Acute Pesticide Poisoning Among Agricultural Workers in the United States, 1998–2005

Geoffrey M. Calvert, MD, MPH,[1]* Jennifer Karnik, MPH,[1] Louise Mehler, PHD, MD,[2] John Beckman, BS,[3] Barbara Morrissey, MS,[4] Jennifer Sievert, BA,[5] Rosanna Barrett, MPH,[6] Michelle Lackovic, MPH,[7] Laura Mabee, BA,[8] Abby Schwartz, MPH,[9] Yvette Mitchell, MS,[10] and Stephanie Moraga-McHaley, MS[11]

Background *Approximately 75% of pesticide usage in the United States occurs in agriculture. As such, agricultural workers are at greater risk of pesticide exposure than non-agricultural workers. However, the magnitude, characteristics and trend of acute pesticide poisoning among agricultural workers are unknown.*

Methods *We identified acute pesticide poisoning cases in agricultural workers between the ages of 15 and 64 years that occurred from 1998 to 2005. The California Department of Pesticide Regulation and the SENSOR-Pesticides program provided the cases. Acute occupational pesticide poisoning incidence rates (IR) for those employed in agriculture were calculated, as were incidence rate ratios (IRR) among agricultural workers relative to non-agricultural workers.*

Results *Of the 3,271 cases included in the analysis, 2,334 (71%) were employed as farmworkers. The remaining cases were employed as processing/packing plant workers (12%), farmers (3%), and other miscellaneous agricultural workers (19%). The majority of cases had low severity illness (N = 2,848, 87%), while 402 (12%) were of medium severity and 20 (0.6%) were of high severity. One case was fatal. Rates of illness among various agricultural worker categories were highly variable but all, except farmers, showed risk for agricultural workers greater than risk for non-agricultural workers by an order of magnitude or more. Also, the rate among female agricultural workers was almost twofold higher compared to males.*

Conclusion *The findings from this study suggest that acute pesticide poisoning in the agricultural industry continues to be an important problem. These findings reinforce the need for heightened efforts to better protect farmworkers from pesticide exposure.* Am. J. Ind. Med. 51:883–898, 2008. *Published 2008 Wiley-Liss, Inc.*†

KEY WORDS: pesticides; surveillance; poisoning; agriculture; farmworkers

[1]Division of Surveillance, Hazard Evaluations and Field Studies, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Cincinnati, Ohio
[2]Department of Pesticide Regulation, California Environmental Protection Agency, Sacramento, California
[3]Public Health Institute, Oakland, California
[4]Office of Environmental Assessments, Washington State Department of Health, Olympia, Washington
[5]Environmental and Injury Epidemiology and Toxicology Branch, Texas Department of State Health Services, Austin, Texas
[6]Florida Department of Health, Tallahassee, Florida
[7]Louisiana Department of Health and Hospitals, New Orleans, Louisiana
[8]Office of Environmental Public Health, Oregon Department of Human Services, Portland, Oregon

[9]Division of Environmental Health, Michigan Department of Community Health, Lansing, Michigan
[10]Bureau of Occupational Health, New York State Department of Health, Troy, New York
[11]New Mexico Occupational Health Registry, University of New Mexico, Albuquerque, New Mexico

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health or each author's state agency.

*Correspondence to: Geoffrey M. Calvert, National Institute for Occupational Safety and Health, 4676 Columbia Parkway, R-17, Cincinnati, OH 45226. E-mail: jac6@cdc.gov

Accepted 23 June 2008
DOI 10.1002/ajim.20623. Published online in Wiley InterScience (www.interscience.wiley.com)

INTRODUCTION

Pesticides are widely used in agriculture to control insects, microorganisms, fungi, weeds, and other pests. The control of these pests serves to increase crop yield and decrease manual labor [Litchfield, 2005]. In 2000 and 2001, over 5 billion pounds of pesticides were used annually throughout the world. The United States was responsible for 24% of this total usage [Kiely et al., 2004]. Within the US, the agricultural industry accounts for approximately 75% of the annual poundage used.

Farming is an essential component of our economy, but agricultural workers suffer elevated rates of injuries, hearing loss, and respiratory disease [Rust, 1990; Linaker and Smedley, 2002; Tak and Calvert, 2008]. Pesticides are also an important source of injury and illness among farmers and farm workers [Calvert et al., 2004]. Previous work has suggested that the agricultural industry's disproportionately high pesticide use puts farmers and farm workers at greater risk of pesticide exposure than others [Reeves and Schafer, 2003; Calvert et al., 2004]. Farmers and farmworkers may be exposed by mixing, loading and applying pesticides, or while performing duties not involved with pesticide application (e.g., weeding, harvesting, thinning, irrigating, or planting).

Recognizing the need for increased worker protections from pesticide exposures, the U.S. Environmental Protection Agency (EPA) promulgated rules in 1974 known as the Worker Protection Standard for Agricultural Pesticides (WPS; 40 CFR 170) and aimed at reducing pesticide exposures among agricultural workers. However, by 1992, EPA estimated that hired farmworkers alone experienced up to 10,000–20,000 illnesses and injuries from pesticide exposures each year [US EPA, 1992] and concluded that the WPS was inadequate in its requirements and scope of coverage. That year, EPA revised and expanded the WPS rules to include changes in labeling, coverage of more workers and agricultural operations, prohibition of employer retaliation against workers attempting to comply with the standard, and the following requirements: notification of workers about pesticide applications; restriction of re-entry into pesticide-treated areas; and, provision of personal protective equipment (PPE), decontamination supplies, emergency assistance, and pesticide safety training. Detailed information on the magnitude, characteristics and trend of acute pesticide poisoning since the revised WPS went into effect in 1995 are unavailable.

The National Institute for Occupational Safety and Health (NIOSH) developed the Sentinel Event Notification System for Occupational Risks-Pesticides (SENSOR-Pesticides) program [Calvert et al., 2001] to monitor risks from pesticide exposure. Data from this program are available beginning in 1998, when standardized definitions for cases and data elements were adopted [Calvert et al., 2001]. The California Department of Pesticide Regulation (CDPR) has a similar surveillance program that has been tracking pesticide-related illnesses for more than 30 years [Calvert et al., 2001]. To assess the magnitude, characteristics and trend of acute pesticide poisoning among agricultural workers in the United States since the revised WPS went into effect in 1995, an analysis of data obtained from these surveillance systems was performed.

MATERIALS AND METHODS

Data were obtained on individuals age 15 through 64 who developed an acute pesticide-related illness or injury and who were employed in the agricultural industry when the occupational pesticide exposure occurred. Census 1990 industry codes (1990 CIC) and Census 2002 industry codes (2002 CIC) were used to identify cases employed in agriculture [US Bureau of the Census, 1992; US Census Bureau, 2005]. The agricultural industry was defined as: agricultural production, excluding livestock (1990 CIC = 010; 2002 CIC = 0170); agricultural production, including livestock (1990 CIC = 011; 2002 CIC = 0180); and agricultural services (1990 CIC = 030; 2002 CIC = 0290). All agricultural industry cases also had their occupation coded using Census 1990 occupation codes (1990 COC) and Census 2002 occupation codes (2002 COC) [US Bureau of the Census, 1992; US Census Bureau, 2005]. Agricultural occupations included: farmworkers (1990 COC = 477, 479, 484; 2002 COC = 6050, 6120, 8710, 8960); farmers (1990 COC = 473–476; 2002 COC = 0200, 0210); processing/packing plant workers (1990 COC = 488, 699; 2002 COC = 6040, 7830, 7850, 8640, 8720, 8800, 8860, 9640); and, other miscellaneous agricultural workers (workers employed in agriculture but whose 1990 COC and 2002 COC did not match any of those specified for the other three agricultural occupations). A pesticide handler was defined as an individual who mixed, loaded, transported and/or applied pesticides, or an individual who repaired or maintained pesticide application equipment at the time of pesticide exposure (insufficient information was available to determine pesticide handler status for 68 individuals). This analysis excluded illnesses associated with non-occupational exposures and illnesses associated with intentional (e.g., suicidal, malicious intent) exposures.

Cases under 15 years of age and those 65 years and older were omitted from analysis. The age range was chosen a priori, and is considered to include the vast bulk of workers who are gainfully employed. A total of 66 cases age 65 and older were identified but not included in this analysis (this represents a rate of 13/100,000 agricultural workers age 65 and older). Furthermore, Current Population Survey (CPS) data, the source of our denominator data, are unavailable on workers less than 15 years of age.

Data Sources

Data for this analysis were obtained from CDPR and the SENSOR-Pesticides program. State health departments in ten states participated in the SENSOR-Pesticides program and contributed data. These ten state health departments were the: Arizona Department of Health, California Department of Public Health (CDPH), Florida Department of Health, Louisiana Department of Health and Hospitals, Michigan Department of Community Health, New Mexico Department of Health (through an agreement with the University of New Mexico), New York State Department of Health, Oregon Department of Human Services, Texas Department of State Health Services, and the Washington State Department of Health. The time frame for data availability varied according to state agency. The years of data availability are provided in Table I. Each of these agencies maintains its own passive population-based surveillance system for acute pesticide-related illness or injury with occasional outreach to potential reporters to stimulate reporting (e.g., contacting poison control centers to encourage them to report or reviewing physician reports submitted to workers' compensation insurance carriers to identify eligible cases) [Calvert et al., 2001, 2004]. Each agency obtains case reports from many different sources. All require physician reporting of pesticide-related illness cases. Other sources of case reports vary by state and include poison control centers, state agencies with jurisdiction over pesticide use (e.g., departments of agriculture), and workers' compensation claims. Because each state removes any personal identifiers from the data prior to submission to the Centers for Disease Control and Prevention this study was exempt from consideration by the federal Human Subjects Review Board.

Once a case report is received, the state agency determines whether the subject was symptomatic and whether the involved chemical is a pesticide. If so, attempts are made to interview the poisoned subject or their proxy to obtain details on the poisoning event, and any medical records are requested. Besides identifying, classifying, and tabulating pesticide poisoning cases, the states periodically perform in-depth investigations of pesticide-related events, and develop interventions aimed at particular industries or pesticide hazards.

Cases obtained from CDPR were cross-referenced with cases from the CDPH based on age, gender, date of exposure, and pesticide name. Matching cases were assumed to be the same individual and were counted only once.

Information Available on Each Case

Data collected for each case by the SENSOR-Pesticides and CDPR surveillance systems include case demographics, signs and symptoms of illness or injury, illness severity, EPA toxicity category, identity of implicated pesticides and the target (e.g., crop) of their application (if any), information on factors that may have contributed to the pesticide exposure that precipitated illness, and the source of the case report.

EPA evaluates the toxicity of and assigns a toxicity category to each pesticide product. The categories range from I to IV, with I representing the most toxic and IV the least toxic substances [US EPA, 1975]. The toxicity category for each case was obtained by the relevant state agency conducting pesticide poisoning surveillance. When toxicity category data was not given, the category was determined by NIOSH based on standardized criteria from a dataset provided by EPA. Cases exposed to more than one pesticide product were assigned the toxicity category representing the pesticide product with the greatest toxicity.

Case Definition

A standardized case definition is used by all participating SENSOR-pesticides states. Cases of acute pesticide poisoning are included in the analyses if they were classified as definite, probable, possible or suspicious. A classification category is assigned to a case based on three factors: (1) the strength of evidence that a pesticide exposure occurred; (2) whether adverse health effects were observed by a healthcare professional versus being self-reported; and (3) the presence of sufficient evidence that the known toxicology of the agent was consistent with the observed health effects. Cases exposed to pesticides for which there is limited toxicological data were classified as suspicious [CDC, 2001a]. CDPR uses a comparable case definition [CDPR, 2006]. In this article, acute pesticide poisoning and acute pesticide-related illness and injury are used interchangeably.

Illness severity was assigned to all cases using standardized criteria which were based on signs and symptoms, medical care received, and lost time from work [CDC, 2001b]. *Low severity illness/ injury* consist of illnesses and injuries that generally resolve without treatment and where minimal time (<3 days) is lost from work. Such cases typically manifest as eye, skin and/or upper respiratory irritation. *Moderate severity illness/injury* consists of non-life-threatening health effects that are generally systemic and require medical treatment. No residual disability is detected, and time lost from work is less than 6 days. *High severity illness/injury* consists of life threatening health effects that usually require hospitalization, involve substantial time lost from work (>5 days), and may result in permanent impairment or disability. *Death* pertains to fatalities resulting from exposure to one or more pesticides.

Data Analysis

SAS v. 9.1 was used for data management and analysis [SAS Institute Inc, 2003]. Chi square statistical analyses were performed on categorical data. Incidence rates (IR) for acute occupational pesticide poisoning were calculated for those employed in agriculture. Rates were calculated for occupational categories within agriculture, for each year studied, by age group, and for three geographic regions in the US. The numerator represents the number of relevant cases

TABLE I. Data on Demographics, Pesticide Toxicity, Pesticide Handler, Pesticide Functional Class, and Application Target for 3,271 Acute Pesticide Poisoning Cases in the Agricultural Industry by Severity Category, 1998–2005

	Fatal, N	High Severity, N	Medium Severity, N	Low Severity, N	Total, N (%)[a]
Total	1	20	402	2,848	3,271
Age					
15–17	0	0	5	19	24 (1)
18–24	0	1	82	521	604 (18)
25–34	0	2	109	786	897 (27)
35–44	0	7	103	630	740 (23)
45–54	0	3	59	358	420 (13)
55–64	1	5	28	138	172 (5)
Unknown	0	2	16	396	414 (13)
State where illness identified (years of data availability)					
Arizona (1998–1999)	0	0	4	17	21 (1)
California (1998–2005)	1	10	274	2,235	2,520 (77)
Florida (1998–2005)	0	0	23	109	132 (4)
Louisiana (2001–2005)	0	4	14	27	45 (1)
Michigan (2001–2005)	0	1	7	14	22 (1)
New Mexico (2005 only)	0	0	2	10	12 (1)
New York (1998–2005)	0	0	6	7	13 (1)
Oregon (1998–2005)	0	0	6	37	43 (1)
Texas (1998–2005)	0	3	40	146	189 (6)
Washington (2001–2005)	0	2	26	246	274 (8)
Gender					
Female	0	6	114	934	1,054 (32)
Male	1	14	288	1,886	2,189 (67)
Unknown	0	0	0	28	28 (1)
Year exposed					
1998	0	2	64	358	424 (13)
1999	1	1	85	337	424 (13)
2000	0	4	64	315	383 (12)
2001	0	0	30	236	266 (8)
2002	0	0	26	576	602 (18)
2003	0	0	43	279	322 (10)
2004	0	11	35	396	442 (14)
2005	0	2	55	351	408 (12)
Toxicity category[b]					
I	1	11	232	1,418	1,662 (51)
II	0	1	68	599	668 (20)
III and IV	0	6	82	792	880 (27)
Unknown	0	2	20	39	61 (2)
Pesticide handler					
Yes[c]	1	10	190	867	1,068 (33)
No	0	10	200	1,925	2,135 (65)
Unknown	0	0	12	56	68 (2)
Pesticide functional class[d]					
Insecticides—all	1	10	210	1,540	1,761 (54)
Insecticides only	0	7	115	747	869 (27)
Insecticides combined	1	3	95	793	892 (27)
Fungicides—all	1	4	90	734	829 (25)
Fungicides only	0	2	28	147	177 (5)
Fungicides combined	1	2	62	587	652 (20)

TABLE I. (*Continued*)

	Fatal, N	High Severity, N	Medium Severity, N	Low Severity, N	Total, N (%)[a]
Disinfectants—all	0	2	56	389	447 (14)
Disinfectants only	0	2	48	238	288 (9)
Disinfectants combined	0	0	8	151	159 (5)
Herbicides—all	0	1	56	400	457 (14)
Herbicides only	0	1	42	318	361 (11)
Herbicides combined	0	0	14	82	96 (3)
Fumigants—all	0	4	44	416	464 (14)
Fumigants only	0	4	44	416	464 (14)
Fumigants combined	0	0	0	0	0 (0)
Other	0	1	18	130	149 (5)
Application target					
Fruit crops	0	3	112	1,047	1,162 (36)
Vegetable crops	0	2	45	411	458 (14)
Soil	0	2	20	316	338 (10)
Grains, grasses and fiber crops	0	1	58	201	260 (8)
Landscape/ornamental	0	1	18	159	178 (5)
Undesired plant	0	0	6	74	80 (2)
Beverage crops	0	0	7	35	42 (1)
Crops that cross categories	0	0	6	32	38 (1)
Building structure/surface/space	0	1	8	35	44 (1)
Oil crops	0	0	5	15	20 (1)
Miscellaneous field crops	0	0	8	11	19 (1)
Veterinary (livestock or domestic)	0	0	4	13	17 (1)
Other	1	2	18	182	203 (6)
Not applicable	0	4	55	161	220 (7)
Unknown	0	4	32	156	192 (6)

[a]Percentages may not sum to 100 due to rounding.
[b]Acute pesticide toxicity category as defined by the U.S. EPA.
[c]A pesticide handler was defined as an individual who mixed, loaded, transported and/or applied pesticides, or an individual who repaired or maintained pesticide application equipment at the time of pesticide exposure.
[d]Cases may be exposed to more than one functional class. The rows labeled with "combined" pertain to cases exposed to more than one pesticide active ingredient, some of which belong to the pesticide functional class specified in the row label and others belonging to other pesticide functional classes.

captured by CDPR and SENSOR-Pesticides from 1998 to 2005. Denominator data, including employment counts and the hours worked estimate, were obtained from the CPS [BLS, 2007]. The hours worked data were used to derive full-time equivalent (FTEs) estimates, with one FTE equivalent to 2,000 hr worked. Denominator data correspond to the states and time periods of data availability (Table I). Although rates were calculated with the two denominator estimates (employment counts and FTE estimates), the rates calculated with FTEs as the denominator are given prominence as they have previously been shown to be conceptually preferable over the use of raw employment counts [Ruser, 1998]. The comparison group consisted of all workers not employed in agriculture. IR for workers employed in non-agricultural industries were similarly calculated, with the numerator and denominator data obtained from the same agencies (SENSOR/CDPR and CPS, respectively) that provided the data on agricultural workers. Finally, incidence rate ratios (IRR) were calculated to determine the risk of acute pesticide poisoning while working in agriculture. This ratio was calculated by dividing the IR among agricultural workers with that among non-agricultural workers. A ratio greater than one suggests an increased risk in farmers or farmworkers, while a ratio less than one suggests a decreased risk. Confidence intervals (95% CIs) were calculated for each rate ratio as described by Rothman [1986].

RESULTS

From 1998 to 2005, 3,271 case reports met inclusion criteria (Table I). Of these, 1,078 (33%) were identified by the SENSOR-Pesticides program and 2,193 (67%) originated from CDPR (527 cases were identified by both SENSOR and CDPR and were included in the CDPR total only). There were 1,942 separate pesticide exposure events, 1,762 of which (91%) involved only one ill agricultural worker. Of the

180 (9%) multi-victim events, the median number of ill agricultural workers was 3 (range 2–123). The number of pesticide exposure events decreased over the time period studied but the average number of cases per event increased (in 1998 there were 308 events with an average of 1.4 cases per event whereas in 2005 there were 209 events with an average of 2.0 cases per event).

Description of the Three Largest Events

More than three quarters of the cases (N = 2,520, 77%) occurred in California. Among these cases, we found a small number of events that exposed large numbers of agricultural workers. In two separate 2002 incidents, irritant vapors drifted from soil treatments with metam-sodium and caused low severity illness in 123 vineyard workers and in 72 workers at a carrot processing facility, respectively [see O'Malley et al., 2005 for detailed information on the event involving 72 workers]. The second largest incident occurred in 2004, when 121 peach harvesters became ill after exposure to drift from an application of methamidophos and mancozeb to a nearby potato field. Most of these workers experienced low severity illness (N = 111, 92%), and the other 10 workers (8%) experienced moderate severity illness.

Incidence Rates

Tables II and III and Figure 1 summarize IRs for agricultural workers and non-agricultural workers from 1998 to 2005. Overall, the average annual IR among agricultural workers was 53.6/100,000 FTEs and 1.38/100,000 FTEs among all non-agricultural workers combined (IRR = 38.9 95% CI 37.2, 40.6). Agricultural workers' annual rates fluctuated between 33.8/100,000 FTEs (2001) and 79.9/

TABLE II. Incidence Rates by Industry, Year of Exposure, Age Group and US Region for 3,271 Acute Pesticide Poisoning Cases, 1998–2005

	Agricultural workers			Non-agricultural workers			
	Count	FTE estimate[a]	Incidence rate[b]	Count	FTE estimate[a]	Incidence rate[c]	Incidence rate ratio[d]
Year of exposure							
1998	424	790,837	53.6	762	40,792,468	1.9	28.7
1999	424	781,985	54.2	656	42,040,152	1.6	34.7
2000	383	781,654	49.0	577	41,041,774	1.4	34.9
2001	266	787,481	33.8	552	49,456,474	1.1	30.3
2002	602	753,595	79.9	598	49,110,280	1.2	65.6
2003	322	756,610	42.6	694	50,151,930	1.4	30.8
2004	442	735,270	60.1	716	50,989,934	1.4	42.8
2005	408	710,851	57.4	638	53,000,554	1.2	47.7
Age group (years)							
15–17	24	99,364	24.2	69	3,140,858	2.2	11.0
18–24	604	792,852	76.2	851	43,536,103	2.0	39.0
25–34	897	1,392,263	64.4	1,246	92,090,687	1.4	47.6
35–44	740	1,601,894	46.2	1,303	106,763,138	1.2	37.9
45–54	420	1,276,042	32.9	968	89,437,936	1.1	30.4
55–64	172	935,868	18.4	356	41,614,845	0.9	21.5
Unknown	414	—	—	400	—	—	—
US region							
West[e]	2,858	3,168,485	90.2	3,556	149,655,538	2.4	38.0
South[f]	366	2,258,774	16.2	1,225	141,962,800	0.9	18.8
East[g]	45	671,024	7.0	412	84,965,229	0.5	13.8
Total	3,271	6,098,283	53.6	5,193	376,583,567	1.4	38.9

[a]FTE, full-time equivalent.
[b]Incidence rate per 100,000 FTEs. Includes agricultural workers in Arizona, California, Florida, Louisiana, Michigan, New Mexico, New York, Oregon, Texas, and Washington.
[c]Incidence rate per 100,000 FTEs. Includes non-agricultural workers in Arizona, California, Florida, Louisiana, Michigan, New Mexico, New York, Oregon, Texas, and Washington.
[d]Compares the rate of acute pesticide poisoning among agricultural workers for a given year with non-agricultural workers. Cases are identified by participating SENSOR-Pesticides states and CDPR. All IRRs were significantly elevated ($P < 0.0001$).
[e]Arizona, California, New Mexico, Oregon, and Washington.
[f]Florida, Louisiana, and Texas.
[g]Michigan, New York.

TABLE III. Incidence Rates by Occupation for 3,271 Acute Pesticide Poisoning Cases in the Agricultural Industry, 1998–2005

Occupation	Number	Percent	FTE estimate[a]	Incidence rate[b]
Farmworker—all	2,334	71	3,119,402	74.8
Farmworker—male	1,620	69	2,625,146	61.7
Farmworker—female	701	30	494,256	141.8
Farmer	89	3	1,852,030	4.8
Farmer—male	80	90	1,510,632	5.3
Farmer—female	9	10	341,398	2.6
Processing/packing plant worker	394	12	108,646	362.6
Processing/packing plant worker—male	108	27	21,094	512.0
Processing/packing plant worker—female	279	71	87,552	318.7
All other agricultural occupations	454	14	1,018,205	44.6
All other agricultural occupations—male	381	84	674,521	56.5
All other agricultural occupations—female	65	14	343,684	18.9
Total[c]	3,271	100	6,098,283	53.6
Total—male	2,189	67	4,831,393	45.3
Total—female	1,054	32	1,266,890	83.2

[a]FTE, full-time equivalent.
[b]Incidence rates per 100,000 FTEs. Includes agricultural workers in Arizona, California, Florida, Louisiana, Michigan, New Mexico, New York, Oregon, Texas, and Washington.
[c]Sex was unknown for 28 cases (farmworkers = 13, processing/packing plant worker = 7, all other agricultural occupations = 8).

100,000 FTEs (2002), driven primarily by the occurrence of large California events (Fig. 1). Limiting the analysis to the five states (California, Florida, New York, Oregon, Texas) that provided data for all 8 years had little effect on the plot in the Figure 1. By US geographic region, the IR for agricultural workers was highest in the West. The rates in the West were largely driven by California and Washington State, where the rates were 100.8 and 113.0/100,000 FTEs, respectively.

Information on age was available for 87% of the cases (N = 2,857; Table I). The median age was 33 years (range

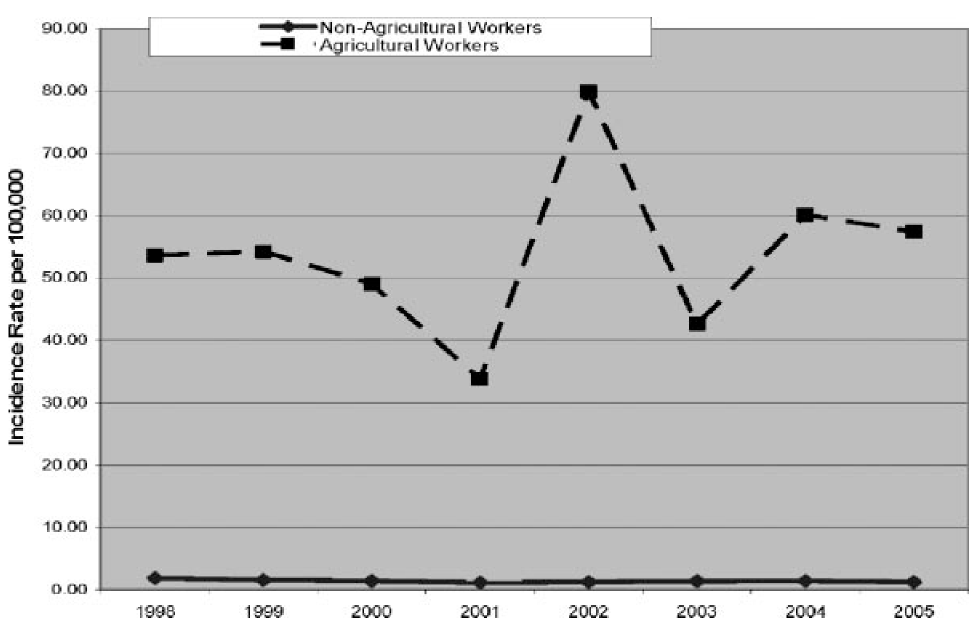

FIGURE 1. Incidence rates for acute pesticide poisoning cases among agricultural and non-agricultural workers by year, age15–64 years, 1998–2005.

15–64), and over half of the cases were between the ages of 25 and 44 years (N = 1,637, 57%). The IR was highest among agricultural workers age 18–24 years (76.2/100,000 FTEs; Table II).

Because agricultural workers employed in the states and time periods covered in this study worked 2,173 hr per year on average, using FTEs in the denominator produced rates that were approximately 7% lower compared to when employment counts were used in the denominator. In contrast, because non-agricultural workers worked 1,935 hr per year on average, using FTEs in the denominator produced rates that were approximately 4% higher compared to when employment counts were used in the denominator. The overall average annual IR among agricultural workers using employment counts in the denominator was 57.6/100,000 workers, and was 1.33/100,000 FTEs among all non-agricultural workers combined (IRR = 43.2, 95% CI 41.4, 45.1).

Occupations of the Affected Agricultural Workers

Most of the 3,271 affected agricultural workers were employed as farmworkers (N = 2,334, 71%; Table III). The 394 affected processing/packing plant workers (12%) represented a disproportionately large share of people so employed, while farmers (N = 89, 3%) seemed less at risk than hired agricultural workers. Most of the "other miscellaneous agricultural workers" were employed as pest control operators (N = 255, 56%). Because CPS data for pest control operators were too sparse (e.g., in 1999 and 2001 no CPS data were available for this occupation), IRs were not calculated for this occupation.

Gender was reported for all but 28 (1%) of the cases. Males predominated in each occupational category except processing/packing plant workers. Paradoxically, IRs were higher among female than male farmers and farmworkers, but higher among male than female processing/packing plant workers. Females were less likely than males to be pesticide handlers (females = 8%, males = 45%, $P < 0.001$). Information on race and ethnicity was available for 727 cases (22%). A total of 502 (69%) were Hispanic, 187 (26%) were non-Hispanic white, 12 (2%) were black, and the remaining 26 (4%) recorded various other races.

Severity and Description of Fatal Case

A vast majority of the illnesses were of low severity (2,848 cases, 87%), while 402 (12%) were of medium severity and 20 (0.6%) were high severity (Table I). One case was fatal. The fatal case occurred in 1999 and involved a 59-year-old Hispanic male who was employed as an irrigator and farmworker supervisor. He was found dead in an orange grove in California, with packages of hotdogs and packets of methomyl near his body. This led investigators to suspect he had violated regulations by opening water-soluble methomyl packets and using the potent carbamate insecticide to contaminate hot dogs for use as bait to kill coyotes. His autopsy found a small amount of methomyl in his gastric contents but none in his blood. His blood and bile also contained a relatively large concentration of benzothiazole, an industrial chemical and a metabolite of cyprodinil (a toxicity category III fungicide). The large concentration of benzothiazole was suggestive of chronic exposure, or heavy acute exposure at least 24 hr earlier. The medical examiner concluded that the cause of death was likely due to an interaction between the methomyl and cyprodinil. The source of the exposure to benzothiazole or cyprodinil was not known. Whether the exposures were accidental or intentional (i.e., suicidal) could not be distinguished.

Signs and Symptoms

Table IV lists the signs and symptoms most often reported in this cohort. It also provides information on the health effects among those exposed to the four pesticide chemical classes most commonly involved in illness.

Pesticides Responsible for Illness

Information on the pesticides responsible for illness is provided in Tables I, IV and V. Insecticides (alone or in combination with other pesticides) were implicated in more than half of the illnesses (N = 1,761, 54%). Cholinesterase inhibitors (organophosphates and *N*-methyl carbamates) were prominent among the insecticides (N = 892, 51%), particularly chlorpyrifos (N = 190), methamidophos (N = 130), dimethoate (N = 84), malathion (N = 78), and diazinon (N = 70). Over half of the cases (N = 1,662, 51%) were exposed to toxicity category I pesticides, the most toxic category as defined by EPA (Table I). We found little variation in illness severity by pesticide category.

Activity at Time of Exposure

Information on activity at time of pesticide exposure was available for 3,203 (98%) of the affected workers. Of these, 33% (N = 1,068) were pesticide handlers and 67% (N = 2,135) were doing routine work not involved with a pesticide application. Most of the handlers (71%) were exposed while making applications. Among the 2,135 doing routine work, half were exposed to off-target drift of pesticide from a nearby application (N = 1,068), and 35% (N = 744) had contact with pesticide residues present on a treated surface (e.g., plant material or treated animal).

Table I lists the targets to which pesticides were applied in incidents that resulted in human illness. Among the

TABLE IV. Illness Characteristics by Pesticide Chemical Class for 3,271 Acute Pesticide Poisoning Cases in the Agricultural Industry, 1998–2005

	Pesticide chemical class[a,b]				
Signs and symptoms	**All[a], N = 3,271 (%)**	**Cholinesterase inhibitors, N = 892 (%)**	**Pyrethroids, N = 182 (%)**	**Inorganics, N = −567 (%)**	**Dithiocarbamates, N = 512 (%)**
Nervous/sensory	1,743 (53)	672 (75)	120 (66)	241 (43)	237 (46)
Headache	1,268 (39)	499 (56)	94 (52)	164 (29)	185 (36)
Dizziness	708 (22)	297 (33)	39 (21)	88 (16)	85 (17)
Muscle weakness	243 (7)	126 (14)	10 (5)	29 (5)	23 (4)
Blurred vision	204 (6)	86 (10)	8 (4)	34(6)	29(6)
Paresthesias	198 (6)	76 (9)	15 (8)	31 (5)	25 (5)
Muscle pain	98 (3)	44 (5)	7 (4)	7 (1)	15 (3)
Diaphoresis	94 (3)	59 (7)	6 (3)	8(1)	7(1)
Salivation	63 (2)	48 (5)	3 (2)	2 (<1)	19 (4)
Fasciculation	47 (1)	32 (4)	3 (2)	3 (1)	3 (1)
Confusion	46 (1)	19 (2)	1 (1)	3 (1)	2 (<1)
Gastrointestinal	1,300 (40)	510 (57)	91 (50)	174 (31)	188 (37)
Nausea	1,063 (33)	438 (49)	74 (41)	131 (23)	152 (30)
Vomiting	582 (18)	261 (29)	39 (21)	73 (13)	91 (18)
Abdominal pain/cramping	371 (11)	161 (18)	15 (8)	34 (6)	75 (15)
Diarrhea	148 (5)	80 (9)	8 (4)	8 (1)	17 (3)
Ocular	1,300 (40)	272 (30)	54 (30)	243 (43)	297 (58)
Irritation/pain/inflammation	1,112 (34)	208 (23)	48 (26)	222 (39)	262 (51)
Lacrimation	443 (14)	92 (10)	14 (8)	51 (9)	166 (32)
Conjunctivitis	80 (2)	8 (1)	5 (3)	23 (4)	1 (<1)
Dermatologic	1,077 (33)	235 (26)	57 (31)	191 (34)	96 (19)
Pruritis	580 (18)	106 (12)	26 (14)	125 (22)	50 (10)
Rash	571 (17)	98 (11)	17 (9)	126 (22)	64 (13)
Erythema	349 (11)	52 (6)	14 (8)	76 (13)	27 (5)
Irritation/pain	321 (10)	81 (9)	34 (19)	48 (8)	23 (4)
Respiratory	1,074 (33)	329 (37)	56 (31)	232 (41)	152 (30)
Upper respiratory pain/irritation	645 (20)	183 (21)	35 (19)	142 (25)	103 (20)
Dyspnea	408 (12)	115 (13)	19 (10)	91 (16)	60 (12)
Cough	278 (9)	67 (8)	5 (3)	75 (13)	32 (6)
Cardiovascular	211 (6)	77 (9)	7 (4)	43 (8)	31 (6)
Chest pain	131 (4)	45 (5)	4 (2)	32 (6)	18 (4)
Tachycardia	33 (1)	17 (2)	1 (1)	2 (<1)	3 (1)

[a]More than one sign/symptom may be reported by a case, and therefore the sum of the specific clinical effects may not equal the total number of system effects.
[b]Cases may be exposed to more than one chemical class. Columns include cases exposed to the labeled chemical class only as well as those exposed to mixtures containing that and other chemical classes.

fruit crops, the most common application targets were small fruits (e.g., grapes; N = 529, 46%), tree nuts (N = 181, 16%), citrus fruits (N = 175, 15%), and pome fruits (e.g., apples; N = 151, 13%). Among the most common vegetable crop targets were root and tuber vegetables (e.g., onions and potatoes; N = 185, 40%), leafy vegetables (N = 180, 39%) and fruiting vegetables (e.g., eggplant, tomatoes, and peppers; N = 48, 10%). Among grain, grass and fiber crops, the most common pesticide application targets were cotton (N = 140, 54%), and cereal grains (N = 61, 23%).

Factors That Contributed to Pesticide Exposure

We identified factors that contributed to pesticide exposure in 1,926 (59%) of the cases (Table VI). The most common factors identified were off-target drift (N = 1,216, 63%), early reentry into a recently treated area (N = 336, 17%), and use in conflict with the label (N = 319, 17%). In 992 (30%) cases, no obvious contributory factors could be identified (e.g., restricted entry interval was observed but worker still became ill; wore all required PPE but still

TABLE V. Fifteen Most Common Active Ingredients for 3,271 Acute Pesticide Poisoning Cases in the Agricultural Industry by Severity Category, 1998–2005

Active ingredient	Functional class (chemical class)	High severity/fatal	Moderate severity	Low severity	N (%)[a]
Sulfur	Insecticide and fungicide (inorganic)	2	45	421	468 (14)
Metam-sodium	Fumigant (dithiocarbamate)	1	5	279	285 (9)
Glyphosate	Herbicide (phosphonate)	3	25	223	251 (8)
Mancozeb	Fungicide (dithiocarbamate)	1	17	184	202 (6)
Chlorpyrifos	Insecticide (organophosphate/cholinesterase inhibitor)	0	33	157	190 (6)
Sodium hypochlorite	Disinfectant (halogen)	2	35	149	186 (6)
Methamidophos	Insecticide (organophosphate/cholinesterase inhibitor)	1	10	119	130 (4)
Abamectin	Insecticide (microbial)	0	18	108	126 (4)
Imidacloprid	Insecticide (neonicotinoid)	4	5	104	113 (3)
Methomyl	Insecticide (*N*-methyl carbamate/cholinesterase inhibitor)	1	7	101	109 (3)
Myclobutanil	Fungicide (triazole)	1	11	97	109 (3)
Propargite	Insecticide (sulfite ester, inhibits oxidative phosphorylation)	0	21	77	98 (3)
Spinosad	Insecticide (derived from *Saccharopolyspora spinosa*)	1	10	85	96 (3)
Methyl bromide	Fumigant (halocarbon)	2	29	60	91 (3)
Dimethoate	Insecticide (organophosphate/cholinesterase inhibitor)	4	6	74	84 (3)

[a]Percentages do not sum to 100, as not all cases are included in this table.

TABLE VI. Factors That Contributed to Pesticide Exposure and/or Illness for 3,271 Acute Pesticide Poisoning Cases in the Agricultural Industry by Severity Category, 1998–2005

Exposure/illness factor[a]	Medium or higher severity, N (%)	Low severity, N	Total, N (%)
All factors combined	219 (11)	1,707	1,926 (59)
Drift	118 (10)	1,098	1,216 (37)
Early reentry	41 (12)	295	336 (10)
Use in conflict with label	40 (13)	279	319 (10)
Failure to use required equipment	19 (12)	139	158 (5)
Oral notification of pesticide application not provided	9 (6)	143	152 (5)
PPE not worn	19 (16)	98	117 (4)
Training not provided or inadequate (excludes applicators)	30 (29)[c]	75	105 (3)
Hazard communication or other OSHA violation	9 (9)	86	95 (3)
Transport for care not provided	5 (6)	84	89 (3)
Application site not posted/notification posters incorrect	3(4)	81	84 (3)
Decontamination facilities inadequate	16 (26)[c]	46	62 (2)
Unsafe equipment/failure	8 (14)	49	57 (2)
Inadequate record keeping	7 (20)	28	35 (1)
Worker not told of health effects caused by pesticides	0 (0)	32	32 (1)
Person in treated area during application	2 (10)	19	21 (1)
Unspecified worker protection standard violation	3 (15)	17	20 (1)
PPE in poor repair	3 (23)	10	13 (<1)
FIFRA-other and unspecified[b]	6 (27)[c]	16	22 (1)
None identified	126 (13)	866	992 (30)
Unknown	78 (22)	275	353 (11)

[a]One factor was identified for 1,279 cases. Two or more factors were identified for 647 cases.
[b]Includes situations when a licensed applicator was not on site(N = 1) and when an applicator was not properly trained or supervised (N = 9).
[c]The proportion with medium or higher severity among cases with the factor of interest was significantly greater than the proportion with medium or higher severity in all other cases ($P < 0.05$). Those with insufficient information to identify factors (i.e., unknown category) were excluded from this analysis.

became ill; all pesticide label requirements appeared to have been followed). Compared to cases where no obvious contributory factors could be identified, identification of a contributory factor was not found to be significantly associated with severity of illness ($P = 0.33$). For 353 (11%) cases, insufficient information was available to identify factors that may have contributed to the pesticide exposure.

Among the 2,367 cases with personal protection equipment (PPE) usage information, 1,157 (49%) wore PPE (Table VII). Women were far less likely to wear PPE (females = 27%, males = 40%, $P < 0.01$). Pesticide handlers were more likely to use PPE (65% overall, 66% among men and 51% among women) compared to non-handlers (21% overall, 18% among men and 26% among women). Those exposed to toxicity category II pesticides were more likely to wear PPE (61%) then those exposed to toxicity category I or III /IV pesticides (53% and 54%, respectively). Table VII also provides information on the health effects experienced by those who used each type of protective equipment. Compared to those who used no protective equipment or had unknown information on its use, those who used protective equipment were less likely to have health effects involving the nervous, gastrointestinal and respiratory systems, but were more likely to have ocular and dermatologic health effects.

Report Source

Case reports were received from many different sources. The three leading sources of case reports were workers' compensation (N = 1,109, 34%), other government agencies (e.g., county health departments and the state department of agriculture; N = 901, 28%), and poison control centers (N = 407, 12%). A variety of sources accounted for the remaining cases including health care professionals, employers, worker representatives (union, legal services), and self-report. The specific number of cases reported by these other sources is unavailable. Females were more likely to have been reported by one of these other sources (females = 41%, males = 23%, $P < 0.01$), and less likely to be identified by workers' compensation (females = 25%, males = 39%, $P < 0.01$) or poison control centers (females = 8%, males = 15%, $P < 0.01$). Females and males were equally likely to have been reported by other government agencies (28%).

DISCUSSION

It is important to conduct surveillance of acute occupational pesticide poisoning to determine whether policies, practices and regulations are effective in preventing hazardous pesticide exposures. National estimates of hospitalized pesticide poisonings in the 1970s and early 1980s, including agricultural workers, are available [Keefe et al., 1985, 1990]; but to the best of our knowledge this is the first detailed multistate assessment of both hospitalized and non-hospitalized acute pesticide poisoning among agricultural workers. Our findings indicate that despite strengthening of the WPS in 1995, agricultural workers continue to have an elevated risk for acute pesticide poisoning. The pesticide poisoning incidence among US agricultural workers was found to be 39 times higher than the IR found in all other industries combined.

Improvement Compared to the 1980s

Although there was not a clear trend in the rates of poisoning during the time period that we studied, there is evidence to suggest that the counts of pesticide poisoning

TABLE VII. Illness Characteristics by Type of Protective Equipment Used 1998–2005

Type of protective equipment	Number that used protective equipment	Of workers who used protective equipment, the number (%) who had signs/symptoms involving these organs/systems				
		Nervous/sensory	Gastro-intestinal	Ocular	Respiratory	Dermatologic
Any PPE	1,157	557 (48)	404 (35)	472 (41)	301 (28)	437 (38)
Air-purifying respirator	261	121 (46)	91 (35)	92 (35)	49 (19)	94 (36)
Dust mask	40	16 (40)	12 (30)	19 (48)	18 (45)	15 (38)
Chemical resistant gloves	700	306 (44)	208 (30)	293 (42)	150 (21)	254 (36)
Chemical resistant clothing	542	230 (42)	177 (33)	214 (39)	105 (19)	213 (39)
Chemical resistant boots	367	170 (46)	110 (30)	152 (41)	63 (17)	127 (35)
Cloth/leather gloves	298	192 (64)	138 (46)	92 (31)	114 (38)	140 (47)
Goggles/eye protection	488	193 (40)	126 (26)	198 (41)	80 (16)	196 (40)
Engineering controls[a]	100	48 (48)	34 (34)	23 (23)	20 (20)	41 (41)
No or unknown PPE use[b]	0	1,186 (56)	896 (42)	828 (39)	773 (37)	640 (30)

[a]Engineering controls included such things as enclosed tractor cabs or closed mixing/loading systems.
[b]A total of 2,114 individuals used no protective equipment or had unknown information on use of protective equipment.

cases among agricultural workers have decreased since the 1980s. Mehler et al. [1992] reported an annual average of 723 cases of pesticide illness or injury in California arising from agricultural establishments from 1982 to 1990. In contrast, the California surveillance programs reported an average of 315 cases per year from 1998 to 2005. The numbers are not entirely comparable. Mehler characterized poisoning cases as being agricultural if the poisoned subject was a worker and the exposure arose from an agricultural establishment. Her definition included non-agricultural workers (e.g., truck drivers, construction workers, school employees), while we included only workers employed in agriculture.

True Incidence Remains Uncertain: Comparison With Data From the Bureau of Labor Statistics, the National Agricultural Workers Survey, and the Agricultural Health Study

In order to put our findings in perspective, acute pesticide poisoning annually accounts for a small percentage of the total occupational illnesses experienced by agricultural workers. The 2005 Bureau of Labor Statistics (BLS) survey of illnesses and injuries (SOII), which excludes agricultural production establishments with 10 employees or fewer, reports an annual injury rate of 5.7% and an annual illness rate of 0.4% (3% of which involve poisonings) among workers in farming, forestry and fishing [Myers, 2007]. Most of these illnesses consisted of dermatitis, respiratory conditions, and other conditions not specified (e.g., musculoskeletal conditions arising from cumulative trauma). We report a rate of pesticide poisoning five times higher than the SOII rate for all poisonings. This may indicate that pesticide poisonings are concentrated among the small establishments excluded from SOII, that under-reporting to SOII is more extreme than SENSOR-pesticide under-ascertainment, or that SENSOR-pesticide classification standards accept a large number of cases that BLS does not count.

Data from the National Agricultural Workers Survey (NAWS), by contrast, suggest an incidence of acute pesticide poisoning among agricultural workers [US Department of Labor, 2004] an order of magnitude greater than that found in this study. NAWS is a nationally representative annual survey of US crop workers conducted by the US Department of Labor. In 1999, NAWS included questions to determine if crop workers were poisoned by pesticides. This information was collected in two parts. First NAWS asked the crop worker if they were exposed to pesticides by "having them sprayed or blown on you," "spilled on you," or "when cleaning or repairing containers or equipment used for applying or storing pesticides." NAWS then asked if the crop worker became "sick or [had] any reaction because of this incident." Our analysis of these data found that 3.2% of crop workers acknowledged exposure during the previous 12 months, of whom 43.4% reported getting sick or having a reaction. That is, 1.4% of US crop workers attributed health effects such as skin problems (59%), eye problems (24%), nausea/vomiting (30%), headache (26%), and numbness/tingling (12%) to pesticide exposure during the preceding 12 months. In a separate NAWS question, 0.6% of all US crop workers reported that in the last 12 months they had "received medical attention by a doctor or nurse due to pesticide exposure." To our knowledge, neither these nor similar questions to assess the incidence of pesticide poisoning were included in NAWS surveys before or after 1999. In comparison, we found an average annual acute occupational pesticide poisoning IR of 0.05% among all agricultural workers, and 0.07% among farmworkers.

Acute pesticide poisoning IR were also assessed among farmers participating in the Agricultural Health Study (AHS), a prospective cohort study sponsored by the National Institutes of Health (i.e., the National Cancer Institute and the National Institute of Environmental Health Sciences) and EPA [AHS, 2007]. The AHS cohort consists of 52,395 farmers, 32,347 spouses of these farmers, and 4,916 commercial pesticide applicators residing in Iowa or North Carolina. In a nested case–control analysis involving 16,416 farmers/pesticide applicators who were interviewed by telephone in 1999–2000, 54 (0.33%) reported "an incident with fertilizers, weed killers, or other pesticides that caused an unusually high personal exposure" in the previous 12 months that resulted in physical symptoms [Bell et al., 2006]. Among these 54 individuals, only 7 (13%, or .04% of the entire subcohort) sought medical care. In contrast, we found an average annual acute occupational pesticide poisoning IR of 0.005% among farmers. However, as was observed in our study, the findings from AHS and NAWS suggest that the risk of pesticide poisoning is lower among farmers compared to farmworkers.

The true incidence of pesticide poisoning among agricultural workers remains uncertain. Our findings (51/100,000) fall between the low SOII estimate (less than 10/100,000) and the high rates elicited by NAWS interviews (1,400/100,000 symptomatic, 600/100,000 sought medical care).

Limitations

One of this study's major limitations is that under-reporting compromises, to varying degrees, all the surveillance systems that provided the data for this analysis. Factors that contribute to under-reporting include: affected people not seeking care, or consulting care providers outside the jurisdiction of surveillance programs; misdiagnosis of this uncommon condition; and health care provider neglect of legal requirements to report. The rates provided should be considered low estimates of the magnitude of acute pesticide poisoning among agricultural workers.

Disproportionate numbers of agricultural workers probably are deterred from seeking health care by lack of health insurance [US Department of Labor, 2005], unfamiliarity with workers' compensation benefits or inability to qualify for them, and fear of job loss if they miss time from work to seek health care [Das et al., 2001; Arcury and Quandt, 2007], as well as concerns related to immigration status. Similarly, a variety of interrelated problems may lead health care professionals to misdiagnose acute pesticide poisoning. Health professionals rarely receive much training in environmental toxicology generally or on pesticide poisoning specifically [Schenk et al., 1996]. Consequently, they may not collect a pesticide exposure history, which is necessary to make a diagnosis of acute pesticide poisoning [Balbus et al., 2006]. Pesticide poisoning is relatively rare in developed countries, and its signs and symptoms often resemble those of more common conditions, which may be diagnosed preferentially. The difficulty and delays of receiving reimbursement through workers' compensation may also bias health care providers against diagnosing and reporting pesticide poisoning. Even among those cases correctly diagnosed, some cases may escape report to public health authorities through ignorance of the requirement (despite the fact that 30 states have a mandatory reporting system of occupationally related pesticide poisoning [Calvert et al., 2001]) or because the health care professionals fear that their patients may be subject to retaliation. Other cases may go unreported because many farmworkers immigrate from Mexico [US Department of Labor, 2005], and some poisoned Mexican farmworkers may prefer to visit physicians in Mexico where cultural and linguistic barriers are removed and fees are lower [US EPA, 1992; Arcury and Quandt, 2007]. Our state-based surveillance partners received only nine reports of pesticide poisoning cases managed outside the US.

Another limitation in our study was that information was incomplete for some reported cases. Most cases lacked information on race and ethnicity. Missing information could lead to misclassification of severity, if not all signs and symptoms were reported, or to inappropriate exclusion of the case. More detailed information on the affected worker's activities, pesticide exposures and health effects might have increased our case totals. Some cases in this report may be false-positives, with compatible symptoms that are coincidental with but not caused by pesticide exposure. Finally, information on factors that contributed to illness was identified in only 1,926 (59%) cases. In many cases a timely and definitive investigation into the factors responsible for exposure and illness was not possible due to insufficient investigatory resources and/or because of tardy notification of the exposure to state authorities.

Rates of pesticide poisoning may also be distorted by inaccuracy in estimates of population at risk. The size of the agricultural worker population, including farmworkers and processing/packing plant workers, is difficult to estimate for several reasons, including the transient employment of many seasonal and migrant farmworkers, migration into and out of the United States in a manner that is not entirely predictable, and the tendency of many farmworkers to avoid government contact [Rust, 1990]. Our agricultural worker population estimates were derived from the CPS, which is conducted by the BLS and the United States Census Bureau. The CPS goes to great lengths to capture reliable workforce data [Bureau of Labor Statistics, 2002]. Nevertheless, a population seeking to escape detection could well be under-counted, leading to inflated apparent rates of illness/injury. Finally, illness rates for those known to have occupational pesticide exposure are not available because the numbers or workers exposed to pesticides are unknown.

Reasons for Higher Poisoning Rates in Western States

Rates of both agricultural and non-agricultural acute pesticide poisoning are higher in the western states as compared to the south and eastern regions of the United States. It is credible that labor-intensive Western agriculture may impose excess risk for acute pesticide poisoning illness, but it is also important to note that California (especially the CDPR program) and Washington have well established, longstanding and experienced state-based surveillance programs with higher staffing levels compared to other states participating in the SENSOR-Pesticides program [Calvert et al., 2004]. In addition, these states were much more likely to be notified about cases through the state workers' compensation system (in Washington State 76% of the cases were so identified; in California 34% of reports were provided by physicians to a workers' compensation insurance carrier). In contrast, only two other states identified cases through their state workers' compensation system: Oregon and Texas (7% and 4%, respectively, of cases in these states were so identified).

Higher Poisoning Rates Among Female Agricultural Workers

Female agricultural workers experienced nearly twice the risk of pesticide poisoning of male agricultural workers (Table III), a finding that was quite unexpected. Before indulging in speculation about possible differences in susceptibility, risk of exposure, or rate of ascertainment, we plan to perform more detailed analyses by geographic region, activity at time of exposure, pesticide, protective equipment, and severity.

Higher Poisoning Rates Among Processing/Packing Plant Workers

Processing/packing plant workers were found to have the highest acute pesticide poisoning IR compared to all other agricultural occupations. Many farms are increasing the amount of food processing that is performed on site [National Research Council and Institute of Medicine, 2008]. This is due to a variety of factors, including the advent of new technology, quest for improved quality control and freshness, and a desire to increase profit. The types of food processing activities performed on farms include cleaning, sorting, packing, and cooling/freezing. Among the 394 poisoned processing/packing plant workers, the pesticides most commonly responsible for illness were fumigants (N = 151, 38%), disinfectants (N = 151, 38%), and insecticides (N = 73, 19%). The fumigant exposures were commonly related to drift from a nearby field (N = 111), the disinfectant exposures where commonly related to malfunction of disinfecting equipment (N = 74) and cleaning produce in disinfectant solutions (N = 31) and the insecticide exposures were commonly related to pesticide residue present on the produce (N = 37). Because the WPS only covers workers involved in the production of agricultural plants, processing/packing plant workers may not covered by WPS.

Chronic Health Effects Associated With Acute Pesticide Poisoning

In addition to acute morbidity with it attendant costs in health care resources, and time lost from work and normal daily activities, acute pesticide poisoning is also associated with chronic adverse health sequelae. For example organophosphate poisoning has been found to be associated with deficits in neurobehavioral and neurosensory function [Steenland et al., 1994]. In addition, the Agricultural Health Study found that those who sought medical care for pesticide poisoning or who experienced an incident involving ‘‘unusually high’’ pesticide exposure had an increased risk for chronic neurologic symptoms (Kamel et al. 2005). These ‘‘unusually high’’ pesticide exposures, which are labeled by the authors as high pesticide exposure events (HPEE), result in acute symptomatic illness about 50% of the time [Bell et al., 2006]. Those who ever experienced an HPEE also had an increased risk for farmers lung (Hoppin et al. 2006). A non-significant elevated risk for prostate cancer was observed among those who had ever experienced an HPEE (odds ratio = 1.11, 95% CI = 0.8, 1.6) [Alavanja et al., 2003]. To our knowledge, the AHS has not published findings on any other associations between HPEE and cancer.

Recommendations

The most common factors that contributed to pesticide exposure included off-target drift, early reentry into a treated area, and use in conflict with the pesticide label. These findings and the observations of other investigators [Arcury et al., 2001] suggest that improved compliance with and enforcement of existing pesticide regulations could achieve important improvements in safety. Measures to minimize drift (including equipment specifications, establishment of buffer zones, and limitations on maximum wind speed conditions during an application) seem likely to provide the greatest benefit. Our finding that 992 (30%) cases had no obvious factors contributing to exposure suggests that pesticide regulations and label requirements may also need to be enhanced. Additionally, reduced-risk pest control measures such as integrated pest management should be adopted, which can achieve reductions in pesticide exposure and misuse [National Research Council, 2000]. The high poisoning rates observed among processing/packing plant workers and the increased amount of food processing performed on farms suggests that processing/packing plant workers should be covered under the WPS.

Given the limitations in this analysis, improved state-based surveillance programs for pesticide-related illness are also needed. A comprehensive system needs to address the limitations described above including: agricultural workers and health care providers need to recognize the pesticide-relatedness of the illness; disincentives to receiving health care, including lack of health insurance, must be overcome; the costs of evaluation and treatment of acute occupational pesticide poisoning should be paid for by workers' compensation; health care providers need to make timely reports to pesticide poisoning surveillance systems; and, surveillance systems need to optimize access to and use of workers' compensation data, poison control center data and data from other state agencies with jurisdiction over pesticides.

CONCLUSION

Agricultural workers are at increased risk of acute pesticide poisoning in comparison to non-agricultural workers, particularly through drift, early reentry into a treated area, and use in conflict with the label. The IR was almost twofold higher in female agricultural workers compared to males. In addition to acute intoxication, pesticide poisoning may also lead to chronic adverse health sequelae. Improved compliance with and stringent enforcement of laws and regulations regarding pesticide applications are needed. Alternative pest control measures such as integrated pest management reduce the use of pesticides and therefore the potential for adverse health effects.

ACKNOWLEDGMENTS

Funding to support this study was provided by NIOSH, EPA, and the state agencies that contributed data.

REFERENCES

Agricultural Health Study. Study and cohort descriptions. 2007. Available: http://www.aghealth.org/study.html. [Accessed 7 February 2008].

Alavanja MCR, Samanic C, Dosemeci M, Lubin J, Tarone R, Lynch CF, Knott C, Thomas K, Hoppin JA, Barker J, Coble J, Sandler DP, Blair A. 2003. Use of agricultural pesticides and prostate cancer risk in the Agricultural Health Study cohort. Am J Epidemiol 157:800–814.

Arcury TA, Quandt SA. 2007. Delivery of health services to migrant and seasonal farmworkers. Annu Rev Public Health 28:345–363.

Arcury TA, Quandt SA, Cravey AJ, Elmore RC, Russell GB. 2001. Farmworker reports of pesticide safety and sanitation in the work environment. Am J Ind Med 39:487–498.

Balbus JM, Harvey CE, McCurdy LE. 2006. Educational needs assessment for pediatric health care providers on pesticide toxicity. J Agromedicine 11:27–38.

Bell EM, Sandler DP, Alavanja MC. 2006. High pesticide exposure events among farmers and spouses enrolled in the Agricultural Health Study. J Agric Saf Health 12:101–116.

Bureau of Labor and Statistics (US). 2007. Current population survey 1998–2004 microdata files. Washington: U.S. Department of Labor, Bureau of Labor Statistics.

Bureau of Labor Statistics (US). Current population survey design and methodology. Technical paper 63RV. Washington: U.S. Department of Labor, Bureau of Labor Statistics. 2002. Available: http://www.census.gov/prod/2002pubs/tp63rv.pdf [Accessed 7 February 2008].

Calvert GM, Sanderson WT, Barnett M, Blondell JM, Mehler LN. 2001. Surveillance of pesticide-related illness and injury in humans. In: Krieger R, editor. Handbook of pesticide toxicology 2nd edition. San Diego, CA: Academic Press. p 603–641.

Calvert GM, Plate DK, Das R, Rosales R, Shafey O, Thomsen C, Male D, Beckman J, Arvizu E, Lackovic M. 2004. Acute occupational pesticide-related illness in the US, 1998–1999: Surveillance findings from the SENSOR-Pesticides program. Am J Ind Med 45:14–23.

CDC. Case definition for acute pesticide-related illness and injury cases reportable to the national public health surveillance system. Cincinnati, OH: Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. 2001a. Available: http://www.cdc.gov/niosh/topics/pesticides/pdfs/casedef2003_revapr2005.pdf [Accessed 7 February 2008].

CDC. Severity index for use in state-based surveillance of acute-pesticide related illness and injury. Cincinnati, OH: Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. 2001b. Available: IR http://www.cdc.gov/niosh/topics/pesticides/pdfs/pest-sevindexv6.pdf [Accessed 7 February 2008].

CDPR. Preventing pesticide illness: California's pesticide illness surveillance program. Sacramento, CA: California Environmental Protection Agency. Department of Pesticide Regulation. 2006. http://www.cdpr.ca.gov/docs/whs/pisp/brochure.pdf [Accessed 7 February 2008].

Das R, Steege A, Baron S, Beckman J, Harrison R. 2001. Pesticide-related illness among migrant farm workers in the United States. Int J Occup Environ Health 7:303–312.

Hoppin JA, Umbach DM, Kullman GJ, Henneberger PK, London SJ, Alavanja MCR, Sandler DP. 2006. Pesticides and other agricultural factors associated with self-reported farmer's lung among farm residents in the Agricultural Health Study. Occup Environ Med 64:334–342.

Kamel F, Engel L, Gladen BC, Hoppin JA, Alavanja MCR, Sandler DP. 2005. Neurologic symptoms in licensed private pesticide applicators in the agricultural health study. Environ Health Perspect 113:877–882.

Keefe TJ, Savage EP, Munn S, Wheeler HW. 1985. Evaluation of epidemiologic factors from two national studies of hospitalized pesticide poisonings, USA. Fort Collins, CO: Colorado State University.

Keefe TJ, Savage EP, Wheeler HW. 1990. Third national study of hospitalized pesticide poisonings in the United States, 1977–1982. Fort Collins, CO: Colorado State University.

Kiely T, Donaldson D, Grube A. Pesticides industry sales and usage: 2000 and 2001 market estimates. EPA-733-R-04-001. Washington, DC: Office of Pesticide Programs, U.S. Environmental Protection Agency. 2004. Available: http://www.epa.gov/oppbead1/pestsales/01pestsales/market_estimates2001.pdf [Accessed 7 February 2008].

Linaker C, Smedley J. Respiratory illness in agricultural workers. Occup Med 2002. 52:451–459.

Litchfield MH. 2005. Estimates of acute pesticide poisoning in agricultural workers in less developed countries. Toxicol Rev 24(4): 271–278.

Mehler LN, O'Malley MA, Krieger RI. 1992. Acute pesticide morbidity and mortality: California. Rev Environ Contam Toxicol 129:51–66.

Myers JR. 2007. National occupational surveillance for the agriculture, forestry and fishing industry sector. Unpublished poster presented at the 2007 Council of State and Territorial Epidemiologists Annual Conference. Atlantic City, New Jersey. June 2007.

National Research Council. 2000. The future role of pesticides in US agriculture. Washington DC: National Research Council.

National Research Council and Institute of Medicine. Agriculture, Forestry, and Fishing Research at NIOSH. Committee to Review the NIOSH Agriculture, Forestry, and Fishing Research Program. Rpt No. 3, Reviews of Research Programs of the National Institute for Occupational Safety and Health. Washington, D.C.: The National Academies Press. 2008. Available: http://www.nap.edu/catalog.php?record_id=12088 [Accessed 1 May 2008].

O'Malley M, Barry T, Ibarra M, Verder-Carlos M, Mehler L. 2005. Illnesses related to shank application of metam-sodium, Arvin, California, July 2002. J Agromedicine 10:27–42.

Reeves M, Schafer KS. 2003. Greater risks, fewer rights: U.S. farmworkers and pesticides. Int J Occup Environ Health 9:30–39.

Rothman KJ. 1986. Modern epidemiology. Boston: Little, Brown. p 164–172.

Ruser JW. 1998. Denominator choice in the calculation of workplace fatality rates. Am J Ind Med 33:151–156.

Rust GS. 1990. Health status of migrant farmworkers: A literature review and commentary. Am J Public Health 80:1213–1217.

SAS Institute, Inc. 2003. SAS: Version 9.1 for Windows. Cary, North Carolina: SAS Institute Inc.

Schenk M, Popp SM, Neale AV, Demers RY. 1996. Environmental medicine content in medical school curricula. Acad Med 71:499–501.

Steenland K, Jenkins B, Ames RG, O'Malley M, Chrislip D, Russo J. 1994. Chronic neurologic sequelae to organophosphate pesticide poisoning. Am J Public Health 84:731–736.

Tak S, Calvert GM. 2008. Hearing difficulty attributable to employment by industry and occupation: An analysis of the National Health Interview Survey—United States, 1997 to 2003. J Occup Environ Med 50:46–56.

U.S. Bureau of the Census. 1992. 1990 census of population and housing. Alphabetical index of industries and occupations. Washington, DC: U.S. Department of Commerce, Bureau of the Census.

U.S. Census Bureau. Industry and Occupation 2002. Washington, D.C.: United States Census Bureau. 2005. Available: http://www.census.gov/hhes/www/ioindex/ioindex02/view02.html [Accessed 7 February 2008].

US Department of Labor. The National Agricultural Workers Survey. Washington, D.C.: US Department of Labor; 2004. Available: http://www.doleta.gov/agworker/naws.cfm [Accessed 7 February 2008].

US Department of Labor. Monetary bonuses and insurance benefits. In: Findings from the National Agricultural Workers Survey (NAWS) 2001–2002. A demographic and employment profile of United States farm workers. Research report No. 9. Washington, D.C.:US Department of Labor; 2005. Available: http://www.doleta.gov/agworker/report9/toc.cfm [Accessed 7 February 2008].

US EPA. General Provisions. Precautionary statements for physical and chemical hazards. 40 CFR 156.78. Washington, D.C. U.S. Environmental Protection Agency; 1975. Available: http://a257.g.akamaitech.net/7/257/2422/08aug20051500/edocket.access.gpo.gov/cfr_2005/julqtr/pdf/40cfr156.70.pdf [Accessed 7 February 2008].

US EPA. Regulatory impact analysis of worker protection standard for agricultural pesticides. Washington, D.C. U.S. Environmental Protection Agency; 1992. Available: http://www.aei-brookings.org/admin/authorpdfs/page.php?id=821 [Accessed 7 February 2008].