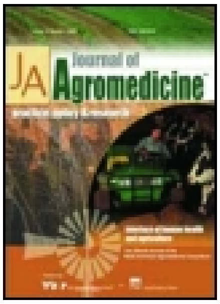

Journal of Agromedicine
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/wagr20

Swine Production Impact on Residential Ambient Air Quality

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Version of record first published: 04 Aug 2009.

Journal of Agromedicine, 14:291–298, 2009

ISSN: 1059-924X print/1545-0813 online
DOI: 10.1080/10599240903041943

ORIGINAL RESEARCH

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ABSTRACT. Numerous residents in agricultural areas are concerned about the impact that the swine industry may have on the ambient air quality. They assume there is a risk because there is limited information on the airborne contaminant that may originate from these facilities. The objective of the project was to assess the impact of swine production on ambient air quality related to public health in farming communities. Of the six chosen communities, three were considered not to be in a swine production area,

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The authors acknowledge the financial contribution of the "Institut national de la santé publique du Québec" toward this project. Thanks must also be given to Research and Development Institute for the Agri-Environment (IRDA) who provided in-kind contributions for this study. The authors also recognize the technical support provided by BPR Inc. (Sylvain Pigeon and Jean-Yves Drolet) and research staff at IRDA and at Laval Hospital Research Centre, Québec. Dr. Duchaine acknowledges a Junior 2 FRSQ scholarship.

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whereas the three others were considered to be within a swine production area. Data were collected during three periods in spring and summer 2006. Ammonia and hydrogen sulfide concentrations were monitored on a continuous basis whereas odor concentrations and intensities were monitored twice a week. Odor concentrations were measured by dynamic olfactometry and odor intensities were determined by trained odor assessors. Public health was evaluated by survey questionnaires sent to a sample of residents in each of the six communities. Average NH_3 concentrations ranged from 6.9 to 12.6 ppb for nonexposed communities and from 8.9 to 18.3 ppb for exposed communities. Average H_2S concentrations ranged from 1.1 to 1.5 ppb for nonexposed communities and from 1.1 to 1.6 ppb for exposed communities. For a community in a swine production area, ambient NH_3 and H_2S concentrations were found to be higher than those communities not in a swine production area; however, that difference was not significant and they were within air quality standards for public health and safety. Odor concentrations showed no significant difference between the nonexposed and exposed communities and between evening and morning periods. Odor intensities were found to be significantly higher in the communities within swine production areas. More research will be required to fully understand the correlation between specific physical symptoms from residents and the presence of odors from swine production.

KEYWORDS. Ambient air quality, ammonia, hydrogen sulfide, odor, public health, swine production

INTRODUCTION

Swine production continues to raise environmental concerns within agricultural communities in Canada. Whenever a new swine facility is proposed, nearby residents believe there may be major risks to the air, soil, and water. Airborne contaminants from swine facilities include carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4), nitrous oxide (N_2O), and some trace gases (aldehydes, amines, aromatics, organic acids, sulfur compounds).[1] Numerous American agencies or organizations have established threshold values for NH_3 and H_2S in ambient air. On average, the NH_3 chronic exposure limit varies from 100 to 300 ppb, whereas the acute exposure limit ranges from 1700 to 4500 ppb.[2–7] For the H_2S, corresponding ranges are 1.4 to 8.0 ppb and from 20 to 200 ppb.[4–9]

Studies of potential health risks to community residents living in the proximity of confined animal feeding operations (CAFOs) have been limited.[10] The symptoms experienced by swine CAFO neighbors are generally oriented toward irritation of the respiratory tract and are consistent with the types of symptoms reported among swine confinement workers.[11,12] Residents who experienced odors in the vicinity of a swine operation also reported increased occurrences of tension, depression, anger, headaches, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes as well as more tension, depression, anger, fatigue, and confusion than other subjects.[10,13,14]

However, to fully understand the impact that swine production has on public health, many aspects would need to be considered, including the environmental exposure, the long-term exposure of residents to swine barn contaminants only, as well as more social aspects such as overall quality of life. Considering this level of complexity, some of these studies have major limitations and some of the data sets cannot be used to link health symptoms to a specific exposure.

The objective of this project was to assess the impact of swine production on ambient air quality as it related to public health in rural communities. More specifically, the objective was to measure and compare airborne contaminants (NH_3, H_2S, bioaerosols) and odor concentrations and intensities among three rural communities considered to be in a swine production area and three communities not considered to be within a swine production area.

METHODS

Community Selection

Selection criteria for communities included the population size, pig and total animal units

(AU), and total land area combined with the percentage of crop land versus forest land. A Ministry of Agriculture database in Québec was used as a source to identify communities within and outside swine production areas. The following selection criteria were used:

- Cultivated land area/total land area ratio: >50%;
- Forest land area/total land area ratio: <30%;
- Number of residents: between 500 and 10,000 people.

Within the province of Québec, a total of 110 communities met these criteria. With the aid of maps and livestock production data, 10 communities were identified. This community selection was presented to a panel of experts, including representatives from the government, universities, and the swine industry. These communities were visited by the research team to confirm their suitability for the study. To maximize the community exposure to swine airborne contaminants and odors, communities with the greatest number of swine production sites to the west (generally) of the community were selected because of prevailing winds. Three communities were identified to be within swine production areas (exposed; E) and three communities were identified to be outside the swine production areas (nonexposed; NE; Table 1). As shown in Table 1, other animal species were also present in the selected areas.

In general, these communities had similar characteristics in terms of total area and topography. On average, the communities in the swine production areas had 19 times more pig AU than those outside the swine production areas for every km^2 (151 versus 7.7 AU/km^2). An AU represents a number of pigs that is equivalent to a 500-kg pig.

Air Quality Measurements

Ammonia and hydrogen sulfide analyzers were mounted in a 5.5-m instrumentation trailer. The experimental campaign lasted for 18 weeks, going from May 12th to September 15th, 2006. The instrumentation trailer was moved to the community on a Friday and was assessing air quality on a continuous basis for 1 week at the chosen sampling location. Then the trailer was towed to another community for a 1-week campaign. Temperature, relative humidity, wind speed, and direction sensors were installed on a 3.7-m mast on the trailer. With the prevailing winds normally blowing from the west or southwest direction, the trailer was located on the west side of each community. The NH_3 analyzer (M201E; Teledyne, API, USA) quantified the nitrogen monoxide (NO) concentration resulting from NH_3 oxidation at 825°C. The H_2S analyzer (Teledyne, API) quantified the sulfur dioxide (SO_2) resulting from H_2S oxidation at 315°C. Once a day the analyzers would monitor a certified calibration gas. Two methods were used to measure odor: the odor intensity by odor assessors and odor concentration by dynamic olfactometry.[15,16]

TABLE 1. General Characteristics of Selected Communities for the Project

Community	Population	Total area (km^2)	Animal unit (AU)[c]			Pig density (AU/km^2)
			Pig	Poultry	Others	
1 NE[a]	6,061	80	575	1	859	7
2 NE	654	79	0	0	1,582	0
3 NE	527	37	584	0	1,280	16
1 E[b]	2,860	73	8,261	284	3,338	113
2 E	875	57	5,717	808	1,837	99
3 E	2,015	88	20,977	5,181	7,103	240

[a]Communities not within swine production areas.
[b]Communities within swine production areas.
[c]AU, animal units.

Two trained odor assessors evaluated the ambient odor intensity at 10 locations surrounding the community with a 9-point n-butanol scale as described in the Standard Practices for Referencing Suprathreshold Odor Intensity Standard (ASTM 544-99).[17] The odor assessors could distinguish between pig- and non–pig-related odors. During the same time periods, four air samples, for odor concentration evaluation, were collected in 37-L flushed tedlar bags at the location with the highest odor intensity (odor concentration or number of dilutions at detection). Because the highest incidence of odor complaints occur in the evening or the morning when the wind speed is at a minimum, two of the air samples were collected between 18:00 and 20:00 every Tuesday evening and the remaining two samples between 7:00 and 9:00 on Wednesday.

Bioaerosols were sampled using a cyclone multi-vial (Burkard Manufacturing, UK). The Burkard Automatic Multi-Vial Cyclone is designed to sample airborne microorganisms (bacteria, fungal spores) for DNA analysis. This sampler is designed for field application. Completely self-contained with its own suction source, the particles are monitored in an air movement of 16.5 L/min. Mounted on precision bearings the instrument is sensitive to wind direction and the sampling orifice is kept into the prevailing wind by the vane mounted on the rear of the cover. Samples were collected into 1.5-ml Eppendorf vials located on a carousel. The movement of the carousel and Eppendorf vials (seven vials for a vial/day and a vial for purge) were programmed to sample air for 23 h/vial/day. Only vials sampled for 23 h were analyzed. Vials containing water, debris, or with sampling time less than 23 h were rejected.

Back to the laboratory, samples were centrifuged at 21,000 × *g* in order to pellet the content. They were frozen (–20°C) until analysis. According to the sampling device flow rate, each sample represented approximately 22.77 m^3 of air. Samples were extracted using commercial silica columns using manufacturer recommendations (Qiagen, Mississauga, ON). Extracted DNA was eluted in 100 μl of TE buffer (10 mM Tris, 1 mM EDTA, pH 7.5). Biodiversity of samples was evaluated using a nested PCR DGGE (polymerase chain reaction denaturation gradient gel electrophoresis) using PCR primers previously published by Muyzer et al.[18] and Bach et al.[19] One microliter of eluted DNA, representing 0.23 m^3 of air, was used in a 10-cycle preamplification using PCR conditions previously decribed by Bach et al.[19] After preamplification 1 μl of the PCR mix was used to perform PCR DGGE under conditions described by Muyzer et al.[18] Positive amplification and amplicons concentration was confirmed on 1.5% agarose gel electrophoresis, run under 70 V for 60 min and visualized under ultraviolet (UV) after the gel was stained using ethidium bromide. Positive samples were used to run on DGGE polyacrylamide using a denaturating gradient of 35% to 55%. DGGE gels were stained using SybrGold (Invitrogen, Mississauga, ON) and visualized under UV light. Bands that appeared on the gel were extracted and sent to a sequencing core facility. Sequencing was done using the 63 forward primers on a ABI 3730/XL. Each DNA sequence was compared with sequences available in databases, using BLASTN from the National Center of Biotechnology Information (http://www.ncbi.nlm.nih.gov/BLAST/). The detection limit for this procedure, excluding the possibility of PCR inhibitors present in sampled environments, was set to 4.3×10^2 cells/m^3 according to PCR sensitivity, dilution, and size of samples.

Public Health Survey

Parallel to this study, an epidemiological study was carried out to compare the health impact on communities within and outside of swine production areas using a questionnaire. The questionnaire asked about symptoms, quality of life, social climate, and mental health. The following criteria were used to select participants: minimum of 18 years of age, nonsmoker, and not living in a residence where smoking occurs, not a swine barn worker, not having a family member involved in swine production, and to be at home during the 5-week monitoring period. In total, the study included 94 households in the E communities and 80 households in the NE communities. Each household filled three questionnaires, one during each measurement period. The final results from this survey will be published at a later date; however, some preliminary results are available.[20]

Statistical Analysis

A mixed model included fixed effects such as the community exposure, season, and the interaction between these two factors was used where the community represented the experimental unit. The area, the community, and their interaction were considered as random effects. The statistical analysis was conducted using SAS's PROC MIXED procedure.[21] Correlations of repeated measurements were carried out on the seasons for each area. Several structures of variance-covariance were considered for the data files using statements RANDOM and REPEATED of SAS's PROC MIXED procedure. The random part of the model was reduced since certain components of covariance were considered null. A fixed effect was considered significant at $p < .05$. The values of odor concentrations and intensities were transformed to a log scale to normalize the distribution of values.

RESULTS

Air Quality

Average 1-h NH_3 concentrations over the three periods ranged from 6.9 to 12.6 ppb for the NE communities and from 8.9 to 18.3 ppb for the E communities, respectively. The community type had no significant effect on the NH_3 concentrations. Evaluating the exposure over an hour rather than on a 10-min basis had a minor impact on the average value, whereas it substantially reduced the maximum value. With acute limits being defined on an hourly exposure, hourly values are more appropriate for assessing the short-term exposure (Table 2).

No significant effect of community type or the season of exposure on the H_2S concentrations was detected (Table 2). The mean ambient concentrations were considered to be very low.

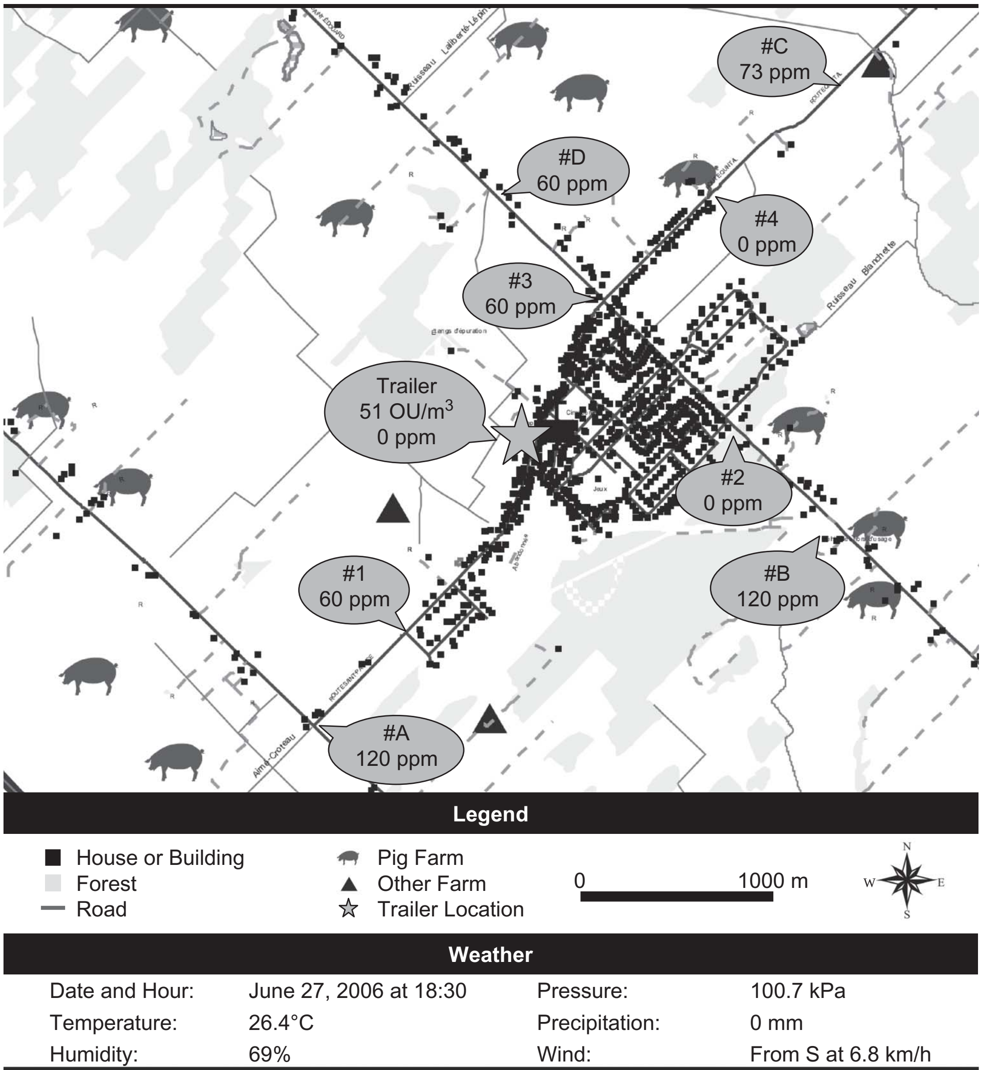
There were no significant differences in odor concentrations between the NE and E communities and between the evening and morning samples. In fact, average odor concentrations ranged from 20 to 54 OU/m^3 for the NE communities and from 30 to 51 OU/m^3 for the E communities (Table 2). However, the odor assessor results indicated that significantly higher odor intensities were detected in the E communities compared to the NE communities ($p < .0001$), and evening odor intensities were higher than the morning values. For the evening values, the E communities had odor intensities ranging from 101 to 144 ppm (n-butanol scale equivalent) compared to 1 to 10 ppm for the NE communities. More odor events were detected during the evening than during the

TABLE 2. Mean NH_3, H_2S, Odor Concentrations and Intensities in the Six Communities

Community	NH_3 concentration over 1 hour (ppb)			H_2S concentration over 1 hour (ppb)			Average odor concentration (OU/m^3)		Average odor intensity[c] (ppm of n-butanol equivalent)	
	Average	Min	Max	Average	Min	Max	Night sampling	Morning sampling	Night sampling	Morning sampling
1 NE[a]	7.1a	1.2	34.5	1.1a	0.0	3.7	20a	47a	1	1
2 NE	6.9a	0.0	24.5	1.4a	0.5	2.3	38a	49a	1	1
3 NE	12.6a	1.0	110	1.5a	1.0	2.0	54a	38a	10	9
1 E[b]	8.9a	0.0	48.9	1.1a	0.0	4.9	41a	33a	101	17
2 E	11.1a	1.6	39.9	1.3a	0.0	11.9	41a	30a	123	19
3 E	18.3a	3.8	147	1.6a	0.0	4.5	51a	43a	144	131

[a]Communities not within swine production areas.
[b]Communities within swine production areas.
[c]Highest values for all the monitored locations.

FIGURE 1. Odor (concentrations and intensities) and weather parameter values for community 1 E on June 27, 2006 (18:30).



morning periods. An example of the odor intensities over an area is illustrated in Figure 1. For this particular example, within the swine production area, odor events were evident; however, at the location of the instrumentation trailer the odor intensity was negligible.

The bacteriological analysis of the samples indicated a presence of *Clostridium* sp., *Enterobacter aerogenes*, *Pantoea agglomerans*, *Candidatus Hamiltonella defensa*, and *Ochrobactrum* sp. in the E communities; however, they were not identified in the NE communities. A quantitative analysis of the presence of total bacteria indicated that the positive samples measured in the E and NE communities were 33% and 47% of the samples, respectively. Although certain bacterial species could be detected in the air of E communities, it seems that the measuring method was probably used at its detection limit.

Public Health Survey—Preliminary Observations

Forty-three percent (43%) of the participants detected odors. Among those participants, 60%

judged them disturbing. Twenty percent (20%) of the participants kept their windows closed during the sampling period. Participants who detected odors (in both the E and NE communities) also indicated symptoms such as headaches, runny nose, cough, and vomiting. By the end of the summer, participants who detected odors expressed more distress than the others. From 78% to 92% of residents living in the E and NE communities were concerned about the impact swine production on the environment and public health. It is important to notice that there was no specific information on the odor source (buildings, manure spreading) or from which animal species it was coming from (pig, dairy or poultry).

DISCUSSION

Ammonia and Hydrogen Sulfide

When compared to chronic and acute exposure limits,[2] the ambient NH_3 concentrations of the E communities does not reflect a health risk to the residents. Also, the NH_3 concentrations in the E and NE communities were similar, thus indicating the negligible impact from the nearby swine production activity in this study. When considering the air quality standards for H_2S (1.4 to 8.0 ppb),[4,7,9] the H_2S concentrations in the E communities do not represent a greater risk than those in the NE communities. Occasionally, the H_2S concentrations may exceed the air quality standards; however, their duration was considered to be very short. No significant effect of community type or the period of exposure on H_2S emissions was detected.

Based on these results, a community that is in a swine production area (151 AU pig/km^2) has higher NH_3 and H_2S concentrations; however, they are within the accepted air quality standards for public health and safety.

Odors

Odor concentrations showed no difference between the NE and E communities and between evening and morning periods. These measurements were very low and may have been lower than the background odor from the sampling bags. This analysis shows that olfactometry is not appropriate for measuring downwind concentrations. However, the odor assessor results are more encouraging as a measurement tool because the nondiluted odor was assessed directly on site and the frequency of odor events can be determined objectively. Odor assessor results indicated higher odor intensities in the E communities compared to the NE communities, and the evening observations tended to be higher than morning measurements. This is the period of the day the residents are likely to be home and be exposed to the odor when involved in outside activities. The median log of the odor intensity value in the E communities (2.07) was twice that of the NE communities (1.11). Odors emitted from swine operations may create a nuisance to nearby residents. More research will be required to define what level of odor intensity is socially acceptable to communities in agricultural areas.

Bioaerosols

The presence of *Clostridium* sp., *Enterobacter aerogenes*, *Pantoea agglomerans*, *Candidatus Hamiltonella defensa*, and *Ochrobactrum* sp. in the E communities should be investigated in subsequent studies. However, concentrations were very low. The presence of microorganisms in the air of the E communities represented rare events. With such low frequencies of detection, potential health effects are very difficult to predict in a precise way. Because no pathogenic microorganism was detected in great concentration, ambient air does not seem to act as a bacteria vector for the targeted population. Because no data are available regarding "normal" background air bioaerosol content (too much variability in nature and concentration), our approach did not allow the determination of signature aerosols in E communities in comparison with NE. Findings are likely due to random events.

Public Health

The low levels of NH_3, H_2S, odors, and bioaerosols measured in this study and the fact that these levels are below defined limits suggest that swine operation related emissions should not impact health in these communities at an animal density of 151 AU/km^2. Preliminary results from the questionnaires suggest a prevalence of symptoms (headaches, runny nose, cough, vomiting) even if there is no relationship between these symptoms and the odor concentration measurements. Considering the higher odor intensities in E areas, odor events may create some nuisance effects and symptoms for local residents as some symptoms such as headaches, running noses, cough, and vomiting are considered to be more prevalent in the E areas than in the NE areas. More research will be required to fully understand the correlation between specific physical symptoms from residents and the presence of odors from swine production.

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