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Exposure to Amorphous Silica Fibers and Other Particulate Matter During Rice Farming Operations

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Occupational exposure to biogenic amorphous silica fibers was found during all phases of rice farming. Exposure during field preparation was the highest, followed by harvest and then rice stubble burning. The highest personal exposure was 1.9 fibers/cc for fibers >5 μm in length in the respirable dust fraction. The highest level seen in area samples was 9.9 fibers/cc for fibers >5 μm in length in the respirable dust fraction. The median fiber length was 2.8 μm, with a range from 0.5 to 20 μm. (Fibers <0.5 μm were not counted.) Ninety percent of fibers were <9 μm in length. The median fiber width was 0.9 μm, with a range from 0.2 to 7 μm. Ninety percent of fibers were <2.5 μm in width. Samples for airborne amorphous silica fibers were collected with personal sampling pumps and polycarbonate filters. Samples were analyzed using X-ray fluorescence to identify composition and electron diffraction to determine the crystalline state of fibers. Fiber counting methodology was adapted from standard asbestos analytical procedures. The biogenic amorphous silica fibers were of complex morphology, often having no parallel sides. Although the fibers did not have needlelike or hairlike shapes, ends of some fibers were sharply pointed. LAWSON, R.J.; SCHENKER, M.B.; MCCURDY, S.A.; JENKINS, B.; LISCHAK, L.A.; JOHN, W.; SCALES, D.: EXPOSURE TO AMORPHOUS SILICA FIBERS AND OTHER PARTICULATE MATTER DURING RICE FARMING OPERATIONS. APPL. OCCUP. ENVIRON. HYG. 10(8):677–684; 1995.

In spite of the importance of farming and the recognition of work-related respiratory disease, studies addressing possible risk factors for respiratory disease in agriculture are limited. Studies have shown increased prevalence of respiratory symptoms and impaired pulmonary function, including morning phlegm production, wheezing, shortness of breath, and chronic bronchitis in many farm settings.[1–4] However, these investigations have seldom included industrial hygiene measurements, limiting the ability to compare with other exposure settings and to evaluate validity of exposure assignment, causality, and dose–response relationships.

One potential hazard that farmers and agricultural workers are exposed to is amorphous silica. Exposure to particulate amorphous silica is generally not considered very hazardous; for example, the American Conference of Governmental Industrial Hygienists threshold limit value for amorphous silica gel is 10 mg/m^3.[5] However, little is known about the effects of exposure to biogenic silica.[6] Biogenic silica may occur in respirable particles that meet the 3:1 length to width aspect ratio that is used to define a fiber.[7–13] There is some evidence that biogenic silica fibers may have health effects beyond those of nonfibrous amorphous silica.[14]

Silicic acid is absorbed into the plant and then precipitated as an insoluble silica gel, which may be called biogenic silica.[15] Biogenic silica is present in many plants, including rice, oats, barley, rye, and wheat.[15–19] One of the highest silica concentrations found in plants is in rice straw, which contains approximately 12 percent silica by weight.[20] When biogenic silica occurs in discrete particles it may also be referred to as a phytolith, an opal phytolith, a silica phytolith, a silica cell, plant opal, or biogenic opal.[21] In the rice plant silica is concentrated in aerial parts of the plant, particularly epidermal and vascular tissue.[22,23] In rice some short and long epidermal cells fill with silica, leading to characteristic silica bodies, typically 20 × 40 μm for short cells and 10 to 20 × 150 to 250 μm for long cells.[22–24] However, silica deposition is so ubiquitous in the rice epidermis that it is estimated that only a fraction of the total epidermal silica is located in the readily identifiable silica bodies.[22]

There are reports of occupational exposure to airborne respirable biogenic silica fibers in sugar cane workers, where exposures up to 0.77 fibers/cc (f/cc) were documented.[11–13] Biogenic silica released by the plants back to the soil through burning or normal plant decay is durable, may last for many years,[25] and typically accumulates in the soil in a range of <1 to 3 percent, and up to 100 percent of the soil in rare cases.[26] Biogenic silica has been found transported in air thousands of miles from land, probably made airborne by burning or dust storms.[10] Wind tunnel studies have previously shown that biogenic silica fibers are released by the burning of rice straw.[27–29]

There has been speculation regarding the cancer potential of amorphous silica fibers, but most attention has been paid to particles beyond the respirable size range, which have been hypothesized to be hazards by ingestion related to the occurrence of esophageal cancer.[30] There has also been speculation regarding a possible association between occupational exposure to respirable biogenic silica fibers and mesothelioma and lung cancer, particularly associated with sugar cane harvest.[31,32] One recent study of sugar cane workers found a slight, not statistically significant, risk of excess lung cancer.[33] Another recent study did not find a correlation between sugar cane work and mesothelioma.[13]

California is one of the largest rice-producing states in the United States, with about 300,000 acres in rice, and production is focused in the Sacramento Valley.[34] The typical agricultural practice in California rice production is to burn rice straw in the field after harvest. Burning, which occurs in the fall and spring, is being curtailed by state regulatory agencies to protect air quality. Burn days are designated and farmers are assigned limited acreage to burn. The state legislature has mandated a phase-out of most rice straw burning. After the year 1999, a maximum of 25 percent of the acreage may be burned, limited to fields significantly affected by pathogens such as stem rot.

Rice farming in the United States is heavily mechanized and is not labor intensive. A field is harvested using combine harvesters and bank out wagons, which transfer rice from the combine to trucks waiting at the field edge. Each machine requires one operator. Most harvesters are air-conditioned, but many bank out wagons are not. Rice straw and stubble in the field are burned after harvest in the fall. This is typically done by one to three employees per field on foot carrying torches and setting a fire as they go. The fire may be set by an employee on a tractor or other vehicle that tows a torch. After the field is burned, field preparation activities are usually performed by one employee. This typically includes leveling small flood irrigation levees in the field using a bulldozer, and plowing and disking using a tractor with towed implements.

The purpose of this study was to evaluate exposures to silica fibers >5 μm in length in the respirable dust fraction during rice farming operations. Air samples were collected and analyzed for silica fibers, including a determination of the fiber size and whether fibers were amorphous or crystalline. Personal exposure and area samples were collected during rice harvest, field burning, and field preparation activities. Samples collected upwind of rice farming operations were used as controls, representing the background level of fibers. Area samples were also collected in towns in the Sacramento Valley on prescribed burn days. Other exposures associated with rice farming which were evaluated included total dust, respirable dust, respirable quartz, and carbon monoxide.

Materials and Methods

Sample Collection

Samples for airborne amorphous silica fibers were collected with personal sampling pumps (MSA model G) using a 10-mm nylon respirable dust cyclone at a flow rate of 1.7 L/min. Flow rates were periodically checked with a precision rotameter. The sampling medium was a 0.4-μm pore size, 25-mm diameter track-etched polycarbonate membrane filter (Poretics) in front of a 5-μm pore size cellulosic diffuser loaded in a carbon-filled polypropylene cassette with a 50-mm extended cowl. The bracket on the cyclone holder was modified to fit the extended cowl cassette. Some area samples in upwind locations and all downwind and community locations were collected with the same sampling media open face using a high flow pump at a flow rate of 8 to 10 L/min, without use of a cyclone. Ranging studies were performed to determine optimal loading for each phase of sample collection.

Respirable dust and crystalline silica samples were collected at a flow rate of 1.7 L/min using a respirable dust cyclone and a 5-μm pore size, 37-mm diameter polyvinylchloride (PVC) filter in a polystyrene cassette. Total dust samples were collected at a flow rate of 2.0 L/min with 5-μm pore size, 37-mm diameter PVC filters in polystyrene cassettes. Personal exposure monitoring for carbon monoxide was conducted using diffusion indicator tubes.

Samples were collected during harvest, burning of rice straw after harvest, and field preparation. Field preparation samples were collected in fields that had been burned from 1 day to 2 months previously. Breathing zone samples were collected simultaneously with samples upwind and downwind of the farming operation. When closed cab equipment was used by the farmer, samples were collected both inside and outside the cab. Samples were also collected from outdoor locations in communities in the rice-growing region on prescribed burn days.

When monitoring rice farming operations, one sampler was placed upwind of the operation at a height of approximately 2 m. A minimum of one downwind sampler was used, at a height of approximately 2 m. During burn operations multiple downwind samplers were used. Three samplers were placed at the downwind edge of the field, two at a height of approximately 2 m and a third on a mast approximately 6 m in the air. One sampler was placed approximately 1.5 km downwind at a height of approximately 2 m. Some of these samples were collected open face without use of a cyclone.

Ten percent of collected samples were field blanks. Ten percent of collected samples were side-by-side duplicates. Duplicate samples were taken within 4 cm of each other and were run simultaneously. One set of eight replicates (side-by-side samples) was collected during harvesting and a second set when burning was done with a torch towed by a tractor. A portable weather station was located on site to indicate wind speed, direction, air temperature, relative humidity, and solar radiation during rice harvest and burn operations.

Sample Analysis

The analytical method is discussed in detail by Scales *et al.*[35] and is only briefly summarized here. Samples were analyzed for amorphous silica fibers using a Hitachi H-600/H-601A transmission electron microscope with electron diffraction and scanning transmission modes, operated at 75 kV. Particles having aspect ratios of three or greater were classified as fibers. Fibers >5 μm in length were tabulated separately. Fibers containing silica were identified by their characteristic fluorescent X rays using a Quantex (thin window) X-ray detector and a Kevex Delta Class Analyzer. Electron diffraction was used to determine the crystalline state of fibers. Fiber counting methodology was adopted from standard asbestos analytical procedures.[36] Reference samples were prepared from ash collected from burns in a wind tunnel at the University of California, Davis, as described by Scales *et al.*[35] Particles where reported as amorphous silica fibers if they met the fiber definition, contained silica but not aluminum, and showed no Bragg reflections.

Gravimetric analysis was used for respirable dust and total dust samples. Filters were preweighed and postweighed on an electrobalance located in a temperature- and humidity-controlled room. Crystalline silica content was analyzed following National Institute for Occupational Safety and Health (NIOSH) Method 7500 using a Diano XRD 8000 diffractometer, with a copper tube operated at 50 kV and 15 mA.[37] The sample PVC filters were ashed in a muffle furnace, dispersed ultrasonically, and filtered on silver membranes. Standards on silver membranes were prepared from NIOSH reference quartz (Q-1).[38]

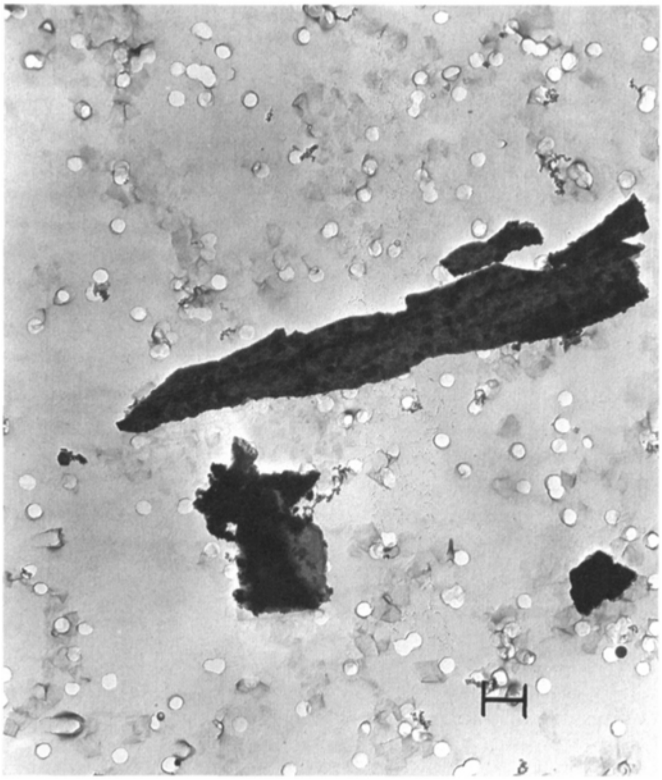
The initial intention of the project was to analyze all samples that were collected. The first samples collected were harvest samples, and therefore the first samples analyzed were harvest samples. It soon became clear that not all samples could be analyzed within the time and budget of the project. The laboratory was instructed to analyze samples with the following priority: burn samples, then field preparation samples, then harvest samples. Within that priority guideline, the laboratory was instructed to randomly select the samples to analyze. The laboratory was blinded to the identity of duplicate samples.

Results

Silica Fiber Analysis

The method could distinguish between amorphous and crystalline particles. Amorphous silica fibers were seen on many of the samples. The method could also distinguish whether particles containing silicon also contained aluminum. Fibers that contained silicon but no aluminum were always amorphous. The fibers were of complex morphology, often with no parallel sides. Although the fibers did not have needlelike or hairlike shapes, ends of fibers were sometimes sharply pointed. The morphology of fibers seen on the samples was similar to fibers in the rice ash reference samples. The median fiber length was 2.8 μm, with a range from 0.5 to 20 μm. (Fibers <0.5 μm were not counted.) Ninety percent of fibers were <9 μm in length. The median fiber width was 0.9 μm, with a range from 0.2 to 7 μm. Ninety percent of fibers were <2.5 μm in width. Photographs of amorphous silica fibers are included as Figures 1 through 5.

Approximately 70 percent of all samples were analyzed because of time and budget constraints. The fiber analysis required an average of a full day of electron microscopy per sample. Samples to analyze were randomly selected within the sampling categories of harvest, burn, and field preparation, and the laboratory was blinded to the identity of duplicates. A decision was made to analyze the first six of ten collected blanks. Samples analyzed included 100 percent of burn samples, 75 percent of upwind samples, 70 percent of field preparation samples, 60 percent of duplicate samples, and 50 percent of harvest samples. Approximately 10 percent of all samples analyzed were too overloaded to yield fiber count results. These were primarily samples which had been run longer than 15 minutes. Five pairs of duplicates that were analyzed had coefficients of variation ranging from 4 to 33



FIGURES 1 to 5. Photomicrographs of amorphous silica fibers from rice farming operations. Fibers consist mainly of silicon and oxygen and are noncrystalline. Scale bar indicates one micron.

percent, with an average of 18 percent for the numbers of fibers detected per sample.

To prevent overloading, sampling times were limited to about 15 minutes for most filters. This gave an effective detection limit of 0.1 f/cc for these samples. Sampling times for downwind, town, and closed cab interior samples were longer and had effective detection limits ranging from 0.02 to 0.004 f/cc.

Exposure to Amorphous Silica Fibers

A total of 86 samples were analyzed. These samples represented 52 distinct personal exposures or area sampling locations, as several samples were sometimes taken for one personal or area exposure location. All results are for fibers >5 μm in length and represent the calculated time-weighted average level for the personal or area exposure location.

Eleven samples collected upwind of rice farming operations were used to control for ambient background levels of amorphous silica fibers. Amorphous silica fibers were observed on 1 of the 11 samples, giving a result of 0.02 f/cc. The mean for all 11 samples was less than 0.02 f/cc (below the limit of detection for those samples). Field blanks were used to control for contamination of the sampling media. No amorphous silica fibers were detected on six blanks.

Amorphous silica fibers were found on most personal and area samples collected at locations within rice fields. In 14 personal exposures, airborne time-weighted average levels for amorphous silica fibers ranged from none detected to 1.9 f/cc

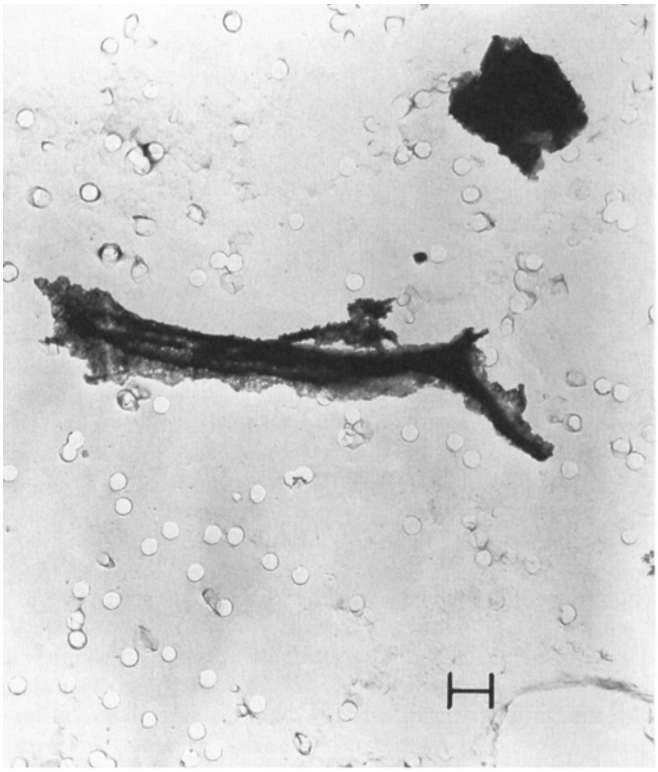


FIGURE 2.

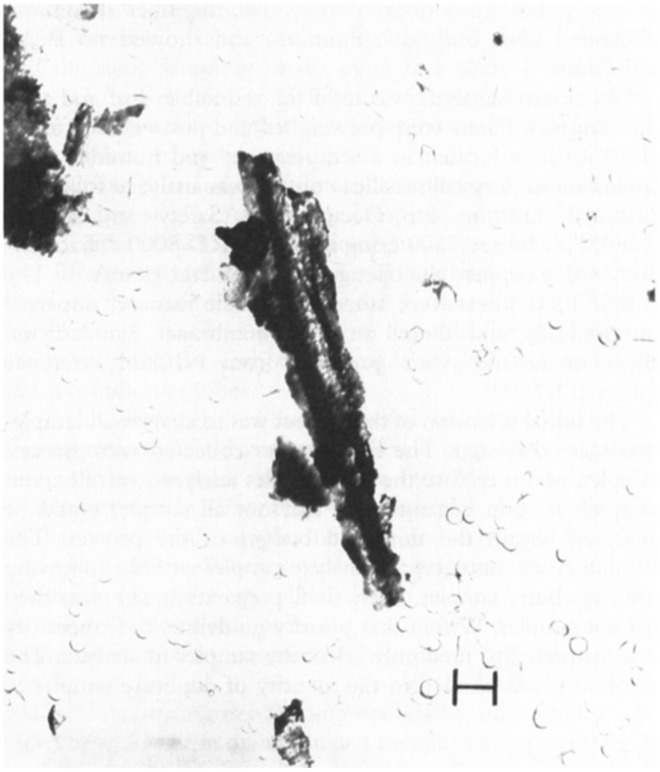


FIGURE 3.

(Table 1). Personal exposures were higher for operators of open cab equipment than for operators of closed cab equipment. Personal exposures were lowest for employees on foot and burning rice stubble. Mean levels for burning on foot were <0.1 f/cc (below the limit of detection for those samples). Mean levels for open cab samples were: 1.8 f/cc, fire-lighting from a tractor; 1.1 f/cc, bulldozer used for field preparation; 0.3 f/cc, bank out wagon used for rice harvest. Mean levels for closed cab samples were: 1.02 f/cc, tractor used for field preparation; 0.13 f/cc, harvester.

Fourteen area samples were collected on the exterior of closed cab harvesters and tractors performing field preparation, representing a total of six different area exposures. These samples ranged from 0.4 to 9.9 f/cc. Mean levels on tractors performing field preparation were 8.4 f/cc. Mean levels on harvesters were 1.2 f/cc.

We compared the difference between measurements taken on the same day on the interior and exterior of air-conditioned closed cab equipment performing the same operation to estimate the level of protection provided by the enclosed cab. Personal exposures inside the cab ranged from 2 to 19 percent of levels measured on the cab exterior. It was clear that some of the exposure in the cab interior was due to entry of outside air when the equipment operator entered and exited the cab periodically to adjust settings or clear jams. Also, a window in the cab was sometimes left open during the nicest part of the day.

Amorphous silica fibers were observed on one of two 1.5-km downwind samples and on two of four field edge downwind samples. The mean level was 0.004 f/cc for all downwind samples. The mean level for the three samples on which fibers were seen was 0.014 f/cc. For community samples, collected on days when there was rice burning, fibers were seen on 4 of the 14 samples. The mean level for all town samples was <0.004 f/cc (the limit of detection for those samples). The range for the four samples on which fibers were seen was 0.005 to 0.010 f/cc (Table 1). As some of these samples were collected without use of a cyclone, these results may be biased to the high side.

Using the SAS general linear models procedure[39] to analyze variance on the log transformation of the data, airborne fiber levels could be divided into four groups, from highest to lowest: (1) field preparation; (2) burning using a torch towed by a tractor and harvest; (3) exposures inside closed cab equipment; (4) burning by employees on foot, upwind, downwind, and town ($p < 0.0001$ for the difference between each group) (Table 2).

Exposure to Other Airborne Contaminants

Measurements were made of airborne levels of total dust, respirable dust, and crystalline silica. One personal exposure sample from an open cab tractor towing a torch gave results of 1.83 mg/m^3 total dust, 0.30 mg/m^3 respirable dust, and 0.07 mg/m^3 respirable quartz. Two exposure samples for personnel burning on foot gave respirable dust levels of 0.14 and 0.31 mg/m^3 and respirable quartz levels of 0.02 and 0.03 mg/m^3. Cristobalite and trydimite were not detected on any of the samples (Table 3).

Area measurements on the exterior of closed cab equipment were collected for total dust, respirable dust, and respirable

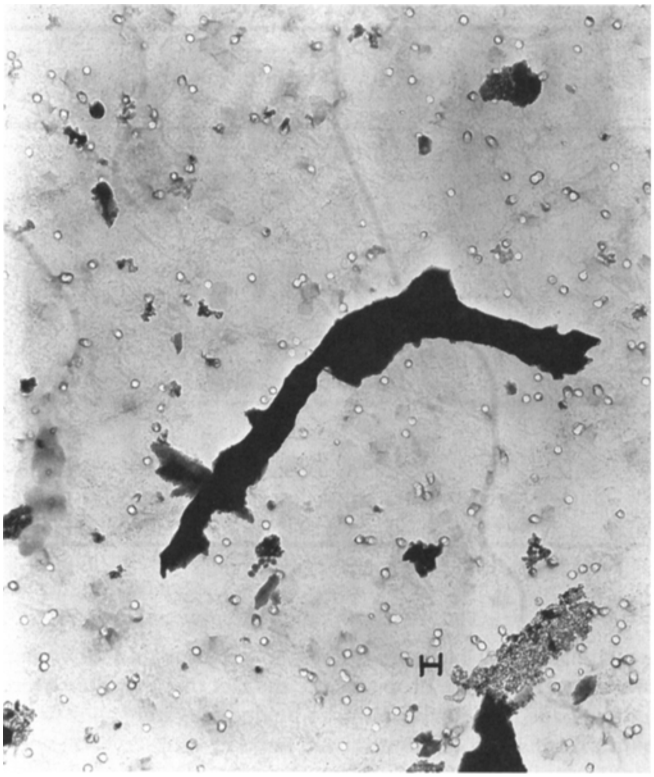


FIGURE 4.

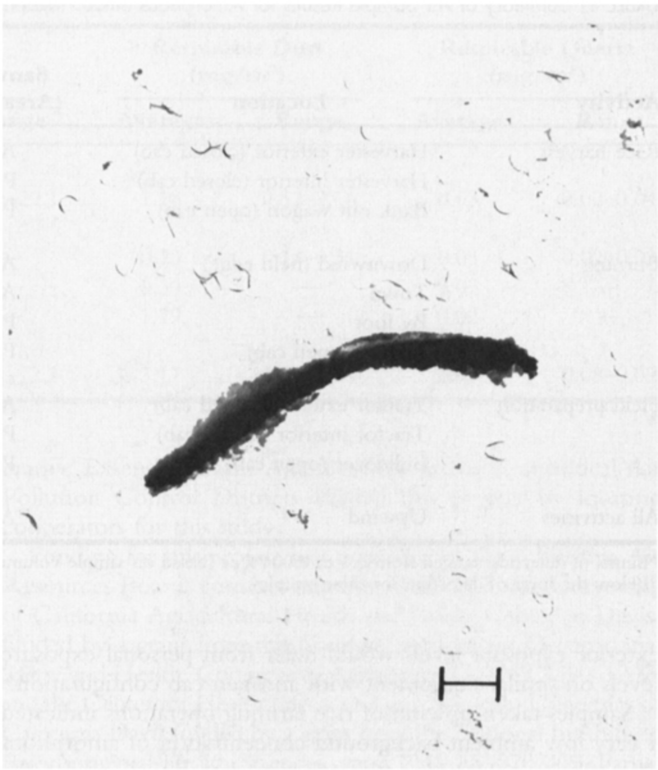


FIGURE 5.

quartz measurements on 5 days of harvest and 3 days of field preparation. Levels ranged from 4.02 to 72.1 mg/m^3 for total dust, 0.52 to 5.24 for respirable dust, and 0.02 to 0.09 for respirable quartz. Field preparation resulted in higher levels than harvest. Cristobalite and trydimite were not detected on any of the samples (Table 3).

Carbon monoxide levels were measured on 4 days of burning. Five personal samples were taken, as well as one sample at the field edge downwind of burning. Levels did not reach the limit of detection of the diffusion indicator tubes (which ranged from 25 to 50 ppm carbon monoxide).

Discussion

This study has shown employee exposure to airborne amorphous silica fibers in all phases of rice farming operations. The fibers are clearly different morphologically from asbestos fibers, fiberglass, other man-made amorphous silica-containing fibers, and nonfibrous forms of amorphous silica. The fibrous shape, the sharply pointed ends seen on some fibers, and the existence of fibers >5 μm in length suggest the potential for direct cell injury. There was no evidence that amorphous silica fibers were being converted to crystalline silica forms during combustion in field burning. If conversion had occurred, we would expect to have found crystalline fibers that contained only silica without aluminum. Although crystalline fibers were sometimes found on samples, they contained both silica and aluminum, did not have rice particulate morphology, and were assumed to be soil silicates.

The exposures to amorphous silica fibers seen in harvest activities and field preparation activities suggest that if employees avoid smoke exposure, then aerosolization of biogenic silica fibers from the soil may be a more significant occupational exposure hazard than fibers in smoke released by burning. These results in conjunction with results from sugar cane farming[7,11–13] raise the possibility that many plants in the grass family, including other commercially important grain crops, are potential sources of occupational amorphous silica fiber exposure.

The highest level of personal exposure observed was 1.9 f/cc (>5 μm in length) in field preparation. The highest level measured outside an enclosed cab was 9.9 f/cc (>5 μm in length) during field preparation. These results exceeded the highest level of airborne silica fibers reported in previous studies of 0.77 f/cc in sugar cane workers.[13] Employee exposure to amorphous silica fibers, respirable quartz, respirable dust, and total dust were all correlated, so that exposures of all types tended to be the highest for the dustiest jobs. Exposure levels were highest with vehicle traffic in the field. Exposure levels were lowest when employees worked on foot. Most harvesters and tractors had enclosed air-conditioned cabs that provided a significant degree of protection, with cab interior fiber levels being 2 to 19 percent of cab exterior levels.

The samples taken on the exterior of closed cab harvesters and tractors may be indicative of historical personal exposures before the use of air-conditioned closed cab equipment. Caution should be used in applying these results to precisely calculate historical exposure, however. The aerodynamics of particle flow around the enclosed cab and constraints on sampler placement on the enclosed cab make it likely that cab

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TABLE 1. Summary of Air Sample Results for Amorphous Silica Fibers (Fibers ≤5 μm in Length, in the Respirable Dust Fraction)

Activity	Location	Sample Type (Area/Personal)	No. of Exposures Sampled	Average Concentration (f/cc)[A]	Range (f/cc)
Rice harvest	Harvester exterior (closed cab)	Area	4	1.2	0.4–2.3
	Harvester interior (closed cab)	Personal	3	0.13	0.06–0.23
	Bank out wagon (open cab)	Personal	2	0.3	0.2–0.4
Burning	Downwind (field edge)	Area	6	0.004	n.d.–0.014
	Town	Area	14	<0.002[B]	n.d.–0.010
	By foot	Personal	6	<0.1[B]	n.d.–0.1
	Tractor (open cab)	Personal	1	1.8	—
Field preparation	Tractor exterior (closed cab)	Area	2	8.4	7.0–9.9
	Tractor interior (closed cab)	Personal	2	1.02	0.13–1.90
	Bulldozer (open cab)	Personal	1	1.1	—
All activities	Upwind	Area	11	<0.02[B]	n.d.–0.02

[A]Limits of detection ranged from 0.1 to 0.004 f/cc (based on sample volume).
[B]Below the limit of detection for these samples.

exterior exposure levels would differ from personal exposure levels on similar equipment with an open cab configuration.

Samples taken upwind of rice farming operations indicated a very low ambient background concentration of amorphous silica fibers, <0.02 f/cc (the effective detection limit for the upwind samples in this study). Therefore, employee exposures to elevated amorphous silica fiber levels were clearly due to the farming operations. Although we could not conclusively determine the origin of the amorphous silica fibers found on the town samples, they were similar in morphology to those from the rice farming samples.

Employees performing burning of rice straw on foot had the lowest exposure levels observed in this study. This was consistent with field observations that employees generally stayed out of smoke plumes and with the low carbon monoxide exposure levels for these employees. Samples downwind of burns also had low levels of detected amorphous silica fibers. This was due largely to the difficulty in placing samplers. All samplers placed at ground level at the immediate field edge which had heavy exposure to the smoke plume shut down due to excessive pressure drop, despite the fact that the filters were lightly loaded. We believe this to be due to water vapor in the plume. Similar problems had been previously observed in wind tunnel studies.[(40)] Consultation with the filter manufacturer confirmed that the filters tend to develop very high pressure drop if moisture droplets occupy the filter pore sites. Samples placed further from the field edge were affected by the tendency of the plume to drift or rise before reaching the samplers.

On average, respirable dust levels were approximately 10 to 15 percent of total dust levels in nonburning activities, indicating that most of the total dust exposure was to very coarse particles >5 μm in length. The exception to this was the single sample set taken downwind from a burn, where the ratio of respirable to total dust was roughly 85 percent. Combustion particles are known to have sizes predominantly less than 1 μm.[(29)]

The sampling and analytical method is still considered pro-

TABLE 2. Comparison of Categories of Exposure to Amorphous Silica Fibers

Activity	Location	Average Concentration[A] (f/cc)	Exposure Category[B]
Field preparation	Tractor exterior (closed cab) + bulldozer (open cab)	6.0	A
Burning	Tractor (open cab)	1.8	B
Rice harvest	Harvester exterior (closed cab) + bank out wagon (open cab)	0.90	B
Field prep/harvest	Interior (closed cab)	0.50	C
Burning	By foot	<0.1[C]	D
Burning	Downwind (field edge)	0.004	D
Burning	Town	<0.002[C]	D
All activities	Upwind	<0.02[C]	D

[A]Limits of detection ranged from 0.1 to 0.004 f/cc (based on sample volume).
[B]Differences between exposure categories significant ($p < 0.0001$), using SAS general linear model, on log transformation of data.
[C]Below the limit of detection for these samples.

TABLE 3. Summary of Air Sample Results for Total Dust, Respirable Dust, and Respirable Quartz

Activity (Location)	No. of Samples	Total Dust (mg/m^3)		Respirable Dust (mg/m^3)		Respirable Quartz (mg/m^3)	
		Average	Range	Average	Range	Average	Range
Rice harvest							
Harvester exterior (closed cab)	5	11.84	4.02–22.1	1.18	0.52–2.16	0.03	0.02–0.04
Burning							
By foot	3	—	—	0.23	0.14–0.31	0.03	0.02–0.03
Tractor (open cab)	1	1.83	—	0.30	—	0.07	—
Downwind	1	1.39	—	1.19	—	0.02	—
Field preparation							
Tractor exterior (closed cab)	3	35.2	11.1–72.1	3.17	1.77–5.24	0.08	0.08–0.09

visional pending further development, including interlaboratory testing and proficiency testing with standard samples.[35] Detection limits were constrained in most cases by the short sampling times necessary to prevent overloading. The number of samples analyzed was limited by the time necessary to analyze samples, which typically was about 1 day of electron microscopy time per sample.

Conclusions

Employees engaged in rice farming are exposed to biogenic amorphous silica fibers. Personal exposures were found up to 1.9 f/cc for fibers in the respirable dust fraction that were >5 μm in length. An airborne level up to 9.9 f/cc was found for fibers in the respirable dust fraction that were >5 μm in length, from an area sample outside an enclosed cab.

The health effects of the exposures to amorphous silica fibers documented in this study are not known and further toxicologic and clinical studies are necessary. The biogenic amorphous silica fibers were of complex morphology, often having no parallel sides. Although the fibers did not have needlelike or hairlike shapes, ends of fibers were sometimes sharply pointed. The median fiber length was 2.8 μm, with a range from 0.5 to 20 μm. (Fibers shorter than 0.5 μm were not counted.) Ninety percent of fibers were <9 μm in length. The median fiber width was 0.9 μm, with a range from 0.2 to 7 μm. Ninety percent of fibers were <2.5 μm in width.

The results of this study suggest that if employees avoid smoke exposure, then exposure to aerosolized biogenic silica fibers from the soil may contribute more to occupational exposure hazard than direct exposure to fibers in smoke released by burning. These results in conjunction with results from sugar cane farming raise the possibility that many plants in the grass family, including other commercially important grain crops, are potential sources of occupational amorphous silica fiber exposure.

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