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To cite this article: Zipora Weinbaum , Steven J. Samuels & Marc B. Schenker (1995) Risk Factors for Occupational Illnesses Associated with the Use of Paraquat (1,1'-Dimethyl-4,4'-Bipyridylium Dichloride) in California, Archives of Environmental Health: An International Journal, 50:5, 341-348, DOI: [10.1080/00039896.1995.9935965](https://doi.org/10.1080/00039896.1995.9935965)

To link to this article: <https://doi.org/10.1080/00039896.1995.9935965>



Published online: 03 Aug 2010.



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Risk Factors for Occupational Illnesses Associated with the Use of Paraquat (1,1'-Dimethyl-4,4'-Bipyridylum Dichloride) in California

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ABSTRACT. This study was conducted to identify risk factors for paraquat-related occupational illnesses. Pesticide-related illness is a reportable disease in California. A total of 231 skin (26.0%), eye (32.0%), local respiratory (3.5%), and systemic (38.5%) paraquat-related cases were reported to the Worker Health and Safety Branch, California Department of Food and Agriculture, during 1971 through 1985. Following paraquat exposure, we found no cases of pulmonary fibrosis. Annual numbers of cases ranged between 1 and 33 (median = 14 cases/y). Information on illnesses reported during 1981 through 1985 ($n = 62$) was merged with detailed information on paraquat use in agricultural settings (111 716 applications) for the same years. We found that crop treated, method of application, and season of application all contributed independently to the risk of reported illness. Hand application was associated with a higher risk of illness, compared with air application (RR = 99.1, 95% CI = 22.16-443.47); summer application was associated with a higher risk of illness than was winter application (RR = 4.1, 95% CI = 1.91-8.61); and fruit trees were associated with higher risk of illness than were other crops (mainly cotton) (RR = 3.6, 95% CI = 1.18-11.21).

PARAQUAT (1,1'-dimethyl-4,4'-bipyridylum dichloride) is a defoliant and contact herbicide that has been used extensively on cotton and in orchards in California. Paraquat has been a medical concern since 1965 when fatalities were reported following both accidental and deliberate (suicide) ingestion.¹ The lethal nature of

ingested paraquat was demonstrated in a recent report from Mexico that documented deaths of 64% of 25 cases who ingested paraquat.² Agricultural workers' deaths resulting from respiratory failure were also reported in association with absorption of paraquat through damaged skin.^{3,4}

Acute systemic effects of ingested paraquat are irritation and ulceration of the gastrointestinal tract and dysfunction of kidneys, liver, heart, and other organs, all of which may progress to acute respiratory distress, respiratory failure, and death.⁵ Nonfatal symptoms associated with occupational use of paraquat reportedly include skin and eye irritation, nail damage, skin rashes, and epistaxis,⁵ but little is known about the epidemiology of occupational morbidity associated with paraquat.⁶ As a result of California's unique mandatory reporting requirements, it is the only state in which data are available on both paraquat use and suspected paraquat-related illnesses. California growers and applicators are required to report paraquat use to the California Department of Food and Agriculture (CDFA). In 1985, the reported use of paraquat was 635 256 pounds on 1 735 239 acres.⁷ Physicians are required by law to report suspected pesticide illnesses, which, by a variety of reporting mechanisms, reach the Worker Health and Safety (WH&S) branch at the CDFA⁸ (now at Cal-EPA).

We have used these two CDFA reporting systems (a) to describe the characteristics and independent risk factors for reported paraquat-related occupational illnesses in California, and (b) to develop a method to assess the relationship between the agricultural use of paraquat or other pesticides and the resulting illnesses.

Materials and Method

CDFA data sources

Pesticide Illness Case Reports (PICRs), years 1971–1985. Copies of the physician's "Pesticide Illness Report" filed with county health officers; the "Doctor's First Report of Work Injury" (DFRWI) submitted to the California Department of Industrial Relations (CDIR); and the subsequent investigation by the local County Agricultural Commissioner (CAC), reported as the Pesticide Episode Investigation Report (PEIR); were compiled by the Worker Health and Safety Branch (WH&S) at the CDFA. These reports were the source of information for this analysis.

PICRs have been computerized since 1976. We found 180 PICRs out of the total computerized list of 197 (91.4%) paraquat illness cases for the years 1976–1985. A manual search of the PICRs revealed one additional record for 1977. PICR review for the years 1971–1975 resulted in 57 case records, thus bringing the overall total to 238. After we eliminated nonoccupational cases (e.g., suicide and accidental drift or ingestion [$n = 7$]), there remained 231 PICRs. All occupational PICRs reported to the CDFA and associated with paraquat were included in this analysis.

Variables were examined only if they were present in at least 80% of the case files. Variables that met this requirement were age and sex of the cases; symptoms and diagnosis of the illness; immediate cause of paraquat contact and body parts involved; location by county of the illness occurrence; crop treated; date of illness onset; job activity; type of illness (local or systemic); and days of disability or hospitalization. Coun-

ties were grouped into six geographical regions that corresponded with agricultural regions of the state⁹: (1) North Coast (Mendocino, Napa, Sonoma); (2) Sacramento Valley (Butte, Colusa, Placer, Sacramento, Solano, Sutter, Tehama, Yolo); (3) San Joaquin Valley (Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, Tulare); (4) Central Coast (Alameda, Contra Costa, Monterey, San Benito, San Mateo, Santa Clara, Santa Cruz); (5) South Coast (Los Angeles, Orange, San Diego, Santa Barbara, Ventura); and (6) Desert (Imperial, Riverside, San Bernardino).

The CDFA coded job activity. "Ground applicator" was defined by WH&S as "working with a vehicular-mounted liquid spray or dust rig or doing ancillary tasks to vehicular applications." This category could also include mix/load activities. "Hand applicators" were defined by WH&S as "people whose exposure occurred while applying hand-pump or backpack sprayers or dusters or any tasks ancillary to those activities." The "other agricultural" category comprised workers who were exposed to paraquat by spray drift or contact with residue, flaggers, and landscape workers. The "clean/fix" category included machinists who repaired or cleaned equipment.

Cases were classified into two illness types, based on symptoms reported: (1) "local/irritant," which included skin, eye, and local respiratory symptoms; and (2) "systemic," which included nonspecific symptoms (e.g., dizziness, headache, nausea, diarrhea) and respiratory symptoms in combination with other nonspecific systemic symptoms. None of the systemic cases was reported to have had pulmonary fibrosis secondary to paraquat exposure. These two groups were compared by chi-square tests and by logistic regression, using the Statistical Analysis Systems (SAS)¹⁰ and BMDP.¹¹ Logistic regression analysis for illness type was limited to job activity and agricultural versus nonagricultural activities—variables for which there were no missing data. Job activity was further categorized, as follows: (a) exposed to concentrates = mixer/loaders, clean/fix, manufacture, firemen, and storage; (b) all applicators; and (c) all other agricultural workers (i.e., the reference group in the regression).

The analysis of agricultural illnesses and paraquat use data (1981–1985) corresponded to the years for which paraquat use data were available. The cases that occurred during 1981–1985 did not differ significantly from the remainder of the agricultural cases with respect to demographic parameters such as age, sex, or illness type. Of the total 78 cases that occurred during 1981–1985, we could not include 16 in the analysis because the information for crop (12 cases) or method (4 cases) was missing.

Pesticide Data Bank (PDB)—paraquat applications in 1984. Detailed paraquat use information was obtained for only 1984 because of budget limitations ($n = 22\ 214$ single applications). Each record (application) contained county; location (township, range, section); crop treated; method of application; amount of paraquat applied (pounds); area treated (acres); and date of application. Dates were categorized into seasons, as

follows: winter, December–February; spring, March–May; summer, June–August; and fall, September–November.

Pesticide Use Reports (PURs), years 1981–1985. The Pesticide Use Reports (PURs) are annual summaries of data collected by the County Agricultural Commissioners,⁷ and they reflect use of all restricted pesticides in the state. The PURs do not contain geographical and temporal data (e.g., method or season of application) about pesticide use. Information extracted from the PURs for paraquat use per *crop* (1981–1985) included the number of applications, pounds applied, and acres treated.

Calculations and Statistical Analysis, Years 1981–1985

Estimation of paraquat use, years 1981–1985. The detailed 1984 paraquat applications data, stratified on crop, method, and season, were used with the *crop* treatment information from the published PURs for 1981–1985 to estimate the combination of applications for crop, method, and season for the years 1981, 1982, 1983, and 1985. In summary, we standardized, by published crop application data (1981–1985), the 1984 stratified data to obtain more detailed information for the individual years.

Comparison of illnesses and use of paraquat rates, years 1981–1985. Illness counts as the numerator and paraquat applications counts as the denominator, totaled for the years 1981–1985 per stratum (i.e., crop, method, and season), were used to estimate illness occurrence, relative to paraquat use. We assumed that the illnesses followed a Poisson distribution because of the small number of illnesses per paraquat application. Poisson regression analysis, as suggested by Frome et al.¹² was performed by a modification of a SAS PROC NLIN program developed by Suissa et al.¹³

Results

Pesticide illness case reports (PICRs), years 1971–1985. The number of PICRs reported to the WH&S each year (1971–1985) ranged from 1 to 33 (median = 14 cases/y; 25th and 75th percentiles, 11 and 22, respectively). In 23.8% of the reported illnesses, multiple pesticide use was mentioned (e.g., paraquat and one or more of the following: dinitrophenol, simazine [princep], sulfur, DEF, oxyfluorfen).

The greatest proportion of illnesses associated with paraquat were systemic (38.5%); eye and skin illnesses were approximately equal (32.0% and 26.0%, respectively); and local respiratory symptoms comprised 3.5% of the illnesses. Eye, skin, and local respiratory illnesses were combined for the purpose of comparison with the systemic illnesses.

Demographics. Many illnesses (i.e., about 41%) affected people younger than 24 y of age; the second largest age group affected was 25–34 y of age (Table 1). The unequal distribution between males ($n = 222$; 96.1%) and females ($n = 9$; 3.9%) limited statistical comparisons between the sexes. Furthermore, approx-

imately one-half (i.e., 4/9) of the females were involved in manufacturing, which was not comparable with agricultural paraquat exposures. We observed no association between age and illness determinants (e.g., illness type, circumstances of illness, outcome of illness, and body parts affected [data not shown]).

Circumstances of illness onset. Paraquat-related illnesses were reported from 34 counties. Counties for which the greatest numbers of illnesses were reported were in the San Joaquin Valley, including Kern (41 illnesses, 17.7%); and in Fresno and Tulare counties (24 illnesses each, 10.4%). The highest percentages of illnesses were associated with “noncrop” or “open land” (19.5%), followed by nut trees (15.6%), fleshy fruit trees (13.4%), and grapes (13.0%) (Table 1). More systemic illnesses occurred from open land applications, and more local/irritant illnesses occurred from fruit, nut, and grape applications.

Agriculture accounted for 93.5% of the cases, and the remaining 6.5% of the cases were nonagricultural workers who were involved in paraquat manufacture, firemen, and workers exposed in storage areas. A significant association was present between illness type and job activity ($\chi^2 = 19.3$, $p < .01$), with more local/irritant illnesses occurring among applicators, but more systemic illnesses occurring as a result of other agricultural job exposures and from concentrated paraquat (Table 1).

Most of the illnesses (39.1%) occurred during handling of spray equipment, either during cleaning or in association with a malfunction while spraying (e.g., hose split, disconnection, hose movement associated with pressure of the pesticide, leaking containers, leakage when folding the equipment at the end of the spraying session, splashes when mixing/loading). This type of a malfunction was more likely to result in a local/irritant illness than in a systemic illness (OR = 2.6, 95% CI = 1.47–4.70).

Thirty percent of illnesses resulted from unspecified events. Environmental causes (including change in wind direction, drift of chemicals after application, slipping on uneven ground) also resulted in a large percentage (12.4%) of illnesses. Eleven percent of the illnesses (“other”) were associated with vehicle accidents, with exposures to concentrates used in manufacturing, or as part of firemen responses. Cases of accidental contact with paraquat also occurred (7.1%) during routine spraying or handling of equipment.

Illness type and body parts in contact with paraquat were associated significantly ($\chi^2 = 93.8$, $p < .001$). More than 70% of the local/irritant illnesses resulted from contact with the face and upper extremity. In 72.9% of the systemic cases, the contact area was unclear, possibly indicating inhalation or absorption by cutaneous routes of exposure.

Analysis of illness type (local/irritant versus systemic cases), controlling for age and agricultural status (yes or no), confirmed that applicators were more likely than other workers to develop a local/irritant illness (OR = 3.7, 95% CI = 1.41–9.62); workers exposed to concentrates (i.e., mixer/loaders, clean/fix, manufacture, fire-

Table 1.—Characteristics of Occupational Paraquat-Related Illnesses (California, 1971–1985*)

Factor/characteristic	Local/irritant (N = 142)		Systemic (N = 89)		Total (N = 231)	
	n	%	n	%	n	%
Age (y)						
17–24	50	37.6	39	45.9	89	40.8
25–34	38	28.6	18	21.2	56	25.7
35–44	26	19.6	12	14.1	38	17.4
45–54	13	9.8	8	9.4	21	9.6
55–64	5	3.8	7	8.2	12	5.5
≥ 65	1	0.8	1	1.2	2	0.9
California region						
San Joaquin Valley	89	64.0	45	51.1	134	59.0
South coast	13	9.4	13	14.8	26	11.5
Central coast	15	10.8	8	9.1	23	10.1
Sacramento Valley	14	10.1	8	9.1	22	9.7
North coast	6	4.3	9	10.2	15	6.6
Desert	2	1.5	5	5.7	7	3.1
Commodities						
Agricultural (nos.)	31	21.8	23	25.8	54	23.4
Open land	21	14.8	24	27.0	45	19.5
Nut trees	24	16.9	12	13.5	36	15.6
Flesh-fruit trees	22	15.5	9	10.1	31	13.4
Grapes	22	15.5	8	9.0	30	13.0
Other crops	14	9.9	8	9.0	22	9.5
Nonagricultural	8	5.6	5	5.6	13	5.6
Season of onset						
Winter	40	28.2	17	19.1	57	24.7
Spring	47	33.1	34	38.2	81	35.1
Summer	35	24.7	23	25.8	58	25.1
Fall	20	14.1	15	16.9	35	15.2
Job activity						
Applicators	96	67.6	47	54.7	143	62.7
Mixer/loaders	18	12.7	11	12.8	29	12.7
Other, agricultural	10	7.0	15	17.4	25	11.0
Clean/fix	10	7.0	6	7.0	16	7.0
Manufacture	8	5.6	1	1.2	9	4.0
Firemen, storage	0	0.0	6	7.0	6	2.6
Factor causal in contact with paraquat						
Spray equipment	66	47.5	22	25.6	88	39.1
Unclear	34	24.5	34	39.5	68	30.2
Environment	15	10.8	13	15.1	28	12.4
Other	11	7.9	14	16.3	25	11.1
Routine spraying	13	9.4	3	3.5	16	7.1
Body part in contact with paraquat						
Face	81	57.0	15	17.7	96	42.3
Unclear contact	15	10.6	62	72.9	77	33.9
Upper extremities	22	15.5	3	3.5	25	11.0
Trunk	12	8.5	3	3.5	15	6.6
Lower extremities	11	7.8	1	1.2	12	5.3
Multiple parts	1	0.7	1	1.2	2	0.9

*Numbers may not add up to totals because some values were missing.

men, storage) were three times more likely to develop a local/irritant illness than other workers (OR = 3.0, 95% CI = 1.00–9.08).

Symptoms, signs, and diagnosis. The systemic cases group included only cases with nonspecific symptoms. Examination of the systemic case data for symptoms and signs associated with paraquat only (no other pesticides involved) resulted in 64 cases, 59 of which had a description of symptoms or signs (Table 2).

Dizziness, nausea, or lightheadedness were the most common complaints (55.9%), followed by headache, chest pain, vomiting, tiredness, shortness of breath, and burning-skin sensations (prevalence range = 11.9%–23.7%). In 14 of 59 of those cases, physicians ordered cholinesterase tests (results of the tests were not available), and 4 of 59 of the cases were also treated with atropine, the recommended treatment for organophosphate (OP) poisoning.

Symptoms and signs of eye injury cases included burning and itching of the eye (42.5%); redness (27.5%); and discharge, constriction of pupils and damage to eyesight (< 12.5%). Among the "skin-" related illnesses, complaints were primarily of rash and irritation (69.7%), followed by itching (21.2%) and swelling (15.2%). Local respiratory irritation was confined mostly to epistaxis (87.5%).

Outcome of illness. Fifty-five (23.8%) of the 231 cases were associated with loss of workdays. Among cases with lost workdays, the number of work days lost ranged from 1 to 30, (median = 2 d). Eleven cases were hospitalized, and the duration of hospitalization ranged between 1 and 17 d (median = 2 d). The median duration of hospitalization for the systemic cases ($n = 10$) was 7 d; one local/irritant case was hospitalized for 1 d. Overall, the systemic illnesses were associated with more frequent workdays lost or with hospitalization. Forty-five percent of systemic cases had work-loss days or hospitalizations versus 24% of the local/irritant cases (OR = 2.6, 95% CI = 1.38-4.74). Specific information on clinical evaluation (chest x-rays) during hospitalization was available only for 4 hospitalized cases, and no information was available on pulmonary-function studies.

Illness Risk (Years 1981-1985)

Three indices of paraquat use were considered as denominators for paraquat-associated illness risk: (1) counts (or frequency) of applications, (2) acreage treated, and (3) pounds of paraquat applied (Table 3). Risk indices were calculated using the counts of applications, but because all the indices of paraquat applications were highly correlated (Spearman rank correlation coefficient for any pair was .94-.98), a choice of any one would have been appropriate.

Crop categories for analysis of paraquat-related illnesses were fleshy fruit trees, noncrop areas, grapes, nut trees, and "other crops." The "other crops" category included all field, grain, and vegetable crops, but only crops with more than 20 paraquat applications were named in this category. Crops associated with illnesses in the "other crops" category were cotton (5 illnesses) and alfalfa (1 illness). The range of crude illness "rates" (without adjusting for other variables, such as season or method of application) was from 0.1 to 1.3 per 10³ applications for "other crops" and fleshy fruit trees, respectively.

The Poisson regression model including crop, method, and season best described the association between paraquat-related illnesses and applications (Table 4). A significantly higher risk of illness from applying paraquat to noncrop areas (RR = 5.6, 95% CI = 1.76-17.53) and to fleshy fruit orchards existed, compared with "other crops." Higher risks existed for summer and spring applications (RR = 4.1, 95% CI = 1.91-8.61) and (RR = 2.7, 95% CI = 1.38-5.15), respectively, than for winter applications.

Among the methods of applications, we found that a higher risk was associated with ground application (RR

Table 2.— Frequency of Paraquat-Related Symptoms and Signs (California, 1971-1985)

Symptoms/signs	<i>n</i>	%
<i>Systemic illnesses (N = 59)</i>		
Dizziness, nausea, lightheadedness	33	55.9
Headache	14	23.7
Chest pain	14	23.7
Vomiting	13	22.0
Weakness, tiredness, "ill"	12	20.3
Shortness of breath	10	16.9
Disturbance in skin sensation	10	16.9
Abdominal cramps	7	11.9
Eye/skin irritation, blurring, vision, loss of appetite, muscle pain, blood loss, dry mouth, diarrhea, fainting, fever, itching, weight loss, sore throat, cough, nervousness, epistaxis	≤ 5	≤ 8.5
<i>Local irritant</i>		
<i>Eye illnesses (N = 40)</i>		
Burning, itching	17	42.5
Redness	11	27.5
Swelling, discharge, constriction of pupils, damage to eyesight, blurring	≤ 5	≤ 12.5
<i>Skin illnesses (N = 33)</i>		
Rash and irritation	23	69.7
Itching	7	21.2
Swelling, burning, numbness, hair loss	≤ 5	≤ 15.2
<i>Local respiratory irritation (N = 8)</i>		
Epistaxis	7	87.5
Skin irritation, sore throat, eye redness	1	12.5

= 5.5, 95% CI = 1.39-21.67) than with aerial applications. "Other methods of application," the majority of which were by hand, had a markedly higher risk than did aerial applications (RR = 99.1, 95% CI = 22.2-443.5).

Discussion

The types of occupational paraquat-associated local/irritant illnesses described in our study were similar to those reported in the literature.^{5,14-16} Whereas the occurrence of systemic illnesses from paraquat is controversial,^{14,15} the CDFA was reporting complaints of systemic illnesses beginning in 1977¹⁷ and continued through 1985, the most recent year included in this study. Recently, systemic symptoms similar to those observed in our study were also reported in a community exposed to paraquat drift in California.¹⁸

Even though some descriptions of systemic illnesses associated with inhalation or skin absorption have been reported in the literature,^{19,20} minimal recognition has been given to occupational paraquat-related systemic illnesses,¹⁵ despite the fact that these illnesses were more likely in our population to result in disability and hospitalizations than were the local/irritant illnesses. This observation accords with animal studies in which the acute paraquat dermal LD₅₀ (80 mg/kg) has been lower (i.e., more toxic) than the acute oral LD₅₀ (100

Table 3.—Paraquat-Related Illnesses and Estimated Frequency of Paraquat Use, Totaled for the Years 1981–1985

Category	No. illnesses		No. applications		Illnesses/ applications (*1 000) (crude rates)
	n	%	n	%	
<i>Crops</i>					
Other crops (alfalfa, landscape, corn, cotton, lettuce, peppers, sugarbeets, tomatoes, wheat, and others not in the categories below)	6	9.7	51 487	46.0	0.1
Noncrop areas (fallow farmland, industrial areas, nonagricultural areas, open land, right-of-way)	11	17.7	10 546	9.4	1.0
Trees—fleshy fruit (apple, apricot, avocado, cherry, kiwi, nectarine, olive, orchard floor, peach, pear, plum, prune, subtropical fruit, citrus, citrus—other, grapefruit, lemon, orange)	16	25.8	12 439	11.1	1.3
Grapes	13	21.0	16 614	14.9	0.8
Trees—nuts (almond, pecan, pistachio, walnut)	16	25.8	20 630	18.5	0.8
<i>Seasons of illness onset</i>					
Winter	18	29.0	45 779	41.0	0.4
Fall	9	14.5	40 364	36.1	0.2
Spring	21	33.9	18 230	16.3	1.2
Summer	14	22.6	7 343	6.6	1.9
<i>Method of application</i>					
Air	3	4.8	43 573	39.0	0.1
Ground	50	80.6	66 974	60.0	0.7
Hand (other)	9	14.5	712	0.6	1.3
Missing			457	0.4	
Total	62	100.0	111 716	100.0	0.6

mg/kg) in male rats. Fatal outcomes resulted when rabbits were treated with eye or dermal (covered) applications of paraquat, indicating that systemic absorption of paraquat had occurred.⁵

Given that paraquat exposure produces nonspecific effects (e.g., headache, nausea, and vomiting) that are similar to OP effects, paraquat exposure may be confused easily with OP toxicity. Our observation of the difficulty in diagnosing paraquat toxicity is in agreement with a National Poison Center study from Taiwan,²¹ in which it was reported that 14 of 97 patients exposed to the herbicide glyphosate were treated with atropine and/or pralidoxime. Another 11 of 97 patients in the Taiwan study were tested or treated for paraquat poisoning, instead of glyphosate exposure. Whereas it is preferable for physicians to ascertain the identity of the pesticide involved prior to treatment, symptoms resulting from many pesticide exposures are nonspecific, and the requirement for clinical response without adequate diagnostic information may dictate emergency treatment for OPs in many cases of non-OP toxicity.

In a recent study of 85 paraquat spraymen in Sri Lanka,¹⁶ there was no difference in pulmonary function

among the cases and two control groups. Similarly, with the exception of 1 questionable case, our cases with systemic illness did not report the classical acute paraquat illness symptoms of lung damage that probably result from higher doses of paraquat than were encountered by cases involved in California occupational settings in the past two decades. However, there was no long-term follow-up of cases to detect delayed effects of exposure, including effects on pulmonary function. The systemic cases included a broad range of symptoms from neurotoxic-type symptoms (e.g., dizziness, nausea, and lightheadedness) to symptoms suggestive of more specific organ toxicity (e.g., hemoptysis). Without prospective evaluation of these cases, we were unable to confirm paraquat toxicity or to distinguish degrees of severity. However, the association of systemic cases with greater likelihood of hospitalization and with more lost work time provided us with an indirect confirmation of greater paraquat-induced morbidity in these cases.

When we compared the local/irritant cases with the systemic cases, we found that variables associated significantly with either group included job activity, caus-

Table 4.—Rate Ratios* of Paraquat-Related Illnesses Estimated by Multiple Poisson Regression Model of Crop, Season, and Method of Application (California, 1981–1985)†

Factors	Rate ratio	95% CI
Crop		
Other crops	1.0	
Noncrop areas	5.6	1.76 – 17.53
Fleshy fruit trees	3.6	1.18 – 11.21
Grapes	3.2	1.00 – 10.48
Nut trees	2.6	0.83 – 7.85
Season		
Winter	1.0	
Fall	2.3	0.92 – 5.71
Spring	2.7	1.38 – 5.15
Summer	4.1	1.91 – 8.61
Application		
Air	1.0	
Ground application	5.5	1.39 – 21.67
Other (hand)	99.1	22.16 – 443.47

*Illnesses/applications.
†N = 62 (based on sample sizes listed in Table 3).

es of contact with paraquat, body parts in contact with paraquat, and the outcome of that contact. Although applicators were more likely to experience a local/irritant illness when they came into contact with paraquat, workers exposed to fumes or concentrates were more likely to experience systemic illnesses.

Among body parts, the face—especially the eyes—were at greatest risk of exposure. Many eye illness cases stated that goggles or face shields were removed to attend to job activities at the time of illness. This suggests that there may be a need to improve eye protection devices for better visibility. Similarly, with respect to skin illnesses on hands, workers apparently removed gloves to perform some sensitive job activity.

The high number of cases who were less than 24 y of age reflects the age distribution of agricultural workers in general. Approximately one-fifth of farmworkers in California are 17–24 y of age.²² This age category comprises about 26.3% of all agricultural-related illnesses and injuries, as reported in 1985 by the California Department of Industrial Relations.²³ The higher proportion of this age group in our population (40.8%) indicated that this group should be a target for research and education to prevent pesticide-related illnesses.

Our conclusions are dependent on the accuracy of reporting. Both systems of reporting to the CDFA (i.e., PICRs and PURs) included the potential for underreporting. Farmers may fail to report paraquat applications, and the number of pesticide-related illnesses is probably underestimated, but the exact potential of underreporting figures is controversial and unknown.²⁴ However, we have no reason to suspect that underreporting of illnesses would affect the descriptive findings or relative risks observed.

Large differences were found among the methods of application with respect to risk of illness. The finding that hand application was at highest risk reaffirms

Smith's conclusions³ that users of backpack sprayers have higher exposures to paraquat than ground applicators, as demonstrated by the higher incidence of local irritant effects and the presence of paraquat in the urine of backpack spray users. Similarly, in a WH&S review of pesticide-exposure studies of mixers/loaders/applicators, the estimated exposure (per hour worked or unit-handled basis) of hand sprayers was much higher than exposure of tractor or aircraft-mounted sprayers.²⁵ In light of the potential toxicity of paraquat, alternatives to the practice of hand spraying of this pesticide should be used whenever possible.

The higher illness rates reported in summer may have resulted from increased absorption of paraquat; or from different physiological responses at higher temperatures, combined with heat stress and reduced use of protective clothing because of heat discomfort. This conclusion is supported by the observation that 11 of 78 (14.1%) violations (cited in the PICRs in 1981–1985) involved the misuse of protective gear or safety equipment, and 72.7% of those violations (8 of 11) were reported in the spring and summer.

We have identified specific factors associated with a higher risk of paraquat illness, and these factors should be targeted for future preventive efforts. Redesign of spray equipment and reduction or elimination of hand applications should help reduce the number of paraquat-related illnesses. Improvement of protective clothing for comfortable and convenient use, especially in the heat of summer, could also reduce the incidence of paraquat-related illnesses. Increased education and outreach efforts at factors associated with higher risk of paraquat illness, such as hand applications, may also be of value.

Paraquat causes both caustic, irritant effects and systemic poisonings—even with low regular-use exposures. Future research should address the potential long-term effects of paraquat-exposed workers and should also address strategies for reducing exposure.

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The authors would like to thank the staff of the Worker Health and Safety Branch of the California Department of Food and Agriculture (now Cal-EPA), among whom are Dr. Keith Maddy, Sue Edminston, Don Richmond, Cliff Smith, and Dr. Michael O'Malley, for providing the paraquat-related illness data and advice during the execution of this work. We also deeply appreciate the invaluable discussions with Dr. Michael O'Malley on case classification issues. We also thank Dr. Jay Beaumont and Jim Singleton from our Department for providing the Poisson regression calculation program and for their useful discussions, and we thank Dr. Ellen Gold for her assistance.

Supported by University of California Agricultural Health and Safety Center at Davis, NIOSH Cooperative Agreement #U07/CCU-906162; and the NIEHS Center for Environmental Health Sciences at UC Davis, Grant IP30 ES-05707.

Submitted for publication August 17, 1993; revised; accepted for publication October 10, 1994.

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