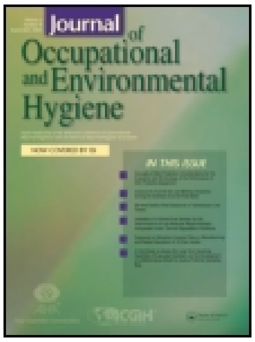

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Personal Exposures to Inorganic and Organic Dust in Manual Harvest of California Citrus and Table Grapes

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The aim of this study was to determine characteristics of personal exposure to inorganic and organic dust during manual harvest operations of California citrus and table grapes. Personal exposures to inhalable dust and respirable dust were measured five times over a 4-month period of harvesting season. We analyzed components of the dust samples for mineralogy, respirable quartz, endotoxin, and total and culturable microorganisms. Workers manually harvesting were exposed to a complex mixture of inorganic and organic dust. Exposures for citrus harvest had geometric means of 39.7 mg/m^3 for inhalable dust and 1.14 mg/m^3 for respirable dust. These exposures were significantly higher than those for table grape operations and exceeded the threshold limit value for inhalable dust and respirable quartz. Exposures for table grape operations were lower than the threshold limit value, except inhalable dust exposure during leaf pulling. Considered independently, exposures to inhalable dust and respirable quartz in citrus harvest may be high enough to cause respiratory health effects. The degree of vigorous contact with foliage appeared to be a significant determining factor of exposures in manual harvesting.

Keywords agricultural dust, bioaerosols, endotoxin, harvest, inorganic dust

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INTRODUCTION

Epidemiologic studies provide clear evidence of increased incidence and prevalence of respiratory symptoms and disease in agricultural populations.(1) The increase in respiratory disease morbidity and mortality in agricultural workers is of particular concern because cigarette smoking prevalence is lower among farming than nonfarming populations.(2,3) Studies of agricultural workers in numerous specific commodities (e.g., swine, grain, dairy, poultry, and grapes) have similarly shown increased respiratory disease prevalence or incidence attributable to workplace dust exposure.(1) We have previously reported a reduced vital capacity among grape workers, consistent with restrictive pulmonary function from mixed-dust exposure in agricultural worker population.(4) The study suggested that inorganic dust exposures to grape workers caused the respiratory effects, but no measurements of dust were made.

Agricultural workers are exposed to multiple pollutants, and the exposure levels can exceed exposure standards.(1) The agricultural workplace is a source of occupational exposure of farmers and farm workers to mixed dust. These components include inorganic dust, pesticides, organic dust, disinfectants, fertilizers, feed additives, and combustion products.(1) Organic dust includes pollen, grain dust, bits of plant debris, animal manure and animal bedding, and bioaerosols of microorganisms such as bacteria and fungi. Exposure levels vary greatly depending on crop, climate, and the specific activity. One of the dustiest conditions occurs during soil preparation for field crops. The dry climate in much of California aggravates dust emission. Various operations generate a wide range of respirable dust concentrations in the dust plume, ranging between 0.33 mg/m^3 from disking corn stubble to 10.3 mg/m^3 from ripping soil.(6)

Harvest is another major activity for farmers and agricultural workers. Mechanical harvesting of certain crops may result in substantial dust production. Mechanical harvest of almonds generated 26,513 mg/m^3 of inhalable dust and 154 mg/m^3 of respirable dust when dust levels were measured in the dust plume.(7) Personal exposure in mechanical harvesting of tree crops averaged 52.7 mg/m^{3}of inhalable dust and

4.5 mg/m^3 of respirable dust.[8] High levels of exposure were also observed in mechanical harvesting of other crops, and the exposures were significantly lower in enclosed-cab tractors.

Although total emission amounts are less and plume size is smaller from manual harvest than from mechanical harvest, the distance between the dust source and the worker is also less. Agricultural workers can be exposed to a significant amount of dust during manual harvest. Means of workers' respirable dust exposure during manual harvest of tree crops and vegetables were 1.82 and 0.73 mg/m^3, respectively, and inhalable dust exposures were 1.91 and 2.61 mg/m^3, respectively.[8] Respirable dust exposure in peach manual harvest was 0.5 mg/m^3.[9] Manual harvest was one of the major contributors to chronic respirable dust exposure, but not to inhalable dust, when annual exposure of farmers was estimated by exposure during tasks, task duration, and task frequency.[10]

The purpose of this study was to examine inorganic and organic fractions of dust to which farm workers were exposed in the production of summer citrus and table grapes in the San Joaquin Valley of California. We characterized the inorganic fraction of the dust from personal exposure samples, dust dislodged from foliar surfaces, and samples taken directly from the soil. We also evaluated organic dust exposures including endotoxin, bacteria and fungi.

METHODS

Experimental Design

Personal exposure samples were collected and analyzed from two groups of agricultural field workers in the San Joaquin Valley of California. The first group was involved in citrus harvest in Tulare County. The second group was involved in table grape operations in Kern County. Airborne dust exposures were measured for a total of 5 working days for each crop over the peak labor months of June through September 1992. Sampling dates were approximately 1 month apart, except in September, when 2 consecutive days were monitored for each crop. Tasks were selected to be representative of those performed by labor crews throughout the summer months. For citrus, harvesting was the task measured for all five sampling visits. For table grapes, the task on the first sampling visit was leaf pulling; harvesting table grapes was conducted for the remaining four sampling visits. For both crops, 14 workers were monitored during each visit. Ten workers were fitted with respirable dust samplers to measure respirable dust and respirable quartz exposures. Four workers were fitted with inhalable dust samplers to measure inhalable dust, endotoxin, and total bacteria and fungi exposures.

Selection of Farm Locations and Worker Participants

A fruit packing company in Tulare County provided access to all the citrus harvest sites. A producer of table grapes in Kern County provided access to all the sites visited for table grape production. Tulare and Kern counties were chosen because they are very significant producers of citrus and table grapes, and because they were the main field locations in a previous epidemiologic study that had found reduced forced vital capacity in grape harvest workers.[4] From each farm location, and on each sampling date, a convenience sample of individual farm workers was used, based on the willingness of individuals to participate. No attempt was made to follow the same individuals throughout the study.

Collection of Samples

We collected inhalable dust, endotoxin, and total bacteria and fungi samples with an open face polystyrene cassette of 37 mm diameter with a 0.4 μm pore size polycarbonate filter, and a pump flow rate of 2.0 L/min. The samples were collected in the breathing zone. Sampling times for endotoxin, total bacteria and fungi, and inhalable dust were regulated with the goal of collecting approximately 1 mg of total mass. On the first sampling day, eight of nine inhalable samples exceeded a total mass of 2 mg. The concentrations for that day are probably conservative because some of the sampled material may have not adhered to the filters. Except on the first sampling day, samples were less than 2 mg of total mass. About half of the samples had less than 1 mg of total mass. For citrus harvest a typical sample time was 15 min. For table grape operations a typical sample time was 1 hour. For respirable dust and respirable quartz samples, a 10-mm nylon cyclone was used with a 5 μm pore size PVC filter, and a pump flow rate of 1.7 L/min. Respirable fraction samples were typically collected for 6 to 8 hours.

A two-stage Andersen sampler (Graseby Andersen, Atlanta, Ga.) was used to collect culturable airborne bioaerosol samples within 2 feet of employees. Fungal samples were collected on Sabouraud media. Bacterial samples were collected on trypticase soy agar with 5% sheep's blood (TSA II). Sampling times averaged 30 sec. One sample and one duplicate (consisting of two plates each) were collected daily for bacteria and for fungi. Field blanks were generated daily, and one laboratory blank was generated per medium batch.

We collected dust from leaf surfaces by agitating the foliage in front of a canopy connected to a high-volume pump (Gast Model 1532, SKC, Fullerton, Calif.). This approach was used to provide sufficient dust samples for chemical characterization of the bulk dust. The pump was operated at 30 L/min and was fitted with a 20 cm $\times$ 25 cm polycarbonate filter with 0.4 μm pore size. All dust shaken off the leaves was collected on the filter. Sampling time was approximately 90 min per sample, with two samples collected from each farm.

Four surface soil samples were collected daily. Two samples each were collected from under plants and from rows between plants. Sample locations were selected to represent the limits of the area worked by employees on that day. For example, samples would be collected from the northeast corner and the southwest corner of the section of orchard or vineyard being harvested. Samples were collected with a stainless steel trowel from approximately 0–3 inches below the soil surface and placed in plastic bags.

Analysis of Samples

Inhalable Dust, Respirable Dust, and Respirable Quartz

The filters were pre- and postweighed, controlling for moisture effects, to determine sample weight and dust concentration. Quantitative analyses of respirable quartz were performed using powder X-ray diffraction. Filters for respirable dust were ashed in a muffle furnace, and the residue from the filter was transferred to a 25 mm diameter silver membrane filter. The silver membrane was step-scanned from about 26 to 27 degrees 2 theta (quartz diffraction maximum) using a Diano XRD-8000 (Waburn, Mass.). The diffraction peak area for each sample was compared with the quartz peak area from a set of prepared standards (20 to 200 μg quartz per filter) to determine the mass of quartz and the corresponding percentage in the original dust (Method 7500).[11]

Dust from Foliage and Soil

Two samples each of the citrus dust and the grape dust were analyzed for total sulfur content by inductively coupled plasma spectrometry (Perkin Elmer Optima 3000 DV ICP, Perkin Elmer, Shelton, Conn.). The mineral composition of the foliar total dusts was determined by X-ray diffraction (Siemens D5000 X-Ray Diffractometer, Bruker AXS, Madison, Wis.) after the dusts were ashed in a muffle furnace and transferred to silver membranes. Total foliar dust samples were dry-sieved to obtain a <10 μm diameter size fraction for particle component analysis.

For particle component analysis, an aliquot of the sample was ashed in a Denton PE-120 Plasma Asher (Cherry Hill, N.J.) for 24 hours to remove all organic matter, and the residue was made up to 100 mL with double distilled water with a drop of Aerosol OT. After sonication, aliquots were filtered through 0.1 μm pore size polycarbonate filters and mounted on carbon planchettes. Using a scanning electron microscope in back-scattered electronic-imaging mode an average of 1000 or more particles in each sample were randomly analyzed for elemental analysis using an energy dispersive X-ray analyzer (Kevex 7000 EDXA System, Kevex International, Foster City, Calif.) at 1000× according to the methods described by Stettler et al.[12]

Soil particle size-distribution (% sand, silt, and clay) of Na-dispersed samples was determined by the standard pipette and sieving method.[13]

Airborne Endotoxin

Filters with collected dusts were analyzed for endotoxin content by means of the kinetic chromogenic modification of the Limulus amebocyte lysate assay (Kinetic-QCL; BioWhittaker, Walkersville, Md.) as previously described.[14] Sterile nonpyrogenic plasticware was used throughout the analyses. Each filter was extracted separately in 10 mL of sterile nonpyrogenic water (LAL Reagent Water; BioWhittaker) by rocking at room temperature for 60 min. The extracts were decanted into separate plastic tubes, centrifuged for 10 min at $1000 \times g$, and the resulting supernatant fluids were assayed in duplicate for the presence of endotoxin. The results are reported in terms of endotoxin units (EU) per milligram of dust, and calculations were made to express the airborne levels in terms of EU per cubic meter of air.

Airborne Total Bacteria and Fungi

Total culturable and nonculturable bacteria and fungi were quantified using the fluorescence microscopy NFE method.[15] For each filter collected for total fungi and bacteria, the collected microorganisms were extracted by washing three times with a filter sterilized aqueous solution of 0.01% Tween 80 and 1% formaldehyde. For each washing, 1.5 mL of wash solution was injected into the support pad through the outlet connection of the cassette, after which the connection was plugged. Five mL of the wash solution was pipetted into the inlet hold, after which the cassette was replugged and vigorously shaken on a shaking table for 5 min. The cassette was then opened and the suspension removed with a syringe. The three wash suspensions were pooled, and serial dilutions of this solution were filtered through black polycarbonate filters. The filter and the adhered microorganisms were stained for 2 min using a filtered acridine orange solution (0.1 mg/mL, pH = 7.2 in phosphate buffer).

The filters were removed, dried in a laminar flow hood, and mounted on a microscope slide with Cargile A immersion oil and a cover-slip. The number of microorganisms on the filter surface was counted at a magnification of 1000× with an epifluorescence microscope. Spores and bacteria were counted until all organisms in 40 high-power fields had been evaluated.

Airborne Culturable Bacteria and Fungi

The collected culture plates were incubated at 30°C and 25°C for bacterial plates and fungal plates, respectively. Colonies were counted using a colony counter. Results were expressed as colony forming units and were adjusted for coincident collection.

RESULTS

Inorganic and organic dust exposures were obtained for both citrus harvest and table grape operations (see Table I). Inhalable dust exposures in citrus harvest had a geometric mean of 39.7 mg/m^3, whereas inhalable dust exposure in table grape operations had a geometric mean of 3.5 mg/m^3. Table II shows inhalable dust exposures for citrus harvest and table grape harvest. The inhalable dust exposures in citrus harvest appeared to increase through the season. Exposures for table grape operations on June 17 were higher than the other days, despite potential loss due to overloading. Exposure on that day was measured during leaf pulling, which causes significant contact between the workers and foliage.

Geometric means of respirable dust exposures were 1.14 mg/m^3 for citrus harvest and 0.23 mg/m^3 for table grape operation (Table III). Geometric means of respirable quartz exposures were 0.08 mg/m^3 for citrus harvest and 0.02 mg/m^3 for table grape operations. The proportion of respirable quartz to respirable dust was similar in both crops. The percentage of

TABLE I. Summary of Dust Exposures in Citrus Harvest and Table Grape Operations

	Citrus						Table Grape					
	No.	Mean ± SD[A]	Median	GM[B]	GSD[C]	Interquartile Range	No.	Mean ± SD[A]	Median	GM[B]	GSD[C]	Interquartile Range
Inhalable dust (mg/m^3)	21	46.9 ± 27.9	41.8	39.7	1.8	21.5–65.1	20	5.7 ± 6.4	3.2	3.5	2.6	2.0–5.5
Respirable dust (mg/m^3)	47	1.2 ± 0.5	1.2	1.14	1.51	1.0–1.5	47	0.39 ± 0.42	0.22	0.23	2.79	0.09–0.49
Respirable quartz (mg/m^3)	47	0.09 ± 0.03	0.08	0.08	1.45	0.06–0.10	47	0.03 ± 0.02	0.02	0.02	1.90	0.01–0.04
Endotoxin (endotoxin units/m^3)	11	293.2 ± 267	122	201	2.5	101–518	10	17.2 ± 32.5	6.2	11	2.8	5.7–12.6
Total bacteria and fungi (organisms/m^3)	10	$1.9 \times 10^8 \pm 1.8 \times 10^8$	1.2×10^8	1.32×10^8	2.3	$0.62 \times 10^8 - 2.1 \times 10^8$	9	$0.65 \times 10^8 \pm 0.72 \times 10^8$	0.3×10^8	0.42×10^8	2.5	$0.24 \times 10^8 - 0.52 \times 10^8$
Culturable bacteria (CFU/m^3)	28	13787 ± 11793	10431	8700	2.9	3707–21793	28	18530 ± 27219	13621	6300	3.3	5276–19241
Culturable fungi (CFU/m^3)	32	13274 ± 21377	6828	11000	2.6	2414–12345	32	8994 ± 7017	6759	6200	2.8	3310–13828

[A] SD = standard deviation.
[B] GM = geometric mean.
[C] GSD = geometric standard deviation.

TABLE II. Inhalable Dust Exposures in Citrus and Grape Harvest (mg/m^3)

Crop	Date	Mean ± SD^A	GM^B	GSD^C	Min	Max	No. of Samples
Orange	June 16	21.21 ± 2.02	21.14	1.10	19.54	24.59	5
	July 8	26.93 ± 6.68	26.31	1.28	20.86	34.56	4
	August 18	37.71 ± 11.01	36.17	1.43	21.26	43.99	4
	September 8	69.73 ± 19.55	67.68	1.33	49.43	92.79	4
	September 9	85.47 ± 15.19	84.38	1.21	65.05	100.83	4
Grape	June 17	17.14 ± 5.68	16.22	1.51	8.81	21.49	4
	July 10	2.91 ± 1.67	2.48	2.00	0.99	4.76	4
	August 10	1.64 ± 1.04	1.46	1.70	0.98	3.19	4
	September 10	4.06 ± 1.51	3.89	1.39	3.12	6.29	4
	September 11	2.57 ± 1.05	2.44	1.42	2.00	4.15	4

Notes: Data from June 16 and 17 may be conservative due to overloading of sampler.
^{A}SD = standard deviation.
^{B}GM = geometric mean.
^{C}GSD = geometric standard deviation.

respirable quartz in the respirable dust averaged 7% for citrus harvest samples and 9% for table grape operation samples. Respirable dust exposure for table grape operations on June 17 (leaf pulling) was higher than on the other days. However, respirable quartz exposures were not higher on June 17.

Temporal variability of personal exposures was determined by analysis of variance (ANOVA). All exposures to inhalable dust, respirable dust, and respirable quartz were significantly different among the 5 sampling days in both crops ($p < 0.01$). Inhalable dust exposures in citrus increased through the season, but exposures to respirable dust and quartz did not. When we excluded the exposure data from the first day of table grape leaf pulling from the ANOVA, the inhalable, respirable dust, and respirable quartz exposures were not significantly different among the 4 sampling days ($p > 0.1$).

Inhalable dust samples were analyzed for endotoxin and total microorganisms (Table I). Endotoxin exposure in citrus was significantly higher than in table grapes throughout sampling periods (ANOVA, $p < 0.01$). Geometric means of endotoxin exposures for the citrus and table grape samples were 201 and 11 EU/m^3, respectively. The ratios of total and culturable microorganisms between two crops were much less substantial than the ratio in endotoxin. The geometric mean of total bacteria and fungi number in citrus was 1.32×10^8 organisms/m^3 while the geometric mean in table grapes was 0.42×10^8 organisms/m^3. Culturable bacteria exposures in citrus and table grapes were 8700 CFU/m^3 and 6300 CFU/m^3, respectively. Culturable fungi exposures in citrus and table grapes were 11,000 CFU/m^3 and 6200 CFU/m^3, respectively. Total bacteria and fungi were represented morphologically by 51.3% cocci, 44.3% bacilli, and 4.4% spores. The morphologic distributions were similar between citrus and table grape operations.

Correlation between dust exposures was determined by Pearson's correlation coefficients with log transformed data, using STATA software.[16] The strongest correlations were observed between inhalable dust and endotoxin in citrus (r = 0.877) and inhalable dust and total microorganisms in table grapes (r = 0.894). The moderate correlations were between respirable dust and respirable quartz in citrus (r = 0.6944) and in table grapes (r = 0.796), between inhalable dust and total microorganisms in citrus (r = 0.677) and between fungi and bacteria in table grapes (r = 0.743). The weak correlations were between fungi and bacteria in citrus (r = 0.460) and between inhalable dust and endotoxin in table grapes (r = 0.548).

The two citrus dusts contained 2.55 and 4.36 g kg^{-1} total S (average 3.46 g kg^{-1}). The two table grape dust samples contained 4.07 and 3.37 g kg^{-1} total S (average 3.74 g kg^{-1}). Qualitatively, the mineralogy of the total foliar dusts from citrus and table grapes is similar (Figure 1). Both foliar dusts are dominated by quartz, feldspar, and layer silicates. Previous work showed that the citrus foliar dusts contained 32 to 37% quartz, whereas the table grape total foliar dust contained 39 to 41% quartz.[17]

The distribution of minerals in the <10 μm diameter foliar dust samples was similar for citrus orchards and table grape vineyards based on the electron microscope particle analysis (Table IV). In both locations, aluminum silicates predominated, followed by quartz, with the ratio of aluminum silicates to quartz of roughly 10:1. Aluminum silicates and quartz comprised almost 86% of the foliar dust. The aluminum silicates are most likely dominated by feldspars and layer silicates such as biotite and smectite (based on X-ray results, above). The percentages of quartz in this fraction were 10.1% for citrus dust and 7.9% for table grape dust. These quartz values are similar to the quartz contents of the respirable dust fractions reported above but are much lower than the quartz contents of the total foliar dusts. Quartz is physically resistant to being broken into finer particles due to its crystal structure and tends to persist in the coarser soil and dust fractions and be less abundant in finer fractions.

We assessed correlations (least-squares linear regression) between soil particle size distribution (soil texture, proportions of sand, silt, and clay) in the citrus orchard or vineyard and exposures to respirable dust and quartz. For citrus dust we found the strongest correlation between respirable quartz and

TABLE III. Respirable Dust and Quartz Exposure in Citrus and Table Grape Harvest

		Respirable Dust (mg/m^3)						Respirable Quartz (mg/m^3)					
Crop	Date	Mean ± SD[A]	GM[B]	GSD[C]	Min	Max	No. of Samples	Mean ± SD[A]	GM[B]	GSD[C]	Min	Max	No. of Samples
Orange	June 16	1.04 ± 0.28	1.00	1.33	0.63	1.53	9	0.068 ± 0.020	0.065	1.351	0.040	0.100	9
	July 8	1.08 ± 0.34	1.02	1.45	0.44	1.61	10	0.066 ± 0.018	0.064	1.334	0.040	0.090	10
	August 18	1.62 ± 0.51	1.54	1.40	0.88	2.39	10	0.118 ± 0.038	0.112	1.422	0.060	0.180	10
	September 8	1.04 ± 0.49	0.92	1.74	0.30	1.95	10	0.089 ± 0.035	0.083	1.478	0.050	0.160	10
	September 9	1.35 ± 0.30	1.32	1.24	0.99	1.87	8	0.088 ± 0.017	0.086	1.200	0.070	0.120	8
Grape	June 17	1.01 ± 0.29	0.97	1.39	0.49	1.36	10	0.048 ± 0.016	0.046	1.416	0.030	0.070	10
	July 10	0.12 ± 0.10	0.09	1.98	0.05	0.36	10	0.020 ± 0.006	0.019	1.427	0.010	0.030	6[D]
	August 10	0.35 ± 0.51	0.19	3.01	0.04	1.73	10	0.026 ± 0.023	0.020	2.067	0.010	0.080	8[E]
	September 10	0.29 ± 0.15	0.26	1.59	0.15	0.60	10	0.024 ± 0.012	0.022	1.719	0.010	0.040	9[F]
	September 11	0.16 ± 0.08	0.15	1.64	0.09	0.28	10	0.013 ± 0.005	0.013	1.414	0.010	0.020	9[F]

[A] SD = standard deviation.
[B] GM = geometric mean.
[C] GSD = geometric standard deviation.
[D] Four samples were <LOD.
[E] Two samples were <LOD.
[F] One sample was <LOD.

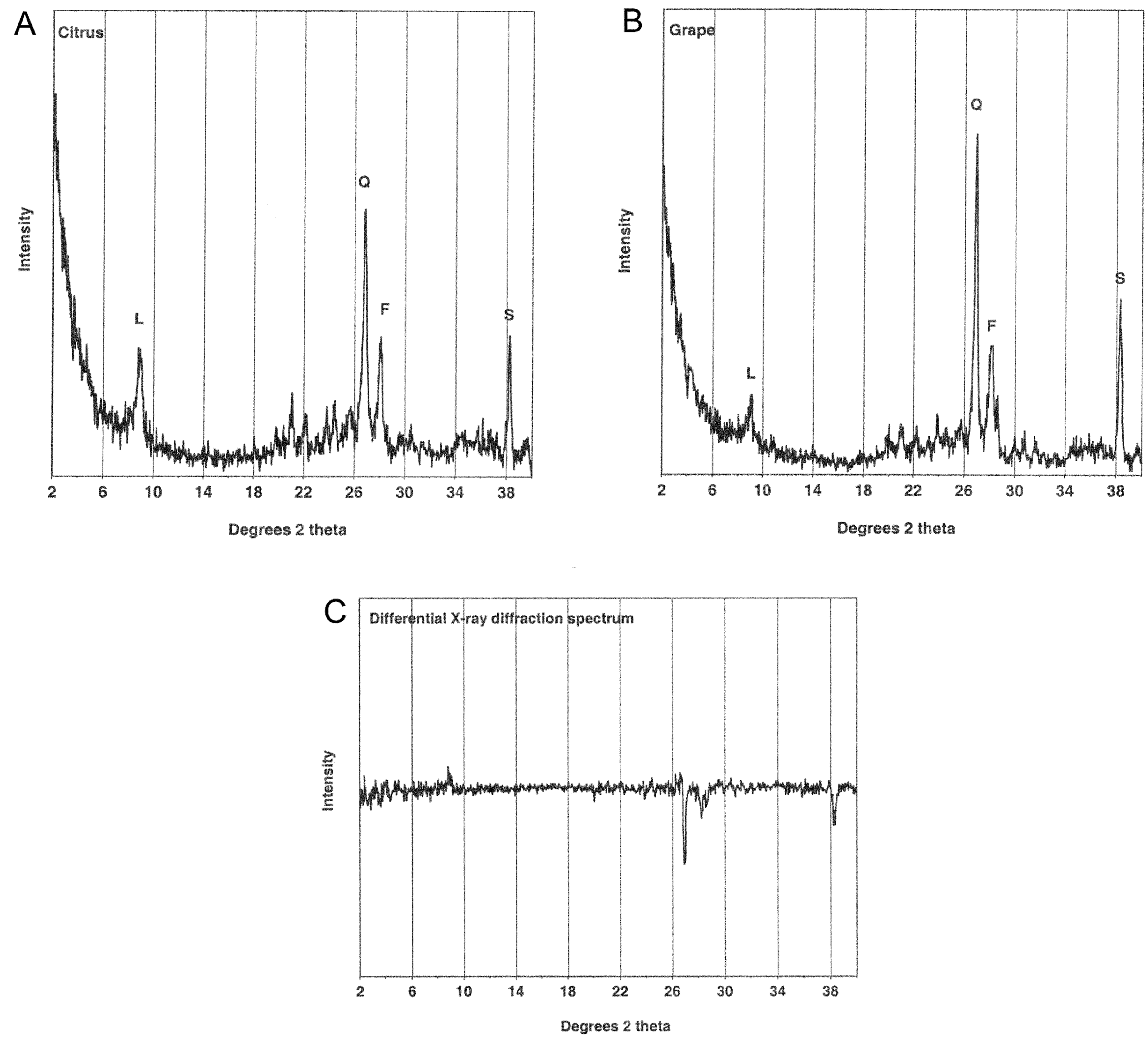

FIGURE 1. X-ray diffractograms of foliar dust mounted on a silver membrane (S). Both citrus (A) and grape (B) dusts contain quartz (Q), feldspar (F), and layer silicates (L), most likely biotite. The differential spectrum (C) was produced by subtracting (B) from (A), and shows that the composition is similar, but that the relative proportion of each mineral (hence, peak intensity) differs in the two dusts.

soil clay content (mg/m^3 respirable quartz = 0.0015 [% clay in the soil] + 0.044, $R^2 = 0.72$, $p = 0.002$). The correlation between respirable dust and clay content was weaker but still significant ($R^2 = 0.55$, $p = 0.014$). For table grape dust we found no significant correlation between respirable quartz or respirable dust and soil texture when all table grape operations were included in the analysis. Leaf pulling activities early in the season produced the highest dust and quartz exposures and obscured any relationship with soil texture. When we excluded leaf pulling we found a stronger correlation between respirable dust levels and soil clay content (mg/m^3 respirable dust = 0.014 [% clay in the soil] −0.045, $R^2 = 0.51$, $p = 0.048$). The correlation between soil clay content and respirable quartz was much weaker ($R^2 = 0.24$) and not significant ($p = 0.21$).

DISCUSSION

Citrus and table grape harvest workers in California are typically Hispanic males and work for a labor contractor.[18] Citrus harvest workers may be able to work almost year-round without significant travel. Within a given geographic area, the winter harvest season for navel oranges nearly overlaps the summer harvest season for Valencia oranges. A typical season for table grapes may extend from April to September as workers travel from early harvest regions in southern California to later harvest regions farther north. Because citrus are not easily damaged during picking, the harvesting can be done quickly. It takes longer to harvest table grapes than wine and raisin grapes because table grapes must be protected from damage.

TABLE IV. Scanning Electron Microscope Particle Analysis of the <10 μm Diameter Fraction of Foliar Dusts

	Citrus (%)^A	Grape (%)^A
Aluminum silicates	76.1	79.7
Quartz	10.1	7.9
Talc-like	0.5	0.4
Iron oxide	0.4	0.2
Rutile-like	0.2	0.2
Silicon rich	3.9	3.4
Iron rich	3.4	2.8
Titanium rich	0.8	1.0
Other Al-Si	1.0	0.4
Aluminum rich	0.1	0.0
Other	3.5	4.0

^{A}Results are reported as percentage of particles identified, with a particle count of 1000 per sample.

We collected inhalable dust samples for short time periods ranging from 15 min to 1 hour because of potentially high dust concentrations in the breathing zone. We attempted to limit sampling time to prevent overloading of the samplers. Even so, several samplers on the first sampling day may have been overloaded, and our estimates of exposure concentrations for those samples may be conservative. We did not collect multiple samples of each worker because it is difficult to get cooperation from workers without significant monetary compensation for loss of time. We estimated overall exposure using the short-term measurement. It may be reasonable to assume that our short-term measurements represent the 8-hour exposure because we observed workers repeating the same activity during working hours.

Citrus harvest exposure levels were higher than exposures for table grape operations, and often exceeded the threshold limit value (TLV®) for inhalable dust and respirable quartz. Popendorf et al.[9] documented a predictable buildup of dislodgeable dust on leaf surfaces of citrus grown in the San Joaquin Valley of California throughout the summer and related this to increasing exposures through the summer months. In citrus harvest, exposures throughout the season increased for inhalable dust but not for respirable dust. We did not observe increased exposure over the season in table grape operations.

Manual harvest of fruit may be among the dustiest operations in agriculture. Inhalable dust exposures observed in citrus harvest were similar to the highest levels reported for tilling bare soil in open cab tractors.[19] Although citrus harvest workers do not appear to be in a thick cloud of dust (as often seen in ground preparation), geometric mean of inhalable dust exposure levels was 39.7 mg/m^3, or about four times the TLV of 10 mg/m^3.[20] Personal exposure levels in citrus harvest were particularly high because workers were immersed in foliage much of the time, and the breathing zone might be inches from the dust source. About 30% of respirable quartz exposures exceeded the TLV of 0.1 mg/m^3 in citrus harvest.[20]

Dust exposures for table grape operations were much lower than for citrus harvest. No dust exposures during table grape operations exceeded the TLV, except for leaf pulling where the TLV for inhalable dust was exceeded on occasion. These results contrast sharply with results for wine grape and raisin grape harvest reported by Popendorf et al.[9] Table grape harvesting is very slow and is done carefully to protect the visual appearance of the fruit. This method contrasts with the rapid and energetic manual harvesting of wine and raisin grapes, resulting in higher dust exposure.

There is no universally accepted reference for endotoxin level associated with respiratory problems in agricultural workers. Dose response relationships in swine workers and poultry workers suggested exposure limit recommendations of 100 EU/m^3 and 614 EU/m^3, respectively.[21] A calculated threshold of zero effect (FEV1) in workers exposed to cotton dust is 90 EU/ m^3.[22] The Dutch expert committee on occupational standards has proposed a health based standard of 50 EU/m^3 over an 8-hour exposure period.[23] A value of 200 EU/m^3 was adopted and promulgated in 2001 as the legal standard. Endotoxin levels in citrus harvest were higher than these estimated threshold concentrations. Our measurements were based on short sampling times, and our comparison to the standard is based on the assumption of a consistent exposure throughout the workday.

Total microbial concentrations in citrus harvest were about three times higher than those in table grape operations, whereas culturable bacteria and fungi concentrations were similar in both crops. Culturable microbe concentrations depend on a number of factors during incubation. Grapes are especially sensitive to various plant diseases so fungicide use is greater for grapes than for citrus. This heavy use of pesticides may cause lower microbial concentration in grapes. The levels observed in this study were in the ranges measured in other agricultural environments but lower than the levels in animal confinement environments.[1,24] The total bacteria and fungi levels found in this study were two orders of magnitude higher than the level observed in farms in Norway[25] where increased occurrence of acute eye and nose symptoms and cough resulted from exposure to microbiological concentrations much lower than in this study.

Elemental sulfur is often used as a fungicide, especially in vineyards. We anticipated that the grape dust might contain more sulfur, which can oxidize to sulfuric acid and pose respiratory risk. Our data showed that the total sulfur contents of the table grape and citrus total foliar dusts were similar.

Personal exposure during manual harvest can be caused by disturbance of foliar dust that most likely originates from the surrounding soil. We tried to determine if soil texture is a reliable predictor of personal exposure to respirable quartz or respirable dust. Our results showed that soil clay content was a reasonable predictor of exposure to respirable dust and quartz for citrus harvest. Soils with high clay content are often the dustiest, especially if the soil is subject to mechanical disturbances by tractors and other mechanical tillage implements. Soil surface disturbance within the orchard probably generates most of the dust, which may be of clay size (2 μm diameter or smaller) and ultimately ends up on the foliage. Foliar dust may also originate from upwind sources and be unrelated to the soils within the orchards or vineyards. The correlations between soil particle size distribution and respirable dust or quartz exposures for table grape operations were weaker, probably because of low concentrations of dust produced by the low energy contact with the foliage during manual harvest and the fairly narrow range of soil textures we sampled. To develop more significant relationships between soil properties and dust exposures for table grapes, a broader array of soil textures and grape harvest operations would have to be investigated.

Predictive factors of high dust exposure in manual harvest previously identified include the crop being harvested, dust loading of leaf surfaces, and rainfall.[9] Our study suggests that the nature of the harvest tasks is also a critical factor, particularly the proximity to the foliage and the extent of vigorous foliage disturbance during harvesting. Although manual harvesting of California fruit has the potential for very high exposure, the actual tasks involved must be analyzed when the potential for exposure is evaluated. Results from table grape harvest show that it is inaccurate to assume that all manual harvest operations in California result in high dust exposure. One likely factor related to elevated exposure is a high degree of contact with vigorous foliage disturbance. These conditions are common to citrus harvest but not to all table grape field operations.

Dust exposures during manual harvesting were complex and varied by at least an order of magnitude. As in many other agricultural settings, exposures included significant levels of culturable and nonculturable bacteria as well as fungi and endotoxin. These organic components were only one element of the exposure. Inorganic dust exposures were also very high, frequently exceeding the levels commonly associated with respiratory problems in workers for inhalable dust and respirable quartz. An obvious limitation of this study was the lack of pesticide analysis of the dust samples. It is possible that the various dusts contained different constituents and levels of pesticides. Exposure during other operations could have been an order of magnitude higher than the exposures in harvest, as shown in the high exposure in leaf pulling of table grapes. The sheer magnitude and complexity of the observed exposures provides a challenge to our ability to predict possible health effects of the exposures.

CONCLUSION

Workers performing manual harvesting of citrus and table grapes in California were exposed to a complex mixture of inorganic and organic dusts. Exposures for citrus harvest were high, particularly for inhalable dust and quartz, and exceeded those for table grape operations by factors ranging from 2 to 20. We concluded that agricultural workers in manual harvesting of some fruits in California could be exposed to inhalable dust and respirable quartz exceeding the TLV. Exposure levels to quartz and to endotoxin in citrus harvest were high enough to raise concern about potential respiratory health effects. The degree of vigorous contact with foliage appeared to be a significant determinant of exposure level. Soil clay content may have significant predictive value for respirable dust exposure, especially in harvest activities that involve significant contact with the foliage.

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