ORIGINAL ARTICLE

Use of a crop and job specific exposure matrix for estimating cumulative exposure to triazine herbicides among females in a case-control study in the Central Valley of California

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Aims: To determine if a job exposure matrix (JEM) could be developed using the California Department of Pesticide Regulation Pesticide Usage Database in conjunction with crop, time, and county specific self reported work history and to determine if this was a feasible method to obtain exposure estimates to triazine herbicides.

Methods: Agricultural work histories were gathered from women enrolled in a population based case-control study of ovarian cancer cases and random controls. The work histories were used in conjunction with the database to construct job exposure matrices which took into account weightings for job type, work location, and crop.

Results: Cumulative exposure estimates were determined for 98 study subjects. Mean exposure estimates were similar for cases and controls. The exposure estimates were robust and insensitive to varying job weight assumptions. The estimates from the original weights were highly correlated with those constructed using the conservative and maximum weights. Estimates from all three schemes produced similar multivariate age adjusted odds ratios comparing cases and controls. There was a high degree of agreement in categorised quartiles of exposure between the original and conservative, and original and maximum weights.

Conclusions: The exposure estimate from the JEM provides a ranking of exposure within the study population that can be utilised as an ''exposure score'' with which to compare groups. Although it is not an absolute exposure measurement, it does offer a substantial advance over dichotomous categories based on self report of herbicide use, particularly when subjects are unlikely to recall specific names and dates of use of herbicides.

The triazine herbicides (atrazine, simazine, and cyanazine) are the most commonly used herbicides in the United States and are used extensively in corn, citrus, nuts, sugarcane, sorghum, and cotton cultivation to control broadleaf weeds.[1] California is economically the leading agricultural state, and the Central Valley of California is the most intensely agricultural area in the United States.[2] Unlike the Midwest where much of the agricultural cultivation is mechanised, much of the cultivation in the Central and Sacramento Valleys of California is labour intensive and manual in nature. Many of the farms are relatively small, consisting of less than 200 acres, and are family operated.[2] An integral part of the agricultural industry in the Central Valley has been the use of pesticides, particularly triazine herbicides. Occupational exposure to triazines occurs mainly via dermal absorption and inhalation, particularly in workers engaged in mixing, loading, and application of herbicides. Hispanic women comprise a substantial proportion of the active agricultural labour force in the Central Valley, and most are commonly working in pruning, weeding, harvesting, and packing.[3]

Job exposure matrices (JEMs) have been commonly used in occupational epidemiology since the early 1980s, and a few studies have described the applicability of JEMs to agricultural work.[4–7] JEMs are particularly valuable when a subject's recall for job activity or location exceeds his/her ability to recall information relevant to particular chemical exposures as is common in agricultural settings, particularly with workers who are not directly involved in preparation or application of the chemicals. California provides a unique environment in which to use JEMs as exposure assessment tools because the California Department of Pesticide Regulation (DPR) has compiled the United States' most comprehensive pesticide usage database.

The objective of this study was to determine whether using the California DPR Pesticide Usage Database in conjunction with crop, time, and county specific self reported work history to construct JEMs was a feasible method to obtain exposure estimates.

METHODS

Study subject selection

The work histories used in the study were obtained from a population based case-control study of epithelial ovarian cancer (EOC) conducted in 22 counties of Central California that comprise the reporting area for two regional cancer registries. Cases were women identified via a rapid case ascertainment procedure as newly diagnosed with histologically confirmed EOC, living in the Central Valley during the period 1 January 2000 to 31 December 2001. The control group consisted of women 18 years or older, selected by random digit dialling techniques, who were residents of the

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Abbreviations: CI, confidence interval; DPR, Department of Pesticide Regulation; EOC, epithelial ovarian cancer; JEM, job exposure matrix; OR, odds ratio

Main messages

- A statewide comprehensive pesticide usage database was successfully used in combination with self reported agricultural work histories to construct robust job exposure matrices that provided cumulative exposure estimates.

Policy implications

- Exposure assessment methodologies using comprehensive pesticide usage databases and agricultural work histories offer a substantial advance over dichotomous categories based on self report of herbicide use, particularly when subjects are unlikely to recall specific names and dates of use of herbicides.
- This methodology shows particular promise for use in short term time periods where more detailed work histories could be collected.

area, who had not been diagnosed with EOC, and who had at least one intact ovary at the time of the interview. Controls were frequency matched to cases on age and race/ethnicity. The overall data collection spanned two years, with a telephone interview being conducted with each respondent only once during this time period. The Institutional Review Boards at the Public Health Institute and George Washington University approved the study protocol.

Data collection

All cases and controls were approached via an introductory letter that included a prompt list describing topics the interview questions would address. For both case and control groups, letters and prompt lists were sent in either English or Spanish on the letterhead of the principal investigator. This prompt list was used to prepare study subjects before the actual interview and aid in recall of work history. Similar approaches had been used in previous studies, resulting in improved subject recall.[8 9] In particular the prompt list asked women to think about all of the places they had worked in the past and if they had ever worked with one or more of the following crops which were selected based on historical usage patterns of triazine herbicides on these crops in the Central Valley: grapes, oranges/lemons, corn/maize, almonds/walnuts, avocado, alfalfa, olives, Christmas trees, and sorghum. The prompt list also instructed women to think about the dates in calendar year and locations by county that corresponded to any work history with one or more of the above crops. Telephone callback interviews with both case and control respondents were conducted by female professional trained telephone interviewers in either English or Spanish as preferred by the respondent.

The two primary sources for exposure data were the California DPR Pesticide Usage Database and self reported agricultural work history obtained from the telephone interview. The self reported history included location by county, crops, job titles, and years of employment. History was only reported for the previously mentioned crops.

The California DPR has a publicly available statewide comprehensive pesticide usage database. Since 1970 all agricultural applications of restricted use pesticides, including triazines, have been reported to the state. In order to create a more complete and detailed system of pesticide use data, full use reporting was implemented in 1990. These reports from 1970 onward include the pesticide applied, date and location of the application, and the crop and number of acres treated.[10] California has a broad legal definition of agricultural use, with the major exception to reporting being private home and garden use.[10]

All pesticide information for 1974–89 was obtained from the Pesticide Databank, which is a database of historical pesticide use records collected by the California Department of Food and Agriculture and maintained at the University of California at Davis. At the time of the study, pesticide use reports from 1970–73 were not available in computerised format. Pesticide data for 1990–99 were obtained from the University of California at Davis Statewide Integrated Pest Management Project online summaries database (www.ipm.ucdavis.edu). The following variables were requested from both data sources: county, crop, year, pesticide, number of acres treated, and pounds of active ingredient applied.

Construction of job exposure matrix

For each participant a job exposure matrix (JEM) was created and utilised to determine quartiles of exposure levels (none, low, medium, and high) and a continuous measure of exposure to the triazines individually (atrazine, cyanazine, and simazine) and as a class. London and Myers[11] constructed a JEM based on work histories including days of exposure, job type, and crop history of fruit farm workers in South Africa. Using secondary data on crop specific annual agrochemical use combined with work history, they developed exposure estimates by weighting days of exposure by job and crop type. Based on the above model, a JEM was created using subject work histories and the California DPR pesticide usage database that incorporated a weighting for specific job activity, type of crop, and additionally county of work. Job type determines the amount of contact a person will have with the herbicide. Because triazines are applied to the soil as primarily pre-emergent treatments, some workers may have little to no direct exposure. London and Myers[11] noted that the exposure estimates constructed from their JEM were highly dependent on job weighting with exposure rankings. Because of concern that the JEM estimates may be dependent on the weights assigned to job tasks, two job weighting schemes were used, one which would provide a higher estimate of exposure (referred to as the original weightings) and one which weighted non-pesticide handling or planting jobs more conservatively (referred to as the conservative weightings). Table 1 displays the job type categories and weightings that were used. These job classifications were chosen based on EPA worker risk assessment and an exposure monitoring study of agricultural workers in California.[12 13] Jobs that did not fit into the classifications utilised in the above references were grouped with tasks that were similar or would provide similar exposure to crops. Weightings were developed based on a system used by London and Myers[11] and Krieger and colleagues.[13] Weights were expressed as proportions on a scale based on a typical high exposure activity such as pesticide mixing which would a relative exposure of 1.00. Because many respondents indicated multiple jobs for each time period, each job was assigned a weight and then the average and maximum weights were calculated for each unique time period. Average and maximum job weights were used because of the above mentioned concern about sensitivity of the exposure estimates to job weighting. If a subject had missing or unknown job information, then a weight of 0.25 was assigned, which was the average job weight for all study participants.

Weightings for crop type and county were derived from the crop and county specific annual data obtained from the

Table 1 Weightings for job categories

Job category	Original weighting	Conservative weighting
Pesticide mixing	1.00	1.00
Pesticide application/spraying	0.90	0.90
Planting/ploughing	0.50	0.50
Harvesting/weeding/pruning/thinning/ tying vines/burning/fertilising	0.30	0.05
Packinghouse/sorting/loading/factory processing/driving equipment/fencing	0.05	0.005
Management/transport	0.01	0.001

pesticide usage database. The weightings for crop type and county were expressed as pounds of active ingredient/acre treated for total triazines and separately for each one (atrazine, cyanazine, simazine). Each work history record with a date between 1974 and 1999 and a valid county location within California was matched with the appropriate crop, year, and county information from the pesticide usage database. The variable of pounds of active ingredient per acre treated was available for each specific crop, year, and county reported. If a job location was missing, unknown, or out of state, the exposure variable was set to missing. Any work that was reported between 1950 and 1974 was set to a missing exposure because pesticide usage data were not available for those years. Any work reported prior to 1950 was set to a zero exposure because triazines were not in use in California prior to 1950. Only exposure prior to the study period was considered so work records for 2000–01 were set to an exposure of zero. If multiple crops or locations were reported during the same year, then the total pounds of active ingredient per acre treated for all locations and crops was utilised. For each particular record, the job weight was multiplied by the pounds of active ingredient applied per acre treated specific to the county and crop type from a particular year. This produced a weighted pounds per acre treated exposure estimate that was summed over all of the years to yield a cumulative exposure estimate. Cumulative exposure was expressed as weighted total pounds of active ingredient of triazine herbicides per acre treated. This estimate was produced for each of the individual triazines as well as for all triazines combined. The calculations were repeated to obtain estimates using the conservative weights and using the maximum job weights. It is important to note that the result of the JEM was not a true estimate of an individual's exposure, but rather provided a method of ranking subjects relative to one another on a continuous scale. Table 2 shows a sample computation of cumulative exposure for a hypothetical study subject.

Statistical analysis

Statistical analysis was performed using SAS version 8.2.[14] Descriptive statistics such as the mean, 95% confidence limits, and frequency distributions were calculated as appropriate for each of the variables. To obtain the multivariate adjusted odds ratios for the ranked quartile exposure variables (none, low, medium, and high), logistic regression models were constructed that contained the following variables: family history of breast and/or ovarian cancer in a first or second degree relative, use of oral contraceptives, use of hormone replacement therapy, history of full term pregnancy, history of breast feeding, and race/ethnicity as categorical variables, and age as a continuous variable.[15] These variables were chosen because of the presence of significant age adjusted results and/or published literature suggesting that these variables were important covariates or potential confounders.

In order to test the sensitivity of the results to job weightings, the logistic regression models for the ranked quartile exposure variables were repeated using the estimates from the conservative weighting scheme and maximum job weighting scheme. Pearson's correlation coefficient was used to determine the degree of correlation between the various continuous exposure estimates. Kappa statistics were used to determine the degree of agreement between the quartile rankings based on the three weighting schemes.

RESULTS

Interviews were completed with 256 cases and 1122 controls. An occupational exposure category was determined for 88.9% (n = 227) of the cases and 90.5% (n = 1015) of the controls. The remaining women had missing data which made it difficult to determine if they had ever worked with the specified crops. Of the completed interviews, 278 women (58 cases and 220 controls) reported working on the specified crops. A total of 184 women (39 cases and 145 controls) reported agricultural work histories of at least one job in California. Of those subjects for whom an exposure category was determined (n = 1242), 7.8% (20 cases and 78 controls) were categorised as exposed to triazines.

Table 3 presents the frequency of working on specific crops and job types, and table 4 displays the means and 95% confidence intervals for various work characteristics. On average women who had agricultural work histories reported working on 2.0 crops and working in 1.2 different job categories. The means were similar for cases and controls. The average duration of agricultural work was 9.5 years, with controls having slightly but not significantly longer time spent in agricultural work. The average duration of work from 1974 to 1999 was 8.9 years, with controls again having slightly longer duration of work in the study period.

Table 5 displays the lifetime average job weighted pounds per acre treated estimates for those women who had reported job histories that had a non-zero estimate of exposure. There were no significant differences between cases and controls on cumulative occupational exposure estimates, although mean exposure was higher among cases than controls for all comparisons except for atrazine.

Estimates from the conservative and maximum job weighting schemes were highly correlated with the estimates derived from the original weightings. There was a correlation of 0.84 (95% CI 0.77 to 0.89) between the conservative weighted total triazine exposure estimates and the original estimates, and a correlation of 0.96 (95% CI 0.94 to 0.97) between the maximum weighted total triazine exposure estimates and the original estimates, with correlations for the individual triazines ranging from a high of 0.97 for simazine to a low of 0.67 for cyanazine. Correlations were similar for cases and controls.

Table 6 presents the multivariate adjusted odds ratios and 95% confidence intervals linking EOC and triazine exposure based on the three weighting schemes. The exposure quartiles for the original and maximum job weighting schemes were defined as none (0 pounds of active ingredient/acre treated), low (0.001–1.0 pounds of active ingredient/acre treated), medium (1.001–4.0 pounds of active ingredient/acre treated), and high (>4.0 pounds of active ingredient/acre treated). For the conservative job weighting scheme the exposure quartiles were defined as none (0 pounds of active ingredient/acre treated), low (0.001–0.30 pounds of active ingredient/acre treated), medium (0.301–1.50 pounds of active ingredient/acre treated), and high (>1.50 pounds of active ingredient/acre treated). Although there was some variation in odds ratio between the weighting schemes, it was relatively small (10–20%) for most categories. A test for linear trend revealed no significant trend of increasing

Table 2 Computation of cumulative weighted pounds per acre treated exposure estimate for a hypothetical worker

Pounds of active ingredient/acre treated* (county)	Crop (year)	Jobs	Original average job weighting	Conservative job weighting	Maximum job weighting	Original weighted estimate†	Conservative weighted estimate‡	Maximum weighted estimate§
3.5 (Mariposa)	Grapes (1980)	Harvesting, sprayer	(0.3+0.9)/2 = 0.60	(0.05+0.9)/2 = 0.475	0.90	2.1	1.66	3.15
5.0 (Solano)	Grapes (1982)	Sprayer	0.90	0.90	0.90	4.5	4.5	4.5
10.0 (Solano)	Grapes (1983)	Mixed pesticides	1.0	1.0	1.0	10.0	10.0	10.0
2.0 (Kern)	Almonds (1984)	Packing, harvesting, sprayer	(0.05+0.30+0.9)/3 = 0.42	(0.005+0.05+0.9)/3 = 0.32	0.90	0.84	0.64	1.8
8.0 (Kern)	Almonds (1985)	Packing, harvesting, sprayer	(0.05+0.30+0.9)/3 = 0.42	(0.005+0.05+0.9)/3 = 0.32	0.90	3.36	2.56	7.2
7.6 (Kern)	Almonds (1986)	Fencing, management, tying vines	(0.05+0.01+0.30)/3 = 0.12	(0.005+0.001+0.05)/3 = 0.019	0.90	0.912	0.014	6.84
				Cumulative exposure estimate		**21.712**	**19.374**	**33.49**

*Taken from California DPR pesticide usage data.
†Calculated as pounds of active ingredient/acre treated × original average job weighting (example: 3.5×6.0).
‡Calculated as pounds of active ingredient/acre treated × conservative job weighting (example: 3.5×0.475).
§Calculated as pounds of active ingredient/acre treated × maximum job weighting (example: 3.5×0.90).

EOC risk with increasing triazine exposure for any of the weighting schemes. The multivariate adjusted odds ratios when exposure was expressed as a continuous variable were virtually identical for the three weighting schemes.

Both alternative schemes showed a high degree of agreement with the original weighting scheme. The conservative scheme had a lower degree of agreement with the original scheme ($\kappa = 0.79$; 95% CI 0.74 to 0.84) than the maximum scheme ($\kappa = 0.97$; 95% CI 0.93 to 0.99).

The telephone questionnaire also contained a section asking women about use of specific trade names of triazine herbicides. Of the 12 women who could report exposure to a specific trade name, 33% (n = 4) were characterised as exposed by the JEM, 50% (n = 6) had no exposure by JEM but did report work on one of the crops outside of the study period, and 17% (n = 2) did not report adequate work history to develop a JEM estimate.

DISCUSSION

Non-differential exposure misclassification is one of the largest concerns in occupational case-control studies and is likely to lead to an underestimate of the true odds ratio. Because we were unable to directly measure personal exposure to triazine herbicides, a surrogate measurement of cumulative exposure was constructed from a JEM. There are many factors that influence how the amounts of herbicide used in any given location relate to the levels in the air and soil including half life, adherence to soil, method of application, and weather conditions.[16–18] Although the JEM estimate may be a reasonable proxy for exposure, many factors influence uptake of the herbicide so it is important to realise that the JEM is essentially a method to rank subjects relative to one another on a continuous scale rather than the traditional categorical scales.

Two major strengths of the study were the use of the prompt list to aid recall of work histories and the comprehensiveness of the California DPR database. Direct questioning of workers about exposure to specific chemicals usually does not yield accurate data because they do not normally apply the pesticides themselves and often are not aware of the specific pesticides applied by others to the fields in which they are working. Nanni and colleagues[4] found that

Table 3 Relative distribution of crops and job types

	Cases n = 256	Controls n = 1122	Total n = 1378
Specific crops	**% working on each crop (n)**		
Grapes	12.5% (32)	11.0% (123)	11.2% (155)
Oranges/lemons	3.5% (9)	4.2% (47)	4.1% (56)
Cotton	8.6% (22)	7.0% (79)	7.3% (101)
Corn	5.5% (14)	4.4% (50)	4.6% (64)
Almonds/walnuts	6.3% (16)	6.1% (69)	6.2% (85)
Alfalfa	5.5% 14)	3.3% (37)	3.7% (51)
Olives	1.6% (4)	2.0% (22)	1.9% (26)
Christmas trees	1.2% (3)	0.6% (7)	0.7% (10)
Sorghum	1.2% (3)	0.2% (2)	0.4% (5)
Avocado	0.4% (1)	0.4% (5)	0.4% (6)
Job types*	**% working at each job type (n)**		
Harvesting/weeding/pruning/thinning/tying vines/burning/fertilising	21.5% (55)	16.6% (186)	17.5% (241)
Packinghouse/sorting/loading/factory processing/driving equipment/fencing	5.6% (15)	7.0% (79)	6.8% (1378)
Management/transport	0.3% (1)	1.1% (12)	0.9% (13)
Other—unspecified	5.6% (15)	3.8% (43)	4.2% (1378)

*No one reported pesticide mixing, pesticide application/spraying, or planting/ploughing.

Table 4 Mean and 95% confidence intervals of various work history factors

Work characteristics	Mean (95% CI) Cases n = 39	Controls n = 145	Total n = 184
No. of crops worked	1.9 (1.4 to 2.5)	2.0 (1.8 to 2.2)	2.0 (1.8 to 2.2)
No. of jobs worked	1.3 (1.1 to 1.4)	1.2 (1.1 to 1.3)	1.2 (1.1 to 1.3)
Total duration of work on specified crops (in years)	8.3 (2.5 to 14.0)	10.1 (7.9 to 12.3)	9.5 (7.6 to 11.4)
Total duration of work 1974–99 on specified crops (in years)	6.7 (4.5 to 9.1)	9.0 (6.7 to 11.3)	8.9 (6.8 to 11.0)

agricultural workers questioned about agricultural work history remembered all crops, but only 15% could remember use of specific chemicals. This was similar to the situation posed by our study, with less than 1% of women actually able to name specific chemicals used. Use of the JEM allowed the exposure to be determined in an objective manner since it did not rely on personal recall of pesticides but used a statewide computerised database and information about work history. The JEM used relative rankings to account for differing exposure by job type and also accounted for changes in herbicide usage over time. The exposure estimates for the JEM also have a distinct advantage over self reported exposure information in that they are unlikely to be influenced by differential recall. In addition, Brouwer and colleagues[7] report that when reliability of job history detail is good, estimates from the JEM have good validity.

There are several concerns when using these types of JEMs. The first is the sensitivity of the JEM estimates to the job weightings. Based on the high correlation, similar odds ratios, and good agreement of the three weighting schemes, the method used in this study appears to be fairly robust to changes in job weighting. In fact using similar methodology, London and Myers[11] showed that a JEM can generate exposure estimates with good repeatability and range to detect dose-response relations, although validation of the job weightings by an industrial hygienist is advisable for future studies. A second concern is that crop weights from the pesticide usage database were average pounds per acre treated, which assumes a homogeneous pattern of use. The work history data were also limited in that women only reported county location and year rather than more specific location and time periods. More detailed work histories would be preferable so that factors such as protective equipment and number of hours per day worked in addition to more specific locations and dates could be considered.

Although the JEM estimate may be a reasonable proxy for exposure, many factors influence uptake and dose including metabolism, distribution to tissues, use of personal protective equipment, and work practices such as hand washing. Lack of data about use of personal protective equipment is a serious concern since the true dose that a subject received may be overestimated by the JEM when use of gloves and long sleeved clothing is not taken into account considering that the primary route of exposure is dermal. Krieger and colleagues[13] report 1.5–3 times decreased transfer of pesticides among workers using gloves versus those wearing only standard clothing (long pants, long sleeved shirts, and shoes). Stewart and colleagues[19] note that use of gloves may provide a 30% reduction in exposure over standard clothing coverage. A California Department of Health Services Study among San Luis Obispo County Farmworkers[20] noted that 90% of workers report wearing gloves, although anecdotal reports indicate that in practice the proportion may be much lower; therefore, it is difficult to estimate the effect that failure to consider these data may have had on the exposure estimates. Furthermore, lack of data on duration variables such as hours worked per week and days worked per year are another gap in the data. More precise estimates of work duration would certainly improve the exposure estimates and add valuable information about intensity of exposure. It is noted that assuming a consistent work pattern over the course of a year could lead to inaccuracies in exposure information due to varying exposure intensities.

Another major concern is the presence of errors in the pesticide usage database. Acres treated are sometimes reported as the entire field even when only part of the field is treated leading to underestimates in rate of use. Some ambiguity with respect to crop also occurs because some crops may be reported more specifically or generally (that is,

Table 5 Mean and 95% confidence intervals for occupational exposure to triazines as a continuous variable based on original average job weighting scheme among those defined as exposed

	Pounds/acre treated Cases Mean (95% CI)	Controls Mean (95% CI)	Total Mean (95% CI)
Total triazine exposure	(n = 20) 4.02 (2.16 to 5.89)	(n = 78) 3.28 (2.30 to 4.25)	(n = 98) 3.43 (2.58 to 4.28)
Total atrazine exposure	(n = 2) 0.17 (−1.70 to 2.03)	(n = 12) 1.16 (−0.14 to 2.46)	(n = 14) 1.02 (−0.09 to 2.13)
Total cyanazine exposure	(n = 5) 4.26 (0.27 to 8.24)	(n = 14) 2.37 (1.06 to 3.67)	(n = 19) 2.87 (1.62 to 4.12)
Total simazine exposure	(n = 19) 3.10 (1.40 to 4.80)	(n = 74) 2.82 (1.86 to 3.78)	(n = 93) 2.88 (2.05 to 3.70)

Table 6 Multivariate adjusted odds ratios* and 95% confidence intervals for triazine herbicide exposure and epithelial ovarian cancer using three job weighting schemes

	Original average job weighted estimates	Conservative job weighted estimates	Maximum job weighted estimates
Exposure quartiles			
No exposure	1.00	1.00	1.00
Low	1.13 (0.44 to 2.90)	1.32 (0.60 to 2.91)	1.21 (0.53 to 2.77)
Medium	1.20 (0.48 to 3.06)	1.41 (0.58 to 3.42)	1.07 (0.34 to 3.31)
High	1.70 (0.73 to 3.98)	1.34 (0.42 to 4.28)	1.70 (0.73 to 3.90)
Exposure measured on continuous scale	1.04 (0.96 to 1.14)	1.06 (0.80 to 1.39)	1.02 (0.96 to 1.09)

*Adjusted for family history of breast and or ovarian cancer in a first or second degree relative, use of oral contraceptives, use of hormone replacement therapy, history of full term pregnancy, history of breast feeding, race/ethnicity, and age.

nuts versus almonds). This could lead to some underestimates of exposure since construction of the JEM for this study was based on specific crop name. Growers will sometimes report the total amount of pesticide used plus diluent use instead of the amount of active ingredient only, resulting in overestimates of the amount of active ingredient used. Despite these potential problems, DPR estimates that the error rate for the use reports is relatively low at 0.5–1% per year.[10] Error rates are presumed to be slightly higher for data collected prior to 1990 when error checking of the reports was not as thorough.

Rull and Ritz used the DPR and land use survey data to assess the misclassification potential in studies linking proximity to a pesticide application and health effects.[21] The simulation found that disease odds ratios were severely attenuated when exposure status was assessed based on larger rather than smaller geographic areas. It was also noted that, in the absence of specific application sites and information on use of solvents and adjuvants in addition to other environmental factors, substantial non-differential exposure misclassification may occur, leading to attenuation of true effect estimates. Overall pesticide exposure was relatively low in this study due to the fact that a large proportion of those who were exposed were engaged in jobs other than handling, mixing, or planting. Most of the workers, therefore, had relatively low direct exposure to triazines. In addition, only 8% of cases (n = 20) and 7% of controls (n = 78) were actually categorised as exposed to triazines. Lack of a consistent trend in dose-response patterns may be reflective of small sample sizes in each of the exposure quartiles.

In spite of the above limitations, the evidence from this study and others[7 21] suggests that the JEM estimates are relatively insensitive to minor changes in the variables composing the JEM. Other attempts at creation of an exposure scale have been published. Bell and colleagues[22 23] used the DPR database in studies of fetal death and congenital anomalies to determine exposure to pesticides within an area as small as one square mile. Similarly, Gunier and colleagues[24] and Reynolds and colleagues[25] developed geographical information methods to summarise agricultural pesticide use by census block group in studies of childhood cancer. Although these methodologies are extremely promising and useful for short term outcomes, they may be more difficult to employ for longer term outcomes such as adult cancers because of the difficulty of accurately recalling detailed location information. Dosemeci and colleagues[26] developed a detailed quantitative method to estimate long term chemical specific exposures, but this method was applied to pesticide applicators who were members of a prospective cohort and were able to specify pesticide names and extremely detailed information on use and handling histories. Stewart and colleagues[19] proposed using a formula with application rates, half life, job type, job duration, and protection factor to create a relative exposure score. This formula is similar to the exposure estimate developed by the JEM in this study in that application rates, job type, and rough estimates of job duration are taken into account. As previously noted, the JEM could be improved by the incorporation of detailed data on personal protection and job duration. Stewart and colleagues[19] compared the relative exposure estimates generated from that formula to actual measurements in three studies and found the correlation between actual measurements and relative exposure estimates was fairly high ($r = 0.77$). This suggests that since the JEM in this study uses a similar formula, the exposure estimates from this study may correlate well with actual measurements. Future studies should be conducted to determine how well the JEM estimates correlate with direct exposure measurements from workers.

Conclusion

The exposure estimate from the JEM provides a ranking within the study population that can be used as an ''exposure score'' with which to compare groups on a continuous scale. It is important to note that although it is not an absolute exposure measurement, it does offer a substantial advance over dichotomous categories based on self report of herbicide use, particularly when subjects are unlikely to recall specific names and dates of use of herbicides. As is the case in many agricultural studies, women were unable to report exposure to specific herbicides by name so that this methodology provided a way to determine potential exposure based on available data of work history and historical pesticide usage data. In cases of long latency periods and exposure over an extended time, methods similar to this may be the only way to generate exposure estimates. Although useful for assessing exposure over longer periods of time, this JEM methodology shows particular promise for use in short term time periods where more detailed work histories including more specific location, duration, and personal protection information could be collected and with work history data collected after 1990 when California pesticide usage data have very specific location records.

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