

# Respirable Dust and Crystalline Silica (Quartz) Exposure Resulting from Potato Harvesting Operations

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## Abstract

Occupational exposure to silica dust has historically been known to cause chronic respiratory conditions. Workers and workplaces within agricultural industries remain removed from the attention of occupational health and safety. The identification and degree of exposure to respirable dust, crystalline silica, and endotoxins throughout the potato harvesting process has been uncharacterized. A description of the potential occupational risks in this setting was therefore warranted. The purpose of this research was to identify the components of dust during the fall potato harvest in the San Luis Valley of southern Colorado. The agricultural practices specific to potato harvest, the geographic region, and the soil of San Luis Valley are believed to contribute to occupational risk. Testing sites included seven farms in this region, chosen based on their location, variable soil types, and owner interest. The following parameters: respirable dust, respirable silica, bacterial endotoxins, and particle identification by scanning electron microscopy were measured. All exposures were based on 8-h time-weighted averages. Exposure impact included: location of the farm, soil type (sand, rock, loam), job description, weather conditions; wind, rain, wet or dry soil during harvest, humidity, and temperature. Results of air monitoring include 122 samples collected, 93 revealed the presence of respirable dust, 18 detected respirable silica (quartz). The maximum respirable dust exposure was 5.05 mg/m<sup>3</sup>, respirable silica 0.105 mg/m<sup>3</sup>, and percent silica of 12.85%. This information will allow employers to recognize where respirable dust and silica are generated and allow for planning and control implementation to adequately protect workers.

*Keywords.* Silica, Respirable dust, Endotoxin, Scanning electron microscopy, Time-weighted average, Tuber.

Essentially all agricultural processes involve the manipulation of soil, including the planting, harvesting, sorting, transportation, and the storage of produce. Therefore, the agricultural work environment has the potential to be extremely dusty. Agricultural operations are the third largest source of particulate pollution in the United States, producing nearly 1,800,000 tons of dust each year (Donham, 1986). Agricultural workers are subsequently exposed to nuisance dusts in addition to the soil components (Donham, 1986). One of the most common

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components of soil, crystalline silica (quartz), has the potential to damage the lung and could present an occupational health hazard in the agricultural setting if it is respired (Merchant, 1986). Silica is the agent responsible for silicosis, a lung disease which is disabling, progressive and often fatal (Merchant, 1986). Silicosis is a preventable occupational disease, although, prevention is entirely dependent upon the identification of the presence of silica and the understanding of its hazards (Merchant, 1986).

Large gaps still exist in our knowledge of the epidemiology of respiratory hazards in this arena (Merchant, 1986). Respiratory risks associated with agriculture reflect the diversity of exposures to the farming population, ranging from organic and inorganic dusts to numerous chemicals and biologic agents. Although clinical studies have documented the existence of many respiratory symptoms and diseases from agricultural exposures, studies are indeed limited (Cordes and Foster, 1991). Further research is needed to determine the characteristics of many health hazards and to evaluate the safety and health implications of farm environments. Evaluation is needed to set meaningful guidelines and exposure limits for work practices and for equipment applications of farm environment. Colorado's potato production volume ranks fourth in the United States. The value of production of all of Colorado's potatoes totaled \$149.9 million in 1995 (CSUCE, 1996).

The San Luis Valley, a desert in south-central Colorado, is one of the most agriculturally productive areas in the United States located at a high elevation, producing 92% of Colorado's Potatoes (Dillon, 1995). Unique in its topography, the elevation of the valley floor is 7,600 feet. The San Luis Valley is a large, flat intermountain valley that varies from 20 to 50 miles in width and is about 100 miles north to south. All crops are irrigated by surface flooding or center pivot sprinklers. This area offers a near perfect environment for growing potatoes, with warm, sunny summer days and cool nights. The high mountains surrounding the valley provide a natural barrier to insects and disease (Franc et al., 1996). As long as the San Luis Valley has existed, spring winds have swept dust and sand across the Valley and deposited them at the base of the Sangre de Cristo Range forming the Great Sand Dunes (USDA-SCS, 1973).

The majority of potatoes grown in North America are now harvested mechanically. Most harvesters are of the two or four row type that harvest directly into bulk trucks. Field trucks transport potatoes from the field to packing sheds, processing plants, warehouses, and storage (PAA, 1993).

Despite the fact that advancing technology is rapidly decreasing the number of employees required for potato harvest, the need for manual labor continues. Currently, the potato harvesting process requires approximately seven different jobs, having multiple workers performing each of the tasks. These harvesting jobs include the harvester and windrower (digger) drivers who perform their duties from a completely enclosed tractor type cab. Riding on each operating harvester are two harvest riders, also called harvest sorters. These individuals spend the entire harvesting day on top of harvesters, where the majority of dust is generated, sorting out poor quality potatoes, rocks, and vegetation. Riding alongside the harvester are a series of alternating trucks receiving potatoes as the harvester is unloading. Once a truck bed is filled, the next truck continues the process. Some of the truck drivers communicate with the harvester operator by radio, others by open window, verbal communication. The physical space between the harvester and the truck is extremely dusty while the harvester is in operation. Numerous employees are required to receive, unload, and sort the truck loads of potatoes. Sorters assist with the unloading process, sort, and discard poor quality potatoes (culls), rocks and

vegetation prior to their storage and shipping. At the end of the harvest operation line is the stacker, also known as a piler. This individual operates a conveyor belt that extends approximately fifteen to twenty feet enabling the stacking of potatoes from floor to ceiling in environmentally controlled metal warehouses for storage. This individual is not exposed to the outdoor weather conditions, but to dust in the enclosed structure. An additional job found at most of the farm sites is the cleaner. This individual works around unloading and potato storage areas keeping the grounds free of excess dust, damaged potatoes, vegetation, and other hazards (CSUCE, 1996; PAA, 1993).

The soil types vary greatly within the valley as well as the silica content. The silica content in each region can affect worker's personal exposure. The soil survey evaluation of the San Luis Valley was broken up into three regions, Alamosa, Rio Grande, and Saguache.

The Alamosa County region is located in the east-central part of the San Luis Valley (USDASCS, 1973). The most common rock in this area are rhyolitic or latitic in composition. These are acidic igneous rocks, relatively high in silica and low in iron, calcium, and magnesium minerals (USDASCS, 1973).

The Saguache County region is located in the eastern portion of the San Luis Valley. The Great Sand Dunes National Monument covers about 36,000 acres in the extreme southeast corner of the region. The sand dunes rise to 750 feet above the valley floor. Prevailing winds from the southwest have deposited sand against the Sangre de Cristo Range. These deposits are composed of fine and medium sand dominated by quartzitic and basaltic rocks. The material is washed down from the surrounding mountains by streams and transported by wind. The gypsum in some of these soils was derived from sulfates and sulfides in the volcanic rocks (Franc et al., 1996).

The Rio Grande County is along the west-central portion of the San Luis Valley. Geologic formations in this region are volcanic rock, mainly tuff, breccia, pumice, and flow rock of Miocene and Pliocene epochs. The composition ranges from rhyolitic to basaltic. Material derived from weathering of the volcanic rock is dominantly sandy, but ranges from clay to large boulders. In chemical composition, most are high to intermediate range of silica content and the low to intermediate range in percentage of calcium, magnesium, and iron minerals (USDA-SCS, 1973).

The San Luis Valley is unique with sandy, silica containing soil type and its enclosed valley surrounded by large peaks. Due to large agricultural production, its environmental setting, and the dust generating nature of potato harvesting operations, this appeared to be the optimum location to begin evaluating agricultural worker exposure to respirable silica. The potential severity of silica exposure in other occupations is a strong reminder of the importance of identifying exposures in all workplaces. Identification of silica's presence is a crucial step to identifying the hazard and preventing the potentially life threatening consequences. Farming should not be overlooked in the identification and prevention of silica exposures capable of inducing silicosis.

## Methods and Materials

The San Luis Valley was chosen for this study because of its productive agricultural sector, its unique topography, and the variability of its soil characteristics. Seven individual farm sites were selected based upon their location in the San Luis Valley, having at least two sampling locations in each of the three main potato producing counties: Alamosa, Rio Grande, and Saguache. The farms were chosen

based upon owner willingness to participate, with the goal of establishing sampling sites equally distributed throughout the farming areas of the valley. Each of these counties have varying soil types, all of which are stated by the United States Department of Agriculture Soil Conservation Service to contain silica.

From the number of volunteers, sampling sites were chosen based upon their locational distribution throughout the San Luis Valley. Seven farms were studied where potato acreage ranged from a low of three circles (center pivot fields, 120 acres per circle) to a high of 18 circles (2,160 acres). Farms employed 3 to 15 full-time employees and 10 to 100 seasonal harvest workers. The number of employees is dependent upon the size of the operation as well as the sophistication of the farming operation. The seven sampling locations were typical of potato harvesting operations in the southwest region of the United States.

Data consisted of 122 airborne dust samples collected from the seven farm sites during the potato harvesting process. The air in the breathing zone of the potato harvest workers (harvester, windrower, harvest rider, truck driver, sorter, piler, and cleaner) was sampled using 10-mm nylon cyclones (Bendix BDX 99, respirable dust lapel sampler) placed on the collars of the workers and attached to an assigned precalibrated HI-Flow personal sampling pump (SKC Aircheck Sampler, MSA Escort Elf, Gillian High Flow Sampler) operated at 1.7 L/min. Precalibration of the instruments was accomplished using the bell jar method and included a polyvinyl chloride (PVC) filter, 37 mm 5.0- $\mu$ m pore size supported with a backup pad in a two-piece, 37-mm cassette filter holder held together by tape or cellulose shrink band (all utilized filters were provided by the NIOSH Technical Assistance Project No. 96-0240). The sampling was performed according to the NIOSH "Sampling Instructions for Filter and Cyclone Samplers" for personal sampling of respirable aerosols (NIOSH, 1994). This sampling method consisted of collecting breathing zone samples during typical potato harvesting operations. Breathing zone samples were taken to establish the actual exposure of the worker during potato harvesting operations. All samples taken were based upon an eight-hour time-weighted average representing a typical work day exposure.

Background respirable dust and respirable silica levels were taken at each of the seven sampling sites, as well as 10% field blanks in accordance with NIOSH Methods 0600 and 7500 (NIOSH, 1994). Background pumps and filters were placed in nonharvest activity locations at each site. The sampling pumps were operated in the same manner as used on worker, and the results were based upon an 8-h time-weighted average.

Each cyclone and assigned pump were postcalibrated immediately upon sampling completion. Precalibration and postcalibration were performed at the sampling elevation and sample pre and postcalibration flow rate did not vary by greater than 5%. All cyclones and filter cassettes used were transported to and from the field in sealed zip-lock plastic bags. Each cyclone was completely disassembled at the end of each sampling period and individual parts were cleaned, utilizing compressed air. This process was performed daily to prevent equipment failure and reduce faulty results.

The samples were analyzed by Data Chem Laboratory (Salt Lake City, Utah) for particulate total weight using gravimetric analysis according to NIOSH Analytical Method 0600 (4th Ed.) With the following modifications: (a) The filters and back-up pads were stored in an environmentally controlled room ( $21 \pm 3^\circ\text{C}$  and  $50 \pm 5\%$  R.H.) subjected to the room conditions for at least two hours for stabilization prior to tare and gross weighing, and (b) Two weighings of the tare weight and the gross weight were performed. The averages of the weighings were used for the total

weight analysis. The total weight of each sample was determined by weighing the sample plus the filter on an electrobalance and subtracting the previously determined tare weight of the filter. Sample values less than the level of detection 0.02 mg (LOD) were reported as not detected (ND) (Gale, 1996).

The instrumental precision of the microbalance was 0.001 mg (Gale, 1996). The method allowable difference between two weighings of a filter is 0.01 mg (Gale, 1996). Due to variable factors such as overloading, and the physical integrity of the filter, the actual precision can be considerably poorer and occasional slight negative particulate weights may be expected. Studies on the physical integrity of various PVC filters have shown that the weight of the filter may vary by 0.02 mg. Because of this factor, the level of detection (LOD) for these results was 0.02 mg (Gale, 1996). The level of quantification (LOQ) 0.03 mg. Data which fell between the LOD and LOQ was considered semiquantitative.

Each sample was analyzed for respirable silica (quartz and cristobalite), using x-ray diffracton. Since all crystals act as three-dimensional gratings for x-rays, the pattern of diffracted rays is characteristic for each crystalline material. This method is of particular value in determining the presence or absence of crystalline silica in dust (Gale, 1996).

NIOSH Analytical Method 7500 was used to analyze the samples with the following modifications: (a) Filters were dissolved in tetrahydrofuran rather than being ashed in a furnace; (b) Standards and samples were run concurrently and an external calibration curve was prepared from the integrated intensities rather than using the suggested normalization procedures. The samples were analyzed by Data Chem Laboratories, Inc. in cooperation with the NIOSH.

Sampling periods in the field were recorded and the volume of air was calculated by multiplying the flow rate by the time operated. Mass was divided by the volume of air sampled to provide mass concentration ( $\text{mg}/\text{m}^3$ ). This method was also used to determine the mass fraction of dust that was within the respirable range. This same basic method of concentration calculation was used in calculating silica.

Endotoxin quantification was performed utilizing area sampling over an 8-h period, twice at each of the seven sampling locations. A total of 17 endotoxin samples, with 10% blanks, were obtained at the seven locations using Hi-Flow pumps (SKC, Gillian, and MSA) precalibrated to run at 2 L/min. These samples were collected on 37-mm VM1 PVC filters. The samples for endotoxin analysis were handled in the same manner as the respirable dust samples.

The endotoxin analysis was performed by the NIOSH Analytical Laboratory in Morgantown, West Virginia. This analysis was accomplished using the Limulus Amoebocyte Lysate (LAL) Test. The standard reference for the endotoxin calibration curve and source of LAL test kit was Biowhitaker.

Scanning electron microscopic (SEM) samples were obtained from each of the seven sampling locations representing a total of 14 filter samples. This analysis was to provide a more detailed evaluation of the organic and inorganic particles and the potential exposures involved in the potato harvesting process. These samples were collected using a Hi-Flow pump operating at 2 L/min and a 37-mm polycarbonate filter in a three piece cassette, during a brief time frame of approximately 15 to 30 min exposure. The dustiest working location of the potato harvesting operation was chosen for SEM collection (on top of the operating harvester).

For samples evaluated using light microscopy, all samples were collected on cellulose ester filters. These filters are unsuitable for direct viewing with scanning electron microscopy but are ideal for light and stereomicroscopy. One filter from each location was selected for polarized light microscopy examination. These

samples were quartered, placed on glass slides and cleared with acetone vapor. A drop of triacetin and placement of a cover slip completed the preparation. Although this is standard procedure for asbestos fiber counting, it has also been found suitable for general particle investigations (Gale, 1996).

The second approach attempted, was to gently shake the filter in water. Later examination of the original filter showed that the particles were efficiently removed. The hydrosol was then filtered through a polycarbonate filter. A portion of this filter was attached to a stub coated with silver paint and gold palladium. The analysis of these samples was performed by the NIOSH Analytical Laboratory.

This study, by design, was to characterize the dust exposures on seven potato farms. As a result of design and number of parameters studied, the data was descriptive. Thus, statistical data presented, using SAS and Excel programs is primarily descriptive with ranges, means, percentages, and standard deviations, using histograms to describe various measurements. In addition, a two-factor analysis of variance was performed with job and site as factors. Sampling location and job site were modeled as random effects. Analysis was done using SAS Pre Mixed (SAS Institute, 1996). The variables examined were total respirable dust, respirable silica, and percent silica exposures. Total respirable dust and respirable silica results were transformed on a log scale. Percent silica log transformation was not necessary.

## Results and Discussion

The goal of this research was to determine whether the varying soil types throughout the valley resulted in differing respirable exposures. Due to changing weather and soil conditions on sampling dates, site comparisons were difficult to ascertain and less likely to be valid.

Of the 122 samples collected, 93 revealed the presence of respirable dust and 18 detected respirable silica (quartz). No cristobalite silica was detected. The maximum detectable respirable dust exposure was  $5.05 \text{ mg/m}^3$ , minimum of  $0.04 \text{ mg/m}^3$ , with a mean of  $0.28 \text{ mg/m}^3$  (fig. 1). Respirable silica detection on 18 of the total samples resulted in a maximum of  $0.105 \text{ mg/m}^3$  at location one (the driest, fine sandy soil), a minimum of  $0.011 \text{ mg/m}^3$  at both sites four and five. The mean for respirable silica exposure was  $0.04 \text{ mg/m}^3$  (fig. 2). The highest and lowest percent silica both occurred at site one with a maximum of 12.85% and a minimum of 3.4% silica. The mean was 7.3% silica (fig. 3).

The second objective of this study was to compare exposure variability between the seven potato harvesting jobs. As anticipated, the harvest riders were exposed to the greatest level of respirable dust. The maximum total respirable dust exposure experienced by a harvest rider was  $5.05 \text{ mg/m}^3$ , the minimum exposure to any worker was  $0.04 \text{ mg/m}^3$ , the mean respirable dust exposure of  $0.56 \text{ mg/m}^3$ . The respirable silica exposure for a harvest rider was also the maximum of all the samples at  $0.11 \text{ mg/m}^3$ , which exceeds the ACGIH TLV and the NIOSH REL for an eight-hour time-weighted average. The minimum respirable silica exposure for a harvest rider was  $0.01 \text{ mg/m}^3$ , and a mean of  $0.05 \text{ mg/m}^3$ . This job category also experienced the highest percent silica exposure at 12.9%.

Second to the harvest rider with exposure risk was the sorter/unloader. Sorters were exposed to a maximum respirable dust of  $1.6 \text{ mg/m}^3$ , a mean of  $0.25 \text{ mg/m}^3$ . This task was the second highest in exposure with a respirable silica maximum of  $0.05 \text{ mg/m}^3$ , which is equivalent to the NIOSH REL. The maximum percent silica noted for this job was 10.2%.

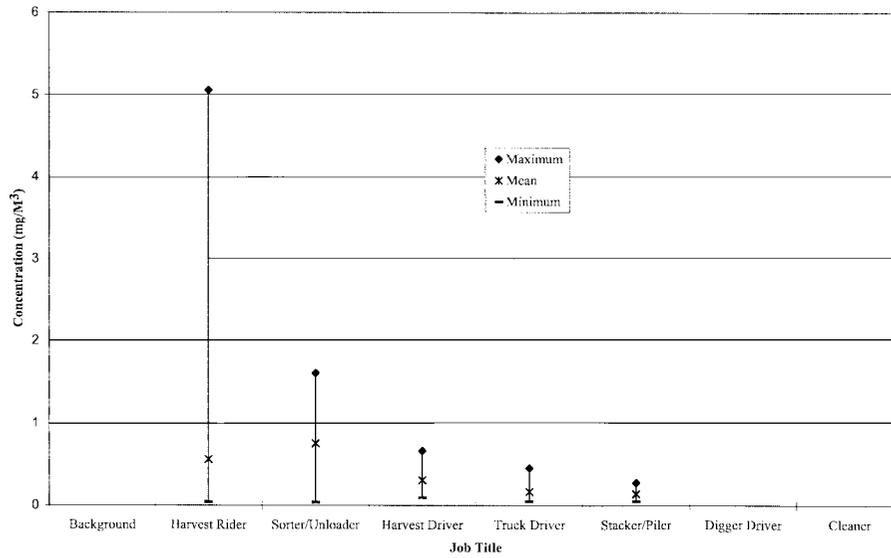


Figure 1–Respirable dust exposure by job title.

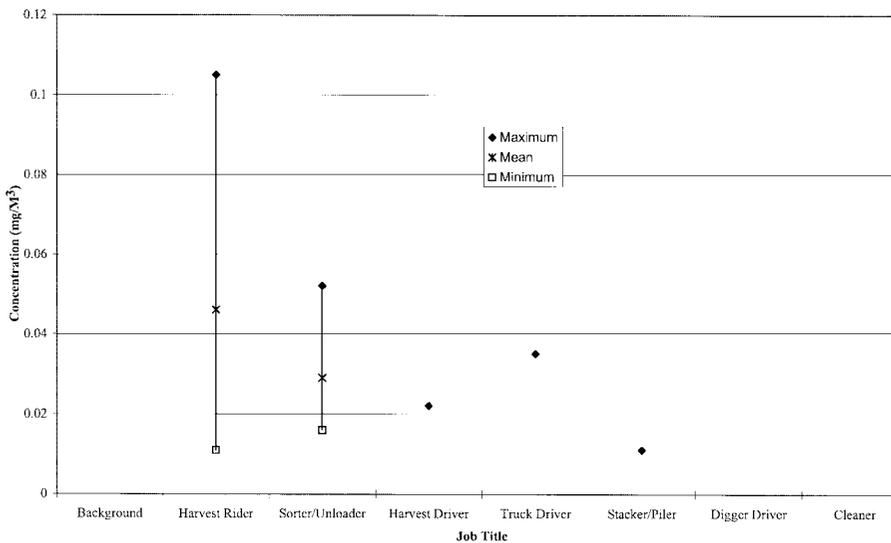


Figure 2–Respirable silica exposure by job title.

The other harvest operation tasks experienced very low respirable exposures. The harvest rider job was the only position to exceed the ACGIH TLV of 0.10 mg/m<sup>3</sup> for quartz. The regulatory limits were minimally exceeded in this evaluation, although the concern remains given the soil types and the extended average length of a working day.

Utilizing a two factor analysis of variance with job and site as factors and modeling site and job as random effects, there was no significance found. Because the raw data was non normal, log transformation of total respirable dust and

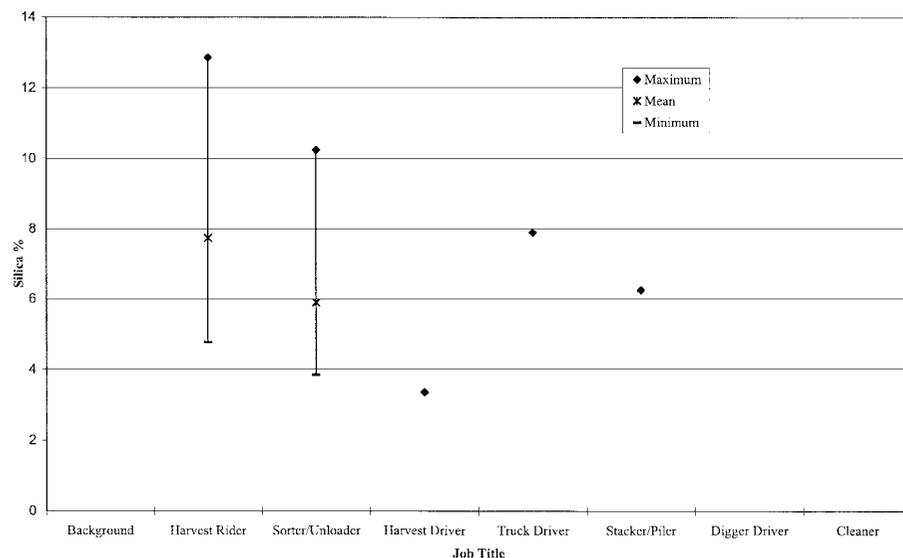


Figure 3—Percent silica by job title.

respirable silica exposure were performed. ANOVA based on the transformed data did not uncover statistically significant results.

An additional objective was to evaluate endotoxin exposure during potato harvest. The peak endotoxin exposure level was 109.7 EU/m<sup>3</sup>, the lowest endotoxin exposure was 3.0 EU/m<sup>3</sup>, with a mean of 31 EU/m<sup>3</sup> and standard deviation of 28 EU/m<sup>3</sup> (fig. 4). The overall endotoxin exposure was low and not in the range of what is believed to be hazardous (200 EU/m<sup>3</sup> and greater) (Rylander, 1994). The potential explanation for low endotoxin exposure may be the early use of sulfuric acid on the potato plants. Sulfuric acid is a highly successful, widely accepted vine desiccant utilized to kill potato plant vines prior to harvest, which may limit the spread of disease. In addition, once the vines are killed, much of the field is cleared of organic matter prior to harvest in an attempt to ease vine entanglement in the machinery. This removal may help to reduce endotoxin exposure.

The final objective for this research was to identify and visualize additional exposures that occur during potato harvest. Stereomicroscopy showed the presence of particles on all filters (14). Sample loadings were adequate for qualitative evaluation. Similar particles were identified on multiple samples. Fungal material (both spores and hyphae), starch grains, cellulose, and various other botanical and mineral particles were detected. Elemental analysis of particles showed predominant silicon and aluminum peaks suggesting the particles were aerosolized from disruption of soil.

## Conclusion

Results of the air monitoring surveys revealed that respirable silica (quartz) is in the air during potato harvesting operations in the San Luis Valley. There was only one over exposure to respirable silica (quartz) based upon regulatory standards, recommended exposure limits and 8-h time-weighted averages. Potato harvest employers must be aware that the potential for over exposure does exist with dry,

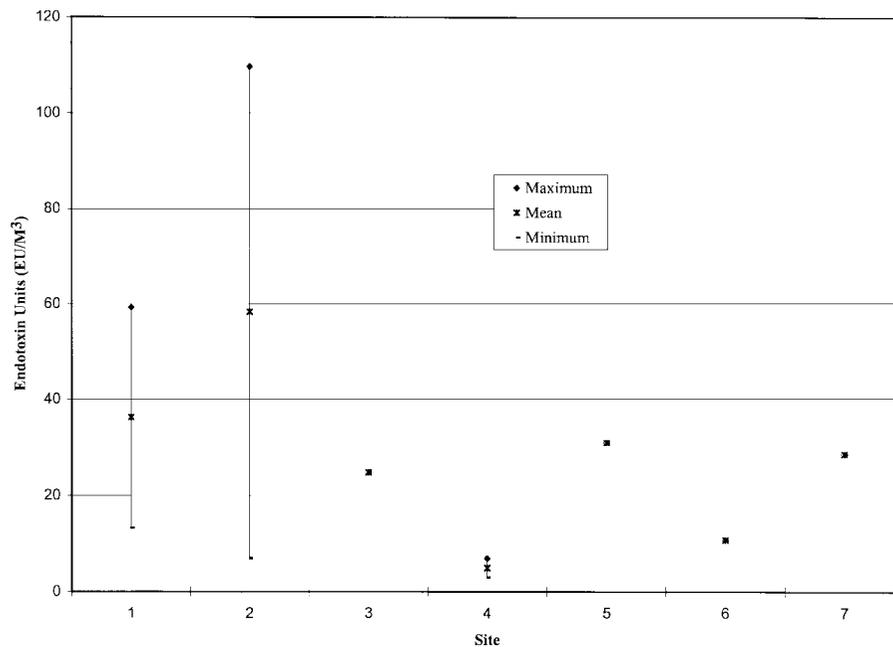


Figure 4—Endotoxin concentrations by site.

windy, working conditions, which are typical of this farming region. For example, on the driest working day, a harvest worker exposure at site one exceeded the ACGIH TLV of  $0.1 \text{ mg/m}^3$  based upon an 8-h time-weighted average. The respirable silica at this location was found to be 12.86%. A respirable silica of 12.86% would allow for an OSHA PEL for respirable dust of  $0.67 \text{ mg/m}^3$  under these conditions. The maximum total respirable dust at site one was  $1.15 \text{ mg/m}^3$  which exceeded the OSHA PEL.

Additionally, there was only one over exposure to respirable dust which occurred at location seven. The TLV for respirable dust is  $3 \text{ mg/m}^3$ , the maximum exposure was  $5.05 \text{ mg/m}^3$ , containing no respirable silica.

Although exposures that occur during potato harvesting operations were not found to be extreme, control measures in this occupational setting should be considered. Controlling respirable dust resulting from potato harvesting operations would increase the respiratory safety of harvest workers as well as improve their working comfort, a frequent complaint. Medical monitoring, management, and follow up would be difficult due to the transient manner in which these workers live.

Based upon air monitoring results and statistical analysis, several conclusions were developed regarding control techniques available to reduce respirable dust and respirable silica. With the intent of protecting the health of workers harvesting potatoes, the following recommendations were made to the growers:

1. The harvest riders were found to have the greatest exposure, at all locations. Most farmers felt that sorting tasks could take place at the storage shed and this position is no longer necessary. The discontinuation of the harvest rider would remove workers from the greatest respiratory exposures as well as safety risks in potato harvest.

2. Farmers should consider slightly dampening the field prior to harvesting operations to decrease the generation of respirable dust as well as improve worker's comfort.
3. Job rotation is another option for employers. The majority of harvest workers return annually and are familiar with the harvesting tasks. Worker rotation would remove employees from continuously working in unsafe conditions.
4. Provide respiratory protection to all employees upon their request, for increased protection and comfort.
5. All workers should be notified of the potential health hazards of respirable dust and respirable silica.

Future research in this area should focus on weather conditions before sampling. In this research, dust generation was greatest when the soil was completely dry and the weather was warm and slightly windy.

Despite notable limitations, this study did accomplish the primary research objective of exploring the presence of respirable dust and respirable silica (quartz) in the potato harvesting operations of the San Luis Valley. Under the 1996 environmental conditions during harvest, there were minimal detectable over exposures to respirable dust or respirable silica. However, the working conditions were extremely dusty and often uncomfortable. Given more typical harvesting conditions of warmer, dryer weather, the exposures could potentially be greater.

When considering the lifetime risk of the majority of potato harvest workers, it must be remembered that the working season and length of exposure is approximately six weeks in length, not year round. The year round, full time employees continue to be exposed to agricultural elements throughout seed preparation, planting, storing, and shipping operations. These are issues to address in the future.

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