Exposures and Health Effects from Inorganic Agricultural Dusts

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Most studies of respiratory disease from dust exposure in the agricultural workplace have focused on allergic diseases caused by inorganic dusts, specifically occupational asthma and hypersensitivity pneumonitis. Exposures to inorganic (mineral) dusts among farmers and farm workers may be substantial. Such exposures are most frequent in dry-climate farming regions. In such locations farming activities that perturb the soil (e.g., plowing, tilling) commonly result in exposures to farm operators of 1–5 mg/m^3 respirable dust and ≥ 20 mg/m^3 total dust. The composition of inorganic dust in agriculture generally reflects the soil composition. Crystalline silica may represent up to 20% of particles, and silicates represent up to 80%. These very high concentrations of inorganic dust are likely to explain some of the increase in chronic bronchitis reported in many studies of farmers. Pulmonary fibrosis (mixed dust pneumoconiosis) has been reported in agricultural workers, and dust samples from the lungs in these cases reflect the composition of agricultural soils, strongly suggesting an etiologic role for inorganic agricultural dusts. However, the prevalence and clinical severity of these cases are unknown, and many exposures are to mixed organic and inorganic dusts. Epidemiologic studies of farmers in diverse geographic settings also have observed an increase in chronic obstructive pulmonary disease morbidity and mortality. It is plausible that agricultural exposure to inorganic dusts is causally associated with chronic bronchitis, interstitial fibrosis, and chronic obstructive pulmonary disease, but the independent contribution of mineral dusts beyond the effects of organic dusts remains to be determined. *Key words*: agriculture, chronic bronchitis, COPD, dust, mineral, particles, pulmonary fibrosis, respiratory, silica. — *Environ Health Perspect* 108(suppl 4):661–664 (2000).
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Agricultural dust exposure was recognized in the 16th century as a cause of respiratory disease (*1*), and dust exposure has continued to be a major source of respiratory morbidity and mortality among agricultural workers (*2*). In general, agricultural dusts may be divided into those of organic and inorganic origin. Organic dusts originate from plant and animal sources and are commonly the source of allergic diseases such as asthma. Inorganic dusts originate predominantly from the soil, and tend to result in nonallergic reactions in the lung. This article addresses diseases caused by exposure to inorganic dusts in the agricultural workplace. It covers sources and composition of inorganic agricultural dusts, exposures to agricultural workers, diseases associated with inorganic dust exposure, and directions for future research.

While the respiratory effects of agricultural organic dusts have been recognized for centuries, there has been little recognition of the effects of inorganic dusts exposure in agriculture. Recent research, particularly in areas of dry-climate farming, has identified a range of adverse respiratory outcomes due predominantly to inorganic dust exposures.

It is important to note that dust exposures in the agricultural workplace are commonly to mixtures of organic and inorganic dusts, and it is not always possible (or valid) to attribute observed health effects to one component or the other, particularly on the basis of epidemiologic studies. I have described health effects resulting from exposure to the predominant dust component causing the observed effect. Conclusions are generally based on the known effects of inorganic dusts in other occupational settings or on clinical or toxicologic studies. Nevertheless, it is recognized that organic dusts may be a contributing factor to some of these health outcomes and in some cases may be the predominant cause.

Inorganic Dust Sources and Composition

Silicates are the predominant inorganic fraction of most soils. They are classified on the basis of how extensively silica is polymerized. The degree of polymerization will in turn determine the resistance to chemical weathering. Respirable quartz also is found in soil dust, although weathering and chemical reactions may make it less fibrogenic than freshly fractured quartz in other occupations such as quarrying and sandblasting (*3*). The inorganic fraction of soils from very arid locations may be dominated by calcium carbonate and more soluble salts rather than by silicates. Soils in warm humid climates may have a greater proportion of oxides and hydroxides of iron and aluminum.

Clays in agricultural soils have a large surface area and charge and can potentially carry organic materials and pesticides. Little is known about the frequency or nature of such adsorbed exposures (*4*).

Exposure to Inorganic Dusts

There are few studies of agricultural dusts exposure, although recent research has begun to fill some of the gaps in this area (*5–8*). Most studies are on nonrandomly selected populations, and thus a population-based picture of inorganic dust exposure is lacking. Characterization of dusts has been limited generally to total and respirable fractions, and speciation has primarily been total inorganic fraction and respirable quartz.

The highest dust exposures occur during soil preparation activities. Tractors pulling soil preparation equipment (e.g., plowing, discing, planing) generate large dust clouds (*9*). Median total particle exposures in an open cab range from 2 to 20 mg/m^3, but exposures up to and exceeding 100 mg/m^3 have been reported (*5,10*). The respirable fraction of dusts in tractor cabs is generally 5 to 40%, with total respirable dust concentrations commonly observed between 1 and 5 mg/m^3. A study of rice farming in California found respirable dust concentrations of 0.52–2.16 mg/m^3 outside the harvester and from 1.77 to 5.24 mg/m^3 outside the tractor during field preparation (*11*).

Respirable quartz exposures in agriculture commonly exceed industrial standards. In one study open-cab exposure to respirable quartz averaged 2 mg/m^3 (*10*). Closed tractor cab exposures to respirable quartz averaged 0.05 mg/m^3 or less. However, in a study of dust exposure during manual harvesting, the quartz content averaged 7–20% of total respirable dust, and over 50% of samples among grape harvesters exceeded the industrial standard (*12*). A study of dust samples from 12 Alberta, Canada, farms found 0.8–17.5% crystalline silica (*13*).

Differences in equipment, task, and climate may affect exposures in tractor cabs. In a recent study the presence of an enclosed cabin on the tractor, higher relative humidity, and lower

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tractor speed were all associated with a decrease in personal dust levels (*6*). In particular, an enclosed tractor cab reduced exposure of the operator to larger dust particles (50% cutoff < 9.8 µm) by 60-fold and reduced exposure to smaller dust particles (50% cutoff < 3.5–4 µm) by 4-fold (*7*).

While an enclosed tractor cab is the single most effective intervention to reduce inorganic dust exposure, little data are available on the prevalence and use of enclosed cabs. One population-based study in California found that 60% of farmers reported that their primary tractor did not have an enclosed cab (*5*). Agricultural workers not driving a tractor (e.g., migrant and seasonal farm workers) do not have the protection of enclosed work environments, but there are little data on the distribution or cumulative particle exposure in this population.

Inorganic dust exposures are generally highest with open field work in dry climates. However, significant inorganic dust exposures may occur with indoor agricultural activities with a variety of commodities such as grain handling.

Diseases Associated with Inorganic Dust Exposure

Several respiratory diseases are associated with agricultural dust exposure (*2*). This section addresses those diseases due predominantly to mineral dust exposure: acute and chronic bronchitis, chronic obstructive airways disease, and interstitial lung disease. It does not cover asthma or asthmalike syndromes, which are primarily due to organic dusts, although inorganic dust may be an exacerbating factor. It also does not address farmers' hypersensitivity pneumonitis, which is caused by organic (biologic) particles (mold dust) or organic dust toxic syndrome due to endotoxin from mold or other biologic dust sources.

As with many respiratory disorders in agriculture, exposures tend to be mixed, and it is difficult to identify specific individual agents associated with the outcome. It has been recognized for many years that occupational exposure to inorganic dusts could result in a reversible syndrome of cough and reduced lung function.

Limited toxicologic studies have been conducted on agricultural dusts. In one study, intratracheal instillation into rats of dust collected from field samples during citrus and grape harvesting demonstrated acute inflammatory changes with the vineyard dust exposure (*14*). This finding is intriguing because it is consistent with epidemiologic data demonstrating a restrictive pulmonary response among grape workers compared to the response in citrus workers (*15*).

Several studies of farmers in different regions have observed increased rates of chronic bronchitis (*16*). While it is plausible that inorganic dust alone can result in chronic bronchitis, it is recognized that actual exposures of farmers are to mixed organic and inorganic dusts and that the organic dust component is likely to be the major component in some work environments.

Most studies of chronic bronchitis have been conducted in Europe and North America; therefore, little is known about respiratory disease among agricultural workers in other parts of the world (*17*). A Finnish postal survey found chronic phlegm production rates almost 3 times higher in farmers (2.0%) than in nonfarmers (0.7%) (*18*). Another Finnish study found 7.5% chronic bronchitis prevalence among farmers and an incidence rate of 2% per year for new chronic bronchitis (*19*).

A study of Saskatchewan, Canada, farmers also found significantly higher prevalence of chronic bronchitis and lower pulmonary function among 1,824 farmers compared to 556 controls (*20*). In another study of Saskatchewan farmers, Chen and colleagues (*21*) also found higher prevalence of chronic bronchitis among farmers than among controls.

A study among California farm workers exposed primarily to inorganic dusts in the field found that agricultural work was a significant independent predictor of chronic bronchitis symptoms (*22*). These investigators also found that grape workers, who have the highest exposure to inorganic dusts, had reduced forced vital capacity, which is consistent with a restrictive effect on pulmonary function (*15*). In another study of dairy farmers, higher rates of chronic bronchitis were observed associated with obstructive pulmonary function (*23*). Although dairy farmers are exposed predominantly to organic dusts (e.g., hay), it is likely that they are also exposed to inorganic dusts during various work activities.

Numerous cross-sectional surveys of farmers and agricultural workers have found increased prevalence rates of chronic bronchitis among animal confinement workers; in most cases this is independent of the effects of cigarette smoking. These have included populations of swine confinement farmers (*24,25*) and poultry workers (*26,27*). Unlike the exposures of field workers, it is likely that animal confinement workers are predominantly exposed to organic dusts.

Several studies have shown an increase in chronic obstructive lung disease among agricultural workers, although the specific causal agent or agents are often unknown. For example, studies of Vancouver grain workers have found an increase in chronic phlegm and dyspnea associated with workplace exposures and higher rates of airflow obstruction among retired workers (*28,29*). Increased respiratory disease mortality has also been observed in several populations of farmers, despite lower rates of cigarette smoking, but the specificity of this observation is unknown (*30–33*).

There are four major types of interstitial disease associated with agricultural mineral dust exposure: *a*) macules, *b*) nodules, *c*) diffuse interstitial fibrosis, and *d*) progressive massive fibrosis (*34*). Macules are focal collections of dust-laden macrophages occurring within the walls of respiratory bronchioles and associated with mild fibrosis (Figures 1, 2). They occur most commonly with exposure to dusts with low fibrogenicity such as silicates. Nodules are common following exposure to mixed dusts including silicates and low crystalline silica (< 20%) dusts (Figure 3). They occur throughout the interstitium. With silicates and mixed dusts these nodules have a characteristic appearance of irregularly oriented collagen. Progressive massive fibrosis usually occurs on a background of simple pneumoconiosis (macules and nodules) and is associated with impaired pulmonary function, which often results in disability and death. Small airway disease induced by mineral dust is a distinct pathologic entity resulting from exposure to fibrous and nonfibrous mineral dusts (*35*). There is overlap between the pathologic changes of dust macules and mineral dust-induced small airway disease. Both of these disorders tend to result from exposure to weakly fibrogenic dusts such as carbonaceous particles. Increasing fibrogenicity seen with fibrous silicates and crystalline

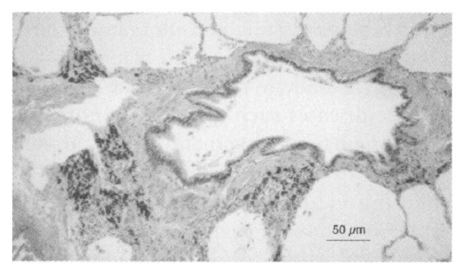

Figure 1. Membranous bronchiole from the lung of a nonsmoking Hispanic farm worker. Thickening of the interstitial walls is present with abundant pigment.

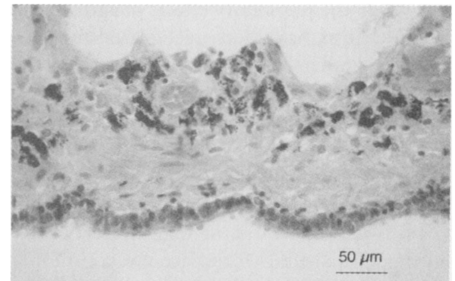

Figure 2. The nonalveolarized portion of a respiratory bronchiole from an Hispanic farm worker's lung. Carbonaceous material is present in the interstitial space of the wall.

silica is associated with greater degrees of collagenous fibrosis.

Several case reports have documented among farmers the occurrence of pneumoconiosis from exposure to silica or silicate (*36–38*). The disease is clinically a mixed-dust pneumoconiosis, and analyses of lung particles have confirmed similar composition to soil particles (*38*). A case–series in California reported on seven cases of silicate pneumoconiosis among Central Valley residents (*39*). Five of the seven were vineyard workers and six of the seven were nonsmokers. All five vineyard workers died of respiratory failure, and pathologic examination revealed interstitial fibrosis, chronic inflammation, and foreign body granulomata. Analysis of particles in the lung confirmed that they had the same composition as soil samples.

While case reports and case–series suggest that mineral dusts from soil can cause clinically significant pneumoconiosis, the prevalence and risk factors for this outcome are unknown. A cross-sectional survey of 178 rice farmers in California found X-ray changes of pneumoconiosis (≥ 1/0) in 10.1% of the population, but X rays were done on a subset of a larger, convenience sample (*40*).

A preliminary study of early histologic changes of pneumoconiosis has been conducted on coroner's cases of death among Hispanic males in Fresno County, California (*41*). Analyses of the first 43 cases found pneumoconiosis changes (macules, nodules fibrosis) in approximately half. Changes were independently associated with mineral dust concentration in the lungs and with a history of agricultural work (*41*). The changes were also independent of smoking-associated changes in the lungs. However, the small sample size and localized geographic distribution of cases limits generalization to other agricultural populations.

Studies of animal populations on farms, in zoos, or in the wild provide additional support for the occurrence of clinically significant pneumoconiosis from exposure to soil dusts. Berry and colleagues have described silicosis in 19 horses in California (*42*). Most of the horses were symptomatic with severe restrictive lung disease. Lung tissue showed a granulomatous interstitial pneumonitis associated with birefringent particles on polarizing microscopy. Particle analyses confirmed both crystalline silica and silicates in the lung tissue, which is similar to soil samples. A report on 100 autopsies of animals that died at the San Diego Zoo in San Diego, California, found interstitial fibrosis associated with mineral dust deposits in 20% of the lungs (*43*).

Research Needs

This article has focused on agricultural dust exposures, specifically on exposure and disease from inorganic or mineral dusts in agriculture. It is somewhat artificial to separate inorganic mineral dusts from other respiratory toxins (including organic dusts) in the agricultural workplace, since agriculture is characterized by exposure to a wide variety of hazardous respiratory agents (*44*). Farmers and farm workers are typically exposed to a wide spectrum of respiratory toxins, and it may be difficult to separate the effects of individual contributing agents. Many respiratory diseases such as bronchitis or asthma are caused by a variety of different exposures that occur in the agricultural setting. For example, asthma may be caused or exacerbated by exposure to organic dusts (grain dusts, animal dander, various plant dusts), toxic gases, and infectious agents. Inorganic dusts and other nonspecific irritants may exacerbate, if not cause, asthma. Mixed exposures may also occur in agriculture to pesticides or other chemicals adherent to inorganic particles, but little is known about the prevalence or significance of such exposures.

The majority of agricultural respiratory disease studies have focused on the effects of organic dusts. This is a result of many factors, including the more easily characterized allergic syndromes from organic dust exposure and the belief that inorganic agricultural dusts were benign. While respiratory disease from organic dusts continues to represent an important problem, there is a need to focus on disease due to inorganic dusts. This need derives in part from the shift in agriculture to labor-intensive crops grown in dry, western climates such as California. For example, California is now the number one agricultural state in the country, with an annual production of over $25 billion. One million farm workers are employed in California, providing approximately 85% of the farm labor. While California agriculture is characterized by a diversity of commodities, the climate is dry most of the year and exposure to mineral dusts during field work is a common hazard.

Pathogenicity of Agricultural Dusts

Major research is needed to characterize the nature and pathogenicity of agricultural dust exposure, with particular focus on inorganic dusts. Too little is known about the exposure of agricultural workers to inorganic dusts and the actual exposure dose. What is the composition of mineral dusts to which agricultural workers are exposed? Using *in vitro* or *in vivo* models, how pathogenic are the individual dust components or the dust mixtures? Is it possible to model risks for different agricultural dust components or for dust mixtures, as has been done for crystalline silica? Can the fibrogenicity of aged silica as is found in agricultural dusts be compared to freshly generated silica dust from other workplace settings?

Research is needed on the distribution and risk factors of inorganic dust exposure among agricultural workers. How do climatic conditions, agricultural operations, soil conditions, and personal characteristics affect dust exposure? What are average and extreme cumulative exposures to inorganic dust among agricultural workers, and where do they occur? What cumulative dust exposure occurs with agricultural work?

What is the pulmonary response to inorganic dusts, and what is the mechanism of that response? What are the critical components and relative potency of different inorganic dusts? Does chronic exposure cause pulmonary fibrosis? Is airway inflammation a critical component of the response? If so, by what mediators? Is the response similar to that seen for organic dusts? How do personal characteristics such as age, gender, smoking atopy, and genetic factors affect the response to inorganic dusts? Is there a similar pattern of acute cross-shift change in pulmonary function, and is it predictive of long-term pulmonary function decline?

How common is inorganic dust-induced airway disease among farmers and farm

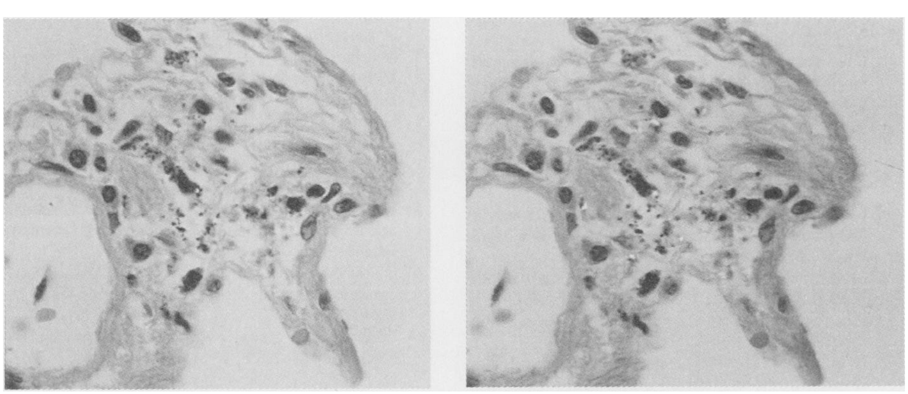

Figure 3. Bright field and polarized photomicrographs at the level of the respiratory bronchiole. Thickening of the alveolar wall septum is present with nodularity present in the bronchiole wall. There are accumulations of intraluminal macrophages containing polarized particles. These particles indicate the presence of birefringent particles, consistent with the presence of crystalline silica.

workers? Can risk factors be identified for this disorder? How often does inorganic dust cause clinically significant pulmonary fibrosis? Does it increase the risk of pulmonary infections?

What are effective measures to reduce exposure and other control methods suitable for the agricultural setting? This should include educational strategies, engineering controls, and regulatory interventions. Should the occupational silica standard be applied to the agricultural workplace? What is the role of the practicing physician in recognizing, treating, and preventing respiratory disease among agricultural workers?

Conclusions

Respiratory diseases associated with agricultural work were one of the first recognized occupational diseases of the lung. Most of the research on agricultural respiratory disease has appropriately focused on disorders caused by organic dust exposures. This is in part due to the heavy exposures to organic dusts that may occur in the agricultural workplace (plant, animal dust) and to the large literature on respiratory effects of these exposures (e.g., occupational asthma, hypersensitivity pneumonitis). More recently it has been recognized that clinically significant exposures to inorganic dusts may also occur in agriculture. Such exposures are most common in so-called dry-climate farming, i.e., areas where rainfall occurs for only a few months of the year and agriculture is watered by man-made irrigation. In such locations farming activities that perturb the soil (e.g., plowing, tilling) commonly result in exposures to farm operators of 1–5 mg/m^3 respirable dust, and total dust exposures of 20 mg/m^3 or more are commonly observed. These exposure concentrations have been observed to cause chronic bronchitis in other industrial settings and are likely to explain in part the increase in chronic bronchitis observed in agriculture, particularly in areas of dry-climate farming.

The composition of inorganic dust in agriculture generally reflects the soil composition. In some agricultural environments crystalline silica may represent up to 20% of the soil composition, and human exposures to these dusts represent a risk for interstitial fibrosis. Other silicates (up to 80% of soil samples) may also cause or contribute to pulmonary fibrosis (mixed-dust pneumoconiosis), although they are less fibrogenic than crystalline silica. While fibrosis has been observed in case reports of agricultural workers, the prevalence and clinical severity of these cases is unknown and more research is needed in this area.

Finally, there is a large body of literature supporting the association of occupational dust exposure and chronic obstructive pulmonary disease (COPD) (*45,46*). Epidemiologic studies of farmers and farm workers in diverse geographic settings have shown an increase in chronic obstructive lung disease morbidity and mortality, a noteworthy observation since farmers and farm workers smoke less than the general population. Thus it is plausible that agricultural dust exposure is a causal factor for the increase in COPD. While it is likely that such exposures are to mixed organic and inorganic dusts, the magnitude of inorganic dust exposure observed in some farm settings suggests that it is a clinically significant etiologic component. Further research is needed to characterize the risk of COPD among farmers and farm workers and the contribution of various agricultural and nonagricultural exposures.

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