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Evaluation of engineering and management control measures for improving air quality in swine production

Yaomin Jin

Prairie Swine Centre Inc. P.O. Box 21057, 2105-8th Street East, Saskatoon, SK S7H 5N9

Bernardo Predicala

Prairie Swine Centre Inc. P.O. Box 21057, 2105-8th Street East, Saskatoon, SK S7H 5N9

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ABSTRACT Dust and ammonia (NH_3) emissions from confined swine operations are major concerns to the industry and to the public. Various measures to control emissions have been proposed in the literature but very little work has been done to correlate the effect of these measures on the reduction of emissions to the actual reduction of worker exposure. Four different engineering and management measures, including low crude protein diet, canola oil sprinkling in building air space, stored manure pH manipulation, and high-level of cleaning of production room, were evaluated for their effectiveness on reducing NH_3 and respirable dust concentrations in swine production rooms. Their impacts on actual exposure of barn workers to these airborne contaminants, as well as on pig performance were also assessed. The study was carried out in six grow-finish rooms located at Prairie Swine Centre Inc. Four rooms were used as treatment rooms while the other two served as control. Five trials were completed, with each trial running for 16 weeks. During each trial, NH_3 and respirable dust concentrations were measured every three weeks, both by area and personal sampling. Area sampling was conducted by installing the samplers at fixed locations in the rooms. Worker exposure to dust and NH_3 were monitored using a personal sampling gear outfitted on the workers while they perform their normal tasks in their assigned rooms. The results indicated that the canola oil sprinkling could significantly reduce the respirable dust concentrations compared with the control. The NH_3 concentration of the rooms fed with low crude protein diet was significantly lower than the control.

Keywords: Canola oil, pH, low crude protein diet, ammonia, dust

INTRODUCTION

The indoor air quality in a swine confinement building is impacted by levels of gases such as ammonia (NH_3), as well as dust and microbes that arise from the presence of animals. Respirable dust can penetrate further into the gas-exchange region of lungs, making it the most hazardous dust component. Prolonged exposure to high concentrations of dust can lead to work-related respiratory symptoms such as asthma, organic dust toxic syndrome and chronic bronchitis in pig barn workers (Cormier et al., 1998; Dosman et al., 2004; Senthilselvan et al., 2007). Dust can also be a carrier of pathogenic microorganisms and harmful gases. Ammonia is derived from the decomposition of nitrous compounds. Increased exposure to ammonia may also have an effect on the health of humans and livestock. Furthermore, NH_3 contributes to the formation of fine particulate matter by reacting with acid gases from combustion sources (Aneja et al., 2000).

A number of engineering and management measures have been shown to be effective in reducing the levels of air contaminants such as NH_3 and dust in barns, but most of these studies fell short of actually documenting the impact of these measures on reducing worker exposure (Aarnink et al., 2007; Cambra-López et al., 2009; Chiba et al., 1987; Dawson, 1990; Zhang et al., 1996). Hence, to protect the health and safety of barn workers, there is a need to bridge the gap between the development of intervention measures and their subsequent evaluation in terms of impact on actual reduction of worker exposure to these constituents.

The development and adoption of measures proven effective to improve the work environment in swine barns will help with retention of workers and reduce costs associated with high staff turn-over rates.

The overall goal of this study is to assess the effectiveness of engineering and management measures in reducing barn workers' occupational exposure to dust and gases from pork production facilities. Specifically, the objectives of this study are to: 1) assess the baseline occupational exposure of barn workers to dust and gas concentrations, 2) apply four types of engineering and management measures to minimize the above airborne contaminants, and 3) evaluate the effectiveness of the applied measures by comparing the occupational exposure to dust and gases of workers assigned to rooms with applied measures (experimental) and those workers assigned to corresponding rooms with no intervention measures applied (control).

MATERIALS AND METHODS

Barn and room characteristics

This study was conducted at the research barn facilities of the Prairie Swine Centre Inc., in Saskatoon, SK. Six grow-finish swine production rooms were used for this study (Table 1). Four types of engineering and management measures (treatment) were applied in four of the rooms in a staggered manner, while the other two rooms were managed as conventional (control) rooms with no measures applied.

The rooms that were available for this project were of two types. The first type has fully slatted floor and dimension of 7.3×19.8 m and a capacity of 100 pigs, with two rows of ten pens. The second type of room has two separate airspaces (East and West) that were identical to each other; treatments assigned to this type of room were applied to both sides. Each side has partially slatted floor and six pens with a capacity of 72 pigs. The dimension of each side is 5.49×14.63 m while the pen is 1.98×4.11 m.

Table 1. Room assignment and experimental treatments applied.

Room #	Type	Treatment
142	I	pH manipulation of manure
146	I	High level of cleaning
148	I	Control
128E & 128W	II	Canola oil sprinkling
129E & 129W	II	Low crude protein diet
130E & 130W	II	Control

Type I: 20 pens*5 pigs/pen=100 pigs, dimension of 7.3×19.8 m, fully slatted floor

Type II: 6 pens*12 pigs/pen=72 pigs, dimension of 5.49×14.63 m, partially slatted floor

Each room was operated on a negative pressure ventilation system. Fresh air typically entered the room from eave air intakes into the attic and through the ceiling air inlets distributed along the ceiling of each room and exhausted through three sidewall fans (Models J-16, J-20, J-24, Del-Air Ventilation Fan, Humboldt, SK). All rooms had similar fan and temperature controller system (Phason) with temperature set-points varied from 25 °C at the start of the trial and gradually reduced to 15 °C at the end of the trial according to standard temperature guidelines for grow-finish pigs. Underneath the pen area was the 0.61 m deep manure pit. The pit was periodically drained by pulling the plugs at each end of the pit.

Animals and Room Preparation

For each trial, a total of 732 pigs were used and distributed into the six rooms according to the capacity of each room. Before the pigs were moved into the rooms, the rooms were cleaned and prepared according to the treatment specifications.

At the start of each trial, pigs were weighed and assigned to each room to attain an average starting pen weight of about 20 ± 2 kg. The pigs were also segregated by gender such that each room had equal number of all-male and all-female pens.

Treatments

The different treatments were randomly assigned to various rooms as shown in Table 1. The treatments are described as follows:

Oil Sprinkling

A variable sprinkling schedule was followed starting from the day of moving the pigs into the rooms: 40 ml/m^2.d for the first two days, 20 ml/m^2.d for the third and fourth days, and 5 ml/m^2.d for the succeeding days. These sprinkling rates and schedule were established from a previous study on oil sprinkling conducted at PSCI. During sprinkling, the sprinkling nozzle was at 3.2 m above the floor, and the entire floor area was sprinkled, including the pen area, and pig bodies.

Low Crude Protein Diet

Normal production grow-finish diets were fed to all rooms except for the room assigned to low crude protein diet treatment (R129E-W). Both feed and water were supplied to the pigs *ad libitum*. Four feeding phases were applied in all rooms: Grower Phase 1 (G1; beginning at 24.5 kg body weight (BW)), Grower Phase 2 (G2; 50 kg BW), Finisher Phase 1 (F1; 65 kg BW), and Finisher Phase 2 (F2; 80 kg BW). For the low crude protein diet (LCP), dietary crude protein was reduced by adding supplemental amino acids to the diet such that the amino acids needs of the pigs were achieved with concomitant reduction in dietary N. Formulated CP for G1 was 19.5% for the control diet and 15% for the LCP diet. For succeeding feeding phases, the amount of formulated CP was proportionally decreased such that the F2 phase contained 18.2% for the control diet and 12% in the LCP diet.

Manure pH Manipulation

Every two weeks, a 28% aqueous aluminum chloride ($AlCl_3$) solution was applied to the manure pit at a rate of 0.75% (volume ratio of manure to the solution) using a bucket and manual sprayer. Prior to application, manure depth in each pit was measured to determine the volume of the manure and to calculate the volume of the solution to be applied. Manure depth was measured at the middle of the pit and the two extreme ends.

High Level of Cleaning

In conventional cleaning, the room surfaces were pressure washed but the pits were not necessarily emptied before the new batch of pigs was moved in if the pits were not yet full. In intensive cleaning, the room was pressure washed, manure pits were always emptied regardless of level of fill, and the walls of the manure pit were thoroughly cleaned. During the course of the trial, the room was maintained at the highest possible cleanliness level through frequent checks and management of the ventilation controls, feeders, animals, daily scraping of the floor and pen surfaces, and proper management of the manure pits (i.e. complete clear-out during scheduled pit-plug pulling, flushing with water if necessary and re-filling the pits with clean standing water after plug-pulling).

Sampling Procedures

Each trial was run for 16 weeks, which included two weeks of animal and room preparation at the start of each trial and 14 weeks of data collection. Due to the number of pigs required in this experiment, actual startup date for each treatment was conducted in a staggered manner. NH_3 and respirable dust concentration were measured using personal/area sampling pumps, sorbent tubes and cyclone-filter-cassette assembly according to National Institute of Occupational Safety & Health (NIOSH) 6015 and 0600 methods (NMAM, 1994). NH_3 concentration was also measured using commercial gas monitors (i.e., GasBadge Pro, Industrial Scientific), which are widely used in the industry. The pigs were weighed at the start (week 0), middle (week 6) and end (week 12) of each trial to determine the average daily gain. NH_3 and dust concentration were measured every three weeks (week 2, 5, 8, 11, and 14) for two consecutive days.

Every three weeks, the occupational exposure of barn workers to dust and NH_3 was assessed by outfitting three barn workers with personal respirable dust samplers and gas monitors over the course of their work shift for 2 days. Two workers were assigned to the experimental rooms (R128E-W and 129E-W; 142 and 146) while the other was assigned to the control rooms (130E-W, and 148). A regular working day of a barn worker also included different tasks in other rooms in the barn after they completed their tasks in their assigned rooms. The workers were instructed to make sure that their personal monitoring equipment was running only when they were in the experimental rooms that they were assigned to, and to record in a logbook the activities they conducted while the personal monitoring equipment was in operation. The same workers were assigned to their respective rooms for the duration of each trial.

RESULTS AND DISCUSSION

Respirable Dust Concentrations

As shown in Figure 1, average respirable dust concentration in the room sprayed with canola oil was lower than in the corresponding control room (0.156 vs. 0.349 mg/m^3), while those in room given low crude protein diet was also slightly lower than the control (0.273 vs. 0.349 mg/m^3). However, the observed differences were not statistically significant (P=0.298), indicating that the canola oil and low crude protein diet treatments had no significant effect on dust concentration. Both the rooms with pH manipulation of manure and high level of cleaning treatments have slightly higher dust concentration than the corresponding control room, although the differences were not statistically significant (P=0.298).

Some researchers reported a reduction of dust concentration after applying rapeseed oil or water-oil mixture in broiler house (Aarnink et al., 2008; Nonnenmann et al., 2004). This measure helps prevent dust on surfaces to become airborne (again). Additionally, Ni et al. (2008) observed that the soybean oil sprinkling in the pig finishing barn could reduce the greenhouse gases (carbon dioxide and methane). However, the mechanism of the gas emission reduction by oil treatment is still not clear.

Mean dust concentrations in control rooms were slightly higher than the reported value of 0.23 mg/m^3 in northern Europe (Takai et al., 1998). The difference of concentrations was probably due to differences in the building structure, ventilation parameters, feeding practices, slurry handing, and weather conditions between northern Europe and western Canada.

The results also indicated that pig age significantly influenced the dust concentration levels in some rooms (P=0.037 for rooms 148, 146, and 142). The dust concentrations were lowest (0.17 mg/m^3) when the pigs were just moved into the rooms (~20 kg) while the highest concentrations (0.35 mg/m^3) were measured when the pigs approached market weight (~120 kg). This trend is expected since larger pigs tend to be more active, require more feed, produce more manure, and consequently generating more airborne dust.

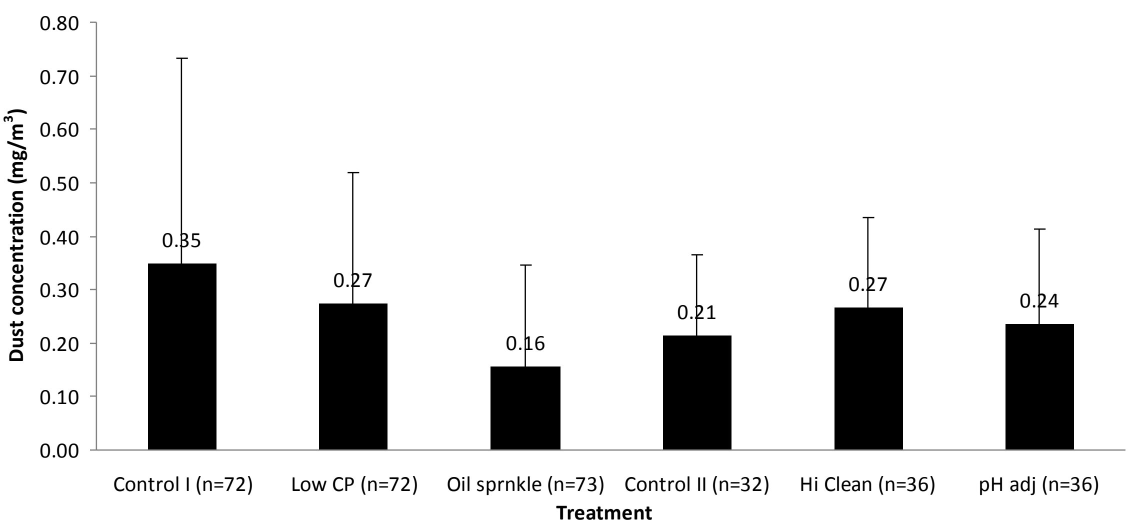

Figure 1. Comparison of respirable dust concentrations measured in the control and experimental rooms by area sampling.

NH_3 Concentrations

Mean NH_3 concentrations in treatment and control rooms measured by area sampling are shown in Figure 2. The results showed that the commercial gas monitor readings were higher than the values obtained from the NIOSH method (sorbent tubes) in both control and treatment rooms. This may be attributed to the fundamental differences in the principles employed by the two methods in generating the target gas concentration values. For the gas monitor, the target gas has to react with a sensor in the device which generated the signal and converted to a concentration read-out determined by calibration. For most ammonia sensors, it is common that the sensor itself exhibits cross-sensitivity to other gases present in the air, thereby generating higher than expected concentration values for the target gas. On the other hand, the NIOSH method involved actual collection of the target gas compounds on a sorbent, which was then analyzed in a laboratory using techniques specific only to the target gas, thus eliminating uncertainties due to presence of other compounds in the sample. Nevertheless, both the gas monitor and the NIOSH method showed that the treatments with low crude protein diet had significant effect on NH_3 concentration ($P<0.0001$), while the other treatments did not show statistically significant effect relative to the control rooms.

The results of this study support the concept that reducing dietary crude protein content, whilst maintaining similar levels of essential amino acids, reduces excess total nitrogen intake and consequently leads to a reduction in the amount of nitrogen excretion. Kendall et al. (2000) reported a reduction in ammonia concentration from 29.6 to 12.9 ppm (approximately a 56% reduction) in the exhaust air from 12.6% and 9.35% crude protein diets, respectively, supplemented with synthetic lysine. Similarly, Hayes et al. (2004) also found that low crude protein diet could reduce the ammonia and odor emissions for pig production. Compared with other measures such as using chemicals to neutralize NH_3 or reduce microbial fermentation, the low crude protein diet requires no additional cost (Ferguson et al., 1998). Dietary manipulation offers a potential method to reduce nutrient excretion by pigs.

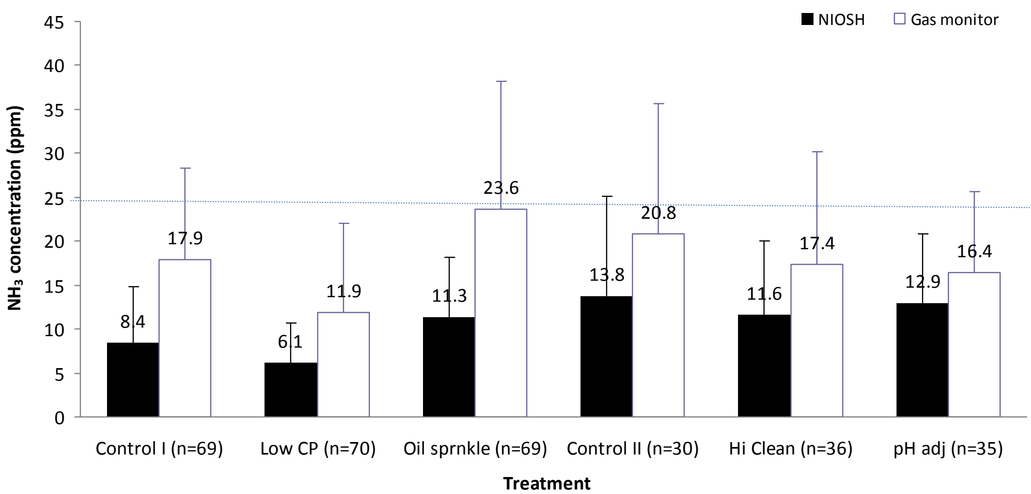

Figure 2. Comparison of NH_3 concentrations measured in the control and experimental rooms using gas monitors and NIOSH method by area sampling.

Worker exposure

All personal sampling results showed much higher respirable dust concentrations than area sampling (3.0 to 6.0 mg/m^3 vs. 0.16 to 0.35 g/m^3, respectively) as shown in Figure 3. This was expected since with personal sampling, the sampler was worn by the worker while performing specific tasks (i.e., manual feeding, filling carts from the bin), thus the samplers could capture more contaminants closer to the source; whereas with area sampling, the sampler was at a fixed location and would be able to capture only the airborne contaminants dispersed by the ventilation system towards the location of the sampler. In addition, personal sampling was usually conducted at daytime when all pigs were active and dust generation was higher, whereas area sampling duration covered both daytime and night time hours when pigs were sleep and dust generation was low. Takai et al. (1998) found that expected mean respirable dust concentration in pig buildings were higher in the day than the night in northern Europe. Additionally, most of the personal sampling results from this study were over the 3 mg/m^3 threshold limit value established by ACGIH for airborne respirable particulates in the workplace.

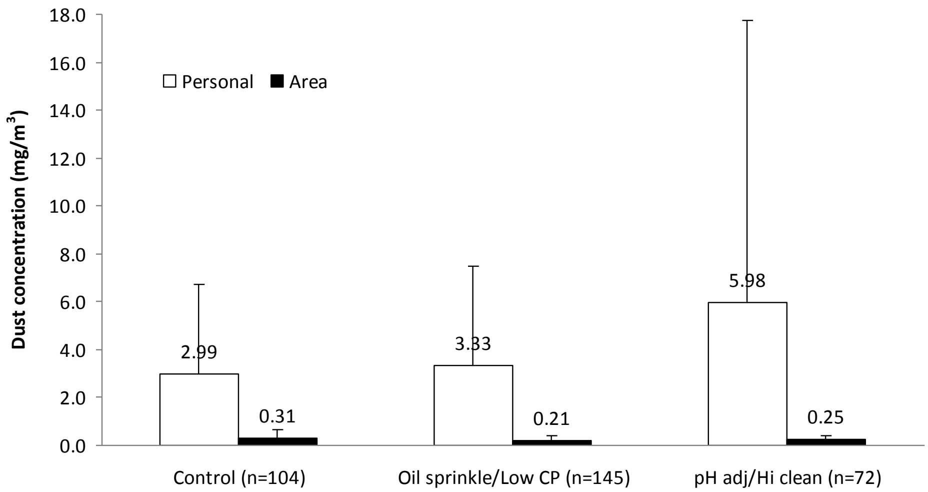

Figure 3. Respirable dust concentrations obtained in the control and experimental rooms by personal and area sampling.

For NH_3 concentration, the gas monitor values were generally higher than the NIOSH method values as previously observed. However, NH_3 readings from both analytical methods showed that personal monitoring yielded values comparable to area sampling as shown in Figure 4. Regardless of which sampling method was used, most of the personal exposure values were below the 25 ppm NH_3 threshold limit value set by ACGIH.

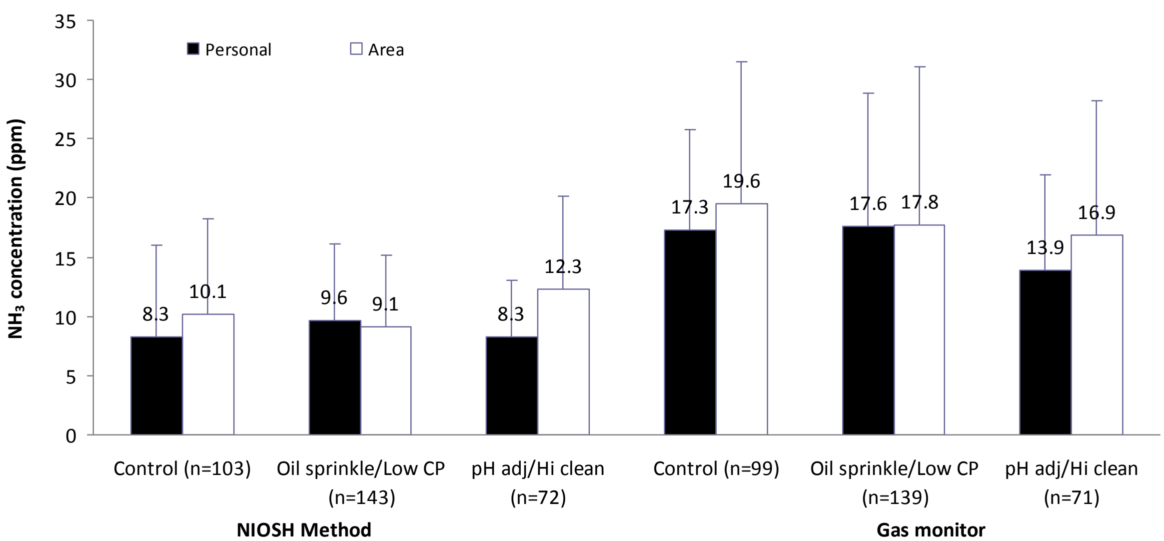

Figure 4. Comparison of NH_3 concentrations obtained by personal and area sampling using gas monitors and NIOSH method.

Pig Performance

From the pig weight data taken on Week 0, 6, and 12 of each trial, the observed average daily gain (ADG) of pigs were relatively similar in both Control and Treatment rooms (Table 2), ranging from

0.98 to 1.07 kg/pig-day. Similarly, the results indicated no statistically significant difference in mortality among the treatment rooms and the control rooms (P=0.286).

Table 2. Daily weight gain and mortality of all the rooms.

Treatment	ADG (kg/day-pig)	Mortality (%)
Control	1.00 ± 0.06	2.75 ± 2.68
Low crude protein diet	1.07 ± 0.15	1.28 ± 1.72
Oil sprinkling	0.98 ± 0.04	1.07 ± 0.82
pH manipulation	0.99 ± 0.07	0.37 ± 0.50
High level cleaning	1.02 ± 0.06	1.33 ± 1.88

CONCLUSIONS

From the completed trials, results showed that ammonia and respirable dust levels in treatment and control rooms measured by area sampling were generally below the threshold limit values (25 ppm for NH_3 and 3 mg/m^3 for respirable dust) set by ACGIH. Personal monitoring, however, indicated that worker exposure to dust exceeded the 3 mg/m^3 threshold limit value. Canola oil sprinkling could reduce respirable dust concentrations, while the use of low crude protein diet tended to lower ammonia concentrations. Supplemental trials are needed to arrive at definitive conclusion on the effect of the different measures on respirable dust and ammonia. Ammonia gas monitors yielded generally higher readings compared to the standard analytical method; this trend does not compromise barn worker safety as this would mean that the use of gas monitors would provide early indication of potentially hazardous levels of ammonia, thus allowing the worker to take appropriate actions.

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