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Characterization of Task-weighted Agricultural Dust Exposure of Vineyard Workers

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ABSTRACT

Agricultural workers are often exposed to high levels of dust during field operations. A systematic exposure assessment of annual task-weighted exposure has not been thoroughly examined. The occupational dust exposure in two wine grape vineyards was measured. Exposure levels to total and respirable dust were determined for a 1-year cycle of work. An operation profile including the frequency of tasks was established. The means of total and respirable dust exposure were 1.08 mg/m^3 and 0.07 mg/m^3, respectively. Based on the exposure for each task and the task frequency, task-weighted mean exposures to total and respirable dust were estimated as 1.115 mg/m^3 and 0.079 mg/m^3, respectively. The task-weighted exposure was significantly represented by three operations and could be attributed to the exposure frequency rather than the exposure intensity of operations. The measurement of a few of the most frequent tasks may be an alternative method of estimating task-weighted exposure. Agricultural dust exposure can be significantly reduced by targeting those tasks most important to task-weighted dust exposure.

Keywords: agriculture, cumulative exposure, occupational exposure, agricultural task

I. Introduction

Agriculture is one of the most important industries in California. Due of arid conditions and the nature of the work, soil dust is often generated in agricultural fields. At an estimated generation rate of 182×10^9 kg/year worldwide, soil dust represents 9% of the total global particulate emissions from natural sources.[1)] Regional concentrations can be significantly higher due to local activities involving soil and arid weather. Dust from agricultural processes has potentially negative human health impacts.[2)] Since the soil dust generation may pose the greatest threat to those in close proximity to the source, agricultural workers are in a position to be most affected by soil dust.[3)]

Agricultural workers are often exposed to high levels of mixed dust, including pesticides and organic and inorganic dust.[4)] A large number of adverse respiratory health problems have been attributed to agricultural dust exposure.[4)] Epidemiological studies provide clear evidence of the increased incidence and prevalence of respiratory symptoms and disease in agricultural populations.[4)] Respirable dust is a concern in agricultural exposure because of its ability to reach the alveolar region of the respiratory system.[4)] Among several risk factors, mixed dust appears to be a significant etiologic factor. However, the implications of such studies are limited by the relative lack of dust exposure measurements in agriculture.

Exposure assessment in agriculture can be difficult due to various operations within a crop and the cyclic nature of the work. Agricultural dust exposure varies greatly over different regions and time periods.[4)] In addition, exposure level or type of exposure may depend on crops, farm operations, environmental factors, such as temperature and humidity and dust control measures. Collecting personal exposure samples in agricultural fields is

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time consuming, costly, and labor intensive. Because of those reasons, an efficient strategy for chronic exposure assessment in agriculture should be established.

Given that the highest levels of respirable dust exposures among various fruit crops were found in grape workers, these workers may be at a higher risk for lung disease due to increased dust exposures.[5)] In previous studies of dust exposure in vineyards, exposure levels were measured during only a few operations, typically during harvest, and were extrapolated as representative exposures.[5,6)] Grape workers demonstrated a reduced vital capacity consistent with restrictive pulmonary function from mixed-dust exposure in this population.[7)] The study suggested that exposure to inorganic dust exposures as a possible cause of the respiratory effects in grape workers; however, no actual dust samples were measured.

Grape dust may cause greater lung damage compared to citrus dust. The fibrogenic potentials of dusts from vineyards and citrus orchards was measured by intratracheally instilling the field dust into the lungs of rats.[8)] The data suggest that dusts collected in vineyards had fibrogenic potential, whereas dusts from citrus orchards were biologically less active. This study did not identify the critical components of the fibrogenic response differences. Because the study applied an identical amount of quartz in both dust samples, the differences in fibrogenic potential may not be directly attributable to the quartz content.

Previous studies have reported high exposure to agricultural dust in vineyards.[5-7)] However, these estimations were based on only a few measurements or indirect evidence of health effects. Agricultural workers perform many operations and the exposure among operations can vary significantly. The purposes of this study were to estimate the task-weighted dust exposure of vineyard workers using comprehensive measurements and characterize the exposures by tasks.

II. Material and Method

Occupational exposures to total (n=38) and respirable (n=110) dust of vineyard workers were measured at two vineyards in the Napa Valley, California.

1. Study location

Two vineyards participated in the study. Both vineyards are owned and operated by the same winery. One vineyard was located in the Carneros region of the Napa Valley and most measurements were taken at this vineyard. Only 13% of all samples were taken at the other vineyard located in Yountville, because the same crew tended both vineyards and were temporarily relocated to this vineyard. The vineyards primarily cultivated pinot noir, pinot munier, chardonnay, and cabernet sauvignon grapes for sparkling wine. The Carneros region vineyard had approximately 760 acres of grapes while the Yountville vineyard cultivated approximately 135 acres.

2. Study population

The vineyards employed approximately 20 workers at one time and we recruited only these workers for the study. The vineyards employed various numbers of workers, primarily during harvest time. The 20 participants were not constant over the study period; therefore, our study population was larger than 20 individuals. A total of 43 workers (42 males and one female) were recruited over the study period. Our participation rate was 97.7%.

3. Air sampling

Workers were asked to wear one of two samplers: an total dust sampler that has a polystyrene cassette with a personal sampling pump running at 2 *l*/min, following National Institute for Occupational Safety and Health (NIOSH) NMAM 0500, and a respirable dust sampler using a cyclone (SKC Inc.), with a 37- or 25-mm Teflon filter and a sampling pump running at 2.5 *l*/min, following NIOSH NMAM0600. The respirable dust sampler provided a median cut-off point of 4.0 μm. Pumps were calibrated before and after sampling using an automated soap bubble flow rate calibrator (mini-BUCK Primary Flow Calibrator, A.P. Buck Inc., FL). After the dust samples were collected, the filters were weighed on a microbalance (Cahn C-35, Paramount, CA) with a sensitivity of 0.1 mg.

4. Sampling plan

Exposure measurements were performed on a regular basis, approximately once a week for a full growing season. We attempted to visit the vineyards on a weekly basis, however, 10 weeks were missed due to scheduling conflicts. This sampling was conducted for 24 weeks during a period of 34 weeks. We sampled regularly to obtain a true frequency of operations. Samples were taken from August to September in 2001 and from March to September in 2002, when workers began operations on a regular basis. Final sampling was conducted in September when harvesting was nearly finished. We did not pre-select the operations, so that our data would reflect the actual frequency of operations.

On each sampling day, a profile of the vineyard's operations was collected through observations. The frequency of each operation was recorded along with the number of workers performing the operation. Because the operation profile represented the actual frequency of exposure events, it was used along with the exposure level data to develop a task-exposure matrix for a yearly exposure matrix. This matrix was used to estimate yearly exposure and identify the factors determining dust exposure.

During the visits to the vineyard, 12 different vineyard tasks were identified. Each task is described in Table 1. For weeks when sampling was not conducted, the manager's report of tasks performed was collected. The reported tasks ranged from land preparation in early spring to harvesting in the fall. Winter activities in the vineyard were minimal and were not reported.

5. Cumulative task-weighted exposure estimation

The cumulative task-weighted exposure for the typical vineyard worker was determined by assuming that the operations on a sampled day were representative of that week's operations. For weeks during which we did not sample, the manager's report of that week's tasks and activities was used. The actual number of workers performing a particular task was weighted. It was necessary because operations such as mowing and disking only require one or two workers, whereas those such as for thinning or harvesting require an entire crew.

To derive cumulative task-weighted mean exposure, the following equation was used:

$$E_{annual} = \frac{\sum_i E_i \times P_i}{\sum P_i} \qquad (1)$$

where,

E_{annual} = Cumulative task-weighted mean exposure
E_i = Arithmetic mean exposure during task i
P_i = Percentage of a 12 member crew performing task i throughout cultivation period, 12

Table 1. Occurrence of observed vineyard tasks and their descriptions

Task	Description	Timing	Proportion of task reported by manager
Vine tying	Mature or dormant grape vines are tied to the trellis system	March-April	10.7%
Shoot thinning	Young buds are thinned out for production reasons	April-June	10.7%
Wires lifting	Wires are lifted around trellis to support plants	May-June	10.7%
Leaf thinning	Canopy leaves are thinned out to allow for air circulation	May-August	17.9%
Cluster thinning	Grape clusters are thinned out for production reasons.	May-August	10.7%
Vine training	Young vines are trained to the trellis system	August	21.4%
Harvesting	Fruit is harvested from the vines	August-November	16.2%
Others			1.6%
Disking	Aisles between trellises are disked	March-June	
Mowing	Aisles between trellises are mowed	March-June	
Tractor driving	Takes place during harvest, tractor is driven down aisles, pulling tubs of grapes behind	August-November	
Supervisor	Crew supervision	Year round	
ATV driving	All-purpose ATV driving around vineyard	Year round	

member crews were operated as one team in the participating vineyard.

$\Sigma P_i = 100\%$

III. Results

During 24 visits to the vineyards, 38 total and 110 respirable dust exposures were measured. Total and respirable dust exposure levels differed greatly. Total dust exposure measurements varied from 0.056 to 4.84 mg/m^3 and the arithmetic mean was 1.08 mg/m^3 with a standard deviation (SD) of 1.094 mg/m^3. Tasks such as training vines, leaf thinning and cluster thinning resulted in the highest total exposure levels (Table 2).

Respirable dust exposure measurements ranged from 0.003 to 0.37 mg/m^3 and the arithmetic mean was 0.07 mg/m^3 with a SD of 0.067 mg/m^3. Similar to total dust, leaf thinning, training vines and harvesting resulted in the highest respirable dust exposure levels (Table 2). Depending on the size of the dust, different operations resulted in different ranks of exposure.

Total dust exposure exhibited seasonal variation. For example, total dust exposure increased from spring to summer and decreased from summer to fall (Fig. 1). However, monthly respirable dust exposures did not show a seasonal pattern.

Based on the exposure measurements and the observed operation frequencies, a task-weighted dust exposure model for wine grape vineyards was developed. The model inputs included total or respirable dust concentrations and the proportion

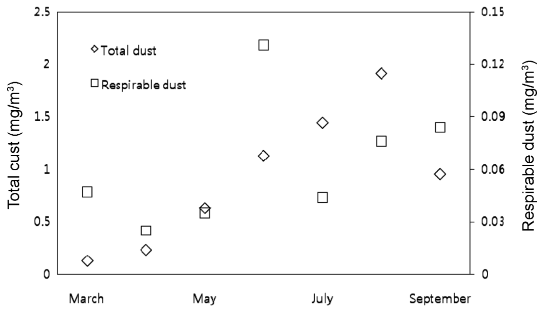

Fig. 1. Total and respirable dust exposures by calendar month.

of days on which a given task was performed over the year. The model using equation 1 resulted in cumulative task-weighted mean total and respirable dust exposures of 1.115 mg/m^3 and 0.079 mg/m^3, respectively.

The effects of using a single weekly measurement to estimate task-weighted exposure was evaluated. Fig. 2 shows distribution of weekly total and respirable dust exposures. For total dust, differences in weekly exposure ranged from 12 to 430% of the cumulative task-weighted exposure from the exposure-task model. Only 3 weekly exposure measurements from 21 weeks were within 20% of the task-weighted mean exposure. For respirable dust, differences in weekly exposure ranged from 7 to 340% of the cumulative task-weighted exposure from the exposure-task model. Only 4 weekly exposure measurements from 26 weeks were within 20% of the task-weighted mean

Table 2. Total dust and respirable dust exposures by tasks

Task	Total dust (mg/m^3)				Respirable dust (mg/m^3)			
	N	GM	AM	SD	N	GM	AM	SD
Vine training	5	1.04	2.05	2.20	15	0.07	0.11	0.10
Leaf thinning	6	0.94	1.26	0.65	17	0.06	0.13	0.12
Cluster thinning	8	1.14	1.25	0.57	25	0.05	0.06	0.03
Harvesting	8	0.78	1.11	0.86	26	0.07	0.09	0.06
Wires lifting	3	0.71	0.71	0.08	9	0.04	0.04	0.02
Others*	4	0.37	0.45	0.27	11	0.05	0.05	0.01
Shoot thinning	4	0.23	0.24	0.07	7	0.01	0.02	0.02
Total	38	0.69	1.08	1.09	110	0.04	0.07	0.067

*Vine tying was included due to small number.

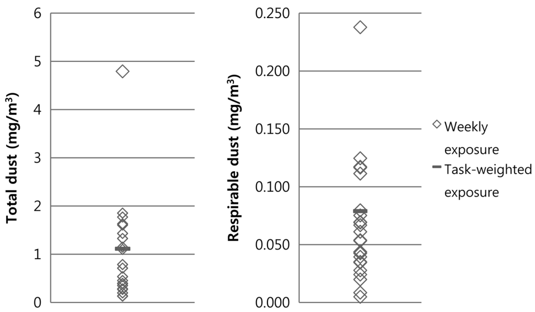

Fig. 2. Distributions of weekly total and respirable dust exposures.

exposure.

The differences in exposure measurements for a single task and the task-weighted exposure were compared. Differences between the mean total dust exposures of a task and the task-weighted mean exposure ranged from 11 to 183%. Differences between the mean respirable dust exposures of a task and the task-weighted mean exposure ranged from 19 to 166%.

The contribution of each task was estimated by the proportion of exposure level for each task divided by the task-weighted mean exposure. Table 3 shows the contribution of each task exposure to task-weighted mean exposure. For estimates of total dust exposure, tasks of training vines, leaf thinning and harvesting contributed 39%, 20% and 16% of task-weighted exposure, respectively. Contribution of these three tasks was 75% of task-weighted total dust exposure. Similar to total dust, tasks of training vines, leaf thinning and harvesting contributed 29%, 30% and 18% of task-weighted respirable dust exposure, respectively. Contribution of these three tasks was 77% of task-weighted respirable dust exposure.

IV. Discussion

Our results demonstrated that total and respirable dust exposure levels may be affected by the nature of the agricultural task. A variety of operations were observed throughout the annual work cycle at the vineyards. Considerable variation of the level of workers' exposure to total and respirable dust was observed, suggesting that estimating agricultural exposure to total and respirable dust may be difficult using measurements from a limited period or for only a few tasks. The cumulative dust exposure of agricultural populations has not been thoroughly investigated.[9,10]

The respirable dust exposure levels of grape vineyard workers were lower than estimates from previous studies. Our total dust exposure cannot be compared with other studies measuring inhalable dust. Popendorf *et al.* measured respirable dust concentrations of 0.90 mg/m^3 during harvest.[5] Lee *et al.* measured table grape harvest exposures of 0.23 mg/m^3 for respirable dust.[6] In this study,

Table 3. Impact of tasks on task-weighted exposures to total and respirable dust

Task	Task proportion reported (P_i)	Total dust			Respirable dust		
		Exposure (E_i, mg/m^3)	P_iE_i	Impact* (%)	Exposure (E_i, mg/m^3)	P_iE_i	Impact (%)
Vine training	21.4%	2.05	0.44	40	0.11	0.02	29
Leaf thinning	17.9%	1.26	0.23	20	0.13	0.02	29
Harvesting	16.2%	1.11	0.18	16	0.09	0.01	18
Cluster thinning	10.7%	1.25	0.13	12	0.06	0.01	8
Vine lifting	10.7%	0.71	0.08	7	0.04	0.00	5
Shoot thinning	10.7%	0.24	0.03	2	0.02	0.00	3
Vine tying	10.7%	0.13	0.01	1	0.05	0.01	7
Others	1.6%	0.45	0.01	1	0.05	0.00	1
Total			1.10			0.08	

$$*\text{Impact} = \frac{P_i \times E_i}{\Sigma P_i \times E_i}$$

respirable dust exposure during harvesting was 0.072 mg/m^3 for respirable dust. These lower exposure levels may be explained by aggressive dust control measures applied in the vineyards, including sustainable farming through cover cropping and composting pressed grapes and stems. Cover cropping involves planting cover crops in between rows, which may help to control dust levels. In addition, soil stabilizing chemicals were applied to the dirt roads, thus retaining moisture and minimizing road dust generation.

Seasonal variation was observed in total dust exposure, but not in respirable dust exposure. We hypothesize that the total exposure is closely associated with soil dust. With increasing temperatures, soil is more likely to generate dust.[11] From March to August, the soil becomes drier, which may cause higher total dust exposure during this period. In September, soil moisture levels increase, which corresponds to decreases in total dust exposure. However, this is not supported by our results. Different tasks by season may be also potential factor for the difference of exposure.

The ranks of total and respirable dust exposures were different depending on the task. Total dust exposure was highest during training vines, thinning leaf and thinning cluster, and respirable dust was highest during thinning leaf, training vines and harvesting. The exposure levels of total and respirable dusts for each task were not correlated. Therefore, the assumption that respirable dust is a fixed percentage of the total dust exposure is not appropriate. Our findings suggest that total and respirable dust exposures for wine grape vineyard workers should be measured independently.

Twelve different tasks were observed during the annual cycle of wine grape vineyards. Each of these tasks varied in completion time from a few days to several weeks. Cluster thinning was performed to adjust the yield from the vines and to remove the fruit that would not ripen by harvest time. Leaf thinning removes the canopy leaves in order to ventilate the crop and to keep the fruit from being completely shaded. This process can increase yield and help reduce disease. During harvest, grapes are cut from the plant and fall into tubs on the ground. The tubs are then kicked across the ground until they are full. This kicking motion may result in increased soil dust exposure. Once full, the tubs are lifted and dumped into a bin that is pulled by a tractor. Harvesting is the most rushed of the operations, because unlike the other operations, workers are often paid by the weight of the yield during harvest. This increased pace results in vigorous treatment of the plants and potentially increased foliar dust exposure.

The task-weighted exposure of vineyard workers was estimated using dust measurements and task frequencies. We assumed that one sample day of exposure measurements and task frequencies represented weekly patterns. The weekly dust exposure measurements were time-consuming; thus, actual measurements for an entire year would be extremely laborious and expensive. Alternatively, exposures could be measured during multiple visits for a particular period or for only a few representative tasks. The results of the task-weighted exposure model supported that assumption that the measurement of a few tasks occurring in high proportions is more appropriate for estimating the task-weighted exposure. When weekly exposures were compared, only 15 to 20% of weekly exposures were within 20% of the estimated task-weighted exposure.

Based on the task-weighted exposure model, several significant tasks were identified. Three tasks, vine training (39%), leaf thinning (20%) and harvesting (16%) accounted for 75% of task-weighted total dust exposure. These same three tasks accounted 77% of the task-weighted respirable dust exposure.

The three significant tasks in the vineyards differed from those for California farmers in general.[10] For California farmers, tasks important to dust exposure were equipment repair, ground preparation tasks, supervision, harvesting, administrative management, irrigation tasks, mechanical mowing, feeding hay, handling hay, wood sawing, checking animals and building maintenance. Harvesting was the only common important task in both populations. The three most important tasks were also the most frequent operations at the vineyard, which was similar to the annual exposure indices for California farmers.[10] Those tasks identified as most important to agricultural dust exposure can be attributed to exposure duration more than to exposure intensity.

This assessment was conducted for one specific crop. Operations may vary at other wine grape vineyards and they certainly vary at table grape vineyards. Our results were based on the assumption that similar dust exposures will occur during subsequent years. Further dust measurements will be necessary to improve our understanding of the risks of seasonal dust exposure in agricultural systems. Since dust exposure measurements are expensive and labor-intensive, we proposed an alternative exposure assessment strategy for agricultural operations.

V. Conclusion

Different levels of dust exposure were observed during the sampling months and for various operations. The task-weighted exposure was estimated by the exposure intensity and frequency. Weekly exposure levels did not adequately represent the task-weighted exposure. The three most frequent tasks, such as vine training, leaf thinning and harvesting, accounted for more than 75% of the task-weighted dust exposure in these vineyards. Measurements of the most important tasks provide an alternative method for estimating task-weighted exposure. In addition, reduction of dust exposure in these three tasks can be an effective prevention for vineyard workers.

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