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Occupational exposure to particulate matter and endotoxin for California dairy workers

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ABSTRACT

Occupational exposure of dairy workers to particulate matter (PM) and endotoxin has been considered by some to be of potential concern. This paper reports personal exposure concentrations of PM ($\mu g/m^3$) and endotoxin (EU/m^3) for 226 workers from 13 California dairies. Arithmetic mean personal concentrations for $PM_{2.5}$, inhalable PM and endotoxin were 48 $\mu g/m^3$ ($N = 222$), 987 $\mu g/m^3$ ($N = 225$) and 453 EU/m^3 ($N = 225$), respectively. Using mixed effects models, time spent re-bedding of freestall barns versus any other job conducted on a dairy led to the highest exposure for $PM_{2.5}$, inhalable PM, and endotoxin. Personal exposure concentrations were found to be greater than those reported for ambient area based concentrations at the same dairies. A pseudo *R*-square approach revealed that one area based measure combined with time spent performing tasks explained a significant portion of variation in personal exposure concentrations.

Introduction

Exposures to particulate matter (PM) and bioaerosols in agriculture are of concern due to potential health effects to both workers and nearby residents (Radon et al., 2004). Particulate matter from agriculture can be directly emitted from farm and transport equipment, re-suspended due to worker and livestock activity or originate from secondary formation of gaseous emissions (Aneja et al., 2008). Agricultural PM contains bioaerosol components such as endotoxin, which is a lipopolysaccharide imbedded in the cell wall of gram negative bacteria that has been associated with adverse respiratory health effects (Vogelzang et al., 1998).

The dairy industry is a large contributor to California's economy, with "Milk and Cream" being the number one agricultural commodity category from 2005 to 2007 (CDFA, 2008–2009). There has been a trend in the state to move to larger dairy operations to increase production efficiency. The number of dairy farms in California has dropped from nearly 3000 in 1978 to under 2000 in 2008, while the average number of cows per dairy has increased from approximately 300 to 1000 over the same 30-year time period (CDFA, 2008). Seventy-one percent of all milk cows in California are housed on dairies that have 1000 or more cows (USDA, 2007). These large dairies are defined as concentrated feeding operations (CAFO's). Concerns exist about the potential impact on air quality on and around dairies (Heederik et al., 2007; Thorne, 2007). Occupational exposures are of particular concern as workers may be exposed to higher concentrations because of their proximity to possible sources of PM on the dairies.

Exposure to PM has been shown to cause increased respiratory and cardiovascular health risks (Pope et al., 2004; Schinasi et al., 2011; Yamazaki et al., 2011). The biological response of the respiratory system varies based on particle size (Madl and Pinkerton, 2010). Small sized particles are more likely to enter the respiratory system than large sized particles, but it is still important to evaluate both sizes because larger particles can be present in high concentrations in the air during re-suspension events. Studies have shown that components of PM, such as endotoxin, can lead to cellular inflammation (Liebers et al., 2006). Both PM and endotoxin have been associated in agriculture settings to changes in pulmonary function (Heller et al., 1986; Heederik et al., 1994), chronic obstructive pulmonary disease (Monso et al., 2004), Organic Dust Toxic Syndrome (ODTS), bronchitis and pneumoconiosis (Schenker et al., 1998, 2005, 2009). More specifically, studies of dairy workers have shown that dairy work may be a factor that can increase the risk of chronic obstructive pulmonary disease (Cathomas et al., 2002) and may be associated with chronic

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bronchitis (Chaudemanche et al., 2003), rhinitis, asthma, and ODTS (Malmberg, 1990).

Previous studies that have reported on occupational exposure of PM and endotoxin on dairies have been conducted in locations that have cold winters, such as New Mexico (Purdy et al., 2009), Wisconsin (Kullman et al., 1998), Switzerland (Cathomas et al., 2002), and France (Gaint et al., 2007) where animal housing tends to be enclosed. These conditions differ from those in California, where cows are mainly housed in naturally ventilated barns and open corrals. There is a need to evaluate exposure to PM and endotoxin on these large, open California dairies. California dairies have herd sizes that are much larger than those in other states and locations abroad. These smaller, more enclosed dairies have been the focus of previous studies. In addition, the large size of the dairies may have a greater portion of workers who perform a single task, thus an overall higher degree of specialization among tasks.

In this study we evaluate occupational exposure in California dairy workers on large diaries, by (i) quantifying exposure levels of $PM_{2.5}$, inhalable PM and endotoxin; (ii) evaluating what impact job task has on exposure levels; and (iii) evaluating if area monitoring can be used for predicting personal exposure.

Materials and methods

Overview

A cross-sectional study was performed from June to October 2008, involving a total of 226 workers from 13 dairies, each with at least 1000 lactating cows. We recruited all the eligible workers from these dairies. Each farm was visited for 2–7 consecutive days, depending on the size of the dairy and consequently number of workers. Single measurements were performed for each worker that was included in the study to allow for the maximum number of workers and dairies possible to be included in the study, although we note that using single measurements limit the ability to adjust for worker day to day variability. Workers wore personal monitoring equipment for the duration of their work shift, which included breaks and lunch. The monitors were removed immediately following their shift. After their shifts, they completed a time activity log that included time and location of tasks performed. Inclusion criteria for worker participation included being between the ages of 18 and 65, male, able to wear the samplers for the entire shift ($\geq$6 h), able to speak Spanish or English, and able to perform multiple Pulmonary Function Tests (PFT's) for the epidemiological component of the study (Eastman et al., 2010). Of the workers recruited, 93% consented to take part in the study. Workers wore personal monitoring equipment for the duration of their shift and after their shifts, they completed a time activity log that included time and location of tasks performed. Tasks performed on the dairies were categorized into 7 job titles:

1. Milking: milking of the dairy cows.
2. Moving: moving animals from one location to another on the dairy.
3. Health care: birthing, calf care, in vitro fertilization and other routine medical care of dairy animals.
4. Re-bedding: scraping, cleaning and removing of dried manure in freestall beds, at times using a tractor.
5. Feeding: mixing and distributing feed, done primarily using a loader and large truck.
6. Waste management: maintaining the lagoon and waste separator.
7. Maintenance: general maintenance around the dairy.

Sampling

A GK2.05SH (KTL) cyclone sampler (BGI Inc., Waltham, MA) with a cut point of 2.5 μm at an air flow of 3.5 l/min, which has been shown by other studies to have good agreement with the PQ200 (BGI Inc.) Federal Reference Method $PM_{2.5}$ sampler (Yanosky and Macintosh, 2001; Majestic et al., 2008), was used to collect $PM_{2.5}$. Teflon 37 mm Millipore filters with a pore size of 0.45 μm (Fisher Scientific, FHLP03700, Waltham, MA) were used. A SKC button sampler (SKC Inc., 225–360, Eighty Four, PA) with a curved multi-orificed inlet for all suspended PM smaller than 100 μm in aerodynamic diameter at an air flow of 4.0 l/min was used to collect inhalable PM. Each button sampler was fitted with a Teflon 25 mm, Millipore PTFE filter with a pore size of 3.0 μm (Fisher Scientific, FSLW02500). Tygon tubing connected the samplers to a Swagelok (Swagelok, Solon, OH) needle valve for flow adjustment. The samplers were attached to a high flow Leland legacy personal sampling pump (SKC Inc.) and placed in a backpack with samplers placed at worker breathing level. Prior to the pumps being connected to the sampling assembly, they were warmed up for 15–20 min. Air flow was measured pre and post sampling using a Defender-series (Bios International, Butler, NJ) electronic piston volumetric gas flow meter. Samples were stored at −20 °C between collection and equilibration for post sample weighing.

Gravimetric analysis

Filters were weighed using a Cahn-35 microbalance (Thermo Fisher Scientific Inc., Pittsburgh, PA). The filters were equilibrated for 24–48 h prior to being weighed at least two times in temperature (90% range: 66–72) and relative humidity (90% range: 44–61) controlled clean room. The microbalance was calibrated at the beginning of each weighing session for accuracy, and a quality check was performed after every tenth filter to account for fluctuation. Any shift of ±0.002 mg resulted in reweighing the ten previous filters.

Duplicate samples were collected from co-located area samplers, for 40 $PM_{2.5}$ and 39 inhalable PM samples to determine precision. Mean relative percent differences between duplicates for $PM_{2.5}$ and inhalable PM were 26% and 14%, respectively. A total of 46 blanks were collected for $PM_{2.5}$ and 47 for inhalable PM following the same protocol for field sampling. The blank samples for $PM_{2.5}$ using nominal volumes had a mean value of 1.62 $\mu g/m^3$ with a standard deviation of 2.66 $\mu g/m^3$ (one blank value not used in calculations). The mean for inhalable PM was 1.39 $\mu g/m^3$ with a standard deviation of 2.42 $\mu g/m^3$. Five samples (2.8%) were below the limit of detection (LOD) for $PM_{2.5}$ while all inhalable PM samples were above the LOD.

Endotoxin analysis (rFC)

Inhalable PM samples were extracted by vortexing the filter in a TWEEN (10 ml at 0.05%) solution with pyrogen free water for 1 h at 20–22 °C and analyzed for biologically active endotoxin using the recombinant Factor *C* assay (Lonza Inc., Walkersville, MD), which detects activation of Factor *C* utilizing a fluorogenic substrate and has been compared to the Limulus Amoebocyte Lysate (LAL) method that has long been used for endotoxin analysis, the results of these studies demonstrated differences were observed in house dusts, yet not in livestock settings; which had similar values for LAL and recombinant Factor *C* (Alwis and Milton, 2006; Thorne et al., 2010). The samples, 100 μl of blank, and an endotoxin standard (*Escherichia coli* 055:B5) were added to a 96 well plate. The plates were then pre-incubated for 10 min at 37 °C. A mixture of 100 μl of rFC enzyme solution, buffer, and fluorogenic substrate at a 1:4:5 ratio were then added. The plates were incubated for 1 h