Silica exposure in South African farming

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ABSTRACT
Objectives: Little information exists on exposure to respirable silica in the agricultural industry. This paper summarises recent data from a comprehensive exposure assessment on three South African farms and discusses occupational health implications and research needs.

Methods: A total of 298 respirable dust and respirable quartz measurements were collected from three farms with sandy, sandy loam and clay soil, using standard international measurement and analytical methods.

Results: Silica exposure above generally used OELs occurred on all three farms with the highest individual concentration measured on the sandy soil farm (626 μg.m⁻³). Of the measurements on the sandy soil, sandy loam soil and clay soil farm respectively 57%, 59% and 81% exceeded the ACGIH TLV of 25 μg.m⁻³. On the sandy soil and sandy loam soil farms respectively, 12% and 13% of respirable quartz concentrations exceeded 100 μg.m⁻³.

Conclusion: There may be significant potential for over-exposure to respirable quartz in farming and even clay soil farming may pose a risk. Given the large numbers of potentially exposed farm workers and the seriousness of silica-associated diseases, dust-related occupational health interventions should be considered.

Key words: Silica, farming, agriculture, exposure, dust control

INTRODUCTION
Diseases associated with silica exposure include silicosis, a fibrotic nodular disease of the lung parenchyma, pulmonary tuberculosis (PTB), lung cancer, chronic obstructive pulmonary disease (COPD) and autoimmune and renal diseases.¹ Silica exposure is an important public health issue particularly in settings of high TB and HIV rates. The mineral has contributed to serious epidemics of TB in southern Africa² and other low and middle-income regions of the world because of the increased risk of PTB in silica-exposed workers.³ It is well known that HIV infection increases the incidence of TB and the risk of TB in individuals with both HIV and silicosis is larger than the sum of each factor.⁴

Most studies of silica exposure and silica-associated disease have focused on the historically known “dusty trades”, such as mining and quarrying, construction and sandblasting, foundries, ceramics and other industries where silica is used as a raw material or abrasive.⁵ Although farming is mentioned as an industry associated with silica exposure,¹ it is still not known to what extent silica exposure is a risk in this industry. Farming may be of particular concern because of the large numbers employed, the possible high background TB and HIV rates and the generally poorer access to health services than urban residents. In many African countries, farming provides a livelihood for more than 70% of the population. South Africa also has a large agricultural labour force and is a significant employer relative to other industries. During 2004-2009 agriculture employment in South Africa ranged from 679 000 - 859 000 with an average of 765 833.⁶ Migrant labour and poor socio-economic circumstances are common in farming, consequently there may be high HIV infection and TB rates amongst farm workers.⁷ Limited data on TB and HIV rates specifically amongst farm workers in South Africa are available, but the Food and Agriculture Organization reported that AIDS has killed around 7 million agricultural workers since 1985 in the 25 hardest-hit countries in Africa and could kill 16 million more before 2020.⁸ Thus, up to 25% of the agricultural labour force could be lost in countries of sub-Saharan Africa by 2020 unless effective interventions are implemented.

SILICA EXPOSURE AND SILICOSIS IN FARMING
Studies on occupational exposure to silica in farming are limited, but have recently been reviewed.⁹ Despite the paucity of data, respirable silica concentrations exceeding generally accepted OELs have been demonstrated in farming internationally.¹¹⁻¹³

In grape crop harvesters, 50% of the personal exposure to silica measurements exceeded the ACGIH TLV of 25 μg/m³ (range 7-105 μg/m³).¹¹ Some remarkably high silica levels were measured on seven different farms in three eastern North Carolina counties (Pitt, Lenoir and Wayne).¹² Although the exposures determined from 37 personal respirable dust breathing-zone samples from 27 farm workers were relatively low on the majority of the farms (overall mean of 1300 ±2900 μg/m³), somewhat surprisingly, the highest level of

ORIGINAL RESEARCH
time weighted average (TWA) respirable silica measured was 3910 μg/m³ during sweet potato transplanting (overall mean concentration of 700 ± 1600 μg/m³). Personal exposure to inorganic and organic dusts during manual harvesting of California citrus and table grapes showed geometric means (GMs) of respirable dust exposures of 1.14 mg/m³ for citrus harvest and 0.23 mg/m³ for table grape operations. However, the GMs of respirable silica exposures were 80 μg/m³ for citrus harvest and 20 μg/m³ for table grape operations.

Some determinants of silica exposure in farming have been identified and exposure may vary substantially as farming most commonly occurs outdoors. An important determinant may be the soil type as sandy and sandy loam soils (i.e. soil of clay and sand with admixture of decayed vegetable matter) have been reported to contain higher levels of silica in the respirable fraction in parts of eastern North Carolina compared with other North Carolina regions.12,14,15

The body of literature on silica-associated diseases in farming is small16-21 and has been reviewed recently.9 Silicosis has been convincingly diagnosed in agricultural workers,17,20 but very rarely and in the main there is little evidence that pneumoconiosis occurs to any extent in the industry. Studies of other silica-associated diseases have not been published. The small number of studies and generally poor access to health services that would link diseases to workplace exposures may partly explain the paucity of reports of silica-associated diseases in farm workers.

Although the literature on occupational exposure to silica in farming is scant, some studies convincingly demonstrated that over-exposure to silica can occur in farming and that respirable dust does not necessarily act as a good surrogate for silica exposure. In view of the relatively high silica concentrations reported in the few studies conducted internationally, the lack of South African studies, the large number of people possibly exposed, and the expected high HIV and TB rates which make silica exposure a potentially serious concern, we conducted a comprehensive exposure assessment of respirable dust and silica on three South African farms. This paper briefly reviews silica exposure in farming, presents recent data showing that there is a potential for over-exposure to silica in South African farming and discusses some occupational health implications for South Africa. The South African exposure data are drawn from two articles9,10 and from unpublished analyses to estimate annual cumulative silica exposure; the occupational health implications have not been published previously.

**SILICA EXPOSURE ON THREE SOUTH AFRICAN FARMS**

**Methods**

Personal respirable dust and silica measurements were done on three South African farms known to have sandy, sandy loam and clay soils10 using the Health and Safety Executive (HSE) Methods for the Determination of Hazardous Substances (MDHS) 14/3 method and MDHS 101. The farms were visited nine times over 36 months, amounting to a total of 27 days of sampling and 298 measurements. The major tasks undertaken on the three farms over the annual farming cycle were identified in conjunction with the farmers. They have been listed in a previous publication9 and were selected to be representative of potentially dusty jobs performed on the sandy, sandy loam and clay soil farms. Respirable dust and silica measurements were done during the summer and winter seasons and were collected over a period of approximately 8 hours (mean = 460 minutes, range = 360-520 minutes). Throughout the study, no engineering dust controls were observed on any of the implements and no formal respiratory protective equipment (RPE) was used by the farm workers, although they may occasionally use some type of personal protection (e.g. a bandana or scarf covering the nose and mouth) during very dusty activities. All the tractor drivers measured during the study used “open-cabbed” tractors.
Informed consent was obtained from all study participants and confidentiality was respected regarding farms, farmers and farm workers. All results of the exposure assessment were communicated to farmers and farm workers. Ethics approval was obtained from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (clearance number M070252).

RESULTS

Table 1 shows eight-hour TWA respirable dust exposures for the three farms. The highest individual respirable dust concentration (6.49 mg.m\(^{-3}\)) was measured on the sandy soil farm, during wheat planting operations. As expected, respirable dust concentrations differed across the three farms (Kruskal-Wallis test; \(p = 0.0006\)). The median respirable dust concentrations of the sandy soil and sandy loam soil farms did not differ significantly (Wilcoxon test; \(p = 0.2\)), but the median concentrations of respirable dust on the sandy soil and sandy loam soil farms were significantly lower than that of the clay soil farm (Wilcoxon test; \(p = 0.002\) and \(p = 0.001\) respectively).

<table>
<thead>
<tr>
<th>Farm</th>
<th>n</th>
<th>AM</th>
<th>GM</th>
<th>GSD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy soil farm</td>
<td>138</td>
<td>0.68</td>
<td>0.3</td>
<td>3.2</td>
<td>0.02</td>
</tr>
<tr>
<td>Sandy loam soil farm</td>
<td>77</td>
<td>0.46</td>
<td>0.2</td>
<td>2.9</td>
<td>0.03</td>
</tr>
<tr>
<td>Clay soil farm</td>
<td>83</td>
<td>0.73</td>
<td>0.5</td>
<td>2.5</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>298</td>
<td>0.64</td>
<td>0.3</td>
<td>3.0</td>
<td>0.02</td>
</tr>
</tbody>
</table>

GM – geometric mean; GSD – geometric standard deviation; AM – arithmetic mean; TWA – time weighted average.

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Table 2. Eight-hour TWA respirable silica concentrations (mg.m\(^{-3}\)) on a sandy, a sandy loam and a clay soil South African farm

Eight-hour TWA respirable silica concentrations for the farms are shown in Table 2. Large proportions (41%) of the silica measurements were below the Limit of Detection (LOD) of 22 μg reported by the analytical laboratory with the clay soil farm being the main contributor (64%). Consequently, values below the LOD were estimated using multiple imputation\(^{22}\) and these are presented in Table 2 for proportions above occupational exposure limits. The sandy and sandy loam soil farms were very similar with respect to the distribution of the concentrations; although, the sandy soil farm had the highest concentration measured (626 μg.m\(^{-3}\)). Respirable silica concentrations exceeded all three occupational exposure reference limits: 100 μg.m\(^{-3}\) (South African Occupational Exposure Limit [OEL]); 50 μg.m\(^{-3}\) (National Institute for Occupational Safety and Health [NIOSH] Recommended Exposure Limit [REL]) and 25 μg.m\(^{-3}\) (American Conference of Governmental Industrial Hygienists [ACGIH] Threshold Limit Value [TLV]) for silica. For the sandy, sandy loam and clay soil farm, 12%, 13% and 0% of the silica measurements respectively exceeded the South African OEL of 100 μg.m\(^{-3}\), and substantial proportions of the measurements exceeded the lower standards of the NIOSH-REL and the ACGIH TLV-TWA.

Although the proportions of measurements above the 100 μg.m\(^{-3}\) level were not significantly different for the sandy and sandy loam soil farms, both were significantly larger than the clay soil farm (prop.test, all \(p\)-values <0.001). Surprisingly, the clay soil farm had a larger proportion of measurements above the 25 μg.m\(^{-3}\) level than the other two farms, but the sandy soil farm had the largest proportion of measurements above the 50 μg.m\(^{-3}\) level (prop.test; all \(p\) values <0.003).

Typically, the annual cycle of farming activities for each farm worker is varied with episodic dusty seasonal tasks (e.g. soil preparation) interspersed with periods of relatively low dust exposure (e.g. mending fences and equipment maintenance). Annual cumulative silica exposure may therefore be poorly described by respirable silica levels found during particular dusty tasks, which may be of short duration. An index of the annual cumulative respirable silica exposure can be estimated for a typical farm worker by summing the exposure for all tasks done by duration in days of the task (i.e. \([\text{task 1 average exposure x days}] + [\text{task 2 average exposure x days}]\).
Table 2. Eight-hour TWA respirable quartz concentrations (μg.m⁻³) on a sandy, sandy loam and clay soil South African farm

<table>
<thead>
<tr>
<th>Farm Type</th>
<th>n</th>
<th>%&lt;LOD</th>
<th>AM</th>
<th>GM</th>
<th>GSD</th>
<th>Range</th>
<th>%≥100*</th>
<th>%≥50†</th>
<th>%≥25‡</th>
<th>%Quartz Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy soil farm</td>
<td>138</td>
<td>35</td>
<td>53.2</td>
<td>31.7</td>
<td>2.7</td>
<td>&lt;LOD - 626</td>
<td>12</td>
<td>30</td>
<td>57</td>
<td>14.3</td>
</tr>
<tr>
<td>Sandy loam soil farm</td>
<td>77</td>
<td>27</td>
<td>46.65</td>
<td>31.6</td>
<td>2.3</td>
<td>&lt;LOD - 413</td>
<td>13</td>
<td>22</td>
<td>59</td>
<td>14.0</td>
</tr>
<tr>
<td>Clay soil farm</td>
<td>83</td>
<td>64</td>
<td>33.8</td>
<td>31.1</td>
<td>1.4</td>
<td>&lt;LOD - 98</td>
<td>0</td>
<td>9</td>
<td>81</td>
<td>13.7</td>
</tr>
<tr>
<td>Total</td>
<td>298</td>
<td>41</td>
<td>46.0</td>
<td>31.5</td>
<td>2.3</td>
<td>&lt;LOD - 626</td>
<td>9</td>
<td>22</td>
<td>64</td>
<td>14.0</td>
</tr>
</tbody>
</table>

%<LOD, % of measurements under the analytical limit of detection; AM – arithmetic mean; GM – geometric mean; GSD – geometric standard deviation; TWA – time weighted average.

*% Measurements greater or equal to the South African Occupational Exposure Limit of 100 μg.m⁻³ for respirable quartz.
†% Measurements greater or equal to the NIOSH Recommended Exposure Limit of 50 μg.m⁻³ for respirable quartz.
‡% Measurements greater or equal to the ACGIH Threshold Limit Value of 25 μg.m⁻³ for respirable quartz.

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The annual cumulative exposure index (CEI) in mg.m⁻³ - days) was estimated for a typical farm worker on the sandy soil farm using the median exposure for each task and days of exposure provided by the farmer, and it was 7.41 μg.m⁻³ - days. This is 0.29 relative to the annual cumulative exposure of a worker exposed at 100 μg.m⁻³ (the South African OEL) and 0.59 relative to the annual cumulative exposure of a worker exposed at 50 μg.m⁻³ (the NIOSH REL). If the highest exposure measured for each task, rather than the median, is used to derive the CEI i.e. a worst case exposure scenario, then the cumulative exposure would be substantially larger than 7.41 μg.m⁻³ - days.

DISCUSSION
The study considerably adds to the evidence that overexposure to quartz may be a risk in farming in some settings and has identified the need for practical interventions and research gaps. It is also the biggest study of its kind in that it is the first to measure a large number of personal respirable quartz concentrations (298) across various tasks on three farms known to have different soil types.

We have shown that silica exposure above two generally used OELs was found on all of the farms, with similar exposures for the sandy and sandy loam soil farms, whereas the clay soil farm generated a smaller proportion of exposures above 50 and none above 100 μg.m⁻³. Of particular interest is that no measurements exceeded the South African OEL of 100 μg.m⁻³ on the clay soil farm; but 9% of them were between 50 - 100 μg.m⁻³. Additionally, on each of the three farms the median silica exposures were all above the ACGIH TLV of 25 μg.m⁻³ suggesting a possible risk of over-exposure to silica even on the clay soil farm. The annual cumulative exposure to silica of the most heavily exposed farm worker on a sandy soil farm may exceed the annual cumulative exposure if exposed at the NIOSH REL of 50 μg.m⁻³.

Two important considerations should be borne in mind when considering these results: the findings may not be generalisable to farming in South Africa; and the potency of silica may be reduced on farms. Farming covers a large variety of commodities and tasks of differing sophistication from simple manual handling to the use of large combine harvesters. Additionally, weather and soil type may affect respirable dust and respirable silica generation. Consequently, findings on three farms are unlikely to reliably describe exposure on the many thousands of South African farms. A number of factors affect the potency of respirable silica, most of them pertinent to farming. The United Kingdom’s Health...
and Safety Executive (HSE) reviewed potency factors with regard to their ability to cause silicosis and summarised their conclusions in a respirable crystalline silica potency matrix.\textsuperscript{23} The HSE concluded that the particle size, age of fractured silica, clays and wetting of freshly cut surfaces influence the potency of silica. Extremely small particle size enhances silica potency and particle size may be relatively large in farm soils; although, this has not been characterised to any degree. Freshly-fractured silica dust is known to be more pathogenic than silica aged by contact with air (e.g. most silica in soil).\textsuperscript{24-25} Silica in soils is likely to be aged, with most farming activities producing little freshly fractured material; although, it might be caused by contact with metal during activities such as ploughing and discing. Only a small portion of the soil is in contact with machinery, while the majority of dust is from the disturbed soil. Thus, it seems likely that freshly fractured dust would not comprise more than a small fraction of respirable soil dust.

Aluminium-containing clay coatings on silica particles reduce potency and clay is a common constituent of farm soils. Wetting of surfaces reduces silica potency compared to dry freshly cut surfaces, but wetting to reduce dust is infrequently practiced in farming as big tractors and implements may get stuck in wet soils.

Despite the probable presence of silica potency reducing factors in farming, given the large numbers of farm workers possibly exposed to silica and the seriousness of silica-associated diseases, a number of dust-related occupational health interventions should be considered in South Africa, particularly because during the course of the studies on these South African farms few if any dust control measures were observed and none of the farms had medical surveillance programmes.

**POTENTIAL DUST-RELATED OCCUPATIONAL HEALTH INTERVENTIONS**

Primary prevention of silica-associated diseases, i.e. the control of dust to concentrations at which disease will not occur, is the optimum form of prevention and should be the overriding goal of national and workplace occupational health programmes. Methods to improve dust control in farming are challenging but are important to protect the health of farm workers particularly those involved in the most dusty jobs. The most common approach followed by occupational hygiene professionals is the “hierarchy of controls”, which suggests that the hazard be removed or controlled at source followed by engineering and administrative controls ultimately ending with the use of PPE. Since silica cannot be removed from farm soils, other methods are necessary to control exposure. Limited studies describe dust control in farming (none in South Africa), but some evidence exists that differences in equipment and the manner in which a task is done may affect exposures.\textsuperscript{26}

The presence of an enclosed cabin on the tractor has been associated with a decrease in personal dust levels\textsuperscript{27,28} and so has lower tractor speed.\textsuperscript{27} However, the effect of machinery on exposure potential should be carefully considered, since mechanisation may either increase or decrease potential for dust exposure.\textsuperscript{29} The proper use of a closed cab may reduce dust exposure of a tractor driver but excessive
silica exposure has been reported even for drivers of cabbed tractors in North Carolina. 

Although an enclosed tractor cab has been suggested to be the single most effective intervention to reduce inorganic dust exposure, it is very costly and dust filters need proper maintenance. Modern tractors fitted with enclosed cabins typically cost around R 2 000 000.00, probably unaffordable for the majority of small scale farmers. Theoretically, wetting, either with water or water with wetting agents, could be used to reduce dust (as is done in quarries, for example) but given the large areas to be covered on farms, the cost, the potential damage to seeds and crops and that wet soils may hinder movement of heavy machinery, wetting is a problematic solution.

Although engineering methods can be used to control dust in farming, the likelihood of their use depends upon the attitudes of farmers and farm workers toward dust exposure and legislation among other things. Two-thirds of Californian farm workers perceived farming to be less hazardous than other occupations, and respiratory problems ranked after injuries and exposure to pesticides.

The provision and use of PPE should be considered by farmers particularly for farm workers involved in dusty jobs. The use of PPE amongst farm workers may however pose a challenge. One study showed that PPE use increased with an increase in exposure to noise and pesticides but not with an increase in dust exposure. Perceptions of workers about dust and silica dust in farming may be a barrier to the implementation of exposure reduction measures, consequently raising awareness of the health effects of dust exposure is needed to promote their use.

Even with the limited exposure data available it seems reasonable to recommend surveillance of long-service farm workers (possibly those employed for 20 years or longer) for silicosis and tuberculosis. Besides the health reasons, this would be an important step to determine the burden of disease in farming. Initially surveillance could be limited to large well-resourced farms targeting long service workers, particularly those involved in the most dusty jobs for substantial times during their yearly routine.

General practitioners practicing in farming areas need to be aware of the potential for silica-associated disease and submit claims under the Compensation for Occupational Injuries and Diseases Act. Silicosis cases should be eligible if they have clinical features consistent with the disease and no other occupations to account for it, but other silica-associated diseases are less clear. The Circular Instruction Regarding Compensation for Pulmonary Tuberculosis Associated with Silica Dust Exposure stipulates that PTB is an occupational disease if the claimant has silicosis and PTB or if there is no radiological evidence of silicosis but the employee has been exposed to silica for two years and silica dust exposure is inherent to his/her work process or occupation. Too little is known about exposures in farming to conclude that silica dust exposure is inherent to many farming jobs. COPD and lung cancer present the same difficulties. A possible approach is to submit long-service heavily dust-exposed workers with these diseases; even if rejected the claims would constitute a rudimentary register of cases.

**RESEARCH NEEDS**

Despite evidence that silica exposure in farming can exceed generally accepted standards, the role of determinants of silica exposure in farming has not been explicitly addressed. Exposure assessment in agriculture is difficult and complicated by a number of factors. For example, workers often perform many tasks, making it difficult to characterise exposure over time. It is not unusual for workers to walk from field to field with potentially different soil types, thereby introducing further variability in personal exposure to silica. This is compounded by the fact that farming is usually conducted outdoors; weather conditions (e.g. rainfall, humidity, wind speed, wind direction and pressure) are likely to play an important role in exposure variability.

"Throughout the study, no engineering dust controls were observed . . ."

Additional exposure assessments should further examine the role these potential determinants of silica exposure (i.e. soil types, commodities, activities, processes [mechanical versus manual] and weather) may have on silica exposures in farming.

Potency modifiers of silica exposure also need to be better defined. The HSE describes possible silica potency modifiers but very little research exists on the impact of these factors in farming. The role of particle sizes and dry, freshly fractured silica during farming activities need to be explicitly addressed so that occupational health professionals can be alert to farming activities producing very fine, freshly fractured, dry particles.

In South Africa, no study has been done to define the burden of silica-associated diseases in farming. A starting point may be to perform radiological surveys on long service farm workers (possibly more than 20 years service and performing dusty jobs) on a sandy soil farm, as sandy soils are likely to produce the highest silica levels. This will give some indication if silicosis occurs in farm workers during worst case exposure scenarios.

An effort should also be made to define the duration and intensity of silica exposure in farming over the annual cycle. Some processes and jobs may produce high levels of silica in the breathing zone of a worker (for example during ploughing and discing) and workers may do these jobs for a large number of days in a farming year, but this is largely unknown. Better definition of cumulative exposure relative to jobs that
are known to cause silica-associated diseases are required to better understand the risk of these diseases in farming.

Lastly, cost-effective methods to reduce respirable dust and silica exposure in farming in South Africa should be identified. South Africa has a large small to medium scale farming sector employing a considerable number of people. These farmers do not have the money to introduce costly control solutions such as closed-cabbed tractors. There is a need to identify cost-effective dust control methods appropriate for settings in South Africa.

FUNDING
University of the Witwatersrand Individual Faculty Research Grant and National Institute for Occupational Health, National Health Laboratory Service Research Grant (001-254-8511101-5121105-4526).

CONFLICT OF INTEREST
There were no conflicts of interest.

LESSONS LEARNED
1. Over-exposure to respirable quartz may occur in farming in South Africa.
2. Over-exposure is probably not only limited to sandy soil farms.
3. Practitioners working in farming areas should be aware that silica-associated diseases may occur in farm workers.
4. Despite limited evidence for silica associated disease, occupational health interventions appear justified.
5. Further research is required to identify possible determinants and exposure modifiers of respirable quartz during farming and to determine if silica occurs in farm workers.

REFERENCES