distance to field and levels of metabolites found in children's urine. However, these metabolite levels were associated with house dust concentrations, which in turn were associated with the dust in cars of farmworkers, indicating a pathway from worksite to home. Among non-farmworkers, distance from dwelling to fields was associated with concentrations in house dust (Fenske et al. 2002b; Lu et al. 2000). This was reflected in higher urine concentrations of metabolites in some (Loewenherz et al. 1997), but not all (Fenske et al. 2002b) studies measuring urinary metabolites.

A variety of housing quality indicators have been linked to greater pesticide exposure for farmworker families. Older dwelling age (Bradman et al. 1997) and renting rather than owning (Arcury et al. 2005) have been examined, based on the belief that longer existence of a house, as well as a greater number of different tenants might lead to the accumulation of greater amounts of pesticides, both simply as a matter of time and because there might be greater opportunity for pest infestations to which pesticides are applied. Both of these measures have been found linked to exposure. Quandt et al. (2004) used an interviewer judgment of how difficult or easy a house was to clean, reasoning that houses more difficult to clean would have a less thorough elimination of pesticides. Cleaning difficulty was associated with greater pesticide exposure.

Several aspects of the household social environment related to household composition have been suggested as major influences on pesticide exposure at home. The logic is that more persons in the household, particularly more farmworkers, will increase the volume of take-home pesticides, and this situation might be most extreme in situations of crowding. The simplest measure, total household size, has been found linked to pesticides in two studies of farmworkers (Arcury et al. 2005; McCauley et al. 2001). This is supported by Goldman et al.'s (2004) study of pesticide-related behaviors. They found that larger household size was associated with fewer in-home safety behaviors. McCauley et al. (2003), in a study of non-farmworker agricultural households, found weak and non-significant associations between household size and OP residues. More specific measures of household social environment (number of adults in the households, number of agricultural workers in the household) have been suggested. However, this association has generally been tested by comparing agricultural and non-agricultural households (Bradman et al. 1997; Lu et al. 2000; Simcox et al. 1995), not by looking at variation in number of adults within farmworker homes. Exceptions are the work of Arcury et al. (2005) and Quandt et al. (2004): comparison of nuclear family households with those containing other adult relatives or non-relatives appears to show more pesticides in the latter. The reasons for this may be due to greater track-in pesticides with more adults, or due to culture-specific issues. The investigators found that women residing in farmworker homes reported difficulty in enforcing standards of household cleanliness when male in-laws lived with the family, due to gender roles that limit the authority of women over the behavior of fathers-in-law and other relatives. Only two studies have used density or crowding (e.g., persons/room, persons/square foot) as a measure of household social environment. McCauley et al. (2001) found no association in homes of farmworkers, and only a slight association in homes of other agricultural worker (McCauley et al. 2003).

Community Environment

Several different measures have been used to associate overall use of pesticides in a community with exposure. None has focused specifically on farmworkers. Fenske et al. (2000) found that a majority of children in an agricultural region from both agricultural and non-agricultural families had urinary metabolites for OPs. Similar findings are reported by Koch et al. (2002), who found no differences due to parental occupation or residential proximity to fields. Lee et al. (2002) measured airborne agricultural pesticides at monitoring stations in California communities. They found that the level of exposure exceeded reference values for non-cancer health effects for half of the population.

In agricultural communities with historical use of some persistent pesticides may have led to long-term contamination of the soil. In areas where lead arsenate was used extensively, soil samples have demonstrated the persistence of arsenic (Wolz et al. 2003). DDT, an OCP, is still found in soil samples, despite its having been removed from use decades ago (Miersma et al. 2003).

Factors Moderating Behavior and Environment: Psychosocial Stressors

Two pathways have been proposed by which psychosocial stressors might lead to pesticide exposure of farmworkers or of growers (Figure 1). None of the studies of these stressors has actually measured pesticides, so no data have been gathered with which to validate these pathways. The first pathway is through stressors on the farmworkers, primarily the result of their social position as immigrants and the process of acculturation that they undergo. Vega et al. (1985) found that Mexican American farmworkers experience high levels of psychiatric symptoms. These are associated with limited social mobility, transience, poverty, discrimination and a high rate of traumatic life events. These findings were supported by Hovey et al. (2002a, 2002b), who found that farmworkers suffer from high rates of anxiety. This anxiety, in turn, is associated with elevated acculturative stress, low self-esteem, ineffective social support, and lack of control over the migrant lifestyle. Looking specifically at female farmworkers, Carruth and Logan (2002) documented high levels of depressive symptoms, which were predicted by poor health, perceived hazards of farm work, having experienced recent farm work-related injuries, and engaging in farm work over long periods of time. These documented stressors and associated mental health deficits may lead farmworkers to take more risks and to neglect to practice safety behaviors protective against pesticide exposure.

The second pathway is through stressors on growers and workers that result from the organization of farmwork. Thu (1998) proposed that the narrow temporal window for growing and harvesting, long work hours in isolated work conditions, and the psychological stress associated with farming can push farmers to minimize safety standards. Others have argued that the psychological and physical demands of the job confronted by day-laborers, including farmworkers, directly promote accidents and injuries through fatigue and distraction (Kidd et al. 1996; Salazar et al. 2004; Thu 1998; Walter et al. 2002). They also argue that other difficulties confronted by farmworkers including economic hardship and job insecurity further elevate the risk of exposure and exacerbate health effects of exposure because farmworkers, who have few other employment options, may fear requesting PPE or may work through dangerous situations.

Factors Moderating Behavior and Environment: Pesticide Knowledge & Beliefs

Farmworkers' knowledge about pesticides has generally been measured relative to prevailing scientific data, while beliefs come from more exploratory, ethnographic investigations. However, conceptually, both provide workers with information upon which they base their actions, so the distinction in somewhat artificial. Farmworker beliefs and knowledge have been collected in a number of studies that do not relate these data to pesticide exposure or to behaviors that might predict exposure. Quandt et al. (1998, 2001) identified several key beliefs held by farmworkers that might increase behaviors that would promote pesticide exposure. These include the ideas that pesticides must be felt, seen, tasted or smelled to be present; the skin blocks absorption and body openings facilitate it; exposure occurs only when pesticide is wet; susceptibility is individualized; acute not low level chronic exposure is the primary danger inherent in pesticide exposure. Elmore and Arcury (2001) found similar beliefs among Christmas tree workers. Salazar et al (2004) found that workers expected to get sick as part of the job. They believe it was all right to work in unsafe conditions if the benefits were high enough. Hunt et al. (1999) found similar beliefs in southern Mexico.

In research with pesticide applicators, Martinez et al. (2004) found that applicators believe, in contrast to farmworkers, that dermal exposure was linked to long-term adverse health consequences, but not acute illness. The knowledge and beliefs held by applicators reflect their participation in required training (Martinez et al. 2004; Perry et al. 2000). Much of it appears to have been learned by rote with less than optimal understanding of the health consequences of exposure.

Some studies have tried to measure the association of pesticide knowledge and beliefs with pesticide-related behavior. These studies (Arcury et al. 2002; Grieshop et al. 1996; McCauley et al. 2002; Vaughan 1993) show that greater knowledge of pesticide risks increases workers' sense of control and willingness to practice safety behaviors that should reduce exposure. Among farm operators, the belief that one had previously experienced adverse events of exposure was linked to taking greater precautiouns when working with pesticides (Lichtenberg et al. 1999).

Factors Moderating Behavior and Environment: Values & Folk Beliefs

Familism (an orientation to the welfare of one's immediate and extended family) has been noted as a strong value among Mexican and Central American immigrants (Salazar et al. 2004; Sabogal et al. 1987; Romero et al. 2004). Among adolescent farmworkers, this value is so strong that researchers (e.g., Salazar et al. 2004) have suggested that these workers are likely to neglect themselves (e.g., not adhere to safety practices) in their agricultural work with pesticides. Other authors (e.g., Sabogal et al. 1987; Romero et al. 2004) have suggested that familism should be associated with more positive health outcomes. Thus, of those farmworkers who have been exposed to pesticides, those with greater familism may experience lower rates of pesticide-related illness.

Two folk illness concepts that are characteristic of Mexico have been identified among farmworkers. "Susto," an illness associated with having experienced a fright (Rubel 1984), was reported by a significant number of Mexican farmworkers in Florida who had experienced pesticide exposure (Baer et al. 1993). Arcury et al. (2001) reported that farmworkers expressed reluctance to use cold water for washing in the field and to shower immediately after returning home from work. They attributed this to a concern (indicative of a belief in humoral medicine [Rubel 1960; Weller 1983]) that their bodies were metaphorically hot from work and that the contact with water which, despite variation in temperature, is metaphorically cold, would result in rheumatism and other adverse health outcomes. These studies suggest that folk beliefs about the causes of illness can promote greater pesticide exposure by undermining protective behaviors such as hand-washing and using PPE.

Summary of the Evidence

While a broad array of factors have been proposed to have direct, indirect or modifying effects on whether or not farmworkers are exposed to pesticides (Table 1; Figure 1), the research connecting characteristics of workers' environments and behaviors with actual measures of pesticide exposure is meager. Behavioral factors for which the best evidence of a direct relationship with pesticide exposure exists are: use of PPE, use of pesticide products in and around the home, and personal hygiene behaviors such as hand washing at work and showering upon returning home from work.

For environmental factors, evidence of factors associated with exposure is lacking for the work environment. Aside from clear evidence that job tasks that bring workers into contact with pesticides produce greater exposure, there has been little attempt actually to measure the effect of workplace safety training or the organization of work on exposure. Far more attention has been paid to the effects of the household environment of farmworkers and applicators on the exposure of workers and family members because we have better access to homes than to work sites.

With some exceptions, research supports the link between proximity to fields and exposure. While studies use different measures, older houses of poorer quality appear to be linked to exposure. Similarly, different measures of household composition have been used; most suggest that a greater number of adults and farmworkers in a house leads to greater amounts of pesticide in the dwelling and more pesticide exposure of the residents.

None of the psychosocial or cultural factors proposed as moderators in the association of environment or behavior with exposure has been examined with actual pesticide exposure data. Thus, the role of such factors in farmworker exposure is unknown.

The review of the evidence also highlights the fact that many of the existing studies that identify predictors of pesticide exposure in farmworkers as well as non-farmworkers have relied on self-reported behaviors rather than true exposure measures. Among those that have measures of exposure, some are environmental samples rather than biological measures. This suggests that further studies of the association between predictors of exposure and actual biomarkers are warranted.

Recommendations for Data Collection and for Future Research

The evidence provided by this review, both of factors with demonstrable links to exposure and those plausible but not well studied, indicates that a minimum set of concepts should be included in studies of farmworker pesticide exposure. The exact measures for each concept are not entirely clear because of the dearth of research that has actually sought to measure the association of predictors and exposure outcomes. Therefore, the recommendation is to obtain a broad enough group of measures to test for likely pathways of exposure.

This minimum set differs if the research focus is limited to occupational pesticide exposure of workers or if the focus includes the para-occupational and environmental pesticide exposure of adults and children who reside with farmworkers. For the latter, some additional measures are included (e.g., child play areas). Measures are presented from proximal to distal determinants (Table 2). Although this paper has included a variety of moderators that are likely important in the exposure pathway, there is currently insufficient research to recommend any particular set of such measures.

Future Research

This review suggests that a productive line of research would be to focus on the role of the organization of work in pesticide exposure. This area of research can help identify aspects of the workplace that can be modified to protect workers from pesticide exposure. It is consistent with the approach of much of occupational safety and health, as it relies less on changing human behavior directly than on "engineering" changes in work and the workplace environment. While the organization of work is a well developed area of research, it has not had widespread application to farmworker pesticide safety research.

The most obvious dearth of data found in this review is in the area of cultural and psychosocial factors that may moderate the effect of household and workplace environments on safety behaviors. Although such factors are clearly not direct influences on exposure, they condition the extent to which behavior or environmental change to protect workers and their families will be accepted and are therefore necessary components of behavioral interventions. It is premature to list specific data to be collected, as such factors do not lend themselves to measurement through simple questions.

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Table 1: Review of literature on predictors of pesticide exposure among migrant and seasonal farmworkers.

Characteristic	Rating*	Citation	Population	Exposure Measurement	Findings
	Relationship to Pesticide Exposure				
1 Workplace Behaviors					
Availability and Use of Personal Protective Equipment	1	Fenske et al. 1990	12 farmworkers	Dermal exposure to lindane	Demonstrated penetration of lindane through workshirt and pants. Recommended adding coveralls and gauntlet-type gloves.
	1	Gomes et al. 1999	532 farmworkers in a United Arab Emirates	Blood sample: Acetylcholinesterase (AChE) activity	Higher AChE associated with changing work clothes and use of work coveralls, gloves, and face scarf.
	1	Lander et al. 1991	100 greenhouse workers and 43 fruit growers; 113 slaughtermen served as controls.	Blood sample AChE activity	Wearing gloves protective of AChE activity in greenhouse workers.
	1	Ohayo-Mitoko et al. 1999	539 agricultural workers in 4 areas of Kenya	Blood sample: AChE activity	Use of coverall resulted in less AChE inhibition than not wearing coverall or just wearing boots.
	1	Spencer et al. 1995	28 peach harvesters, California	Dislodgeable foliar residue of azinphos-methyl (AM) pesticides measured on skin and clothing	More pesticides found on outer of two shirts, indicating the protective effect of clothing from dislodgeable residues.
	1	Hernández-Valero et al. 2001	26 Mexican-American migrant farmworkers in Baytown, Texas	Blood samples: 21 organochlorine pesticides (OCPs)	Wearing gloves and hats resulted in less OCP exposure in farmworkers than wearing only hats.
	2	Arbuckle et al. 2002	126 pesticide applicators in Ontario	Urine samples: Phenoxy-herbicides 2,4-dichlorophenoxyacetic acid (2,4-D) or 4-chloro-2-methylphenoxyacetic acid (MCPA)	Reduced pesticide in urine following application associated with use of rubber gloves for mixing/loading, and wearing rubber boots for clean-up.
	2	Fenske et al. 2002a	6 pesticide applicators in central Florida citrus groves	Exposure to organophosphorus (OP) insecticide ethion during airblast application by fluorescent tracer	Among applicators, compared dermal exposure to pesticides for cotton work shirts/pants, woven

				deposition on skin surfaces beneath garments, video imaging analysis instrument (VITAE system), and alpha-cellulose patches placed outside and beneath the garments	coveralls, non-woven garments. All garments allowed fabric penetration. Exposure highest with non-woven garments, mostly because of large sleeve and neck openings.
	2	Nigg et al. 1993	3 greenhouse pesticide applicators in Florida	Pads placed inside and outside three types of protective coveralls measured exposure to chlorpyrifos, fluvalinate, and ethazol	Less penetration of synthetic disposable coverall than reusable treated twill coverall.
Field Sanitation	1	Curwin et al. 2003	12 Hispanic male tobacco harvesters near Kinston, North Carolina	Hand-wipes: acephate residues	Farmworkers removed 96% of acephate on hands by washing.
2. Household Behaviors					
Residental Pesticide Use	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	Residential pesticide use is associated with higher levels of OP metabolites samples from children and adults living in farmworker dwellings.
	1	Bradman et al. 1997	5 farmworker and 6 non-farmworkers dwellings in California's Central Valley	House dust and handwipe sample: 33 pesticides	Residential application of agricultural and residential pesticides is related to presence of pesticides in dust samples.
	1	McCauley et al. 2001	96 farmworker homes and 24 grower homes in two agricultural communities in Oregon	House dust samples: residues of major OPs used in area crops	Found no relationship between pesticides in wipe samples and "family use of pest control products."
	1	Quandt et al. 2002, 2004	41 farmworker family homes in North Carolina and Virginia	Wipe samples from floor, toys, and children's hands: 8 locally reported agricultural pesticides and 13 pesticides commonly found in U.S. houses	Found a greater number and weight of residential pesticides than agricultural pesticides in dust samples collected in farmworker dwellings.
	2	Fenske et al. 2002b	12 farmworker homes in Central Washington	House dust samples and children's urine samples: 2 diethyl OP pesticides--	OP pesticide use in garden associated with increased metabolite

			State; 14 nonagricultural reference homes	chlorpyrifos and parathion	concentrations in children's urine.
	2	Lewis et al. 2001	Single household	Samples of indoor air, vacuumable carpet dust, carpet dislodgeable residues, deposits on bare floors, table tops and dinnerware, surrogate food, and residues on children's hands and toys: diazinon and chlorpyrifos.	Demonstrates that indoor and outdoor residential pesticide application results pesticides on surfaces in homes accessible to human contact.
	2	Lu et al. 2001	110 children, ages 2-5 years, from 96 households in the Seattle metropolitan area	Urine samples: 6 dialkylphosphate (DAP) compounds	Children's OP pesticide concentrations higher if parents reported garden pesticide use, but not based on indoor residential pesticide use.
	2	McCauley et al. 2003	24 agricultural families in northwestern US	House dust samples: OP pesticides	Pesticide use in the home not related to levels of total OP residues.
	2	Morgan et al. 2001	Single family dwelling in Chatham County, North Carolina	Soil, turf, and carpet samples, 24 hour air samples, handwipes, and samples taken from dog fur and paws.	Children and adults exposed to pesticides applied to yards which were transferred into the house by pets (dogs), adults, and children.
	2	Nishioka et al. 2001	11 occupied and 2 unoccupied homes	Indoor air samples, surface wipes from floors, table tops, and window sills, and floor dust samples before and after lawn application of the herbicide 2,4-D.	Children and adults exposed to pesticides applied to yards which were transferred into the house by pets (dogs) and adults.
Cleaning	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	Living in a dwelling that is easier to clean and that has a vacuum cleaner associated with lower levels of OP metabolites among children and adults.
	1	Bradman et al. 1997	5 farmworker and 6 non-farmworkers dwellings in California's Central Valley	House dust and handwipe samples: 33 pesticides	Frequency and type of cleaning (mopping, vacuuming) related to presence of pesticides in dust samples.
Laundry	1	Arcury et al.	9 Latino farmworker	Urine samples: OP metabolites	Higher levels of OP metabolites for

		2005	family households in western North Carolina and Virginia		adults and children associated with improper handling of laundry, including storage of work clothes in house and laundering of work clothes with family clothes.
Delay changing clothes and bathing	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	Higher levels of OP metabolites for adults and children associated with farmworkers who delay changing from work clothes and bathing.
	2	McCauley et al. 2003	24 agricultural families in northwestern US	House dust samples: OP pesticides	Level of total OPs and of azinphos-methyl higher in homes where workers waited >2 hours before changing out of work clothes.
Household Pets	2	Lu et al. 2001	110 children, ages 2-5 years, from 96 households in the Seattle metropolitan area	Spot urine samples: six dialkylphosphate (DAP) compounds	OP pesticide concentrations in children not different based on reported pet treatment.
	2	McCauley et al. 2003	24 agricultural families in northwestern US	House dust samples: OP pesticides	Total number of pets in the home not related to levels of total OP residues.
	2	Morgan et al. 2001	Single family dwelling in Chatham County, North Carolina	Soil, turf, and carpet samples, 24 hour air samples, handwipes, and samples taken from dog fur and paws: pesticides	Pet dog was a vehicle for the transfer of pesticides residues from lawn to house.
	2	Nishioka et al. 2001	11 occupied and 2 unoccupied homes	Indoor air samples, surface wipes from floors, table tops, and window sills, and floor dust samples: before and after lawn application of herbicide 2,4-D.	Pet dog was a vehicle for the transfer of pesticides residues from lawn to house.
Child Activity Patterns	2	Morgan et al. 2001	Single family dwelling in Chatham County, North Carolina	Soil, turf, and carpet samples, 24 hour air samples, handwipes, and samples taken from dog fur and paws: pesticides	Children were a vehicle for the transfer of pesticides residues from lawn to house.
	2	Mandel et al. 2005	95 farm families (grower, spouse, and child) in Minnesota and South Carolina	24-hour urine samples: 2,4-D; glyphosphate; and metabolite of chlorpyrifos	Children's urine pesticide concentrations lower than growers, but higher than growers' spouse, reflecting children's activity patterns.
Diet	2	Curl et al. 2003	39 preschool age children (18 children	24-hr urine samples: 5 OP pesticide metabolites	Urine of children who ate an organic diet contained significantly lower

			with organic diets and 21 children with conventional diets) in Seattle, Washington		levels of OP metabolites than those who ate a conventional diet.
	2	Stehr-Green et al. 1988	85 rural-dwelling persons	Blood samples: 11 pesticide residues and metabolites	In "rural-dwelling persons", consumption of home-produced eggs and root vegetables associated with increased serum concentrations of pesticides.
Transportation	1	Curl et al. 2002	218 farmworker households in Washington State	House and vehicle dust samples: 6 pesticides Urine samples: 5 dialkylphosphate (DAP) metabolites	Found pesticides in dust samples collected in farmworker vehicles.
	1	Thompson et al. 2003	571 farmworkers in the Lower Yakima Valley in Washington State	Urine samples of farmworkers and children, house and vehicle dust samples: pesticides	Found pesticides in dust samples collected in farmworker vehicles.
3. Workplace Environment					
Task Variety	1	Hernandez-Valero et al. 2001	26 Mexican-American migrant farmworkers in Baytown, Texas	Blood samples measured 21 organochlorine pesticides (OCPs)	Number of tasks that bring farmworkers into contact with pesticides associated with elevated serum levels of mirex, DDT, and trans-nonachlor.
Job Design	1	Coronado et al. 2004	213 farmworkers in 24 communities and labor camps in eastern Washington State	Urine samples: OP metabolites; House and vehicle dust samples: OP pesticides	Workers performing tasks not regulated by Worker Protection Standard (e.g., thinning) more likely to have detectable levels of azinphos-methyl in house and vehicle dust.
4. Household Environment: Dwelling Characteristics					
Dwelling Location relative to exposure sources)	1	McCauley et al. 2001	96 farmworker homes and 24 grower homes in two agricultural communities in Oregon	Home dust samples: OP residues	Found azinphos methyl concentration decreased with increased distance from fields.
	1	Curl et al. 2002	218 farmworker households in Washington State	House and vehicle dust samples: 6 pesticides Urine samples: 5 OP metabolites	Strong correlation between pesticides in cars and in house dust. Weaker correlation between house dust and child urine. No association

					between distance to fields and child’s urine, suggesting behaviors, not proximity to fields, responsible for exposure.
	1	Quandt et al. 2002, 2004	41 farmworker family residences in North Carolina and Virginia	Wipe samples from floor, toys, and children’s hands: 8 eight locally reported agricultural pesticides and 13 pesticides commonly found in U.S. houses	Proximity to agricultural fields related to the number of agricultural pesticides detection in dust samples collected in dwellings.
	2	Fenske et al. 2002b	12 farmworker homes in Central Washington State and 14 nonagricultural reference homes	House dust samples and children’s urine samples: chlorpyrifos and parathion	Homes in close proximity (200 ft/60m) to pesticide-treated farmland had higher chlorpyrifos and parathion house dust concentrations than did homes farther away, but this effect was not reflected in the urinary metabolite data.
	2	Loewenherz et al. 1997	88 children under 6 years in 48 pesticide applicator and 14 reference families	Urine samples: OP metabolites	Higher DMTP levels in applicator children living < 200 feet from an orchard than nonproximal applicator children.
	2	Lu et al. 2000	109 children, 9 months to 6 years, in an agricultural community in central Washington State	Urine and hand wipe samples: OP pesticides. House dust samples and wipe samples: OP pesticides.	Higher levels of pesticides were found in dust samples from dwellings closer to orchards.
Dwelling Type	1	McCauley et al. 2001	96 farmworker homes and 24 grower homes in two agricultural communities in Oregon	Home dust samples: residues of major OPs used in area crops	Housing type (labor camp, trailer, apartment) was not related to pesticide residues.
Dwelling Tenure	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	Renting rather than owning associated with higher levels of OP metabolites samples from persons living in farmworker dwellings.
Housing quality / state of repair	1	Bradman et al. 1997	5 farmworker and 6 non-farmworkers dwellings in	House dust and handwipe sample: 33 pesticides	Dwelling age is related to presence of pesticides in dust samples.

			California's Central Valley		
	1	Quandt et al. 2002, 2004	41 farmworker family residences in North Carolina and Virginia	Wipe samples from floor, toys, and children's hands: 8 locally reported agricultural pesticides and 13 pesticides commonly found in U.S. houses	More residential pesticides found in dust samples collected in dwellings judged to be difficult to clean.
5. Household Environment: Household Characteristics					
Total household size (total number of residents)	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	Larger household size associated with higher levels of OP metabolites for adults and children.
	1	McCauley et al. 2001	96 farmworker homes and 24 grower homes in two agricultural communities in Oregon	Home dust samples: OP residues	More persons in household was related to greater azinphos-methyl in dust.
	2	McCauley et al. 2003	24 agricultural families in northwestern US	House dust samples: OP pesticides	Weak, non-significant correlation between number of household residents and levels of total OP residues.
Number of adults in household	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	More adults in the household associated with higher levels of OP metabolites for adults and children.
Number of farmworkers in household	1	McCauley et al. 2001	96 farmworker homes and 24 grower homes in two agricultural communities in Oregon	Home dust samples: OP residues	More farmworkers in household related to greater azinphos-methyl in dust.
	1	Bradman et al. 1997	5 farmworker and 6 non-farmworkers dwellings in California's Central Valley	House dust and handwipe sample: 33 pesticides	Higher amounts of pesticides in dust in farmworker than non-farmworker homes. Pesticides found on hands of children in farmworker, but not non-farmworker homes, suggest take-home pesticides.
	2	Lu et al.	109 children, 9 months	Urine and hand wipe samples: OP	Households with agricultural

		2000	to 6 years of age, in an agricultural community in central Washington State	pesticides. House dust samples and wipe samples from various surfaces: OP pesticides	workers had higher levels of OP pesticides in dust wipe samples and on children's hands, and higher levels of metabolites in children's urine samples than reference homes.
	2	Simcox et al. 1995	26 farming, 22 farmworker, 11 nonfarming residences in eastern Washington State	House dust and soil samples: 4 OP insecticides	OP pesticide residues found more often in homes of agricultural workers than in reference homes.
Household Composition	1	Arcury et al. 2005	9 Latino farmworker family households in western North Carolina and Virginia	Urine samples: OP metabolites	Higher levels of OP metabolites for adults and children associated with non-nuclear family household composition.
	1	Quandt et al. 2004	41 farmworker family residences in North Carolina and Virginia	Wipe samples from floor, toys, and children's hands: 8 locally reported agricultural pesticides and 13 pesticides commonly found in U.S. houses	Non-nuclear family household composition weakly associated with agricultural but not residential pesticides.
Household Density or Crowding	1	McCauley et al. 2001	96 farmworker homes and 24 grower homes in two agricultural communities in Oregon	Home dust samples: OP residues	Found no relationship between pesticides and area of home.
	2	McCauley et al. 2003	24 agricultural families in northwestern US	House dust samples: OP residues	Weak correlation between total area of home and levels of total OPs residues.
6. Community Environment					
Overall level of agricultural pesticide use	1-2	Fenske et al. 2000	109 children in agricultural community in eastern Washington State (91 had parents working in agriculture)	Urine samples: OP metabolites	Most children living in an agricultural region during the spray season had measureable dialkyphosphates, and a substantial fraction had doses > reference values for azinphos-methyl.
	2	Koch et al. 2002	44 children living in an agricultural	Urine samples: dialkylphosphate (DAP) metabolites	DAP metabolites elevated when OP pesticides were sprayed in the

			community in central Washington State		region. No differences due to parental occupation or residential proximity to fields.
	2	Lee et al. 2002	California communities	Ambient air sampling of multiple classes of airborne pesticides	Exposure estimates ≥ risk of noncancer health effects reference values occurred for 50% of exposed population for several pesticides.
Historical agricultural pesticide use	2	Wolz et al. 2003	58 homes in agricultural community in Washington State	Soil and house dust samples: lead arsenate	Dwellings near land used for orchard production during 1905-1947 had significantly higher soil and household lead, and soil arsenic than other homes.
	2	Miersma et al. 2003	Elementary school yards in 8 cities near the Texas-Mexico border	Soil samples: OCPs	Attributed OCPs found in school yards to historical agricultural activity.

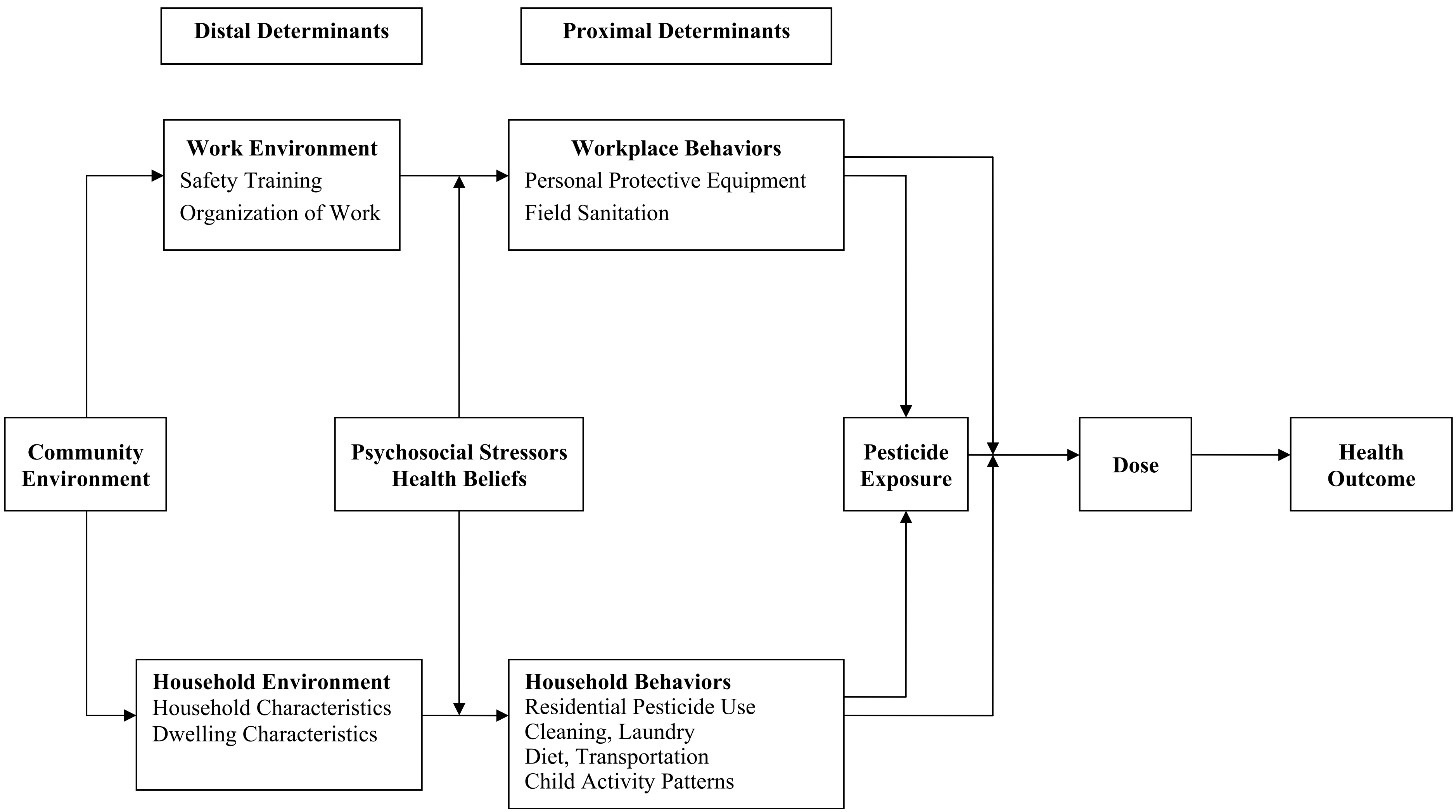
* 1=Association with pesticide exposure demonstrated in farmworkers
2=Association with pesticide exposure demonstrated in non-farmworker sample

Table 2: Recommended measures of predictors of pesticide exposure among migrant and seasonal farmworkers.

Workplace Behaviors	1. Wear clean clothes to work (frequency) 2. Wash hands at work (frequency) 3. Use of personal protective equipment (type, frequency)
Household Behaviors	1. Residential use of pesticides (type, frequency), including pet products 2. Wear work clothes into dwelling 3. Wear work shoes into dwelling 4. Time to changing from work clothes after work 5. Time to bathing after work 6. Contact with others before changing clothes after work 7. Contact with others before bathing after work 8. Storage of soiled work clothes 9. Laundry method (machine, hand) 10. Separation of work and family clothes in laundry 11. Child play areas (inside, outside)
Work Environment	1. Safety training (contents, quality) 2. Work task (fieldwork, mix & load, apply) 3. Access to hygiene facilities 4. Availability of personal protective equipment 5. Ability to communicate with supervisor
Residential Environment	1. Location relative to pesticide application 2. Housing structure type 3. Housing overall repair 4. Housing size (area, rooms) 5. Bathing facilities per resident 6. Laundry facilities per resident 7. Total number residents 8. Total number of farmworkers 9. Crowding; adult/room; workers/room; workers/sleeping room
Community Environment	1. Agricultural acreage 2. Volume pesticides applied/year

Figure Legend:

Figure 1: Conceptual model of the relationship the predictors of pesticide exposure among farmworkers and their relationship to health outcomes.


Distal Determinants
Proximal Determinants
Work Environment
Safety Training
Organization of Work
Workplace Behaviors
Personal Protective Equipment
Field Sanitation
Community Environment
Psychosocial Stressors
Health Beliefs
Pesticide Exposure
Dose
Health Outcome
Household Environment
Household Characteristics
Dwelling Characteristics
Household Behaviors
Residential Pesticide Use
Cleaning, Laundry
Diet, Transportation
Child Activity Patterns