American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

Exposure to Dust and its Particle Size Distribution in California Agriculture

Mark J. Nieuwenhuijsen , Hanneke Kruize & Marc B. Schenker

AUTHORS
Mark J. Nieuwenhuijsen[a]*
Hanneke Kruize[b]
Marc B. Schenker[c]

[a]Imperial College of Science, Technology and Medicine, 48 Prince's Gardens, London SW7 2PE, UK; m.nieuwenhuijsen@ic.ac.uk;
[b]RIVM, Bilthoven, The Netherlands;
[c]Epidemiology and Preventive Medicine, University of California–Davis, Davis, CA

APPLIED STUDIES

Exposure to Dust and its Particle Size Distribution in California Agriculture

The aim of this study was to measure personal dust exposure levels and the dust particle size distribution during various agricultural operations in California. Personal dust exposure levels were measured with four-stage cascade impactors and respirable dust cyclones during field crop, fruit and nut farming, and dairy operations at three farms. Altogether, 103 cascade impactor measurements and 108 cyclone measurements were taken. High personal dust exposure levels were measured during various operations, in particular during ground preparation operations such as land planing (geometric mean [GM] = 57.3 mg/m^3, geometric standard deviation [GSD] = 2.4) and discing (GM = 98.6 mg/m^3, GSD = 2.9). Dust particles were relatively large and the great majority belonged to the extrathoracic fraction. Dust levels were considerably lower when an enclosed cabin was present on the tractor; for example, during discing, dust exposure levels were reduced more than sixtyfold for the larger dust particle fraction and more than fourfold for the respirable dust fraction.

Keywords: agriculture, dust, particle size, respirable dust

Farming has been associated with a wide variety of hazardous exposures,(1) including airborne exposures, that have been associated with respiratory disease.(2–5) The development of respiratory disease depends in part on the nature, level, and particle size distribution of airborne exposures. Several studies have measured the exposure to dust, its constituents, and its particle size distribution, and have evaluated control measures.(6–15) Reported dust exposure levels for operations such as ground preparation and harvesting were often well above the American Conference of Governmental Industrial Hygienists' (ACGIH's) threshold limit value (TLV®) of 10 mg/m^3 for inhalable dust(16) but were considerably lower when there was an enclosed cabin on the tractor.(12–15) Exposure assess-ment in agriculture is difficult because of the varied and cyclic nature of the farmers' work and the diverse locations of the farms. Exposures may vary with local farming practices, commodities grown or raised, geography, climate, and other factors.

In California, farm size, quantity and variety of commodities, agricultural practices, soil types, and climate are extremely diverse and substantially different from those in other parts of the United States and the rest of the world. In 1993 California's farmers sold an estimated $19.9 billion of farm products, making it the largest agricultural state based on cash receipts. That year, California had some 76,000 farms; average size was 391 acres.(17) As many as 1.5 million people were directly employed on farms in California.(18) California agriculture produces approximately 250 different crops, and California leads the nation in the production of over 60 crops and livestock commodities including eggs, broccoli, almonds, lemons, wine grapes, and safflower.(17) The diversity of California farming is associated with a wide range of potentially hazardous exposures. However, there has been little investigation of the magnitude and determinants of these exposures, particularly of dust exposure.

The aim of this study was to measure personal dust exposure levels and the dust particle size distribution during various agricultural operations in California agriculture.

*Author to whom correspondence should be addressed.
This work was supported by the National Institute for Occupational Safety and Health, cooperative agreement U07/CCU906162-05, and the National Institute for Environmental Health Science center grant 1 P30 ES05707.

Material and Methods

Three experimental farms were selected around Davis, California; one field crop farm growing corn, tomatoes, and wheat (72 acres); one fruit and nut farm with peach, plum, pistachio, and prune trees (107 acres); and one dairy farm with approximately 90 milking cows. These farms were chosen because they were easily accessible. Working practices and commodities were similar to those on other farms in Northern California, but the size of the experimental farms and their plots were smaller compared with the average farm in Northern California. On the field crop farm, dust exposure levels were measured during all operations (Table I) in the growing season (April–November). Measurements were taken approximately 50% of the time an operation was done. On the fruit and nut farm, only the harvesting was measured because it was the only operation that took place. On the dairy farm three regularly occurring operations—feeding, milking, and manure removal (Table I)—were measured. On the fruit and nut and the dairy farm the measurements were taken from August through November.

TABLE I. Description of Operations

Operation	Machinery/Manual	Aim
Field crop operations		
Ground preparation	tractor with attachment	
ripping		to tear open the soil
ploughing		to turn the soil
discing		to loosen the soil and make it finer
land planing		to level the field
listing		to make beds
rolling beds		to roll beds
incorporating		to mix pesticides with soil
Spraying compost	tractor with spreader	to spread compost
Mowing	tractor with mower	to cut weeds
Planting	tractor with attachment	to drop seeds (corn, wheat) or put plants (tomato) into soil
Cultivating	tractor with attachment	to cut weeds between rows of crops
Harvesting	harvester	to cut, shake, and sort crop
Swathing	tractor with attachment	to cut weeds
Baling	tractor with attachment	to pick up straw or hay and bale it
Irrigating	manual	to open valves and keep irrigation canals open
Fruit and nut		
Hand harvest	manual	to pick fruit
Machine harvest	shaker and conveyer belt	to shake trees to make fruit, nuts fall
Dairy farming		
Milking	milking machinery	to milk cows
Feeding	tractor with truck and manual	to feed cows
Manure removal	tractor with scrape attachment	to push away manure

Workers on the farms were asked to wear either cascade impactors or respirable dust cyclones during various operations (Table I). The cascade impactor was a four-stage personal Sierra Marple 294 cascade impactor (Graseby Andersen, Smyrna, Ga.) with inlet cowl and inlet visor (cut points at 21.3 µm, 14.8 µm, 9.8 µm, and 3.5 µm, plus one backup filter). It contained Mylar™ membranes coated with a Dow Corning silicone 316 spray (Graseby Andersen) and was connected to a personal sampling pump running at 2 L/min. The personal respirable dust cyclone (BGI Inc., Waltham, Mass.) contained a 37-mm diameter polyvinyl chloride filter (pore size 5 µm) and was connected to a small pump run at 2.2 L/min (cut point 4 µm). The samplers were worn one after another. A calibrated rotameter was used to check the required flow rates for both samplers. This was done at the beginning of each sampling period and then checked at the end of the sampling period. During all the measurements an observer was present. The membranes and filters were weighed before and after sampling on a six-figure ATI Cahn C-35 microbalance (ATI Orion Cahn, Boston, Mass.). For the cascade impactor, weights were corrected for internal loss and inlet efficiency. The sampler efficiency correction factors for the stages were, from top to bottom: 0.26, 0.70, 0.82, 0.94, and 0.99.[19] The median sampling time for the cascade impactor was 76 min and for the cyclone 87 min. For the cascade impactor, the detection limit for each stage was 0.031 mg and 0.015 mg for the backup filter. The detection limit of the cyclone filters was 0.022 mg per filter. Measurements with values below the detection limit were assigned half the value of the detection limit for statistical analyses. In total, 103 cascade impactor measurements were made, of which for the first stage 3% were below the detection limit, for the second stage 11%, for the third stage 14%, the fourth stage 18% and the backup stage 32%. In total, 108 cyclone measurements were taken, of which 20% were below the detection limit. Both the cascade impactor and respirable cyclone measurements could be best described with a log-normal distribution (Shapiro Wilk test on log-transformed concentrations: $W = 0.96$, $p < 0.02$; $W = 0.96$, $p < 0.05$; $W = 0.96$, $p < 0.01$, respectively, for cascade impactor measurements for all particles, particles with 50% cutoff diameter smaller than 9.8 µm, and particles with 50% cutoff diameter smaller than 9.8 µm, and $W = 0.89$, $p < 0.0001$ for the respirable dust cyclone measurements).

The SAS software package (SAS Institute, Cary, N.C.) was used for statistical analyses. Proc Means and Proc Univariate were used for descriptive analyses. Cascade impactor data were used to estimate a mass median aerodynamic diameter (MMAD). The MMAD was estimated with a computer program (Proc Reg and Proc Means) and in accordance with the procedure in the manufacturer's instruction manual (Graseby Andersen). An average MMAD for all measurements was derived by estimating an MMAD for each individual measurement first and then taking the average for all the measurements.

Results

With the cascade impactor, the highest dust exposure levels were measured during ground preparation operations such as land planing, discing, and rolling beds, followed by tomato harvesting (sorters on the machine), feeding of cows, planting, and mechanical harvest (shaking) of fruit and nuts (Table II, Figures 1 and 2). The lowest dust exposure levels were measured during milking. The presence of an enclosed cabin considerably reduced the personal dust exposure levels of the farm workers, for example, by more than sixtyfold in the case of discing (dust on all stages together). The largest proportion of the dust belonged to the extrathoracic fraction; dust concentrations for particles with a 50% cutoff diameter smaller than 9.8 μm or 3.5 μm were only a fraction of the dust exposure levels measured on all stages together. Since most of the dust deposited on the top stage or stages, it was difficult to estimate an accurate MMAD; the average MMAD estimate for all measurements together was 49 μm (range 22–150 μm). No attempt was made to present an MMAD for the various tasks. To investigate differences in particle sizes, the levels for particles with a 50% cutoff diameter smaller than 9.8 μm were expressed as a percentage of the dust exposure levels on all stages together and will be referred to as $\text{percentage}_{< 9.8\ \mu m}$. The $\text{percentage}_{< 9.8\ \mu m}$ varied slightly between operations, but considerably between the presence or absence of a cabin (Table II). Generally, low $\text{percentage}_{< 9.8\ \mu m}$ was estimated but was higher when there was a cabin present on the tractor. The dairy farming operations also had higher $\text{percentage}_{< 9.8\ \mu m}$. There was moderate increase in the $\text{percentage}_{< 9.8\ \mu m}$ with an increase in log-transformed dust exposure levels measured on all stages (Pearson correlation coefficient between log-transformed values = –0.57, $p < 0.0001$), suggesting that the fraction of larger particles increases with an increase in dust exposure.

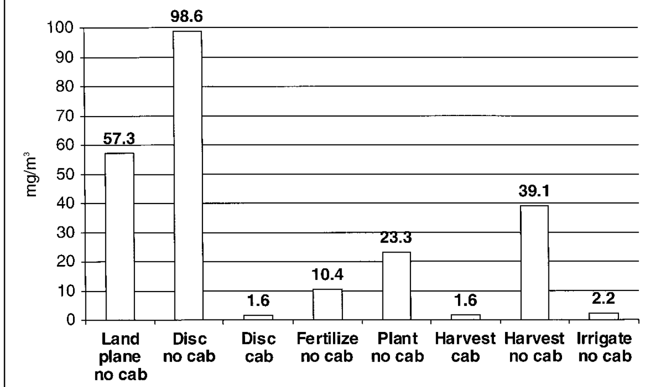

Figure 1. Geometric means of the personal dust exposure levels (mg/m³) for various operations during field crop farming in California (operations with three measurements or more). Cab = cabin present, no cab = no cabin present.

TABLE II. Exposure Levels (mg/m³) for Various Dust Fractions During Agricultural Operations in California

		All Stages			50% Cutoff < 9.8 μm			50% Cutoff < 3.5 μm			
	n	AM	GM	GSD	AM	GM	GSD	AM	GM	GSD	$\%_{< 9.8\ \mu m}$[A]
Field crop farming											
Land planing (no cab)	18	82.7	57.3	2.4	4.6	2.9	2.7	0.5	0.3	2.8	5.7
Discing (no cab)	16	158.6	98.6	2.9	8.6	4.3	3.5	1.1	0.5	3.5	4.8
(cab)	8	1.9	1.6	1.9	0.3	0.3	2.0	0.1	0.1	2.0	16.9
Listing (no cab)	2	11.0	10.3	1.7	0.4	0.3	2.6	0.1	0.1	2.3	3.9
(cab)	1	1.5			0.1			0.0			3.8
Incorporating (no cab)	2	12.9	12.4	1.5	0.8	0.7	2.5	0.2	0.2	2.1	5.9
Rolling beds (no cab)	2	48.4	46.7	1.5	2.2	2.2	1.2	0.5	0.5	1.0	4.6
Ripping (cab)	2	2.2	1.9	2.4	0.6	0.5	2.4	0.2	0.2	1.9	26.5
Ploughing (cab)	1	4.4			0.5			0.2			12.2
Fertilizing (no cab)	3	10.4	10.0	1.4	0.5	0.4	2.2	0.1	0.1	1.4	4.6
Mowing (no cab)	2	14.0	11.5	2.5	1.2	0.8	3.5	0.2	0.2	2.3	7.5
Planting[B] (no cab)	1	9.8			0.4			0.0			3.9
Planting[C] (no cab)	6	23.3	15.4	3.7	1.9	1.2	4.2	0.2	0.1	3.0	8.2
Cultivating (no cab)	1	9.3			0.6			0.1			6.9
Harvesting[D] (cab)	5	1.6	1.4	1.9	0.2	0.2	1.8	0.1	0.1	2.1	12.9
Harvesting[B] (no cab)	4	41.0	39.1	1.5	3.0	2.7	1.7	0.4	0.4	1.7	7.1
Swathing (cab)	1	1.8			0.3			0.2			14.1
Baling (cab)	1	4.9			0.2			0.1			3.6
Irrigating (n.a.)	4	2.3	2.2	1.4	0.2	0.2	1.2	0.0	0.0	1.6	7.8
Fruit and nut farming											
Hand harvest[E] (n.a.)	4	5.2	5.1	1.3	0.2	0.2	1.4	0.0	0.0	1.6	3.6
Mechanical harvest[F] (no cab)	10	13.0	10.6	1.9	0.7	0.6	1.3	0.2	0.1	2.0	6.8
Dairy farming											
Milking (n.a.)	3	0.8	0.7	1.4	0.1	0.1	1.7	0.0	0.0	1.6	13.7
Feeding (n.a.)	3	26.1	25.9	1.2	2.9	2.8	1.2	0.3	0.3	1.1	11.0
Manure removal (n.a.)	3	3.7	2.6	1.4	0.5	0.5	1.6	0.2	0.2	1.1	18.6

Notes: n = number of samples, AM = arithmetic mean, GM = geometric mean, GSD = geometric standard deviation, cab = cab present, n.a. = not applicable
[A]Concentrations of particles with a 50% cut off < 9.8 μm as a percentage of the total dust
[B]Tomatoes
[C]Corn, wheat, and winter cover
[D]Wheat and corn
[E]Peaches and plums
[F]Pistachios and prunes

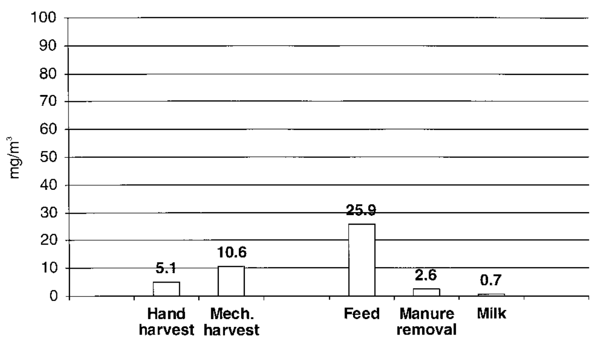

Figure 2. Geometric means of the personal dust exposure levels (mg/m³) for various operations during fruit and nut and dairy farming in California (operations with three measurements or more). No cabins were present.

With the respirable cyclone, the highest dust exposure levels were measured during ground preparation tasks, such as land planing and discing and feeding cows, followed by cultivating, rolling beds, tomato harvesting, and mowing (Table III). The lowest respirable dust exposure levels were measured during milking and irrigation. The latter was a manual operation, whereby the farm worker switched on the taps and kept the furrows open. Respirable dust exposure levels measured with the cyclone were in the same order of magnitude as dust measured on the last stage of the cascade impactor (50% cutoff < 3.5 µm). Respirable dust exposure levels were lower when there was a cabin on the tractor. For example, in the case of discing there was more than a fourfold reduction in average dust levels when an enclosed cabin was present (Table III).

TABLE III. Exposure Levels for Respirable Dust (mg/m³) During Agricultural Operations in California

	n	AM	GM	GSD
Field crop farming				
Land planing (no cab)	12	0.64	0.46	2.5
Discing (no cab)	16	1.19	0.58	3.7
(cab)	7	0.18	0.14	2.3
Listing (no cab)	1	0.38		
(cab)	1	0.17		
Incorporating (no cab)	3	0.29	0.28	1.3
Rolling beds (no cab)	3	0.56	0.43	2.7
Ripping (cab)	4	0.22	0.21	1.3
Ploughing (cab)	1	0.22		
Spraying compost (no cab)	1	0.09		
Mowing (no cab)	3	0.31	0.30	1.4
Planting[A] (no cab)	2	0.09	0.09	1.9
Planting[B] (no cab)	8	0.18	0.14	2.1
Cultivating (no cab)	4	0.57	0.45	2.1
Harvesting[C] (cab)	3	0.11	0.11	1.2
Harvesting[A] (no cab)	4	0.69	0.59	2.0
Swathing (cab)	1	0.14		
Baling (cab)	1	0.13		
Irrigating (n.a.)	6	0.09	0.07	2.3
Fruit and nut farming				
Hand harvest[D] (n.a.)	5	0.09	0.08	1.7
Mechanical harvest[E] (no cab)	13	0.22	0.19	2.0
Dairy farming				
Milking (n.a.)	3	0.06	0.06	1.6
Feeding (n.a.)	3	0.69	0.59	2.0
Manure removal (n.a.)	3	0.15	0.15	1.3

Notes: n = number of samples, AM = arithmetic mean, GM = geometric mean, GSD = geometric standard deviation, cab = cab present, n.a. = not applicable
[A]Tomatoes
[B]Corn, wheat, and winter cover
[C]Wheat and corn
[D]Peaches and plums
[E]Pistachios and prunes

Discussion

In this paper it has been shown that high personal dust exposure levels occur during various farming operations in California agriculture, particularly during ground preparation operations such as land planing and discing. The dust particles were relatively large, and the great majority belonged to the extrathoracic fraction. Dust levels were considerably lower when an enclosed cabin was present on the tractor.

In California, farm size, quantity and variety of commodities, agricultural practices, soil types, and climate are substantially different from those in many other parts of the United States and the rest of the world. The agricultural regions of California have an arid climate. During the measurement period of this study there was no rainfall of any importance and fields were, as usual, irrigated. Given the differences, it is hard to compare this exposure data with data from outside California. Also, there are many determinants of dust exposure in agriculture, and they are not mentioned in many of the papers. The few agricultural dust exposure studies[(8,12)] that have been carried out in California show similar dust exposure levels to those measured in this study. Operations where machinery attached behind tractors is used to disturb the soil, such as land planing or discing, and operations where farm workers have close contact with dusty material, such as hay during feeding or dust on leaves during harvesting, showed high levels of personal dust exposure in this study. Poppendorf et al.[(8)] measured total dust levels of 13 mg/m³ and respirable dust levels of 0.50 mg/m³ during hand-harvesting in peach orchards. Lawson et al.[(12)] measured total dust levels of 35.2 mg/m³ and respirable dust levels of 3.17 mg/m³ during field preparation operations. These levels are on the same order of magnitude as this study. Studies from elsewhere around the world show similar results, but direct comparisons are difficult because of the different climates and limited information provided.[(6,9,13,14)] If the exposure in this study had lasted for an 8-hour period, the respirable dust levels would be well below the ACGIH's TLV of respirable nuisance dust (3 mg/m³), but the inhalable dust exposure levels would be well above the current TLV (10 mg/m³) for many operations.[(16)]

Other studies[(12–15)] showed that the presence of an enclosed cabin on the tractor generally reduced the dust exposure levels experienced by the tractor drivers more than twentyfold, but that there was a considerable amount of variation in the reduction factors. Little information was provided on the cause for this variation. In this study the reduction was more than sixtyfold for the larger dust fraction in the case of discing, and more than fourfold for the respirable dust fraction. If exposure had lasted for an 8-hour period, tractor operations without an enclosed cabin would have shown dust levels well above the ACGIH's TLV for inhalable nuisance dust (10 mg/m³).[(16)] Tractor operations with an enclosed cabin present would have shown levels well below the TLV. The efficiency of cabins depends in part on leaks and condition of the filter, information not collected for this study. Operations with tractors were also identified as a major determinant of dust exposure in a large epidemiological study of California farm operators.[(18)]

In this study the particle size distribution seems to be larger than in other reports from outside California.[13,14] Atiemo et al.[14] found MMADs varying from 12 to 20 μm during various field operations such as seeding, cultivating, and baling. Noren[13] reported that dust in the operator's breathing zone largely consisted of particles smaller than 6 μm. Most of the dust in the present study deposited on the first stage or stages of the cascade impactor; therefore, an accurate estimate for an MMAD could not be calculated. An MMAD of 49 μm was estimated for all operations together, much larger than in previous studies.[13,14] This might be due partially to the measurement instrument, different weather conditions, different soil conditions, and composition and working practices in California. For example, the other two studies[13,14] were carried out in wetter climates. Detailed comparisons are difficult because little information was given on the measurement instrument used or other factors, such as soil conditions.

The percentage of smaller particles, expressed as $\text{percentage}_{< 9.8\ \mu m}$, differed slightly between operations, but considerably between the presence or absence of a cabin. This suggests that cabins not only reduce the dust levels, but also that they appear to decrease exposure to larger particles to a greater extent than they reduce exposure to smaller particles. Atiemo et al.[14] also showed a smaller dust particle size distribution inside the cabin compared with outside. There was moderate increase in the $\text{percentage}_{< 9.8\ \mu m}$ with an increased dust exposure levels measured on all stages, suggesting that the fraction of larger particles increases with an increase in dust exposure.

The sampling time in this study was generally short. Preliminary studies showed that the cascade impactor showed signs of dust overload at longer sampling times due to high dust exposure levels. Sampling times were therefore kept short to prevent overload. Cascade impactor membranes were visually inspected after each sampling period to look for signs of dust overload or other irregularities. A second reason for the short sampling times was the short duration of many operations.

The number of samples for various operations was small, resulting in unstable dust exposure level estimates. This is largely due to the large number of different operations, the relatively small farms, and the unpredictability of the farm work. For example, at the field crop farm only approximately 50% of the operations were measured, partly because of machinery breakdowns, or because other more important work had to be done by the farmers. Exposure monitoring in agriculture is difficult and very time consuming, which often leads to a small number of samples.[6–15] For many operations, more samples need to be taken to improve the exposure estimates. The results of this study should be used to direct the measurement effort for future studies, which, for example, could mean taking more samples for fewer operations to increase the statistical robustness of the estimates.

This study was carried out over one season. Experimental farms were selected for practical reasons such as accessibility. These farms were smaller than the average Northern California farm and could well represent the smaller farms in California better than the larger farms, although working practices are often similar. Also, most samples were taken during the driest period of the year, and the sampling results could well be more representative for this period of the year than for others. Surprisingly enough, only a few dust exposure studies have been carried out in California agriculture, an industry with as many as 1.5 million workers and an increased prevalence of respiratory disease[20] and impairment of lung function.[21] More investigation on dust exposure in California agriculture is needed, including an increase in the sampling effort to produce statistically robust dust exposure level estimates for the various operations, exposure assessment studies in other regions of California, and detailed analyses of the constituents of the dust, such as whether it contains silica and silicates, endotoxins, and certain allergens. A control strategy needs to be designed to reduce the excessive dust exposure levels in California agriculture.

Acknowledgments

The authors would like to thank Dr. Steve Samuels and Dr. Noah Seixas for their advice, the management for their cooperation, and all the workers for their participation.

References

1. **Cordes, D.H. and D.F. Foster (eds).:** *Health Hazards of Farming.* State of the Art Reviews. Philadelphia: Hanley and Belfus, 1991.

2. **Malmberg, P. and K. Larsson:** Acute exposure to swine dust causes bronchial hyperresponsiveness in healthy subjects. *Eur. Respir. J. 6*:400–404 (1993).

3. **Clancy, R.L., J. Ruhno, R. Scicchitano, A.W. Cripps, et al.:** Wheat dust-associated respiratory disease in a farming community. *Austr. New Zealand J. Med. 21*:222–226 (1991).

4. **Sherwin, R.P., M.L. Barman, and J.L. Abraham:** Silicate pneumoconiosis of farm workers. *Lab. Invest. 40*:576–582 (1979).

5. **Jorna, T.H.M.J, P.J.A. Born, K.D. Koiter, J.J.M. Slangen, et al.:** Respiratory effects and serum type III procollagen in potato sorters exposed to diatomaceous earth. *Int. Arch. Occup. Environ. Health 66*:217–222 (1994).

6. **Louhelainen, K., J. Kangas, K. Husman, and E.O. Terho:** Total dust concentrations of dust in the air during farm work. *Eur. J. Resp. Dis. 71(suppl 152)*:73–79 (1987).

7. **Olenchock, S.A., J.J. May, D.S. Pratt, L.A. Piacetelli, et al.:** Presence of endotoxins in different agricultural environments. *Am. J. Ind. Med. 18*: 279–284 (1990).

8. **Popendorf, W.J., A. Pryor, and H.R. Wenk:** Mineral dust in manual harvest operations. *Ann. Am. Conf. Gov. Ind. Hyg. 2*:101–115 (1982).

9. **Jones, W.G., J.W. Dennis, J.J. May, M.P. Whitmer, et al.:** Dust control during bedding chopping. *Appl. Occup. Environ. Hyg. 10*:467–475 (1995).

10. **Robertson, J.F.:** Exposure to inspirable dust and crystalline quartz during potato processes. *Farm Build. Prog. 114*:7–11 (1993).

11. **Robertson, J.F.:** Dust in farm mill-and-mix plants. *Farm Build. Prog. 106*: 8–14 (1991).

12. **Lawson, R.J., M.B. Schenker, S.A. McCurdy, B. Jenkins, et al:** Exposure to amorphous silica fibers and other particulate matter during rice farming operations. *Appl. Occup. Environ. Hyg. 10*:677–684 (1995).

13. **Noren, O.:** "Dust Concentrations During Operations with Farm Machines." Paper presented at the summer meeting of the American Society of Agricultural Engineers, Michigan, June 1995. Abstract 85-1055.

14. **Atiemo, M.A., K. Yoshida, and G.C. Zoerb:** Dust measurements in tractor and combine cabs. *Transactions* pp. 571–576 (1980).

15. **Burg, W.R., O.L. Shotwell, and B.E. Saltzman:** Measurements of airborne aflatoxins during the handling of 1979 contaminated corn. *Am. Ind. Hyg. Assoc. J. 43*:580–586 (1982).

16. **American Conference of Governmental Hygienists (ACGIH):** *1995-1996 Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs).* Cincinnati, OH: ACGIH, 1995.

17. **California Department of Food and Agriculture:** California Agriculture Statistics. Sacramento, CA: California Department of Food and Agriculture, 1993.

18. **Nieuwenhuijsen, M.J., M.B. Schenker, S.J. Samuels, J.A. Farrar, et al.:** Exposure to dust, noise and pesticides, their determinants and the use of protective equipment among California farm operators. *Appl. Occup. Environ. Hyg. 11*:1217–1225 (1996).

19. **Radar, D.J., L.A. Mondy, J.E. Brockman, et al.:** Stage response calibration of the Mark III and Marple cascade impactors. *Aerosol Sci. Technol. 14*:365–379 (1991).

20. **Farrar, J.A., M.B. Schenker, S.A. McCurdy, R.S. Green, et al.:** Agricultural dust exposure and respiratory symptoms among California farm operators. [In preparation]

21. **Gamsky, T.E., S.A. McCurdy, S.J. Samuels, and M.B. Schenker:** Reduced FVC among California grape workers. *Am. Rev. Resp. Dis. 145*:257–262 (1992).