Agricultural Dust Exposure and Respiratory Symptoms Among California Farm Operators

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Objective: *To study whether dust exposure in California agriculture is a risk factor for respiratory symptoms.* ***Methods:*** *A population-based survey of 1947 California farmers collected respiratory symptoms, occupational and personal exposures. Associations between dust and respiratory symptoms were assessed by logistic regression models.* ***Results:*** *The prevalence of persistent wheeze was 8.6%, chronic bronchitis 3.8%, chronic cough 4.2%, and asthma 7.8%. Persistent wheeze was independently associated with dust in a dose–response fashion odds ratio, 1.2 (95% confidence interval [CI] = 0.8–2.0) and 1.8 (95% CI = 1.1–3.2) for low and high time in dust. A borderline significant association between chronic bronchitis and dust exposure was found. Asthma was associated with keeping livestock, but not with dust exposure.* ***Conclusions:*** *Occupational dust exposure among California farmers, only one third of whom tended animals, was independently associated with chronic respiratory symptoms.* (J Occup Environ Med. *2005;47:1157–1166*)

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Farming is one of the oldest human endeavors and holds an important place in the national and world economy. Despite progress in production methods, modern farming is associated with numerous hazardous exposures.[1] Many of these, including agricultural dust exposures, may cause a wide range of respiratory diseases.[2,3]

Most previous studies of respiratory disease among agricultural workers have been conducted in the midwest and northeastern United States or in other countries, and have generally focused on organic dust exposures associated with production of specific farm commodities. These studies have commonly involved populations working in enclosed facilities such as swine or other animal confinement buildings, dairy barns, or silos.[4–11] Research has commonly focused on asthma, organic dust toxic syndrome, hypersensitivity pneumonitis, and other agriculture-related respiratory diseases from these environments. Few studies of respiratory disease in agriculture have been conducted in the western United States, where differences in agricultural practices and climate may result in disparate exposures to farmers and farm workers.

California provides a unique and important setting for conducting respiratory health studies among farmers. The state has a broad range of climates and soil conditions, allowing impressive year-round agricultural variety and productivity. Approximately 30% of California's land area of just over 100 million acres is devoted to agricultural production, and the state has led the country in agricultural production for the past 50 years. There are almost 80,000 farms that produce over 200 major commodities.[12] Rainfall occurs only a few months of the year, and the long dry season may further increase exposure to agricultural dusts.

Recent research has documented high levels of dust exposure among California's agricultural workers.[13–15] Case reports suggest that this agricultural dust exposure may result in a silicate or mixed-dust pneumoconiosis,[16] but the respiratory effects of this exposure in population-based studies are largely unknown.

We report here the results of a cross-sectional survey designed to characterize the respiratory health of California farm operators and to identify occupational risk factors for respiratory disease. The study represents baseline data on a representative cohort of California farmers: the UC Davis Farmer Health Study.

Materials and Methods

Sample Selection

A random sample of 4500 farms was selected from the California Agricultural Statistics Service (CASS) list of approximately 57,000 farms. Details of the Farmer Health Study's sampling strategy have been described.[17,18] A farm is defined by CASS as a location that produced, or normally would have produced, $1000 or more in sales of agricultural products during the previous year. The survey was directed to the Primary Farm Operator (PFO) of the farm on the CASS database. The PFO is defined as the individual who is responsible for making the day-to-day decisions on the farm. The PFO may be the owner, a member of the owner's household, a salaried manager, or a tenant. In some instances, two or more individuals jointly made the day-to-day decisions. In these situations, interviewers attempted to question the individual making the majority of the decisions.

Questionnaire Development and Administration

A computer-assisted telephone interview (CATI) survey lasting approximately 40 minutes was administered by trained interviewers. We attempted to contact all 4500 potential participants.

Respiratory Outcome Measurements. Respondents were asked about respiratory symptoms and doctor-diagnosed asthma using standardized questions from the ATS-DLD questionnaire.[19] Chronic bronchitis (CB) was defined as producing phlegm on most days of the week for 3 or more months for 2 or more years. Chronic cough (CC) was defined as having a cough on most days or nights for 3 or more months. Persistent wheeze (PW) was defined as the chest sounding wheezy on most days or nights or if the chest sounds wheezy with colds and apart from colds.

Exposure Measurements. Farmers were asked the following question: "In the past year, approximately what percentage of the time that you spent farming did you spend working at a dusty job?" They were also asked to report the numbers of hours they personally worked on their farm operation over the last year (by season) and the percentage of time spent in the general categories of administrative, field, and livestock tasks.

We have previously reported the concentration and particle sizes of dusts found on farms in the same geographic area,[13,14] as well as the composition of dusts with respect to inhalable and respirable particles, endotoxins, and crystalline silica.[15] An analysis of the ability of farm workers on 10 farms in the UC Davis Farmer Health Study cohort to estimate their exposures to inhalable and respirable dust indicated that group subjective dust estimates correlated well with measured inhalable dust.[20]

Statistical Analysis

Analyses were completed using the SAS software package.[21] The dust exposure variable was created from the question "In the past year, approximately what percentage of the time that you spent farming did you spend working at a dusty job?" The average weekly hours spent farming in each season of the year was also asked. Both the percent time in a dusty environment (0–100%) and a combination continuous variable consisting of percent time in dust multiplied by average hours per week farming were considered as exposure variables. After univariate analysis of associations between selected independent and dependent variables, multivariable logistic regression models were constructed. These models all contained the following independent variables: age, sex, smoking status, and, when relevant, asthma. We considered in addition, socioeconomic status (SES), region, farm type, living on the farm, pesticide use, nonfarm exposures, and air pollution. The additional variables were only included in the logistic regression models if they affected the magnitude of the observed association between dust exposure and respiratory symptoms by at least 20%.

We defined an indicator of SES by multiplying ordinal responses for total family income and highest grade completed by the PFO. Low SES was defined as those PFOs in the lowest quartile, medium SES as those PFOs in the second and third quartiles, and high SES PFOs were those in the fourth/highest quartile.

A job/occupation variable was created to determine if off-farm occupation during the last 12 months was associated with any of the respiratory outcome variables. An occupational dust exposure variable was constructed from the farm operator's preceding-year nonfarming job history and classified as high, medium, or low dust exposure by an industrial hygienist independent of knowledge of symptoms or disease outcome status.

An air pollution variable was derived using county-specific PM-10 and ozone data. PM-10 and ozone were selected because they are the dominant air pollutants in California.[22] Additionally, ozone is an excellent indicator of photochemical smog. A table listing the most recent yearly averages for PM-10 and ozone levels for each county was constructed using data from the California Air Resources Board,[22] and an overall subjective classification of low, medium, or high air pollution was assigned to each county by an industrial hygienist.

Farm type was based on a classification we have previously used in analysis of California farmers.[14] Farms are classified as small or large mixed farms, field, fruit/nut, livestock, nursery, and vegetables depending on their main commodities.

Results

We were able to contact 2388 of the 4500 farms selected from the CASS list. Telephone interviews were completed by 1947 PFOs (80.4%) and 441 (18.2%) refused to be interviewed with the remainder unable to complete the interview. The representativeness of this sample compared with the CASS is good and has been discussed elsewhere.[17,18] Essentially there were no statistically significant differences found between the 4500 PFOs selected and the 52,943 PFOs not selected. We also assessed the representativeness of our respondents by comparing them with operators who refused to participate. In this comparison, refusals had significantly fewer total acres than respondents (399.2 vs 762.3, $P < 0.05$) but did not differ on acres of cropland, number of cattle, land in fruits/nuts, or land in vegetables. Other variables such as age, race, and income were not available from the CASS database.

One hundred PFOs who completed the telephone survey were randomly selected for a brief second telephone interview within 2 to 3 weeks of the original interview. Agreement between the dichotomous variables on the original and the reinterview was very good, with kappa values ranging from 0.74 to 0.92. Comparison of the two continuous variables (age and number of acres) showed a high degree of correlation (r = 1 and 0.997, respectively) and no significant difference in the means using a paired t test.

Demographic Characteristics

Most respondents were white, non-Hispanic (84.5%), and the mean age (±standard deviation [SD]) was 54 (±13.4) years (Table 1). Approx-

TABLE 1
California Farmer Health Study Demographics

	Males	Females	Total
Total [no. (%*)]	1751 (89.9)	196 (10.1)	1947 (100)
Age [years]			
Mean ± SD	54.4 ± 13.3	54.3 ± 13.8	54.4 ± 13.4
Median	54	54	54
Percent living on farm	1248 (71.3)	159 (81.5)	1407 (72.3)
Ethnicity [no. (%)]			
White, not Hispanic†	1471 (84.0)	174 (88.8)	1645 (84.5)
Hispanic‡	111 (6.3)	9 (4.6)	120 (6.2)
Asian, not Hispanic	82 (4.7)	7 (3.6)	89 (4.6)
Other, not Hispanic	81 (4.6)	6 (3.1)	87 (4.5)
Missing/unknown/refused	6 (0.3)	0	6 (0.3)
Education [no. (%)]			
<12 yr	169 (9.7)	17 (8.7)	186 (9.5)
12 yr	479 (27.4)	51 (26.0)	530 (27.2)
13–15 yr	520 (29.7)	63 (32.1)	583 (29.9)
16 yr	374 (21.4)	31 (15.8)	405 (20.8)
≥17 yr	202 (11.5)	33 (16.8)	235 (12.3)
Missing/unknown/refused	7 (0.4)	1 (0.5)	8 (0.5)
Percent of income from farming [no. (%)]			
<25%	567 (32.7)	92 (47.0)	659 (33.9)
25–50%	284 (16.4)	34 (17.4)	318 (16.4)
51–75%	127 (7.3)	15 (7.7)	142 (7.3)
>75%	754 (43.5)	49 (25.2)	803 (41.3)
Missing/unknown/refused	19 (1.1)	6 (3.1)	25 (1.3)
Smoking status [no. (%)]			
Never	950 (54.3)	129 (65.8)	1079 (55.4)
Former	592 (33.8)	35 (17.9)	627 (32.2)
Current	201 (11.5)	32 (16.3)	233 (12.0)
Missing/unknown/refused	8 (0.4)	0	8 (0.4)
Farm type [no. (%)]			
Large mixed	322 (18.4)	15 (7.7)	337 (17.3)
Field	142 (8.1)	6 (3.1)	148 (7.6)
Fruit	800 (45.7)	77 (39.3)	877 (45.0)
Livestock	206 (11.8)	49 (25)	255 (13.1)
Nursery	56 (3.2)	9 (4.6)	65 (3.3)
Small mixed	198 (11.3)	34 (17.4)	232 (11.9)
Vegetables	16 (0.9)	4 (2.0)	20 (1.0)
Missing/unknown/refused	11 (0.6)	2 (1.0)	13 (0.7)
Percent time at dusty job [no. (%)]			
0% time	358 (20.5)	72 (36.7)	430 (22.1)
1–49% time	1065 (60.8)	90 (45.9)	1155 (59.3)
>50% time	306 (17.5)	30 (15.3)	336 (17.3)
Missing/unknown/refused	22 (1.3)	4 (2.0)	26 (1.3)

*Percentages may not add to 100 as a result of rounding.

†Number of white farm operators in 1992 US and California Agricultural Census calculated by subtracting the sum of blacks, Asian/Pacific Islanders, and others from the total number of farm operators.

‡In the California and US 1992 Agricultural Census, Hispanic refers to “of Spanish origin” and includes many race/ethnic groups. These numbers are not comparable to the results from our survey which differentiates white non-Hispanics and black non-Hispanics from Hispanics.

SD indicates standard deviation.

TABLE 2
Prevalence of Respiratory Symptoms and Asthma by Farm Type

Farm Type	Persistent Wheeze (%)	Chronic Cough (%)	Chronic Bronchitis (%)	Asthma (%)
Large mixed	30 (8.9)	10 (3.0)	12 (3.6)	31 (9.2)
Field	16 (10.8)	6 (4.1)	6 (4.1)	11 (7.4)
Fruit	64 (7.3)	36 (4.1)	30 (3.4)	51 (5.8)
Livestock	29 (11.4)	17 (6.7)	10 (3.9)	30 (11.8)*
Nursery	2 (3.1)	3 (4.6)	4 (6.2)	4 (6.2)
Small mixed	22 (9.5)	9 (3.9)	11 (4.7)	22 (9.5)
Vegetables	4 (20.0)	1 (5.0)	1 (5.0)	2 (10.0)
Total	167/1947 = 8.58%	82/1947 = 4.21%	74/1947 = 3.84%	151/1947 = 7.8%

*$P \leq 0.05$ χ^2 test of independence.

imately 90% were male and one third completed 16 years or more of education. The median duration of full-time farming was 15 years, and the median acreage farmed during the previous year was 60 acres (not shown here[17]). A slightly higher proportion of females had 17 or more years of education compared with males. Additionally, females reported a lower percentage of total income from farming compared with males and were more likely to be never smokers.

The reported prevalence of current smoking among female farm operators (16%) was higher than among male farm operators (11.5%) (Table 1). Approximately 37% of the respondents worked at least 50% of the time at fieldwork such as planting, harvesting, or irrigating, whereas 22% reported no time spent in fieldwork. There was no association observed between amount of time spent on fieldwork and age. Approximately 62% of farm operators reported raising fruit, 26% reported raising field crops, 15% reported raising vegetables, and 34% reported raising livestock (total greater than 100% because of farmers raising multiple commodities).

Respiratory Symptoms

Among smokers, prevalences were significantly higher for PW, CC, and CB. PW was reported in 8.6% of respondents (Table 2) (21.5% of current smokers and 5.9% of never smokers), CB in 3.8% (10.7% of current smokers and 2.0% of never smokers), and CC in 4.2% (15% of current smokers and 2.5% of never smokers). There was little difference in physician-diagnosed asthma (overall prevalence 7.8%) between current smokers (8.2%) and never smokers (7.3%). Age (categorized as 18–39, 40–59, 60–79, 80+ years) was significantly associated with CC and was included in all logistic regression models.

Race/ethnicity was not associated with any of these outcomes in a chi-squared test of independence and was not included in the final models. Males had a significantly higher prevalence of PW compared with females (9.1% vs 4.1%, respectively, $P < 0.05$), but other symptoms showed no differences in prevalence by sex.

Asthma prevalence was higher among livestock farmers (11.8%) than among other PFOs; the difference was of borderline statistical significance ($P = 0.05$) (Table 2). PW prevalence was also slightly but not statistically significantly elevated among livestock farmers ($P = 0.08$). CC and CB showed no association with farm type.

Exposure Characteristics

Both the percent time in dust (0–100%, not normally distributed) and a combination variable of percent time in dust multiplied by average yearly hours per week farming were considered as exposure variables. The combination variable did not change the association between continuous dust exposure and respiratory symptoms and was not considered further. The time-in-dust variable was categorized as follows. The mean (±SD) for time spent in dust was 19.9% (±24.2) and the median was 10%. Respondents were grouped into "no" (0% time = 22.1% of respondents), "low" (1–49% time = 59.3% of respondents), and "high" (≥50% time = 17.3% of respondents) dust exposure groups (Table 1). Similar categorization of self-reported exposure to dust has been described in two other papers from this study.[23,24]

Farm operators reported infrequent use of protective respiratory equipment when working at a dusty job.[18] More than 80% of respondents answered that they rarely or never used cartridge respirator (84.5%) and 50% reported that they rarely or never used a disposable dust mask when working at a dusty job. Use of protective equipment was not correlated with increased dust exposure, and wearing a disposable dust mask was not a statistically significant independent predictor for any of the respiratory outcome variables.

Association Between Respiratory Symptoms and Exposures

A positive dose–response association with dust exposure was observed for PW (Table 3) after controlling for smoking (current, former, and never), age, sex, and physician-diagnosed asthma. The high dust category had

TABLE 3
Logistic Regression Model for Respiratory Symptoms and Adjusted Prevalence Odds Ratios* (95% Confidence Intervals)

	Persistent Wheeze	Chronic Cough	Chronic Bronchitis	Asthma
Age (yr)				
18–39	1.0	1.0	1.0	1.0
40–59	0.9 (0.5–1.5)	1.3 (0.6–3.1)	0.9 (0.4–1.9)	0.7 (0.5–1.2)
60–79	1.0 (0.5–1.6)	2.4 (1.0–5.6)	1.4 (0.6–3.0)	0.7 (0.4–1.2)
>79	0.2 (0.0–1.7)	3.2 (0.6–16.7)	2.5 (0.6–10.3)	1.6 (0.6–4.2)
Smoking status				
Never	1.0	1.0	1.0	1.0
Former	1.3 (0.9–2.0)	1.0 (0.5–1.8)	1.9 (1.0–3.4)	1.2 (0.8–1.8)
Current	4.7 (3.1–7.3)	7.3 (4.2–12.5)	5.8 (3.1–10.6)	1.2 (0.7–2.0)
Dust exposure				
None	1.0	1.0	1.0	1.0
Low	1.2 (0.8–2.0)	1.5 (0.8–2.8)	1.0 (0.5–1.8)	1.1 (0.8–1.8)
High	1.8 (1.1–3.2)	1.3 (0.6–2.9)	1.8 (0.9–3.7)	0.9 (0.5–1.6)
Live on farm	1.7 (1.1–2.6)	1.6 (0.9–3.0)	1.6 (0.9–3.0)	Not included
Male sex	2.9 (1.4–6.4)	2.0 (0.8–5.1)	2.4 (0.8–6.8)	0.9 (0.5–1.5)
Asthma per MD	7.7 (5.1–11.8)	1.2 (0.5–2.7)	4.3 (2.4–7.8)	Not included
Kept livestock in last year	Not included	Not included	Not included	†1.9 (1.3–2.6)

*Each odds ratio is adjusted for all other variables listed in the model for each symptom.
†For asthma, keeping livestock in the last 12 mo was included in the model instead of living on the farm.
NS indicates not significant.

nearly a twofold increased adjusted prevalence odds ratio (APOR) for PW compared with the no dust exposure category. Additionally, living on the farm, male sex, and self-reported physician-diagnosed asthma were also significantly associated with PW. There were no significant interactions observed between dust and geographic region in any of the models. Current cigarette smoking (APOR = 4.7) was approximately 2.5 times more strongly associated with PW than was high dust exposure (APOR = 1.8) in the multivariate model. Current smokers were more likely to report high (>50%) time in dust than were ex- and never smokers (25% vs 16–17%), but no interaction between dust exposure and smoking was significant ($\alpha = 0.05$) in the models.

A positive association was also observed for dust exposure in the logistic regression model for CB, but there was no evidence of a dose–response. We observed a positive trend for age in the models for CB and CC. As observed in the model for PW, the APOR for cigarette smoking in CB was nearly three times the APOR for high dust exposure. For doctor-diagnosed asthma, the only positive association was found with farmers who kept livestock over the previous year. Smoking status and current agricultural dust exposure were not significant in the model (Table 3).

Sex, physician-diagnosed asthma, and living on the farm were not significantly associated with CC and CB and did not alter the association between respiratory symptom and other variables. SES and geographic region were also evaluated as independent variables and were not statistically significant for any respiratory outcome. The nonfarm job/occupation variable described in "Methods" was also not statistically significant in any of the models after controlling for age, sex, and smoking.

Average annual PM-10 values ranged from a high of 78.9 $\mu g/m^3$ in San Bernardino County (Ontario Airport) to a low of 11.9 $\mu g/m^3$ in Lake County (Lakeport). Average annual ozone levels ranged from 0.011 ppm in Alameda county to 0.057 ppm in San Bernardino county with an annual mean of 0.028 ppm.[22] After controlling for age, sex, and smoking status, neither pollution variable achieved statistical significance or appreciably change the remaining coefficients in logistic regression models for any outcome.

We examined the effect of mixing, loading, or applying pesticides during the last year on PW, CB, CC, and asthma while controlling for the variables listed in Table 3. Pesticide use, categorized as high (>7 days in the last year), medium (1–7 days), and low (0 days), was not a statistically significant independent predictor for PW, CC, CB, or asthma.

Discussion

We report an independent association of persistent wheeze with self-reported dust exposure among California farm operators. Chronic cough and bronchitis also showed an association with dust exposure, although these were of borderline statistical significance. Living on the farm was also independently associated with an increased prevalence of wheezing.

Asthma was not independently associated with dust exposure, and there was no appreciable change in the magnitude of the prevalence odds ratios for PW, CC, or CB when asthma was removed as a covariate in the logistic regression models. The observed association of asthma with livestock farms may reflect the known association of farm animal exposure and asthma.[25–28] Asthma, including atopic and nonatopic forms, is less frequent in farmers than in the general population, but specific farm exposures may cause or exacerbate asthma.[29,30] Eduard et al found an association of total dust and asthma in nonatopic farmers, but exposures were mixed and a dose–response was not observed.[29] The influence of selective retirement of farmers because of asthma (healthy farmer effect) may also play into this complex relationship, but more specific research would be useful to characterize exposures on livestock farms and airway reactivity among California farmers.

Although cumulative and current exposure may both contribute to respiratory symptom prevalence, several studies show that current exposure is a more significant risk factor than historical exposure, and symptom prevalence decreases with time since exposure stopped.[31,32]

For example, there is very good evidence that current exposure to cigarette smoking is more pertinent to the association between smoking and current respiratory symptoms than historical smoking status.[32] This is also true of current exposures versus historic for "industrial bronchitis."[33] The reported prevalence of current smoking among our male respondents (11.5%) was lower than the adult statewide prevalence (17.0%), but the smoking prevalence among female farmers (16.3%) was higher than the statewide rate for adult females (12.3%).[34] These prevalences are not directly comparable because of different smoking criteria, but the lower prevalence in male farmers is consistent with other studies of farming populations that show lower smoking prevalences for farmers than for nonfarmers.[2,35] The higher prevalence of smoking among female California farm operators requires further investigation. We observed the expected strong association between chronic respiratory symptoms and current smoking and a smaller, nonsignificant but positive association among exsmokers. A dose–response association of occupational dust exposure with PW and with CB persisted after adjustment for the stronger associations with smoking. Restricting the model to farmers who had never smoked resulted in an APOR for PW of similar magnitude, but with wider confidence intervals, such that the association with dust exposure was no longer statistically significant (data not shown).

The magnitude of the association between PW and the variable "living on the farm" was intermediate between the association of PW with low-dust and high-dust variables. Because the focus of this study was occupational exposures, no effort was made to explore residential exposures. Approximately 70% of the respondents lived on the farm they operated. Although our expectation is that adverse respiratory exposures are quantitatively, if not qualitatively, greater in the farm work environment, ambient residential exposures may compound or exacerbate the effects of work exposures. More study is needed to characterize ambient dust and other exposures in rural farm residences.

The major strengths of this study are its large size and inclusion of the broad range of California agriculture. One potential source of bias is the healthy worker effort. It is possible that farmers with more serious respiratory symptoms self-selected themselves out of farming jobs with heavier dust exposure or high exposure to other respiratory irritants. Longitudinal studies would be necessary to confirm this hypothesis among California farmers. Another possibility is that sicker farmers selectively retired from farming. By using the CASS database, we were limited to those farms that produced $1000 or more in sales of agricultural products during the previous year. This may have eliminated some retired farmers. In a study of rural Iowans who were 65+ years old, those who were currently working were healthier than those who were retired.[36] Recent studies of Swedish and Dutch farmers have also observed a "healthy-farmer effect."[37,38] If the healthy worker effort is present in this study, the prevalence of respiratory symptoms we found is likely to be a conservative estimate of the true prevalence among farm operators, especially for those with more severe disease such as physician-diagnosed asthma.

Small farms are likely underrepresented in this study; the distribution of farm size differs from the California and U.S. Agriculture Censuses. A 1992 National Agricultural Statistics Service assessment of the CASS database showed that only 23% of the small farms (defined as having sales of agricultural commodities totaling $1000–$999 in the previous 12 months) were included in the CASS database.[39] In contrast, over 82% of large farms (sales of $100,000+) were included. This overrepresentation of larger farms may limit the generalizability of our results to farms generating more than $100,000 in sales, although we have no reason to suspect a bias as a result of this. In addition, of the 1871 respondents whose average weekly hours farming were greater than zero (51 did not answer), 25% worked less than 12.5 hours a week and only 38.4% spent 40 or more hours a week on farm tasks (mean average hours per week 33.7, SD 23.8, median 30). If only full-time farmers were surveyed, the distribution of dust exposure may have been different, and it is possible there would have been a greater proportion in the high dust category, where it is expected the greatest effect of irritant particles on respiratory symptoms would be seen.

For exposure subgroups of approximately 500, our study had adequate power to detect relative risks of 2.0 or greater for conditions occurring in 5% of unexposed persons.

Because many of our subgroups such as swine farmers held fewer than 500 subjects, it is possible that the small sample size precluded the finding of significant positive associations.

It was not within the scope of this study to include an objective exposure assessment for the numerous tasks performed by farmers. Although questionnaires do not allow for objectively validated exposure assessments, they do provide a qualitative assessment of exposure for respiratory hazards. Moreover, there is evidence that subjective assessments of dust exposure may be meaningful surrogates for more expensive quantitative measurements. In a study of the relation between subjective dust exposure estimates and quantitative dust exposure measurements in California farm workers, Nieuwenhuijsen and colleagues found that subjectively grouped estimates of workers' inhalable dust exposure were strongly correlated with quantitative measurements ($r^2 = 0.81$), although a lower correlation was seen for individual estimates of inhalable particles ($r^2 = 0.67$).[20] Age, the number of years working in agriculture, education level, and the presence of any respiratory symptoms did not have a significant independent effect on the relationship between measured dust levels and subjective dust estimates.

The primary effect of relying on a questionnaire is likely to be imprecise exposure assessment, making it difficult to detect true associations. Results may also be biased if persons with respiratory disease are more likely to perceive their work environment as dusty. We do not know the magnitude of these two potential sources of error. However, consistency of the observed association between dust exposure and respiratory symptoms, the presence of a dose–response, and their persistence after controlling for history of asthma and other potential cofounders all support the likelihood of a causal association of these observations.

We are not aware of similar studies using a population-based sample of farm operators in the western United States. However, studies among farmers producing specific agricultural commodities (eg, swine, dairy cattle, beef cattle) have, in general, observed higher prevalences for respiratory symptoms than we report here for California farmers.[6,40–43] For example, Zejda reported a prevalence of 25% for wheezing among swine and grain farmers in Saskatchewan.[44] Dosman observed a prevalence of 27.4% for wheezing among grain and beef cattle farmers in Saskatchewan.[45] However, in a study of Ohio cash grain farmers, similar prevalences for wheezing were observed, although cough and phlegm prevalences were higher than in California farmers.[46] A study of cattle farmers in Germany found higher prevalences of work-related respiratory symptoms with no difference by cigarette smoking status.[47] A recent European study of animal farmers found the highest prevalences of respiratory symptoms among pig farmers and increased prevalences of cough with phlegm among all animal farmers compared with the general population.[48] Another recent European study of farmers also found higher prevalences of bronchitis, but lower asthma and atopy prevalences than in the UC Davis Farmer Health Study population.[49]

Interpretation of differences among these and other studies is difficult because of differences in adjustment for age, smoking, and definition of symptoms and exposures. Wheezing in particular is based on different questions, and higher prevalences may be in part the result of less restrictive definitions than the one used in this study. A direct comparison of the UC Davis Farmer Health Study population with a European farming population (taken from Denmark, Germany, Switzerland, and Spain)[50] demonstrated lower prevalence of asthma (2.8% vs 4.7%) in the European versus Californian group but a higher prevalence of chronic bronchitis (10.7% in Europe vs 4.4% in California). The difference in asthma prevalence may relate to sociodemographic characteristics of the farm operators, given that the region (California vs Europe) was no longer a significant risk factor for asthma after adjusting for age, sex, income, and smoking status. The higher rates of chronic bronchitis in Europe were thought to be related to work inside confinement buildings and greenhouses with high exposures to organic dusts, which are less common in California. Again, differences in farming practices between the warm, dry California climate, and other farming regions are a likely explanation for many of the discrepancies in respiratory symptom prevalences.

This study encompassed a broad range of farmers and commodities. Seventy-six percent of the operators surveyed in our study were personally involved in cultivating crops, but only 31% of the operators raised livestock during the last 12 months. Therefore, in comparison to studies in which the primary population consists of farmers with exposure to indoor farming environments (eg, animal confinement), the lower prevalence of PW found in our study is not surprising. There has been much work demonstrating respiratory symptoms among farmers exposed to organic dusts from animal confinement and other crop-generated dusts (eg, molds, fungi, pollen, endotoxin, Gram-negative bacteria, and mites).[41,48] Conversely, little attention has been paid to exposures of farmers to dusts comprised predominantly of inorganic particles. Most dusts generated by agricultural operations have a mix of organic and inorganic components, and currently it is impossible to attribute respiratory symptoms to specific exposures in these mixtures. Respiratory outcomes such as PW, CB, and CC as a result of repeated exposure to inorganic agricultural dust are biologically plausible. Exposure to ambient inorganic particles from environmental, industrial, or traffic (particulate and gaseous emissions) sources has also been associated with increased respiratory symptoms.[51,52]

We are unable to distinguish between atopic and nonatopic etiologies with the range of symptoms found in this study. In addition to airway irritant effects, respiratory symptoms resulting from dusts comprised predominantly of inorganic particles in this population may reflect early changes of dust-induced interstitial fibrosis.[53] Agricultural dusts in dry climate areas such as California have been associated with pneumoconiosis in case reports and case series.[16,54,55] A cross-sectional survey of rice farmers in California found radiographic changes suggestive of pneumoconiosis (ILO [International Labor Organization] profusion score ≥1/0) in 10.1% of the sample,[56] and studies of California farm workers exposed to agricultural dusts have observed reduced forced vital capacity consistent with restrictive lung function.[57]

In the last few years, the composition of and exposure to agricultural dusts in California and other dry climate regions have begun to be characterized.[53,58] Silicates are the predominant mineral present, but crystalline silica may represent up to 20% of soil and dust particle composition.[15,59] In a study of California rice farms, Lawson reported total dust levels as high as 72 mg/m^3 and respirable dust levels as high as 5.24 mg/m^3 during field preparation.[60] Clausnitzner reported a high of 10.3 mg/m^3 for respirable dust levels on a sample of 18 California farms in one county.[61] In a series of studies, Niewenhuijsen and colleagues have reported personal dust exposures with a geometric mean (GM) of up to 100 mg/m^3 during various ground preparation operations and inhalable and respirable dust concentrations up to 50 and 5 mg/m^3 GM, respectively.[13–15,23,62.63] In general, the composition of California agricultural dusts is similar to soils, with the predominant mineral comprised of silicates.[15] Animal studies suggest an independent association of these dusts with respiratory pathology. Using samples of dust collected from farms in this Farmer Health Study cohort, Rajini et al[64] showed that rats experienced inflammatory responses after being exposed to the dusts in inhalation studies conducted in laboratories at University of California, Davis. Nieuwenhuijsen[15] determined in this cohort of farms that crystalline silica made up on average 18.6% of the total mass of respirable dust samples.

This study represents the first attempt to characterize the respiratory health of a large and diverse population of California farm operators. The observed association between respiratory symptoms and dust exposure suggests that California farmers have exposures to agents in agricultural dust that adversely affect respiratory health, and inorganic dust may be a significant contributor to the risk. Future studies should address the prevalence and risk factors for atopic versus nonatopic wheezing and asthma, identifying active agents, mechanism, associated changes in pulmonary function, airway reactivity, and long-term consequences.

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