Ann. Occup. Hyg., 2016, Vol. 60, No. 5, 597–607
doi:10.1093/annhyg/mew009
Advance Access publication 4 March 2016

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Evaluation of a Low-Cost Aerosol Sensor to Assess Dust Concentrations in a Swine Building

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Submitted 20 July 2015; revised 15 January 2016; revised version accepted 19 January 2016.

ABSTRACT

Exposure to dust is a known occupational hazard in the swine industry, although efforts to measure exposures are labor intensive and costly. In this study, we evaluated a Dylos DC1100 as a low-cost (~$200) alternative to assess respirable dust concentrations in a swine building in winter. Dust concentrations were measured with collocated monitors (Dylos DC1100; an aerosol photometer, the pDR-1200; and a respirable sampler analyzed gravimetrically) placed in two locations within a swine farrowing building in winter for 18–24-h periods. The particle number concentrations measured with the DC1100 were converted to mass concentration using two methods: Physical Property Method and Regression Method. Raw number concentrations from the DC1100 were highly correlated to mass concentrations measured with the pDR-1200 with a coefficient of determination (R^2) of 0.85, indicating that the two monitors respond similarly to respirable dust in this environment. Both methods of converting DC1100 number concentrations to mass concentrations yielded strong linear relationships relative to that measured with the pDR-1200 (Physical Property Method: slope = 1.03, R^2 = 0.72; Regression Method: slope = 0.72, R^2 = 0.73) and relative to that measured gravimetrically (Physical Property Method: slope = 1.08, R^2 = 0.64; Regression Method: slope = 0.75, R^2 = 0.62). The DC1100 can be used as a reasonable indicator of respirable mass concentrations within a CAFO and may have broader applicability to other agricultural and industrial settings.

KEY WORDS: CAFO, dust measurement, Dylos, DC1100, low-cost, swine

INTRODUCTION

High-density, large (>2000 head) enclosed livestock operations, also known as concentrated animal feeding operations (CAFOs), have proliferated across the USA over the last 20 years to address a growing demand for animal products. Full-time employees are necessary to operate a CAFO, resulting in worker exposure to airborne dust of higher intensity and longer duration than what is found in smaller operations (Wenger, 1999). This dust is a complex mixture of waste, dander, feed, mold, pollen, insect parts, and mineral ash (Donham *et al.*, 1989; Wenger, 1999; Pedersen *et al.*, 2000). Adverse health effects associated with exposure to dust in a swine CAFO include bronchial inflammation, allergic alveolitis, and occupational asthma (Whyte, 1993). Many factors influence the magnitude of exposure to dust, including building ventilation, distance from source, and amount of animal and human activity (Anthony *et al.*, 2014). Building ventilation is a major driver of fluctuations in dust concentrations, with higher concentrations occurring when a CAFO is sealed to maintain optimal temperatures (winters in upper Midwest, and summers in the South USA) (O'Shaughnessy *et al.*, 2010).

The Occupational Safety and Health Administration (OSHA) requires that worker exposures are maintained below occupational exposure limits, which are designed to protect worker health from exposure to airborne contaminants. Exposures are measured with traditional filter-based sampling (e.g. NIOSH Manual of Analytical Methods 0500) to determine compliance with exposure limits. These samplers require workers to wear lapel-mounted samplers with belt-mounted air pumps over a substantial fraction of a full work shift. Such sampling is intrusive, requires trained personnel, and is expensive, resulting in the collection of few samples to represent many workers across highly varied settings. Moreover, results of exposure measurements are typically not available for days or weeks after sampling because samples must be weighed in a laboratory with relative humidity and temperature control. For swine CAFO, OSHA regulations require that dust concentrations be maintained below 5 mg m^{-3} respirable and 15 mg m^{-3} total, and the ACGIH recommends dust be below 3 mg m^{-3} respirable and 10 mg m^{-3} inhalable.

In contrast, aerosol photometers, a type of direct-reading instrument, can be used to rapidly measure dust concentrations. Photometers illuminate particles in a sensing zone with a light source, typically a laser. The light scattered by the particles is detected at an angle ~90° from the incident light; this light intensity is linearly related to gravimetrically measured mass concentrations (Chakrabarti *et al.*, 2004). Examples of commonly used field photometers include the personal DataRAM (pDR-1200 and pDR-1500, Thermo Fisher Scientific, Waltham, MA, USA), the DustTrak (8520, TSI, Inc., St. Paul, MN, USA), and the Sidepak (AM510, TSI, Inc., St. Paul, MN, USA). Compared to traditional filter-based sampling with subsequent gravimetric analysis, photometers offer real-time measurements, ease of use, time savings, and cost effectiveness (Lehocky and Williams, 1996). Photometers can also be operated with a particle size separator attached to the inlet, allowing measurement of particles within a specific size range (e.g. respirable mass concentration). However, photometers are factory calibrated to an aerosol that may not scatter light the same way as the aerosol in the field, resulting in inaccurate measurements (Benton-Vitz and Volckens, 2008). They are also expensive ($5000–$10 000), limiting widespread adoption in agricultural and other occupational settings.

Recently, low-cost optical particle counters (OPCs) have become commercially available, namely the DC1100 ($200) and DC1700 ($425) from Dylos Corporation (Riverside, CA, USA). These monitors use the scattering of laser light to detect the number concentration of particles in two size bins: a total bin for particles >0.5 µm (this bin is called the 'small' bin by the manufacturer) and a large bin for particles >2.5 µm. Traditional OPCs use similar binning technology but offer many more size bins. The two models are identical, except that the DC1700 contains an internal battery and a data logger. The number concentrations measured with the DC1700 has been shown to correlate well to mass concentrations measured by photometers in ambient and indoor environments. Semple *et al.* (2013) found a coefficient of determination (R^2) for concentrations measured with a DC1700 and a photometer (AM510, SidePak) of 0.86 for secondhand tobacco smoke in homes. In an urban outdoor setting, concentrations measured with a DC1700 were highly correlated to those measured with a to a high-cost OPC (R^2 = 0.99, ~$12 000, GRIMM, Model 1.108, GRIMM Aerosol Technixk GmbH & Co., Ainring, Germany) and well correlated to a photometer (DustTrak II, 8532, TSI, Inc., St. Paul, MN, USA) (Holstius *et al.*, 2014). To our knowledge, the Dylos monitors have not been tested in occupational environments where typical particle concentrations are substantially higher than in homes and urban settings. They have also not been tested in workplaces where particle sizes are typically large, such as a swine CAFO.

In this study, we evaluated the performance of the DC1100 in a swine CAFO. We first established the relationship between the DC1100 and an aerosol photometer, the pDR-1200. Secondly, two methods were used to convert the DC1100 particle number concentrations into mass concentrations. One conversion method used the physical properties of particles (density and particle diameter) and the other used regression modeling to estimate mass concentration.

Mass concentration estimates from the DC1100 were then compared to concentrations measured with the photometer and gravimetrically.

METHODS

Site description

Measurements were made at the Mansfield Swine Education Center of Kirkwood Community College (Cedar Rapids, IA, USA) from December 2013 to February 2014 on 18 randomly selected days. This study was conducted in conjunction with an investigation on the effect of engineering controls on dust and gas concentrations in a CAFO (Anthony *et al.*, (2015). Community College students in the swine rearing program entered the building periodically (~2–4 h per day) during the study to feed and provide care to the swine. This CAFO is representative of industry but in many cases workers spend their full-work shift in larger industrial operations.

The building consisted of four rooms: one nursery, two farrowing, and a heated hallway. All measurements were taken in the larger farrowing room depicted schematically in Fig. 1. The room contained three rows of five crates and one row of four, for a total of 19 crates. Each crate had its own feeding trough and water system, and two 0.91-m-deep pull-plug manure pits that were each vented by a 0.41 m^3 s^{-1} exhaust fan. The farrowing room relied on general ventilation to bring hallway and outside air into the room to make up the exhausted pit air, where outside vents were closed to reduce heating costs during this study period. One open-flame heater with unvented exhaust (Guardian 60 Model AW060, L.B. White, Onalaska, WI, USA) was operated to provide heat inside the room. An air pollution control device (Shaker-Dust Collector, SDC, Model 140, United Air Specialists Inc., Cincinnati, OH, USA) was located outside, with the ducts arranged along the east wall of the CAFO. Room air was captured at two intakes positioned 0.5 m above the floor at the feeding isles, was subsequently treated by the SDC, and then returned to the room through two fabric diffuser ducts (Softflow Diffusers, Air Distribution Concepts, Delvan, WI, USA) suspended from the ceiling.

Dust measurement

Dust concentrations were measured at two locations in the farrowing room (Location I and Location II, Fig. 1). At each location, multiple instruments were placed in an open-walled storage container at 1.5 m above the floor. The storage container at Location I contained one DC1100 and that at Location II contained two DC1100s, which allowed for determination of monitor precision. The serial output from the DC1100s were captured with a microcontroller (Ardunio Mega, Ivrea, Italy), which then logged small and large bin number concentrations to an SD card every two minutes using a data logging shield (Adafruit, New York, NY, USA). We found that the

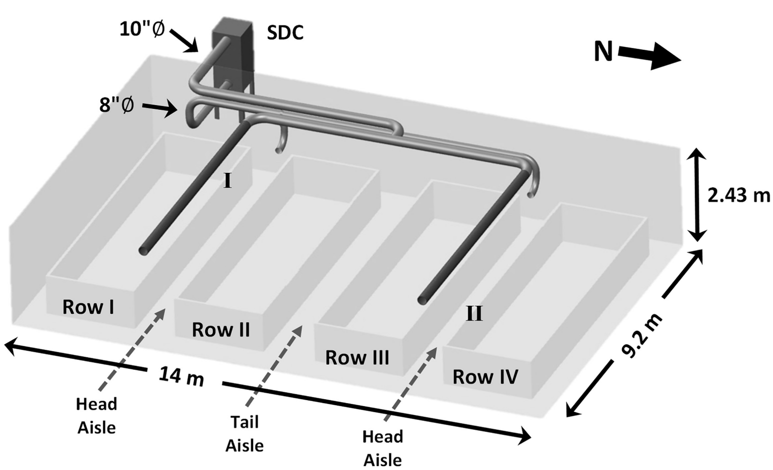

Figure 1 Schematic diagram of farrowing room with locations of sampling identified by Roman numerals. A Shaker Dust Collector (SDC) was located outside the CAFO, with a 20-cm (8-inch) circular duct pulling air from the room, and a 25.4-cm (10-inch) circular duct for returning air to the room through fabric diffusion ducts (identified as darker pipe).

output from DC1100 occurred approximately, but not exactly every 60 s. Thus we adopted the 2-min logging to ensure that at least one measurement was collected during all measurement periods. Each storage container also included an aerosol photometer (pDR-1200, Thermo Fisher Scientific, Waltham, MA, USA) set to log mass concentrations every 60 seconds, and operated with a respirable cyclone (BGI GK2.69, BGI, Walthman, MA, USA) on the inlet and a polyvinyl chloride (PVC) filter (225-5-37 mm-diameter, 5 μm-pore, SKC, Eighty Four, PA, USA) on the outlet. A sampling pump (PCXR4, SKC) was used to pull air at 4.2 L min^{-1} through the cyclone/photometer/filter system.

Filters were conditioned in a humidity- and temperature-controlled room for seven days prior to weighing. A microbalance (MT5, Mettler-Toledo, Columbus, OH, USA) was used to measure the weight of respirable filters in triplicate before and after sampling. Before each deployment, the pDR-1200s were calibrated to zero with a HEPA filter according to manufacturer specifications, and the airflows of the air pumps were pre-calibrated and post-checked with a Bios DryCal (Mesa Labs, Butler, NJ, USA).

The equipment was deployed between 7:00 and 8:00 a.m. and collected 24-h later for 18 days during the 2-month span of the larger study (11 days with the SDC on and 7 days with SDC off). Each day at both locations, approximately 1440 measurements from the pDR-1200 (1 measurement per 60 s for 24 h) and 720 measurements from the DC1100 (1 measurement per 120 s for 24 h) were recorded, and a single average mass concentration was obtained from the respirable dust sampler.

Data analysis

Time-paired, raw concentrations measured with the DC1100, and pDR-1200 were averaged over 10 min, resulting in the following: the total number concentration from the bin referred to as 'small' by the manufacturer (>0.5 μm) of the DC1100 ($DC1100_{total,RAW}$); the number concentration from the 'large' bin (>2.5 μm) of the DC1100 ($DC1100_{large,RAW}$); and uncorrected mass concentration from the pDR-1200 (pDR_{RAW}). The number concentration of small particles between 0.5 and 2.5 μm ($DC1100_{small,RAW}$) was calculated by subtracting $DC1100_{large,RAW}$ from $DC1100_{total,RAW}$. The pDR_{RAW} measurements were corrected to the respirable filter mass (pDR_{MC}) by multiplying by the 24-h filter concentration and dividing by 24-h average of pDR_{RAW}.

Two methods were used to convert 10-min average number concentrations of small particles from the DC1100 ($DC1100_{small,RAW}$) to 10-min average mass concentrations. Both methods are based on the premise that a site-specific calibration is needed and that the information from the pDR can be used to determine that calibration. In the Physical Property Method (Method 1), mass concentration (M) in μg m^{-3} was estimated using (1):

$$M = N\frac{\pi}{6}d^3\rho\times 3531.5 \tag{1}$$

where N is the number concentration of particles in particles/0.01 ft^3 from the DC1100, d is the diameter of the particles in meters, and ρ is the average density of particles in μg m^{-3}. The density of swine CAFO dust was assumed to be 1450 kg m^{-3} (Jerez, 2007). The constant in (1) (3531.5) was used to convert the units of number concentration provided by the DC1100 (particles/0.01 ft^3) to particles m^{-3}. We assumed that the particle size distribution was unimodal. The particle diameter to the nearest hundredth of a micrometer was selected as that giving the lowest percent bias, *B*, for data pairs, *i*, calculated as (EPA, 2009c):

$$B = \frac{1}{n}\sum\frac{y_i - x_i}{x_i} \tag{2}$$

where *y* is the estimated mass concentrations (from (1)), *x* is the pDRMC, and *n* is the number of data pairs.

In the second method (Method 2: Regression Method), linear regression was used to determine a best-fit linear model from a random selection of 20% of the 10-min-averaged, paired particle number concentration of small particles from the DC1100 ($DC1100_{small,RAW}$) and the corrected mass concentration from the pDR-1200 (pDR_{MC}). This linear model was used to convert the remaining 80% of the 10-min-averaged $DC1100_{small,RAW}$ measurements to mass concentration (validation data). The model was also used to convert 100% of the 10-min-averaged $DC1100_{small,RAW}$ measurements to mass concentration for comparison to 24-h, gravimetric, respirable mass concentrations. Lastly, the regression analysis was conducted using five random selections of calibration data to determine the consistency of the regression model.

Several performance metrics used by the US Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) to establish equivalency of a candidate method to a reference method were computed to evaluate the DC1100. A primary (X) sampler and duplicate (Y) sampler were designated for each pairwise comparison, and measurements made with the primary sampler were used to represent the true concentration to compute bias. For EPA, these criteria specify that the linear relationship between a candidate PM_{10} sampler and reference method must have a slope of 1 ± 0.1, a *y*-intercept of 0 ± 5 μg m^{-3}, an $r \geq 0.97$ from Table C-4 of EPA (2016a), and a percent bias within ±10% (EPA, 2016b). NIOSH has less stringent criteria for evaluation of direct-reading gases and vapor monitors. They require a linear slope of 1 ± 0.1 and percent bias of ± 10%, but have no criteria for the *y*-intercept. NIOSH also states that 95% of test monitor recordings must be within 25% of the reference monitor (NIOSH, 2012).

Average bias was calculated following EPA (2016c), which specifies calculation of 95% confidence limits ($CL_{0.95}$) as:

$$CL_{0.95} = B \pm t_{0.975,\mathrm{df}}\, se \qquad (3)$$

where B is the average bias (Equation 2), df is the number of data pairs minus one, $t_{0.975,df}$ is the 97.5 percentile of the Student's *t* distribution, and se is the standard error of the bias measurements. For each sampler pair, the Pearson coefficient (*r*) was determined, and the slope, *y*-intercept, and R^2 were determined using linear regression.

RESULTS

The DC1100s operated throughout the study with no measurement failures. As shown in Fig. 2, a strong linear relationship with an R^2 of 0.85 was observed for the raw number concentration measured with the DC1100 (Y-Sampler, $DC1100_{small,RAW}$) and the raw mass concentration measured with the pDR-1200 (X-Sampler, pDR_{RAW}). Although $DC1100_{small,RAW}$ was substantially greater (typically ~50×) than $DC1100_{large,RAW}$, they were closely related with $r = 0.98$ and $R^2 = 0.96$. We opted to use only the DC1100 small particles because we were attempting to match respirable concentrations. However selecting either small, large, or total particles would yield similar results due to the fact that small and large particles were highly correlated. The paired $DC1100_{small,RAW}$ measurements from Location II had an average percent bias of −1.9%, an *r* of 0.95, R^2 of 0.91, and coefficient of variation of 8.2%.

The 10-min-averaged data were used to determine the parameters for the two methods used to convert DC1100 number to mass concentration. Bias

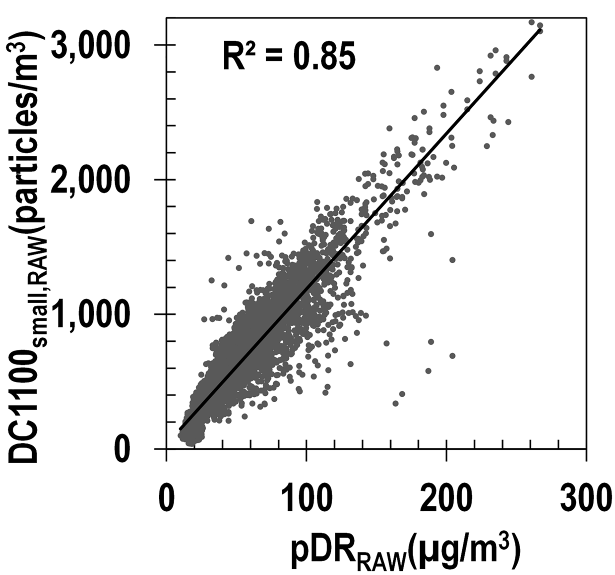

Figure 2 Particle number concentration measured with the DC1100 compared to uncorrected mass concentration measured with the pDR-1200 for 10-min averaged data

minimization efforts to determine the particle diameter using the Physical Property Method (Method 1) are summarized in Supplementary Table S1 is available at *Annals of Occupational Hygiene* online. For $DC1100_{small,RAW}$, when the SDC was on, the diameter that had the lowest average percent bias for the three DC1100s was 3.36 µm, and when the SDC was off the diameter was 3.28 µm. As these diameters were similar, the analysis was run with all data (including both SDC-on and SDC-off) to obtain an averaged particle diameter of 3.32 µm. For the Regression Method (Method 2), the slope and intercept from the linear regression of number concentration measured with the DC1100 on the mass corrected pDR-1200 data (pDR_{MC}) resulted in the equation:

$$M = 0.053N + 48 \tag{4}$$

where M is the mass concentration (in µg m^{-3}) and N is the number concentration (in particles/0.01 ft^3) recorded by the DC1100. The coefficient of variations of the slope and intercept for regressions conducted on five different random 20% selections of data was less than 5%, as summarized in Supplementary Table 2 is available at *Annals of Occupational Hygiene* online.

Pairwise comparisons of mass concentrations estimated with the DC1100 compared to those measured with the reference photometer for 10-min-averaged data (pDR_{MC}) and the respirable sampler for 24-h averaged data are shown in Table 1. Scatterplots of mass concentration estimated with the DC1100 ($DC1100_{small,MC}$) compared to the mass-corrected pDR-1200 data (pDR_{MC}) for 10-min-averaged data are shown in Fig. 3. For the Physical Property Method (Method 1, Fig. 3a), the bias was −1.7%, $R^2 = 0.72$, and r was 0.85. The best-fit line had a slope (1.03 ± 0.01) and intercept (−6.2 ± 1.5 µg m^{-3}) with 53% of the $DC1100_{small,MC}$ estimates falling within ± 25% of pDR_{MC} measurements. Similar results were obtained with the Regression Method (Method 2, Fig. 3b) with $R^2 = 0.74$ and $r = 0.86$. However, compared to Method 1, the bias was higher (7.4%), a higher percentage of $DC1100_{small,MC}$ estimates (63%) were within ± 25% of the pDR_{MC}, and the slope of the best-fit line was substantially lower than unity (0.72 ± 0.01).

A time-series plot of mass concentrations from $DC1100_{small,MC}$ (Physical Property Method) and pDR_{MC} for a representative 24-h period is shown in Fig. 4. Both monitors responded similarly with changes in the magnitude of the mass concentration that varied from ~50 to ~380 µg m^{-3} over this time period. This performance was typical for the entire winter study period.

Scatterplots of 24 h, average mass concentrations estimated with data from the small bin of the DC1100 ($DC1100_{small,MC}$) compared to the respirable mass concentrations measured gravimetrically are shown in Fig. 5. A small bias (−3.1), slope near unity (1.08 ± 0.13), and 60% of the $DC1100_{small,MC}$ within ± 25% of respirable mass concentration was observed for the Physical Property Method (Fig. 5a). Similar relationships were observed when using the Regression Method (Fig. 5b), although the slope (0.72 ± 0.09) was substantially lower compared to that determined with the Physical Property Method and a higher percentage (73%) of the $DC1100_{small,MC}$ recordings were within ± 25% of respirable mass concentration.

DISCUSSION

The low-cost (~$200) DC1100 responded similarly to a substantially higher-cost (~$5800) photometer in a swine CAFO in winter. The number concentrations measured with the DC1100 accounted for 85% of the variability in mass concentrations measured with the pDR-1200 ($R^2 = 0.85$; Fig. 2). Moreover, the response of the DC1100 was temporally in sync and similar in magnitude to that of the pDR-1200 for mass concentrations ranging from 57 to 372 µg m^{-3} (Fig. 4). This favorable agreement, surprising given the difference in costs between monitors, suggests that the DC1100 can be used as an indicator of dust concentrations in swine CAFOs and may have broader applicability in other agricultural and industrial settings. Such an indicator could be used to trigger the use of personal protective equipment (e.g. respirator) or turn on a ventilation system with air pollution control.

Direct comparison of concentrations measured with a DC1100 (or DC1700) to those measured with a pDR-1200 are unavailable in the literature; however, measurements made with these monitors have been compared to those made with other commercially available photometers. Holstius *et al.* (2014) compared the DC1700 with a DustTrak II for $PM_{2.5}$ and found $R^2 = 0.78$, which is similar to comparisons found here in the swine CAFO. Semple *et al.* (2015) compared a DC1700 to a TSI Sidepak AM510 in a chamber study of cigarette smoke. The data was fit

Table 1. Summary of DC1100 performance metrics compared to criteria for equivalent monitors

	Method 1 physical property method		Method 2 regression method		EPA PM_{10} criteria	NIOSH criteria
	10-min[a]	24 h[b]	10 min[a]	24 h[b]		
Data pairs	5085	43	4956	44		
Slope ± std. error	**1.03** ± 0.01	**1.08** ± 0.13	0.72 ± 0.01	0.72 ± 0.09	1 ± 0.10	1 ± 0.10
Intercept ± std. error (μg m^{-3})	−6.2 ± 1.5	−15 ± 20	42 ± 1.0	41 ± 14	0 ± 5	—
R	0.85	0.80	0.86	0.78	≥0.97	—
R^2	0.72	0.64	0.74	0.62	—	—
% Bias (95% CI)	**−1.7 (−1.72, −1.64)**	**−3.1 (−3.9, −2.3)**	**7.4 (7.24, 7.58)**	**2.3 (1.70, 2.87)**	±10	±10
95% accuracy interval (%)	—	55	—	40	—	±25
% of samples within ±25%	53	60	63	73	—	—

Bold values indicate criteria were met.
[a]X sampler was the mass-corrected pDR.
[b]X sampler was the respirable sampler.

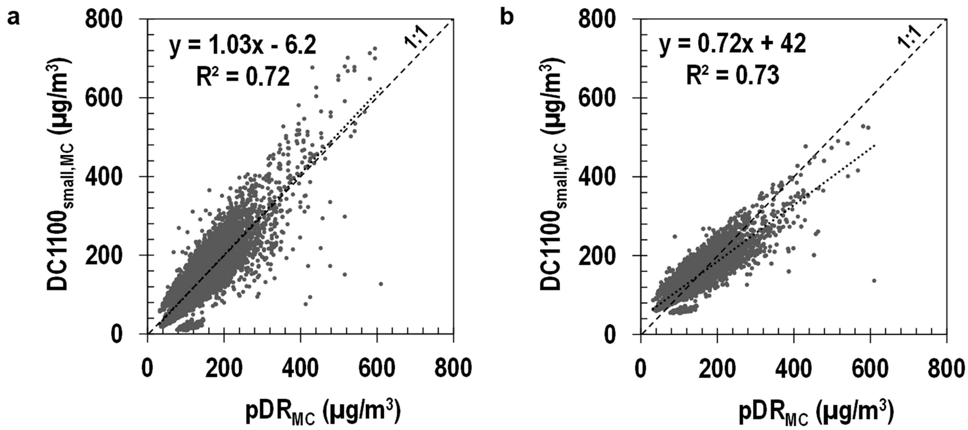

Figure 3 Particle mass concentration estimated with data from the small bin of the DC1100 using (a) Method 1 (Physical Property Method) and (b) Method 2 (Regression Method) compared to respirable mass corrected pDR-1200 for 10-min averaged data.

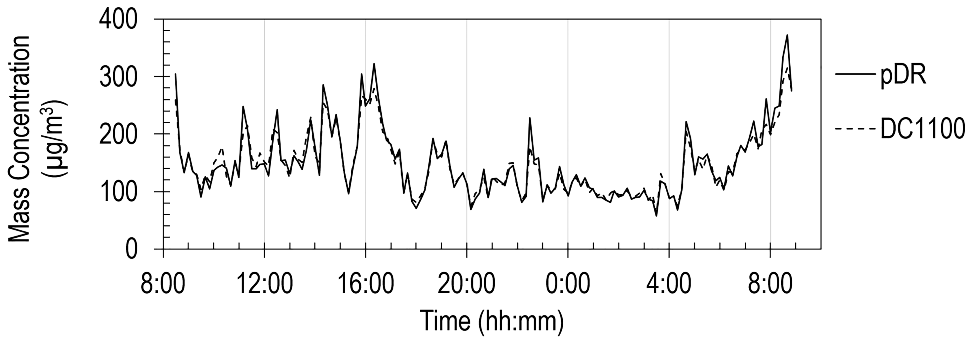

Figure 4 Time series plot of mass concentration DC1100 small particles using Method 1 (Physical Property Method) and respirable mass corrected pDR-1200 for 10-min averaged data.

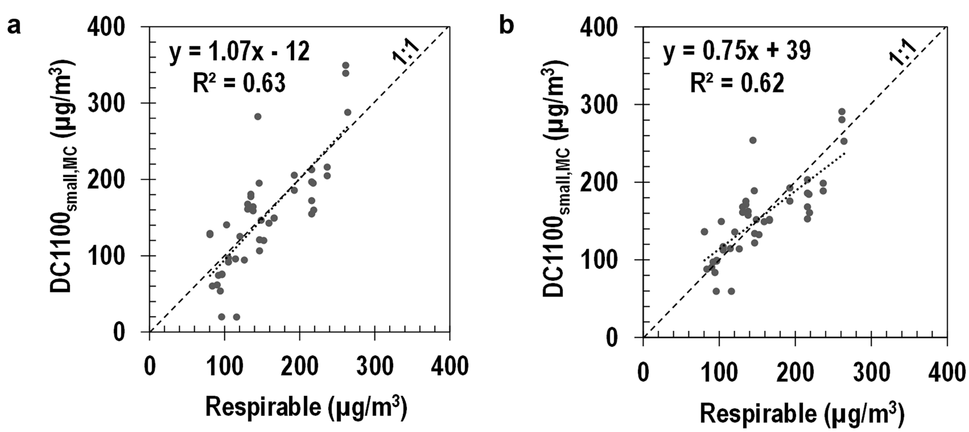

Figure 5 Particle mass concentration estimated with data from the small bin of the DC1100 using (a) Method 1 (Physical Property Method, full data), (b) Method 2 (Regression Method) compared to respirable mass concentration measured gravimetrically for 24-h averaged data.

with a second-order polynomial shape of the scatterplot between DC1700 and AM510. The best-fit regression curve gave an R^2 of 0.90 over the concentration range 0–1000 μg m^{-3}. In a follow-up study using field data, the best-fit regression curve resulted in an R^2 = 0.86, with a concentration range of 9–1182 μg m^{-3} (Semple *et al.*, 2013).

Number concentrations measured with the DC1100 can be used to estimate mass concentrations that compare favorably to respirable mass concentration measured gravimetrically. The Physical Property Method provided the best results, with slope and % Bias that met the EPA criteria for both 10-min and 24-h averaged data. For this method, the intercepts (−6.2 for 10-min and −15 μg m^{-3} for 24-h averaged data) and correlation coefficients (0.85 for 10-min and 0.80 for 24-h averaged data) were outside of the EPA criteria. In contrast, results obtained with the Regression Method only satisfied the % Bias criterion, with substantially greater excursions from EPA criteria for intercepts (42 μg m^{-3} for 10-min and 39 μg m^{-3} for 24-h averaged data). Neither method satisfied NIOSH's 95% accuracy interval criteria (± 25%) with an accuracy of 55% obtained with the Physical Property Method and 41% for the Regression Method.

Although mass concentrations estimates made with the Dylos data failed to satisfy EPA and NIOSH comparability criteria, they were found to provide a good indication of dust concentrations and relative changes in those concentrations (Fig. 3). The failure to meet comparability criteria means that the Dylos is not suitable to replace a gravimetrically adjusted pDR. Despite this fact and that OSHA regulations call for gravimetric sampling, there are many ways a low-cost monitor, like the DC1100, can be used in occupational settings. Having a way to determine respirable mass concentration, in real time, can be a valuable tool for agricultural workers to visibly identify areas or tasks of concern. Using a DC1100 can allow for real-time understanding of high exposures to warn workers to take precautions such as personal protective equipment (respirator) or to activate ventilation systems. Many CAFOs use technologies that control heating and ventilation to create optimal living conditions for the animals, but the DC1100 could be integrated into a control system to regulate ventilation to reduce the amount of airborne contaminates present. Another potential use for the DC1100 is tracking dust levels over time, which can raise worker awareness of exposures that they face in the workplace.

The reason that the Physical Property Method performed somewhat better than the Regression Method is unclear from this dataset. In the Physical Property Method, bias was minimized by adjusting the assumed particle diameter when calculating mass from number concentration for 10-min averaged data. As a result, % Bias was lower for the Physical Property Method (Table 1; −1.7% 10-min averaged data) than the Regression Method (7.4% for 10-min averaged data), although the difference was less than expected. The more important difference was in the slopes estimated from the two methods with that from the Physical Property Method (1.03 for 10-min averaged data) much closer to unity than that from the Regression Method (0.72 for the 10-min averaged data). The fact that the mean size used for the Physical Property Method (3.32 μm) was outside of the range of 0.5–2.5 μm suggests that most of the respirable mass concentration may be associated with coarse (particles larger than 2.5 μm) aerosol. Information on the size distribution of the aerosol in the swine barn, which was beyond the scope of this field effort, would help resolve why the two methods perform differently.

Our results are similar to those of others. Northcross *et al.* (2013) mass converted DC1700 data using the Physical Properties Method for a laboratory-generated aerosols with known particle size and density. They compared their results to mass concentration measured with a DustTrak 8520 and mass corrected daily using from a beta attenuation monitor. They observed that mass concentration estimates with the DC1700 were highly correlated to measurements made with the DustTrak (R^2 = 0.81–0.99), which is higher than that observed in this CAFO work (R^2 = 0.62–0.72). Lower R^2 values in this study may be due to the unknown aerosol diameters in the swine CAFO, whereas Northcross *et al.* (2013) generated aerosols in a chamber with known physical properties.

While the DC1100 was found to provide reasonable agreement with respirable dust concentrations in an agricultural building, there are some limitations in its design that may hamper use in an occupational environment. The airflow in the DC1100, provided with a box fan at the exhaust of the device without control, may alter when fouled with dust. This issue and the fact that the device comes without a presize selector could be addressed with design upgrades. Issues of cleaning and calibration of the DC1100 also need to be addressed in future work to ensure that measurements are accurate in occupational settings with high dust concentrations.

There were several limitations of this study. The ability to estimate particle mass concentration with the DC1100, which provides particle count concentration output data, is likely to be specific to the size distribution and composition of particles in the workplace. We anticipate that the relationships developed in this work will be generalizable to other CAFOs because the source, composition, and size distribution should be fairly similar among operations, although this assumption requires additional analysis. Workplaces with different aerosol sources will require analyses of mass conversion relationships appropriate to the specific aerosol, although we expect that the DC1100 should respond similarly to other photometric monitors. The DC1100 only provides one-min logging, although this limitation may be relatively unimportant for workplaces with slowly changing aerosol concentrations, such as in the swine CAFO, and in situations where longer-term averages are desired. The DC1100 also has preset particle size bins of small particles (>0.5 µm) and large particles (>2.5 µm). Thus, a direct comparison to size-selective occupational exposure limits (respirable 50% cut-off size is 4.0 µm) may not be reasonable. Additionally, the DC1100 has no airflow control and the inlet precludes the attachment of a size selector, like the cyclone and respirable filter arrangement used in this work with the pDR-1200.

CONCLUSIONS

Particle number concentrations measured with a low-cost (~$200) DC1100 were highly correlated to mass concentrations measured with a substantially higher-cost (~$5,800) photometer in a swine CAFO in winter. Mass concentrations estimated from number concentrations measured with the DC1100 also compared favorably to respirable mass concentration measured gravimetrically. We expect that these results are generalizable to other CAFOs but further work is required to confirm this expectation. Studies to convert the DC1100 particle count concentration to mass concentration will be necessary for workplaces in different industries. These results indicate that the DC1100 is a useful indicator of respirable concentrations in a swine CAFO and may be more broadly applicable to other agricultural and industrial occupational settings.

SUPPLEMENTARY DATA

Supplementary data can be found at http://annhyg.oxfordjournals.org/.

FUNDING

This research was funded by CDC/NIOSH Great Plains Center for Agricultural Health (U54 OH007548).

DECLARATION

The authors declare no other conflict of interest relating to the material presented in this Article.

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