Chronic Agricultural Chemical Exposure Among Migrant and Seasonal Farmworkers

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Laboratory studies and case reports of accidental exposure to large amounts chemicals indicate that there are immediate and long-term negative health con quences of exposure to agricultural chemicals. Logically, the consequences chronic low-level exposure also should be negative. Establishing a connecti however, between the more usual (chronic, low-level) exposure experienced by far... workers and health outcomes using epidemiological methods has been difficult. In this article we examine the reasons why this has been difficult, using specific examples from our ongoing research in rural North Carolina. We argue that because of the diverse nature of farming systems in the United States and the social organization of farm work, the combination of social-science methods for establishing the patterns of exposure and for devising appropriate measures with epidemiological methods for linking exposure to outcomes may provide the best methodological approach for studying this problem.

Keywords agriculture, chemical exposure, environmental health, migrant farmworker, occupational health, pesticide, seasonal farmworker

Agriculture exemplifies the human–environment interface as it affects health. It is farming that has allowed humans to harness sufficient environmental resources to feed and sustain large sedentary populations. At the same time, the disruption of the natural ecosystem by farming and the large population concentrations that have resulted from food production have led to a variety of health threats to humans. These health threats are both direct (e.g., parasitic and infectious diseases) and indirect (e.g., malnutrition and disease as a result of famine from plant disease–induced crop failure). Technological advances of modern agriculture therefore have included techniques to control these health threats. Chief among these has been the dependence on chemicals. Agricultural chemicals are a diverse class of substances used to control crop pests (pesticides, including insecticides, herbicides, fungicides, rodenticides, nematicides, acaricides, mollusicides, piscicides, and avicides) and enhance production (fertilizers, ripening agents, and fuels). These pesticides and other chemicals come in different forms including gas, liquid, dust, and

Received 19 February 1998; accepted 16 March 1998.
Supported by a grant from the National Institute of Environmental Health Sciences (ES08739).
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Society & Natural Resources, 11:829–843, 1998

0894-1920/98 $12.00 +.00

granular. They are applied through spray, in irrigation water, and from the air. Although new products and techniques (no-till agriculture, integrated pest management) are being developed to reduce the amounts of chemicals and therefore the potential environmental and human-health effects of these agricultural chemicals, chemicals remain important and widely used.

Ironically, just as chemicals are meant to assist humans through crop protection and enhanced production, they pose a serious health threat to those who work most closely with them, including seasonal and migrant farmworkers. For as long as there has been large scale agriculture in the United States, there has been a seasonal labor force to cultivate and harvest it. The harshness of farmworkers' lives has been a constant, characterized by deprivation and disease. President Truman pronounced in 1951 that "[w]e depend on misfortune to build up our force of migratory workers and when the supply is low because there is not enough misfortune at home, we rely on misfortune abroad to replenish the supply" (*Migratory Labor in American Agriculture* 1951). Today over 85% of the fruits and vegetables produced in this country are hand-harvested or cultivated (Oliveira et al. 1993) by workers who have little power to control their exposure to chemicals.

In this article we focus on the health implications of the intersection of this dependence in U.S. agriculture on chemicals and on migrant and seasonal farmworkers. We discuss the problems in linking chemical exposure to health in farmworkers and suggest ways of blending social science and epidemiological methods in this area of research. In addition to the published literature, we draw on our experiences in an ongoing study in North Carolina. This study uses community participation research to develop and test culturally appropriate interventions to reduce agricultural chemical exposure in migrant and seasonal farmworkers. Our efforts are concentrated on farms producing tobacco and cucumbers.

Agricultural Chemicals and Human Health

Many agricultural chemicals are readily absorbed by the body, through contact with the skin, the respiratory tract, the eyes, and the gastrointestinal system. There is a growing body of evidence that exposure to many of these chemicals can have negative health consequences. Such consequences include acute and chronic effects, as well as increased cancer risk (Woodruff et al. 1994). The most serious acute effects result from poisoning and can include death. In the United States, this usually is due to poisonings with organophosphate pesticides that create toxic effects by inhibiting cholinesterase, a neurotransmitter found throughout the body. Other deaths result from the effects of chlorinated hydrocarbons that act as central nervous system stimulants. Other more minor acute effects include skin rashes and irritations of the eye and respiratory tract.

Chronic effects are less well documented but have been reported for a variety of occupational groups, including chemical applicators and farmers, both as a result of low levels of exposure insufficient to cause acute reactions and as the long-term consequences of acute poisonings. These chronic effects include neurological problems, such as anxiety, memory deficits, mood changes, vision impairments, and delayed neuropathy. Reproductive effects of many pesticides used in agriculture are known from animal and human studies. These indicate that a whole range of effects—sterility, spontaneous abortion, and birth defects—are possible. Although the most conclusive human data are from studies of reproductive endpoints linked to sperm and in which type of chemical exposure was known (Olshan and

Faustman 1993), ecological studies that deal with confounding variables in seeking to link exposure and outcome have reached similar conclusions for a variety of pregnancy outcomes (Savitz et al. 1997).

Cancer, a delayed effect, has been linked to exposure to pesticides and other agricultural chemicals. Animal studies provide strong evidence that many agricultural chemicals are carcinogenic. These studies cross functional categories (e.g., herbicides insecticides, and fertilizers) and different chemical classes (Zahm and Blair 1993; Zahm et al. 1997). Epidemiological studies among farmers and other occupational groups routinely exposed to such chemicals find excesses of a variety of cancers among farmers, including leukemia, non-Hodgkin's lymphoma, multiple myeloma, soft-tissue sarcoma, and cancers of the skin, brain, and prostate (Blair and Zahm 1995; Zahm et al. 1997). Although the excesses of these cancers among farmers are small, the heterogeneity of exposure due to variability in farming operations and the grouping of all farmers together in epidemiological studies likely underestimates the risk for cancer in those farmers most exposed to agricultural chemicals (Zahm et al. 1997).

The evidence linking exposure to agricultural chemicals with health outcomes, therefore, has consisted of animal studies, case reports, and epidemiological studies in which the subjects had documented participation in farming activity (farm owner/operators or professional applicators), with chemical use assumed because of occupational class.

The past decade has seen increased attention to general farm safety, much of it focused on farm operators (Donham and Rautiainen 1997; Langley et al. 1997; Myers 1990; Myers and Hard 1995). There is currently growing concern that the health consequences of environmental and occupational factors are disproportionately borne by disenfranchised and medically underserved populations (Brown 1995; Sexton and Anderson 1993). This environmental-justice or environmental-equity movement has resulted in an extension of the concern for farm owner operators and chemicals applicators about the health consequences of agricultural chemical exposure to other groups (Moses et al. 1993). Examples of these nonfarmer and nonapplicator groups include children, farm families, and seasonal and migrant farmworkers (Ciesielski 1991; Ciesielski et al. 1994; Committee on Pesticides in the Diets of Infants and Children 1993; Moses 1989; Peyster et al. 1993; Simcox et al. 1995; Tarone et al. 1997). In this paper we concentrate on concerns directed to farmworker exposure.

There are public claims that 800 to 1000 farmworkers die every year of acute exposure to agriculture chemicals and that thousands of others experience immediate or delayed illness (Perfecto 1992; Pollack and Grozuczak 1984), but published data do not support such claims (Blondell 1997). Although some of the lack of data can be attributed to limited monitoring systems, even California, which has an established system for monitoring chemical-related morbidity and deaths, reports far fewer cases of injury or illness than these mortality figures suggest (US General Accounting Office 1993). Although there are case reports of individual farmworker exposure in which the health outcomes are serious and can be linked convincingly to exposure, such cases are rare. Thus, instead of acute accidental poisonings, the appropriate focus for much of the concern with farmworker health and agricultural chemicals is on chronic, low-level exposure, particularly exposure to chemical residues. These remnants of applied chemicals are found on plants, in soils, on equipment, and in water, and they become airborne or are transferred to the skin during activities in the treated fields (e.g., cultivating and harvesting). Although this exposure is less on any given day than that of a chemical handler, mixer, or applicator, the number of days per season in the fields can result in a substantially greater cumulative exposure (Fenske 1997).

There have been a number of studies linking chronic low-level chemical exposure in farmworkers to depressed cholinesterase levels, an indicator of exposure. Most of these are small, localized studies (Bodgen et al. 1975; Wicker et al. 1975). The largest study to date, conducted in North Carolina, did not produce strong associations of illness symptoms to cholinesterase (Ciesielski et al. 1994). Although this could be due to the lack of effects of chronic low-level exposure on farmworker health, we suggest that the data currently available are not sufficient to support such a conclusion. Rather, data gathered for epidemiologic study that has been informed by a thorough understanding of farm work and with adequate measures of exposure and outcome are needed to test the linkage of agricultural chemical exposure and health consequences for farmworkers.

Farmworkers and Exposure to Agricultural Chemicals

Who Are Farmworkers?

Nationwide, there are an estimated 4.2 million migrant and seasonal farmworkers and their dependents, with 1.6 million classified as migrant (HRSA 1990). There have been several definitions of *migrant* and *seasonal farmworker*, but for the purposes of this discussion we use the definition used in federal statutes governing migrant health funds. A *migrant farmworker* is an individual or dependent whose principal employment is in agriculture on a seasonal basis, and who, for purposes of employment, establishes a temporary home. The migration may be from farm to farm within a state, interstate, or international. A *seasonal farmworker* is an individual whose principal employment is in agriculture on a seasonal basis and who is not a migratory worker. In both cases the definition extends to employment obtained within the past 24 months. Migrant and seasonal farmworkers are employed in at least 42 of the 50 states.

As recently as 1991, the national migrant and seasonal farmworker population could be described as racially and ethnically diverse (including African Americans, Asian Americans, European Americans, Hispanics, Haitians, and other Caribbeans) and having regional variation in its ethnic composition (Mines et al. 1991). Today migrant and seasonal farmworkers in the United States are overwhelmingly Hispanic (Mines et al. 1993, 1997). As of 1995, 70% of all farmworkers were foreign born, and 94% of these foreign-born farmworkers (65% of all farmworkers) were from Mexico, with workers from several Central American nations making up most of the remainder (Mines et al. 1997). Even among Mexican nationals individuals come from different states and thus vary in language and background (Grieshop 1997).

North Carolina ranks fifth in the nation in size of its farmworker population. During the growing season the North Carolina Employment Security Commission (1995) estimates that there are over 140,000 migrant farmworkers and dependents in the state, with approximately twice this number of seasonal farmworkers. These farmworkers are largely minority, medically underserved, and economically disadvantaged. The vast majority of North Carolina farmworkers are Hispanic, with most coming from Mexico, Guatemala, Honduras, and Puerto Rico. As recently as

10 years ago, most North Carolina farmworkers were African American, but members of this ethnic group now constitute less than 10% of the farmworker population.

Factors that Influence Farmworker Exposure to Agricultural Chemicals

A variety of factors influence whether farmworkers are exposed to agricultural chemicals, to what chemicals they are exposed, and in what amounts. These factors include the characteristics of the farmworkers, the characteristics of the farming systems in which they work, changes over time in the chemicals used in agriculture, changes in the regulations governing the use of chemicals in agriculture, and the nature of exposure. These sources of variation mean that measuring the exposure and connecting this exposure to health outcomes for specific individuals take considerable detailed knowledge of specific farmworkers and the farmers systems in which they work.

Differences in age, gender, and body size are extremely important in determining exposure to agricultural chemicals, as well as to the biological effects of exposure. Farmworkers include men and women. Children, even those too young to work, often come with parents to the fields. Current law permits children under age 15 years to engage in agricultural labor (National Committee for Childhood Agricultural Injury Prevention 1996; Stallones and Gunderson 1994). Farmworkers range in age from their teens through their 60s. The body sizes and masses of farmworkers are variable. Most Mexican farmworkers we have interviewed or observed in North Carolina are less than 5.5 ft tall, while most of the African-American workers are closer to 6 ft tall. In general, the same chemical exposure is more dangerous to an individual with smaller body size than larger.

The living situations of farmworkers are also variable. In North Carolina, many migrant farmworkers still live in camps provided by the grower for whom they work. This is not the case in California. Even in North Carolina, farmworker living conditions vary greatly. Some farmworkers are responsible for finding their own housing; for others, crew leaders secure housing. The housing may be adjacent to fields to which agricultural chemicals are applied, or several miles away from actively farmed fields. The availability and quality of washing, bathing, and laundry facilities vary among these living situations but are frequently inadequate (Mines et al. 1991; Zahm and Blair 1993). The variability in such facilities may be complicated further by cultural factors. Our research in North Carolina indicates that beliefs of Hispanic farmworkers related to the hot-cold (humoral) system of disease causation may make them reluctant to use some washing facilities provided in fields and camps when they have been working in the fields and therefore exposed to chemicals.

The farming system in which farmworkers are employed greatly affects the work that they do and their exposure to chemicals. Farmworkers work in orchards (e.g., oranges, apples), in vegetables (e.g., cucumbers, lettuce), in root crops (e.g., sweet potatoes), in row crops (e.g., tobacco), in ferns and flowers, and in ornamentals and trees (e.g., Christmas trees) on which different agricultural chemicals are used. The physical situation in which work is done varies from crop to crop and over a season. For example, some farmworkers only work in greenhouses; others work in greenhouses only at the start of a season when seedlings are gathered for replanting. Workers are in greater contact with some plants than with others; they hold tobacco leaves but pick only sweet-potato roots. Riding on a mechanical harvester results in far less exposure than a "reach and pick" work task such as harvesting strawberries or tomatoes (Krieger 1995b).

The chemicals applied to a crop vary by the time of year in which it is grown; spring-canning cucumbers are not sprayed with insecticide; fall-canning cucumbers are sprayed. There is regional variation in the size of fields, even for the same crops. For example, tobacco fields in eastern North Carolina can be several acres in size; those in western North Carolina tend to be an acre or less in size.

An individual farmworker will work in several different crops in a single year. An eastern North Carolina farmworker may help set cucumber plants in April and tobacco in May, pick cucumbers in June, top and sucker tobacco in July, prime (harvest) and house tobacco in August and September, pick more cucumbers in September, and pick sweet potatoes in October. If the farmworker migrates, he or she may travel to western North Carolina in November to work in Christmas trees and then leave for Florida for the citrus harvest. Knowing the chemicals to which the worker has been exposed and the length of exposure is a matter of herculean record keeping.

Tobacco production offers an important example of how detailed knowledge of farming systems is needed to understand possible exposures of farmworkers to chemicals in the workplace. Most North Carolina farmers produce their tobacco crop on many plots scattered over a wide area because of the tobacco quota system and the rules that regulate where and who can grow tobacco. Each plot has its own ecology: soil type and quality, drainage pattern, and field size. One farmer with whom we have spoken farms 90 acres of tobacco with his brother. These 90 acres are scattered on 26 fields from 23 different farms, which are over 5 miles apart at their farthest. Most fields are under 3 acres in size. The application of fertilizers, insecticides, and ripening agents depends on the needs of each field. Some need more fertilizer. Some become infested with horn worm, others with blue mold. The possible exposure of workers who work for this one grower varies by the fields in which they work, when during the season they work in these fields, and which year they work in these fields. (This grower also stated that he keeps his records as to what was applied to which field all in his mind. Going back to earlier years for records is not possible.)

The chemicals used in agriculture continue to change. Farmers report having used such materials as lead arsenic in their youth (Arcury 1995, 1997). Several, such as DDT and aldrin (Moses 1989), have been banned more recently because of the risks they pose to the environment and human health. Others, such as the organophosphates, are being used less by many farmers because of their highly toxic nature. Industry continues to introduce new agricultural chemicals. Knowing when an individual has done farmwork is vital to measuring exposure.

The regulations that apply to how farmworkers are exposed to agricultural chemicals in the workplace also result in variation in exposure over time and from place to place. States differ in these regulations, with California having the strongest regulations for the protection of farmworkers and the only statewide surveillance system for reporting work-related pesticide illness (Maizlish et al. 1995). Nationally, the first change in regulations applying to farmworker exposure to agricultural chemicals since the 1972 amendment to the Federal Insecticide, Fungicide, and Rodenticide Act (which shifted the emphasis of the Act from efficacy to safety) came in 1992 with Worker Protection Standards instituted by the Environmental Protection Agency (Fenske 1997). These regulations, which were supposed to be in place by April 15, 1994 (Environmental Protection Agency 1992, 1993), require that agricultural employers (1) provide information about pesticide application requirements at a central location, (2) provide emergency assistance to any worker poisoned or injured by a pesticide, (3) provide decontamination sites, (4) restrict work in areas that are being treated, (5) enforce restricted-entry intervals, (6) provide posted and oral warnings about areas that have been treated, (7) provide pesticide safety training, and (8) not retaliate against workers who request information and compliance with these requirements. Pesticide-safety training must include 11 topics. Compliance with these regulations is incomplete, and their effectiveness has not been directly evaluated (Langner 1997). A farmer may comply with the training requirements of these regulations by showing his workers an approved video and having them sign a form stating that they have been trained.

The nature of exposure also varies. Everyone who works in agriculture is exposed to chemicals to some degree. At one extreme there is acute poisoning. In such instances chemicals are poured directly on a worker, a worker inhales chemicals, or a worker ingests chemicals. Such direct exposures are rare events, with usually catastrophic results. More common is exposure among chemical applicators and handlers in which small amounts of chemicals spill or splash on them. Our in-depth interview data with farmworkers in North Carolina, however, indicates that the most common exposure among farmworkers is to the residue that remains on crops after the restricted-entry period has expired. This exposure is low-level and chronic. It can result in skin reactions, but not always, and often is confused with reactions to plants (e.g., green tobacco sickness). In most instances, workers are not aware that they are exposed in this limited way. Analysis of our in-depth interview data indicates that most farmworkers are aware of exposure only when they can see, smell, or taste a chemical.

In summary, there is considerable variation in how a farmworker might be exposed to agricultural chemicals. Measuring exposure for farmworkers takes considerable knowledge of the individuals and the farming systems in which they work. From an epidemiological perspective, each of these sources of variation must be controlled if exposure is to be accurately measured and the effects of exposure on worker health are to be accurately estimated.

Measuring Exposure to Agricultural Chemicals

To relate chemical exposure to illness using epidemiological methods, there must be a measure of exposure for each individual sampled. Such a measure needs to have as little error as possible, so it will be an accurate indicator of exposure, hence preventing misclassification. Because establishing chemicals as a *cause* of subsequent disease requires determining a dose-response relationship, the best methods are those quantifying exposure (Blair et al. 1996). There are several established methods of measurement, but all have problems when applied in the study of farmworkers.

Current exposure and exposure history can be measured through a variety of means. *Self-reports* of exposure, although easy to obtain, are generally unreliable for both current and historical exposure, as farmworkers often do not know what chemicals have been used in the fields they work. In one study in Washington, 89% of farmworkers could not name any of the pesticides to which they had been exposed (Mentzer and Villalba 1988). In addition to lack of knowledge and general problems with memory in recall, the power relations between farmworkers and their employers may prevent truthful reporting of known exposures. Standardized and validated questionnaire methods for obtaining self-reports of exposure for farmworkers are badly needed, but the obstacles to their development are formidable (Zahm and Blair 1993).

Passive dosimetry measures are among the least invasive and frequently used measures of current exposure. A number of studies have measured chemical residues using "surrogate skin techniques" that involve placing a patch or other collection medium on the skin and later analyzing it for chemical residues. These patches are placed on different parts of the body, and the amount of chemical on each is then extrapolated to the surface area of that anatomical region. Although the assumption that exposure is evenly distributed over the region may not be warranted, this technique is simple and relatively noninvasive. It has been used to make general hazard evaluations and (when patches are placed inside and outside of clothing) has been especially useful in measuring the permeability of gloves and other protective clothing to chemical residues. Similar to the patch technique, whole-body garments and gloves have been analyzed to produce a measure of dermal exposure. All of these methods assume that the patch or clothing collects and retains chemicals in the same way as skin, but this assumption has not been systematically validated (Fenske 1997).

Other passive-dosimetry methods include using skin wiping to remove chemical deposits and skin washing (usually of hands). The accuracy of these has been questioned by controlled experiments in which chemical removal by washing was shown to be incomplete and related to time since exposure (Fenske and Lu 1994). Fluorescent-tracer techniques also have been developed (Fenske et al. 1986) that are particularly effective in demonstrating to workers the limits on effectiveness of protective clothing and hygienic practices. Their application in epidemiological studies may be in estimating the exposure from different types of work practices and quantifying the exposure reduction possible from washing.

Despite the ease of application, such passive-dosimetry measurements cannot be assumed to represent an absorbed dose (Krieger 1995b), as skin and clothing both act as barriers to the absorption of chemicals. In addition, personal hygiene–related behaviors (e.g., frequency of hand washing and clothing changes) vary among individuals, also introducing variability into the relationship between dermal exposure to chemicals and absorption. Work-task behaviors also introduce variability into how and where on the body chemicals are deposited. Krieger and colleagues (1990) have explored differences in contact with dislodgeable residues across different types of hand-labor activities to try to estimate "dermal transfer factors" representing the amount of foliage contacted by a worker per unit of work time. Foliage contact will vary between crops, as well as within crops. For example, picking oranges involves contact with the whole body including the head; picking strawberries involves the lower body and hands. In our work in North Carolina we have noted that tobacco harvest involves an initial pass through the fields to remove the first ripe leaves at the bottom of the plant. This brings much of the worker's body in contact with the foliage, as he or she stoops to reach under the plant to cut the leaf and then carries it under his or her arm. Later picking of leaves involves less lower-body contact, as the ripe leaves are higher on the stalk.

The most promising methods for measuring internal doses of chemicals are *biomarker techniques*. The advantage of such methods is that they account for the various routes of absorption (e.g., dermal, oral, and respiratory) and behavioral factors that regulate exposure. At present biomarker techniques are expensive, but they hold promise both for measuring exposure and for measuring the effects of exposure.

Exposure is measured by quantifying pesticides or their metabolites in body fluids such as urine. Because the appearance of these in urine is governed by human physiology and the pharmacokinetics of absorption and elimination of the particular chemical, one needs to collect all urine over a period of time (usually impossible with farmworkers) or have scientifically informed urine-collection protocols that allow extrapolation of a spot urine sample to an exposure measure (Wilson et al. 1997; Woollen 1993). There is promising work on developing these protocols (e.g., Dong et al. 1996), but they are oriented to a single chemical. For farmworkers exposed to multiple chemicals on multiple crops, there is no single biomarker in urine that can be measured. Recently, there has been considerable interest in developing salivary measures of exposure because of the relative ease of collecting samples and the expectation that salivary levels will approximate tissue levels (Nigg and Wade 1992). At present, these, too, can measure single chemicals only.

Each type of quantitative measurement of farmworker exposure to chemicals—self-report, passive dosimetry, or biomarkers—has specific types of error likely to reduce the accuracy of an exposure measure. In addition, factors such as cost and invasiveness enter into determinations of feasibility. Although it will probably be easiest to develop accurate measures of current exposure to single chemicals, what is needed in the study of farmworker health is a summary measure. Fleming and Herzstein (1997), for example, cite the need for a lifetime body-burden evaluation, and others urge a combination of studies of worker behavior with development of biomarkers (Krieger 1995b).

Linking Health Outcomes to Exposure to Agricultural Chemicals

Health outcomes of agricultural chemical exposure range from short-term effects such as dermatitis and dehydration to long-term effects such as cognitive deficits and cancer. There are specific difficulties in obtaining all of these types of health-outcome data for farmworkers, and the requirements of standard research designs used in occupational health are often impossible to meet.

Because many of the symptoms of chemical exposure (e.g., dermatitis, dizziness, diarrhea, and dehydration) are nonspecific, they do not effectively discriminate between chemical exposure and other common conditions of farmworkers. These include heat stress and reactions to plants. In our work in North Carolina, some workers in tobacco develop these symptoms as "green tobacco sickness," a form of nicotine poisoning caused by absorption of the drug through the skin during fieldwork (Boylan et al. 1993). Because green-tobacco sickness affects some but not all farmworkers, it is usually the lay diagnosis made by workers, crew leaders, and growers when symptoms arise, and it is often treated by home remedies and self-care rather than by seeking medical care. Even if such care is sought, the focus is on treatment of the symptoms, rather than differentiating chemical exposure from other causes, because the treatments are generally the same. Other crops can produce reactions as well. Harvesting cucumbers, for example, can lead to skin irritation from the sharp spines on the vine. Baer and Penzell (1993) have shown that there is an important cultural component to the recognition of chemical exposure. Mexican farmworkers interviewed in a Florida clinic in which they were being treated for pesticide exposure attributed their symptoms to the folk illness *susto* rather than chemicals. Such health beliefs play a role in the reporting of symptoms and exposure in any research.

In addition, because many farmworkers live in crowded substandard housing with inadequate bathing and laundry facilities, they tend to have health problems whose symptoms may be confused with chemical exposure. Alcohol and substance abuse, significant problems among farmworkers, can, for example, produce neurological effects that mimic those of chemicals (Fleming and Herzstein 1997). Thus, a simple self-report of symptoms is inadequate to identify chemical-related conditions.

For both short-term and chronic exposure, cholinesterase is the most commonly used biomarker of exposure. Exposure to some of the most widely used insecticides, organophosphates and carbamates, produces inhibition of the activity of cholinesterase, an enzyme found in muscle and brain. Levels of cholinesterase in plasma or red blood cells approximate levels in other tissues. Because the cumulative effects of long-term exposures, as well as short-term recent exposures, are reflected in cholinesterase measures, and because it can indicate exposure to a large class of chemicals, cholinesterase is a biomarker of interest for studies of farmworkers. There are no established laboratory standards, however, for the handling of specimens and analysis (Fleming and Herzstein 1997; Wilson et al. 1997). Development of these will reduce the error in measurement of exposure, making cholinesterase testing more suitable for research.

The same serious health outcomes—long-term neurological effects and cancer-related morbidity and mortality—are extremely difficult to obtain in farmworkers because of the study-design requirements, the nature of the population, and the natural history of the disease. The standard designs acceptable in occupational medicine are *cohort*, in which a group of workers is identified and either followed prospectively to measure disease outcomes or historically reconstructed to measure exposure, and *case-control*, in which the exposure histories of cases with a disease outcome are compared to controls who have no disease (Blair et al. 1996).

Cohort studies in environmental or occupational medicine usually depend on a community of workers, such as a union or employees of a large plant or company, to obtain a complete listing of workers. In all such studies, there is a problem because of the "healthy worker effect," the tendency of ill workers to drop out of the labor force and be lost to follow-up. In farmworkers, this problem is magnified. The population is extremely mobile, and farmwork places extreme physical demands on workers. Those too ill to work usually lack support systems and so often return to their country of origin. It is impossible to trace them and know the outcome of their illness—death, disability, or recovery. Because many workers are not legal residents, employers have few records that would help trace a farmworker.

Cancers can take many years to develop after an environmental or occupational exposure, and only a small portion of those exposed will ever develop cancer. Therefore, the number of farmworkers that would have to be followed to detect cancer and other rare conditions is large and the required follow-up period long, making cohort studies of farmworkers with adequate power to detect an effect of chemical exposure nearly impossible. For this reason, case-control studies may be the best suited to trying to link chemical exposure and delayed health effects in farmworkers.

Future Directions: Action and Research

The large-scale use of chemicals in modern agriculture is not likely to change. Neither is the fact that fieldworkers, most of them poor and minority, are disproportionately placed at risk for the negative health consequences of environmental exposure to chemicals. Our review of evidence linking chemical exposure and farmworker health indicates that current data are insufficient to determine whether or not farmworkers are suffering negative consequences of chronic low-level exposures to agricultural chemical residues. This is due primarily, however, to lack of good exposure measures. It is important to note that these null results do not indicate no effect but rather reflect the limits of our capacity to detect effects (Krieger 1995a) and the relative lack of attention to developing measures for this disenfranchised population. Traditional epidemiologic measures connecting exposure and outcome at individual levels are largely unsuitable for establishing the consequences of exposure in this population. It is, therefore, both prudent and ethical to make every reasonable effort to reduce exposure of all persons to chemical residues, including farmworkers. Current work funded by the National Institute of Environmental Health Sciences to develop culturally appropriate interventions to reduce exposure for farmworkers in North Carolina, Florida, and Oregon is a step in this direction, as are other efforts to enforce the Worker Protection Standards.

At the same time, our review suggests that the research issue of farmworkers and chemical exposure presents an opportunity for fruitful collaboration between social scientists and epidemiologists. Because of their focus on the concept of culture and its importance for understanding beliefs and behavior, social scientists can contribute to research to enhance our understanding of exposure and health outcomes: Who is likely to be exposed and under what circumstances? How does variability in farming systems affect exposure opportunities? How have secular changes in the organization of farm work affected exposure? What are farmworker beliefs about the relationship of chemicals to health? How do those beliefs affect exposure, through both contact with chemicals and the use of personal hygienic behaviors to remove chemical residues? How do beliefs about chemicals affect the self-report of exposure and health effects? Social scientists' methods for investigating such questions, including ethnographic fieldwork combining participant observation with other survey data-collection methods, also lend themselves to investigating such questions.

Social scientists and epidemiologists interested in farmworker health should focus on the development of measures of chemical exposure that can take into account the varied nature of farmwork (e.g., cropping systems, chemicals used, work tasks) and lifestyle exposure opportunities (e.g., living conditions, hygienic practices). The work of Siemiatycki and colleagues (Siemiatychi 1995; Siemiatycki et al. 1997) and Stewart and colleagues (P. A. Stewart and W. F. Stewart 1994; W. F. Stewart and P. A. Stewart 1994; Stewart et al. 1996) provides a template for developing exposure measures in farmworkers. Both these groups have based their methods on the assumption that different work tasks (not occupational categories) produce differences in exposure. By using detailed interviewing to understand individual workers' opportunities for exposure, coupled with expert raters with knowledge of the type and amounts of chemicals with which a worker is likely to have had contact in any particular task, they have produced valid and reliable systems for establishing exposure. The development of such detailed data for farmworkers could be used now to interpret evidence of short-term effects and later for case-control studies of long-term effects of chemical exposure.

This article focuses on methodological issues encountered in demonstrating the health consequences of chronic exposure to chemicals used in agriculture. It also highlights the need for moving beyond the comfortable disciplinary boundaries of the social sciences and epidemiology to confront issues of environmental justice and the sociopolitical distribution of health risk. Research in this area may be met with suspicion from farmers, who are concerned about issues of liability and loss of essential chemicals, as well as farmworkers, whose immediate and pressing concern is job security. It is contentious territory, requiring both creativity and commitment in research.

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