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Community and occupational health concerns in pork production: A review¹

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ABSTRACT: Public concerns relative to adverse consequences of large-scale livestock production have been increasingly voiced since the late 1960s. Numerous regional, national, and international conferences have been held on the subject since 1994. This paper provides a review of the literature on the community and occupational health concerns of large-scale livestock production with a focus on pork production. The industry has recognized the concerns of the public, and the national and state pork producer groups are including these issues as an important component of their research and policy priorities. One reason large-scale livestock production has raised concern is that a significant component of the industry has separated from traditional family farming and has developed like other industries in management, structure, and concentration.

The magnitude of the problem cited by environmental groups has often been criticized by the pork production industry for lack of science-based evidence to document environmental concerns. In addition to general environmental concerns, occupational health of workers has become more relevant because many operations now are employing more than 10 employees, which brings many operations in the United States under the scrutiny of the US Occupational Safety and Health Administration. In this paper, the scientific literature is reviewed relative to the science basis of occupational and environmental impacts on community and worker health. Further, recommendations are made to help promote sustainability of the livestock industry within the context of maintaining good stewardship of our environmental and human capital.

Key words: environment, health, swine

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INTRODUCTION

Since the ending of hunter-gatherer societies and the beginning of agricultural societies, there has been a trade-off between the process of producing food for society, and stress on the natural environment and people that provide the food. Furthermore, the advent of the industrial revolution in the early 1800s charted a path of increasing intensification of agricultural and nonagricultural industry that has further stressed the natural environment that we live in. The latter not only challenges the urban environment, but also our rural environments, as urban discharges and emissions reach the streams and air of our rural residents that connect urban and rural landscapes. As the economies of indus-

trialized nations grew strong and basic necessities of life were generally cared for, the political and social controversies have increased as fewer people are involved in production agriculture.

Research has indicated that water and air pollution are now global issues, projecting environmental issues into the international arena. As production agriculture has become more concentrated into larger and more intensive operations, awareness and attention has increased from the public and regulatory agencies regarding water, air, and soil contamination and related community and worker health concerns. Emotions are increased among people who are concerned, complicating specific diagnoses for persons who claim to suffer health problems from these exposures. On the other hand, a large portion of the production agricultural community feels threatened that their industry has been negatively portrayed, and they fear excessive regulation will unnecessarily economically burden their operations, making it impossible to farm. For all these reasons, rural health professionals, livestock producers, veterinarians, and animal scientists should be as aware and concerned about environmental issues and their potential health effects, as are their urban counterparts.

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My objective is to review current scientific information to help create, to the extent possible, an unbiased awareness on the part of readers, enabling them to be better prepared to participate in informed public debate and provide information regarding the nature and prevention of resulting community and occupational health effects associated with livestock production and principally swine production. My overarching objective is to provide information that will assist in the sustainability and profitability of livestock production.

ANIMAL FEEDING OPERATIONS

The proliferation of animal feeding operations (**AFO**) has been a feature of the increased intensity, concentration, specialization, and consolidation that has been occurring in agriculture in industrialized countries over the past 3 decades. The US Environmental Protection Agency (**EPA**) has a specific definition of AFO that includes the confinement of animals for at least 45 d in a 12-mo period, and in a structure or lot where vegetation or crops will not grow. The term confined animal feeding operation (**CAFO**) is used to describe AFO over a specified size that are a risk as a point source for water pollution and, therefore, require regulation (US EPA, 2009). In regard to water, air, and solid waste pollution, CAFO have similar environmental concerns to other agricultural operations. However, there are special concerns for CAFO because of the sheer size, the concentration of animals, feed, manure (usually handled in liquid form), dead animals, flies, associated gases, particulates, odors and odorants, and infectious diseases all concentrated on a small land area. There also are concerns that the manure cannot be recycled without pollution on such a small area and that local and regional air and water quality suffers.

Public concerns relative to adverse consequences of livestock production have been increasingly voiced since the late 1960s (Thu and Durrenberger, 1998). Numerous regional, national, and international conferences and commissions have been held on the subject since 1994 (Thu, 1995; Merchant et al., 2002; Donham et al., 2007). The Pew Foundation recently published its Commission report on Industrial Farm Animal Production 2008 (Pew Commission on Industrial Farm Animal Production, 2008).

Although general water and air quality issues have been raised as concerns by the public, scientists, and regulatory agencies, this paper concentrates on the potential occupational and community health consequences from air emissions of large-scale livestock operations. Physical health as well as social and economic concerns of individuals and communities are considered. A broad definition of health is used here as defined by the World Health Organization (**WHO**). The WHO states that health is "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO, 1972).

One reason large-scale livestock production has raised public concern is that it has separated from traditional family farming and has developed like other industries in management, structure, employment, and concentration. One of the concerns of the public is that in the US there is 130 times more animal waste produced (by weight) yearly than human waste and this waste generally is not treated sanitarily as is human waste before it is returned to the environment (Esteban, 1998). In the subsequent discussion, the scientific literature is reviewed, and this updates a previous review published in 2006 (Donham and Thelin, 2006), with a focus on the assessed health effects of air contaminants from swine CAFO on community residents and the occupational health of pork producers and employees.

COMMUNITY HEALTH ISSUES

Air Emissions from CAFO

Merkel et al. (1969) published the first qualitative assessment of gases emitted from liquid swine manure. Nearly 200 compounds emitted from animal manure have been detected (O'Neill and Phillips, 1992). These compounds can be grouped into the following chemical classes: mercaptans, sulfides, disulfides, amines, organic acids, phenols, alcohols, ketones, indole, skatole, carbonyls, esters, and nitrogen heterocycles. The health risks of most of these substances, at the concentrations present in swine manure, are not known. Some of these substances have a very low odor threshold [e.g., 1 part per billion (**PPB**)]. Ammonia and hydrogen sulfide are the most important emittants from livestock waste in regard to direct human health risks. Methane and carbon dioxide are important greenhouse gases.

The primary sources of gaseous compounds originate from the degradation of feces and urine applied to land and from animal wastes stored in liquid or solid phase. Ammonia is a by-product of almost any treatment method of animal waste. Other fixed compounds and trace compounds come primarily from the anaerobic decomposition of manure in liquid storage systems.

In addition to gases, often overlooked are the particulate substances that are emitted from livestock feeding operations. There is a large quantity of organic dust generated from feed sources and pigs (e.g., hair, dander, and dried feces). This dust contains bioactive substances, including endotoxin and glucans, 2 very important inflammatory substances (Donham et al., 1986; Schulze et al., 2006). Also, there is a bioaerosol component of this dust. Many gram-negative and gram-positive bacteria, fungi, and molds have been identified (Thorne et al., 1992). Some of these organisms also grow within confinement buildings, contributing to concentrations of organisms that are also found in the air outside the building (Kiekhaefer, 1995). The vast majority of organisms identified in the air are saprophytic, and very few pathogens are identified. They are combined with

dust that becomes a part of the total aerosolized particulates. The size of the particulates emitted is relatively small. Approximately 50% are less than 10 μm , which means they are inhalable and will penetrate to the airways.

Odors, Odorants, and Particulates

Most of the public concern on CAFO has been about odor (Nimmermark, 2004; Radon et al., 2004). An odor is an unpleasant sensation in the presence of an odorous substance or odorant. The odorant may or may not have additional harmful toxic effects. Ritter and Chirnside (1984) identified the classes of compounds from animal manure that are odorants, as previously mentioned. Ammonia and H_2S , among the fixed gases, are also odorants. Riskowski (1991) described an odor phenomenon associated with the livestock environments where NH_3 and H_2S are detected at lesser odor threshold concentrations than previously published, apparently due to interactions within the mixture of emitted chemicals and particulates.

Researchers have looked at the fixed gases (e.g., NH_3 and H_2S) as potential surrogates for emissions and odors. However, the results of several researchers have shown that there is a poor correlation between NH_3 and H_2S and odor strength (Payne, 1994; Smith and Kelly, 1996).

Goodrich (1975) showed, relative to background, increased amount of viable organisms downwind of manure sprinklers, as well as inside beef and turkey facilities. Pickrell (1991) showed swine barn environments to have significantly greater particle and microbe concentrations compared with other livestock environments. These concentrations are up to 10^6 times greater inside swine buildings compared with outside (Kiekhaefer, 1995). Very little is known about hazardous concentrations of odorants in outdoor air around CAFO. We do know there are worker health problems caused by H_2S and NH_3 and dust in the interior; however, it is difficult to infer health risks outside these buildings based on occupational health studies. Available data (Reynolds et al., 1996) indicate NH_3 and H_2S are on the order of 10^3 times greater inside buildings compared with outside.

Concerns about odors from livestock facilities can be considered a nuisance, which is often how courts treat them. However, there is growing evidence that odors may cause physical illness (Nimmermark, 2004; Radon et al., 2004; Wing et al., 2008). Schiffman et al. (1995) indicated that odors may cause nausea, vomiting, headache, shallow breathing, coughing, sleep disorders, upset stomach, appetite depression, irritated eyes, nose and throat irritation, and mood disturbances including agitation, annoyance, and depression. Ackerman (1990) reported that odors can result in strong emotional and physical responses, particularly after repeated exposures. Schiffman et al. (1995) studied the profile of mood states of 44 people living near large animal facilities.

Compared with controls, they found that people living near the facilities were more angry, confused, tense, depressed, and fatigued. To determine acceptable odors relative to distance from the source, Walsh et al. (1995) surveyed persons living in a 5-km area surrounding a large cattle feedlot. Walsh et al. (1995) measured odors according to an odor panel and found acceptable odor levels within the 5-km radius. Results of other research indicate that the physical symptoms (which are more relevant to worker exposure than community residents) may also be caused by chronic inflammation secondary to inhaled dust, and gases (Pickrell, 1991; Donham et al., 1995).

Physical Health

When considering the health hazards of residents living in the vicinity of CAFO, there is relatively sparse dose-response or objective evidence of physical damage to human tissues from air emissions. For example, Jacobson (1997) and (Davidson et al., 1987) reported H_2S concentrations in the vicinity of CAFO, well under the threshold limit value (TLV) for occupational health set at 10 ppm (PPM). Also, in a study by Reynolds et al. (1997), concentrations of NH_3 in the vicinity of swine CAFO were generally less than 1 PPM. Concentrations of endotoxin and dust were near the minimum limits of detection of the instrumentation used, which was around 10 endotoxin units/ m^3 of air and <0.5 mg of dust/ m^3 of air). However, several studies have reported findings of excess respiratory symptoms in community residents compared with controls, including symptoms of bronchitis and asthma (Merchant et al., 2005; Sigurdson and Kline, 2006; Radon et al., 2007). Possible reasons for this observation include the fact that residents live in the area more than 8 h/d. Also, there may be vulnerable populations that react at much less concentrations than occupational limits. For example, several states have limits for H_2S at 20 to 50 PPB, 3 orders of magnitudes below the occupational exposure limit, and the EPA and Agency for Toxic Substances and Disease Registries limit is 30 PPB for long-term community exposures (Merchant et al., 2002).

Kilburn (1997) reported on neurobehavioral effects of H_2S gas. This small study reported neurological deficits in 16 exposed persons, including decreases in balance, reaction times, visual field performance, color discrimination, hearing, cognition, motor speed, verbal recall, and mood states. Hydrogen sulfide is a toxin with several effects, including tissue irritation and poisoning of cellular respiration mechanisms with a predilection for brain cells. However, the health effect of chronic exposure in the vicinity of CAFO to reduced concentrations of H_2S remains uncertain.

These studies of physical and mental health concerns of residents near CAFO have reported similar findings. These were controlled studies of self-reported symptoms, and no attempts were made to document objective correlates of health impairment (Schiffman et al.,

1995; Thu et al., 1997; Donham et al., 2007). Thu et al. (1997) reported respiratory symptoms (almost identical in type and pattern to workers in CAFO) at a statistically significant increased rate relative to unexposed community comparison populations. Schiffman et al. (1995) reported excessive mood alterations in CAFO neighbors. There are numerous instances of similar studies in other environmental settings, including concerns of communities around paper pulp mills, hazardous waste sites, refineries, and solid waste disposal sites (Shusterman, 1992). Although most of these studies have not documented objective findings of toxic physical insult to humans, a few studies have reported subtle objective findings, such as increased concentrations of urinary catecholamines or mucosal immune alterations (Avery et al., 2004). Additionally, most of these studies have not shown evidence of known toxic concentrations of substances in the environment.

Extra-Toxic Mechanisms

Although the concentrations of potentially hazardous air contaminants are usually below known harmful amounts, adverse health symptoms are commonly reported by community residents. One possible explanation for this is the phenomenon described by one researcher as extra-toxic effects of decreased concentrations of emissions (Shusterman, 1992). This literature has focused on trying to explain symptoms of community members who may be exposed to waste sites, sewage treatment plants, and other large population-based community exposures. Medical research and regulatory agencies have difficulty dealing with these situations because they are not clear-cut. Clear-cut findings would include an objective finding (e.g., a measurable effect, such as an altered blood chemistry or abnormal radiograph) of an adverse health effect, measured toxic substances at known toxic concentration, and an obvious dose-response relationship. These community exposures are much more complex because they are a mix of physical, mental, emotional, and social stressors. Genetic memory and other very basic limbic-level self-preservation mechanisms may be involved. The following paragraphs will review some of the literature that helps to explain adverse health symptoms that people in the community may experience where there is an absence of objective health and toxicological data.

The Somatization of Adverse Odors

Two cranial nerves innervate the nasal mucosa: the first cranial nerve (i.e., the olfactory nerve) and the fifth cranial nerve (i.e., the trigeminal nerve; Shusterman, 1992). The olfactory nerve is primarily responsible for odor detection. The trigeminal nerve has many branches that penetrate the oral mucosa and provide additional information to the brain on odor sensation, such as irritation or pungency, which trigger protective responses including decreased respiratory rate, rhini-

tis, tearing, cough, gag reflex, and bronchoconstriction. These are all warning indicators that something associated with the odor may be harmful, and our genetically based instinctive-protective mechanisms tell us to make physiologic changes to meet the impending insult or to get out of the area (Shusterman et al., 1988; Shusterman, 1992). Therefore, it makes sense that odors can result in symptoms of mucosal irritation, including respiratory symptoms, nausea, and feelings of "dis-ease" (Shusterman et al., 1988, Shusterman, 1992).

Complexed with these physiological responses to small amounts of irritants and odors, there are behavioral interactions (e.g., perceived loss of property value, loss of control of personal space) that may explain health symptoms of illness associated with odors. There are 5 theoretical mechanisms for extra-toxic odor-related physical symptoms (Shusterman, 1992).

Innate Odor Aversions

As a basic protective mechanism, our body wants to avoid certain odors that may signify potential harm. For example, odors in putrefaction gases (e.g., H_2S , mercaptans, and other sulfur-containing chemicals) are common substances that stimulate physiologic effects and the drive to avoid those substances at less than toxic concentrations. These gases may be associated with spoiled food, but are also associated with animal manure, as are many of the odors associated with these innate odor responses.

Negation of Normal Pheromonal Phenomena

Pheromones stimulate physiologic responses, especially around sexual reproduction. These are most overt for insects, but many mammals, including humans, respond to them. Some odors may destroy normal positive pheromone responses, resulting in impaired sexual function for people living in the vicinity of CAFO. (Shusterman et al., 1988; Shusterman, 1992; Schiffman et al., 1995)

Exacerbation of Underlying Conditions

Previous research has shown that workers with underlying conditions (e.g., asthma, atopy, bronchitis, heart conditions) are more susceptible to the CAFO environment than others (Schiffman et al., 1995). Furthermore, it is now evident that individuals differ genetically in their susceptibility to endotoxins. Research by Meggs et al. (1996) and Rylander (2004) also lends strength to the theory that underlying conditions, such as asthma, may amplify exposures.

Aversive Conditioning

Some people previously exposed to increased concentrations of odorous gases causing toxic effects may respond physiologically to less than toxic amounts (i.e.,

slight odor) of this substance in future exposures. The condition described as multiple chemical sensitivity may have similarities to aversive conditioning (Bell et al., 1992).

This author has observed this condition in several cases of CAFO workers who experience symptoms and anxiety when smelling CAFO odors after a severe CAFO gas exposure episode. This conditioned stimulus is probably an innate protective mechanism. This can also happen with exposures to decreased amounts over a long period of time (i.e., acquired odor intolerance; Meggs et al., 1996).

Stress-Induced Illness

Odor-related stress-induced illness has been discussed as a component of what is known as environmental stress syndrome. This phenomenon has been seen after disaster sites such as Three Mile Island (Shusterman et al., 1988). Studies have shown there are increased urinary catecholamines in affected individuals (Davidson et al., 1987). Affected individuals also have a feeling of depression, helplessness, and an increased degree of environmental worry, which is exacerbated by detection of the offending odor. Community members may be excessively worried that their property values are falling because of the odor source in their neighborhood. Odors can act as a cue for these individuals stimulating adverse physiologic risks relative to an associated exposure. Long-term stress can be associated with muscle tension, headaches, coronary artery disease, and peptic ulcers.

Summary of Extra-Toxic Mechanisms

In studies of physical health complaints in communities around CAFO, it would be expected that objective findings of toxicity would be difficult to obtain. However, that does not and should not discount the fact that people experience valid symptoms. The reasons have to do with complex interactions of the brain and somatic systems. First of all, odors may initiate somatic symptoms based on enervations of the trigeminal nerve. Furthermore, odors may initiate physiologic activity as a response to primordially acquired (limbic-level) aversions to toxic substances. These responses may be modulated and exacerbated by the person as the person worries about environmental threats and the frequency with which odors are experienced. Furthermore, these conditions may be exacerbated by previous toxic exposures to the substances in question, creating a learned response of avoidance even when minimal exposures are present. Further exacerbation may occur when combined with a feeling that the person has no control over the situation, with fears of declining property values. The combined physical and psychological effects have been described as resulting in environmental stress syndrome. If an individual has an underlying

health condition, such as asthma, further complications may be present.

OCCUPATIONAL HEALTH OF SWINE PRODUCERS AND EMPLOYEES

Research on the health and safety of people working in swine confinement environments first began in 1977 (Donham et al., 1977). Potentially hazardous dust and gases are present in many swine CAFO buildings. The following paragraphs will review the air exposures, their sources, known health effects, and prevention. There are additional occupational health concerns noted that consist mainly of acute injuries, noise, or infection. These latter conditions will not be addressed in this article.

What Toxic Dusts and Gases Are Found in Confinement Houses?

The dust in CAFO is a complex mixture of agents that are generated primarily from the animals (i.e., hair and dander), dried feces, and feed (Donham and Gustafson, 1982; Nilsson, 1982; Donham et al., 1985; Donham and Popendorf, 1985). Additional to the dust, gases are generated inside the building that arise from decomposition of animal urine and feces (i.e., NH_3 and H_2S). In those buildings with manure storage under slatted floors, H_2S is a greater acute health risk. Furthermore, fossil-fuel-burning heaters present in some farrowing and nursery facilities may emit CO at toxic concentrations. The respiration of the animals and the fossil-fuel-burning heaters emit CO_2 . These dusts and gases often accumulate to concentrations that may be acutely or chronically hazardous to human and animal health (Donham and Gustafson, 1982). The mixture and concentrations of dusts and gases inside CAFO vary depending on numerous factors including management practices, ventilation and other engineering controls, the age, number and type of animals in the building, and the design and management of the feeding and waste handling systems.

Dust particles in CAFO contain approximately 25% protein, and range in size from $<2\text{ }\mu\text{m}$ to $50\text{ }\mu\text{m}$ in diameter (Donham and Popendorf, 1985). One-third of the particles are within the inhalable size range (i.e., $<10\text{ }\mu\text{m}$ in diameter; Nilsson, 1982; Donham and Popendorf, 1985). Fecal material particles are quite small (i.e., $\leq 10\text{ }\mu\text{m}$) relative to other dust components and consist of increased concentrations of gut-flora bacteria and exfoliated gut epithelium. This component of the dust constitutes a major burden to small airways and alveoli. The larger particles are mainly of feed grain origin and primarily affect the upper airways. Also present are animal dander, broken bits of hair, bacteria, endotoxins, pollen grains, insect parts, and fungal spores (Donham et al., 1985; Donham, 1986). In recent years, researchers have focused on the micro-

bial by-products contained in this dust as the primary hazardous substances. Endotoxin and 1,3- β -D-glucan, respectively, originate from the cell wall of gram-negative bacteria and certain yeasts, molds, and bacteria. They are known toxins and inflammatory mediators. The dust absorbs ammonia and possibly other toxic or irritating gases, adding to the potential hazards of the inhaled particles (Donham and Gustafson, 1982; doPico, 1986; Sigurdarson et al., 2004). A recent study has shown that the mixed exposure to dust and NH_3 in CAFO results in 2 to 4 times the health hazard (assessed by decline in pulmonary function over a work period; Donham et al., 2002).

At least 160 different gases are generated in anaerobically degenerating manure. However, H_2S , NH_3 , CH_4 , CO_2 , and CO are the primary hazardous gases present (Donham et al., 1982; Donham and Gustafson, 1982; Donham and Pendorf, 1985). These gases may escape into the work environment in buildings with manure pits under the building. Furthermore, 40% of the NH_3 measured in-building is released by bacterial action on urine and feces on the confinement house floors (Donham and Gustafson, 1982). Carbon monoxide and CO_2 are generally not produced in hazardous concentrations from the manure pit but may rise to toxic concentrations from fossil-fueled heating systems in winter as well as by the respiration of the animal (i.e., CO_2 ; Donham and Gustafson, 1982). These latter gases are usually only hazardous when the heaters or ventilation systems malfunction. Methane is not a respiratory hazard in these buildings. However, CH_4 may be an occasional fire or explosive hazard in some buildings.

Who Is Exposed to These Dusts and Gases, and When?

In the United States, an estimated 700,000 people work in livestock and poultry confinement operations (Donham, 1990). This number includes owner-operators, hired farm workers, women, children, veterinarians, and service technicians. Included in the hired farm workers in the United States are minority populations, including those of Hispanic, Asian, and Bosnian descent, among others. The risk of acute and chronic respiratory health effects in CAFO workers are related to the relative genetic susceptibility to endotoxin or allergens of the individual, the length of time the person has worked, whether the person smokes or not, whether they have other respiratory conditions, and the concentration of exposures in these buildings. Although some individuals may have adverse health effects within the first week of work, most will not develop symptoms unless they have worked more than 2 h daily and for 6 or more yr (Donham et al., 1977, 2000; Donham and Gustafson, 1982).

Dust and gas concentrations increase in winter when houses are tightly closed and ventilation rates are reduced to conserve heat (Donham et al., 1977). Also, dust concentrations increase when animals are being

moved, handled, and fed, or when buildings are being cleaned by high-pressure spray washing or sweeping (Nilsson, 1982). Ventilation systems are designed to control heat and humidity in the building and often will not reduce dust or gas adequately to ensure a healthful environment for humans. During the cold seasons, should the ventilation systems fail for several hours, CO_2 from animal respiration, combined with CO_2 and CO from heaters and manure pits, can rise to toxic or asphyxiating amounts. In the warm seasons, the greater risk to animals from ventilation failure is heat stress from elevated temperature and humidity. Although massive animal losses have been attributed to these latter situations, they would not create an acute human health threat because they are not so acute as to prevent workers from leaving the building in a safe time.

Hydrogen sulfide may pose an acute hazard whenever the liquid manure slurry is agitated (Osborn and Crapo, 1981; Donham et al., 1982). During agitation, H_2S can be released in seconds from usual ambient levels of <5 PPM to lethal levels of >500 PPM (Donham et al., 1988). The greater the agitation, the more rapid and greater the amount of H_2S that is released. Animals and workers have become seriously ill or died in swine CAFO when H_2S has risen from agitated manure in pits under the building. Several workers have died when entering a pit during or soon after the emptying process to repair pumping equipment or clean out solids (Donham et al., 1982; Beaver and Field, 2007). People attempting to rescue these workers also have died. Workers may be exposed to increased H_2S concentrations when they enter the pit to retrieve animals or tools that have fallen in or to repair ventilation systems or cracks in the cement. Hydrogen sulfide exposure is most hazardous when the manure pits are located beneath the houses. However, an acutely toxic environment may result from outside storage facilities if gases backflow into a building, due to inadequate gas traps or other design fault, or if a worker enters a separate confined-space storage facility.

How Commonly Does Excessive Exposure Occur?

Typical dust concentrations in swine CAFO are 2 to 6 mg/m^3 (Donham et al., 1985). Buildings with dust concentrations at 10 to 15 mg/m^3 may be seen during cold weather or when moving or sorting the pigs. The maximum recommended safe concentrations of dust to prevent chronic respiratory conditions is 2.5 mg/m^3 (Donham et al., 1995; Reynolds et al., 1996), which is considerably less than the 15 mg/m^3 for nuisance dust set by the Occupational Health and Safety Administration for industrial standards. The greater relative toxic nature of this dust is due to its high degree of its biological activity, its inflammatory nature, and the additive and synergistic actions of the mixed dust and gas exposures. Nearly 60% of swine confinement workers who have worked for 6 or more years experience

one or more respiratory symptoms (Clark et al., 1983; Donham et al., 1989). Prevalence of respiratory symptoms among workers in CAFO is 25%, compared with approximately 12% in nonconfinement swine workers (Donham, 1990).

Respiratory Effects of Inhaling Confinement House Dusts and Gases

Human health effects of work in swine CAFO were first described in veterinarians by Donham et al. (1977). Since that time, numerous studies by many different authors in various countries around the world have been published regarding the complex set of respiratory responses that include symptoms of acute and chronic bronchitis, nonallergic occupational asthma, mucous membrane irritation, and organic dust toxic syndrome (Mustajbegovic et al., 2001). These inflammatory and toxic processes may occur alone or in combination in combination, resulting in one or perhaps several conditions simultaneously (Donham et al., 1989; Prior et al., 2001).

Cigarette smoking, along with other risk variables mentioned previously, increases the risk and severity of symptoms. In general, the symptoms are more frequent and severe among smokers (Donham and Gustafson 1982; Markowitz et al., 1985) and in those working in larger swine operations (related to longer hours working inside CAFO buildings) or working in buildings with increased amounts of dusts and gases (Donham et al., 1995, 2000; Reynolds et al., 1996).

Although irreversible airway obstruction has not been a general finding in confinement house workers, there is objective evidence that long-term lung damage may be occurring. Pulmonary function studies show evidence of air trapping in the lungs. Lavage studies of bronchial fluids show a persistent leukocytosis, and sputum studies show persistent inflammatory cells and epithelial cells (Schwartz et al., 1990; Djuricic et al., 2001). Baseline pulmonary function studies [i.e., forced vital capacity and forced expiratory volume in one second (FEV_1)] of healthy confinement workers usually show that pulmonary function does not differ significantly from those of workers in conventional swine buildings (Donham et al., 1989, 1990). However, flow rates at 25 to 75% of lung volume (FEF_{25-75}) are significantly less. Furthermore, work shift declines in FEV_1 and flow rate values are seen in most confinement house workers after a 2- to 4-h exposure. These findings indicate that chronic obstructive pulmonary disease may occur among these workers in future years (Schwartz et al., 1990). Although end-stage lung damage in CAFO workers has not yet been systematically studied, the authors have experienced many anecdotal case studies in which workers have quit because of health reasons. One study of owner-operators revealed a dropout rate of 10% over a 6-yr period for respiratory health reasons (Holness et al., 1987).

A point to note is that it is rare to find producers or workers who have allergic asthma (also called atopic asthma) from swine house exposures. This is thought to be the result of early exposures in life to these dusts and, thus, the acceptance of the body of these foreign substances (hygiene hypothesis; Ernst and Cormier, 2000; Riedler et al., 2001). An additional explanation is that workers who are allergic may leave the job early, leaving a healthy workforce.

Although respiratory exposures are extremely common among CAFO workers, there are several other occupational hazards that should be considered. There are certain infectious agents involving the respiratory tract that humans may contract from animals in CAFO. These include, but are not limited to, swine influenza, erysipeloid, *Streptococcus suis*, and methicillin-resistant *Staphylococcus aureus* (Holness et al., 1987; Smith et al., 2009). Injuries to CAFO workers from animals, pinch points in gates and pens, cuts, and needle sticks are common. Furthermore, increased noise levels in these facilities can lead to noise-induced hearing loss. These hazards are discussed elsewhere (Donham and Thelin, 2006).

Prevention

Health hazards associated with confinement houses must be addressed through improvements in the environment through 1) decreased generation of dusts and gases by improved management procedures and engineering controls, 2) dilution of contaminants once in the air (e.g., ventilation), and 3) proper protection of the individual with respirator use. A prevention model for confinement house problems, based on education and industrial hygiene consultation, has demonstrated its effectiveness (Donham et al., 1990). Some examples of management practices to reduce the sources of dusts and gases include 1) delivering feed by extension spouts into covered feeders, rather than letting feed fall freely several feet from automatic delivery systems into open feeders; 2) using extra fat or oil in the feed to reduce dust; 3) sprinkling or misting the environment with vegetable-based oil, and regular (every 3 to 4 wk) washing of buildings with power sprayers (operators must use respiratory protection during this procedure); 4) using flooring that is relatively self-cleaning (e.g., plastic-coated wire mesh); and 5) assuring that heating units are clean, vented, and functioning properly. Details of control measures are published elsewhere (Donham, 1991). Effectiveness of control techniques can be assessed by measuring dust and gas concentrations. These buildings should be routinely monitored to assure air contaminants are within healthful limits.

Because it is economically impossible to completely eliminate the formation of dusts and gases in CAFO, techniques for removing contaminants from the air of confinement houses are critically important. Ventilation will help reduce dusts and gases to healthful amounts.

Ventilation systems must be properly designed and maintained and ventilation rates adjusted to include consideration of air quality. Operators often reduce these rates in winter because of concerns for conserving heat, causing dust and gas concentrations to rise. Several engineering techniques (e.g., use of heat exchangers, which allow increased ventilation while capturing some waste heat) have been tried with varying degrees of success (Donham, 1993).

Anyone working in a swine or poultry confinement house for 2 or more hours per day should be advised, at a minimum, to wear a National Institute for Occupational Safety and Health (NIOSH)-approved N-95 2 strapped dust mask, even if the concentrations of dusts and gases are below Occupational Safety and Health Administration threshold exposure limits. Recent research has shown that different tasks in pork production operations have greater exposures than others. Because it is inconvenient and uncomfortable for workers to wear respirators 100% of the time while working, we recommended wearing dust respirators at a minimum during the following tasks: 1) processing piglets, 2) feeding, 3) moving and sorting hogs, and 4) load out (O'Shaughnessy et al., 2010). Persons exposed to houses with increased dust or gas concentrations, or persons with respiratory conditions, may need to use a more sophisticated respirator, such as a half-mask cartridge respirator or powered air-supplying respirator (e.g., 3M air helmet).

Preventing exposure to increased concentrations of H₂S from manure pits requires stringent controls. General safety measures include constructing manure pits outside of the confinement building, constructing openings so that lids or other objects cannot fall into the pit requiring a worker to enter the pit for retrieval, and erecting safety guards around open pits and warning signs. Whenever a pit that is under a confinement house is being agitated, people should stay out of the building, ventilation of the house should be maximized, and animals should be removed or observed from outside the building.

Even when not being agitated, manure pits can seldom be entered safely. If entrance is imperative, adequate protection is only assured when a self-contained breathing apparatus is worn by an individual trained in its use. All operators should understand that increased concentrations of H₂S cannot be smelled and that H₂S greater than 1,000 PPM produces unconsciousness and respiratory arrest in only 1 to 3 breaths. A variety of H₂S gas alarms give an accurate indication of hazard.

Poor air quality in the confinement house has also been shown to be associated with health problems and reduced productivity in swine (Donham, 1991). Advising this economic fact to a swine producer may be the most expedient way to create environmental improvement that would help the person, the animals, and the economics of the operation. Two relevant comprehensive multifactorial prevention programs, the Swine Confinement and Respiratory Health Project and the Certified

Safe Farm program, have been trialed with success in pork production (Ferguson et al., 1989; Gjerde et al., 1991; Kline et al., 2007). These programs incorporate the combination of environmental assessment, education, health screening, safety audit, health and safety goals setting, with incentives for achieving objectives. These programs work to reduce the risks of adverse occupationally related health incidents and reduce health care costs to address them; however, they do require a commitment and resources to administer and maintain them.

SUMMARY AND CONCLUSIONS

Michael Savitz suggests that sustainability of any industry depends on a positive "triple bottom line" that includes not only economic viability, but also environmental preservation and care and advancement of its human capital (i.e., the producers and employees; Savitz and Weber, 2006). There will always be ups and downs in agricultural commodity markets. However, Savitz suggests that to help ensure long-term sustainability of the industry, the other 2 legs of the triple bottom line need to be integrated into the daily business of the industry. This author thinks there are sufficient science and program examples to guide this action, and advances are being made in the industry in this regard. However, it seems apparent that broader and more integrated implementation is a work in progress that should be encouraged.

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