This is to certify that the

thesis entitled

EFFECT OF SOY OIL AND CHOICE WHITE GREASE ON FARROWING FACILITY ENVIRONMENT AND SOW PERFORMANCE

presented by

DANIEL JAY JENNINGS

has been accepted towards fulfillment of the requirements for

MASTERS degree in ANIMAL SCIENCE

Elwyn R. Miller

Major professor

Date June 24, 1993

EFFECT OF SOY OIL AND CHOICE WHITE GREASE ON FARROWING FACILITY ENVIRONMENT AND SOW PERFORMANCE

BY

Daniel Jay Jennings

A THESIS

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Department of Animal Science

1993

ABSTRACT

EFFECT OF SOY OIL AND CHOICE WHITE GREASE ON FARROWING FACILITY ENVIRONMENT AND SOW PERFORMANCE.

By

Daniel Jay Jennings

Ninety-six sows were used to evaluate the effects of dietary soy oil (SO) and choice white grease (CWG) supplementation on air quality and sow performance in environmentally regulated farrowing facilities. A 2x4 factorial design was used which consisted of a corn-soybean meal control diet (C), and C supplemented with either 1, 3, or 5% SO or CWG. Trial length was 4 wks. As dietary level of both SO and CWG increased, there was a linear reduction in both total airborne dust (P<.03 and P<.09, respectively) and dust in the nonrespirable range (P<.01 and P<.002, respectively). No other source by level interactions existed (P>.25) for remaining criteria measured so data were pooled for main effect analysis. Increasing the level of dietary lipid reduced mold colony forming units (P<.001), lactation weight loss (P<.003), settled dust (P<.09), NH_3 (P<.002), CO_2 (P<.003, and respirable range dust (P<.04). These data suggest that the level of dietary SO or CWG has a greater influence on facility dust , gases, and sow lactational weight loss than does lipid source.

ACKNOWLEDGMENTS

I would like to thank Dr. Tom Turner for his training in livestock evaluation and encouragement in furthering my education at Michigan State University.

I also would like to thank my major professor Dr. Andy Thulin for his guidance and friendship during my masters program, and for his positive attitude when things seemed hectic or impossible.

I also acknowledge my graduate committee Dr. Elwyn Miller, Dr. Howard Person, and Dr. Mel Yokayama for their assistance and advice.

My appreciation goes out to all the farm help at the Michigan State University Swine Teaching and Research Farm for their help with the daily activities of my research.

A special thank you to Kim Howard for her friendship and help with statistics. I don't think I could have seen as many movies or analyzed my trials without her.

I also wish to thank my parents Richard and Mary Lou Jennings for their continued support and love all through grade school and high school when they wondered if I would make it to the next grade. I also thank them for their understanding and financial support through undergraduate and graduate school as they were mesmerized on how I made it through.

Self-reliance is the greatest gift a parent can give a child, and I thank them for it.

Last I wish to express my love and thanks to my wife Johnna. She has been by my side all through my academic studies and I will no longer hear her nag those infamous words "got that thesis done yet?" She has supported me in all that I do and has even relocated a couple of times for me. Her love and companionship has meant a lot to me and has inspired me to finish. Socrates wrote, "By all means marry; if you get a good wife, you'll become happy; if you get a bad one, you'll become a philosopher." I am not a philosopher.

Every day I read the following quote which helps me move forward in my endeavors.

"Nothing in the world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated failures. Persistence and determination alone are omnipotent."

-Calvin Coolidge

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

LITERATURE REVIEW

INTRODUCTION

An improvement of air quality by reducing dust in swine housing is an important challenge to the swine industry. A serious air quality problem is the high concentration of suspended solid particles (Donham et al., 1986). An aerosol consists of solid or liquid particles of sufficiently small size to remain in suspension for a long time or indefinitely. Dust implies solid particles of a wide size range. Airborne particles can include both solid and liquid particles. Any particle that includes a living micro-organism is termed viable. Viable particles can be a liquid or solid particle to which an organism is attached (Carpenter, 1986). Smaller airborne particles will remain suspended while larger more dense particles tend to settle on surfaces in the facility.

Isolated constituents of swine dust are in order of prevalence: feed particles, swine proteins (urine, dander), feces, molds, grain mites, insect parts, mineral ash, bacteria and endotoxins, ammonia adsorbed to particles, (Donham et al., 1990). The major components of airborne and settled particles in swine units originates from feed (Heber et al., 1988). Swine diets contain large numbers of fine particles as a result of grinding whole grains and adding vitamins and minerals. Some feed particles become airborne dust when aerodynamically segregated during feed delivery, winnowed by pigs, and mechanically agitated by pigs and workers (Heber and Martin, 1988).

The Importance of Dust Particle Size

Aerosols are particles with diameters of .0001 micron to over 100 microns. As a comparison, the smallest grains of flour we can see are about 50-100 microns in diameter. Some bacteria and molds are only 1-2 microns (Donham, 1990b). Particles in confinement units range from approximately .6 to 50 microns. However, more than 80% are 8 microns or smaller in diameter. Particles over 25 microns generally settle out of the air onto surfaces. Particle size determines how long the particle, once airborne, remains so (Curtis et al., 1975c). Those particles we inhale (<10 microns) are trapped in the nose and in mucus in the upper respiratory tract. The mucus is constantly pushed upward by the movement of tiny ciliary hair-like projections in the bronchial tubes and is eventually coughed up, spit out, or swallowed.

Smaller particles, however, tend to stay in a stream of moving air, including the air inhaled deep into the lung. The smaller the particle, the deeper into the lung it will travel. Particles less than 5.8 microns are considered respirable, as they can be carried deep into the lung and reach the alveolar sacs. Once they have reached this point they are not removed by the natural clearing mechanisms of the upper respiratory system (Donham, 1990b). Particle size is often related to the number of bacteria cells per particle. Obviously, the larger the dust particles the more bacteria they may hold because of a greater surface area. Particle form and size determine the bacteria cell's aerial survival period. The matrix in which aerial bacteria may be embedded may protect the cells from environmental rigors such as temperature, humidity, and ultra-violet radiation (Curtis et al., 1975c). Curtis et al., (1975c) reported that mean aerial bacteria colony forming particles in swine houses range from 15 to 42 μm in size.

Dust Origin And Composition

Dust in livestock production systems may be of organic or inorganic nature and arise from the feeding of dry friable (easily pulverized) products, the attrition of building materials, the drying and fragmentation of waste products and the removal of hair and skin tissue from animals (Bundy and Hazen, 1975; Stroik and Heber, 1986). Qualitative microscopic analysis of swine confinement aerosols have revealed them to be heterogeneous in nature with a great diversity of shape and composition. Donham et al., (1986) identified the following components:

1. feed: starch granules, grain meal, trichomes and corn silk

2. swine fecal materials (including bacteria, gut epithelial cells and undigested feed)
3. swine dander
4. mold: hyphae, spores and sporangia
5. pollen and grains
6. insect parts
7. mineral ash
8. ammonia adsorbed to particles
9. endotoxin

Feed components and fecal material compose the bulk of collected particles. The size range of the feed dust and swine dander are such that they are largely collected at stage 1 of the cascade impactor sampler which represents the largest particulate matter. The fecal material is primarily collected on stages 3 to 8 which represents the respirable or smallest size range from .43 to 5.8 microns (Donham et al., 1986). Both gram positive and negative bacteria (bacteria origin is primarily intestinal microflora) previously have been found in association with swine confinement dust (Curtis et al., 1975). Fecal material appears to be a major constituent of this dust and bacteria may make up as much as 50% of fecal solids (Donham et al., 1986). Gram-negative fecal coliform counts (cfu) in swine confinement units have been found to vary from 3.5×10^2 to $2.4 \times 10^4/m^3$ of air (De Boer and Morrison, 1988). A study of Swedish swine buildings revealed even higher levels, averaging 8.8×10^4 cfu/m^3 of air (Clark et al., 1983).

In the latter study, 26% of the cfu were in the respirable size range (<5 microns) and contained gram-negative bacteria. Approximately 90% of the total bacteria isolated from swine feces were gram-positive (Clark et al., 1983).

Although gram-negative bacteria are less abundant than gram-positive bacteria, they are of special significance since they contain a lipopolysaccharide compound known as "endotoxin" in their cell wall. Endotoxins have a high biological potency regardless of whether the bacteria are alive or dead (Rylander and Snella, 1983). Relationships have been identified between acute symptoms of organic dust toxic syndrome and airborne endotoxin levels among workers (De Boer and Morrison, 1988). Recently, Donham et al. (1989) examined the relationship between 16 different environmental factors and health parameters of swine workers. The single most notable association was found between endotoxin level and the pulmonary function test involving a decrease in forced expiratory volume in one second (FEV_1) over the work period. This may indicate that environmental monitoring and control for acute health effects may best be focused on the measurement of endotoxin. In a study of swine and poultry confinement units, (Clark et al., 1983) endotoxins from gram-negative bacteria were measured at .12 $\mu g/m^3$ in swine confinement units (grow-finish) and .31 $\mu g/m^3$ in poultry houses. Endotoxin concentrations in airborne dust were much higher in poultry units than in swine units. The researchers concluded that airborne concentrations of total and gram-negative bacteria in swine and poultry confinement units were as high or higher than those found in waste water treatment plants, solid waste sludge composting plants, and cotton card rooms where microbiologically contaminated organic dusts were also present. Furthermore, endotoxin concentrations were in the range (.08 ug/m^3) where clinical effects have occurred in other populations and thus a health study of swine confinement workers with concurrent estimations of the individual daily exposure dose is warranted. Donham et al., (1988) reported endotoxin levels ranging from .01 to .56 $\mu g/m^3$ of air in swine confinement building.

Clark et al (1983) measured bacteria and mold levels inside eight Swedish swine confinement buildings. They reported total bacteria levels at 3.0×10^5 cfu/m^3 and the gram-negative bacterial portion of this to be 8.8×10^4 cfu/m^3. The largest portion of these bacteria (75%) were identified as gram-positive enterococci which means 25% of the total bacteria collected contains endotoxin.

Molds are important due to their potential allergic properties they may impose on workers (Clark et al., 1983). Donham et al., (1986) sampled dust for mold and bacteria counts in 21 swine confinement units from a 27-county area in eastern Iowa. The major mold species isolated were Aspergillus, Penicillium, and Fusarium. The median mold count was 3.0×10^3 cfu/m^3. Results showed total mold levels to be

9.4×10^2 cfu/mg of dust and bacteria were 5.4×10^3 cfu/mg of dust.

Guidelines For Threshold Limit Values

Upper tolerance limits of contaminants have not yet been fully defined. The present lack of data often forces guideline setting agencies such as the American Conference of Governmental Industrial Hygienists (ACGIH) to adopt interspecies information, although wide species differences in tolerance levels have been documented (Nordstrom and McQuitty, 1976). There is an active debate among scientists regarding the minimum levels of contaminants capable of causing harm following extended exposures of animals and humans to the confinement house atmosphere. This is further compounded by the suspected interactions among the various contaminants which are present in combinations not normally encountered in industrial work places (De Boer and Morrison, 1988).

Threshold limits exist in many countries for so-called "nuisance" dusts. The limits vary from 5 to 15 mg/m^3. Some countries have an 8 hour time-weighted average threshold limit value (TLV) for organic dust, (eg. Sweden 5 mg/m^3). The ACGIH in 1985 proposed a 4 mg/m^3 TLV for grain dust (Clark, 1986). More standardized measurements should be undertaken including various areas of the farmer's exposure to organic material (grain handling, hay handling, swine houses, etc) to allow for more precise recommendations.

The ACGIH publications specify three categories of Threshold Limit Values as follows:

A. Threshold Limit Value - Time Weighted Average (TLV-TWA)

The time-weighted average (TWA) is the concentration for a normal 8-hour work day and a 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effects.

b. Threshold Limit Value-Short Term Exposure Limit(TLV STEL)

This value serves to supplement the TWA limit. It is the concentration to which workers can be exposed continuously for a short period of time without suffering from: (1) irritation, (2) chronic or irreversible tissue damage, or (3) narcosis which may increase the likelihood of accidental injury, impair self-rescue, or materially reduce work efficiency. The exposure should be no longer than 15 minutes, four times a day with at least 60 minutes between successive exposures, and provided that the daily TLV-TWA was not exceeded. STELs are recommended for those substances for which toxic effects have been reported from high short-term exposures in either humans or animals.

c. Threshold Limit Value - Ceiling (TLV-C)

This is the concentration that should not be exceeded even instantaneously during any part of working exposure. This value is appropriate for substances that are fast acting, for example, irritant gases or substances known to cause physical impairment. Depending on the nature of the substance, time-weighted averages may permit excursions above the limit providing that they are compensated by equivalent excursions below the limit during the work day. The ACGIH warns that there is insufficient toxicological data on the vast majority of substances to allow for safe STEL values to be determined. Reasoning is presented in the ACGIH guidelines for the newly recommended excursion limit, which specifies that short-term exposures should not exceed three times the TLV-TWA for more than a total of 30 minutes per day, and under no circumstances should they exceed five times the TLV-TWA. Whenever STEL values are available, they take precedence over the excursion limit (De Boer and Morrison, 1988; ACGIH 1986/87).

Several agencies have been instrumental in the standards setting process for airborne substances in the workplace. The TLVs set by ACGIH are the most widely adapted. They represent a measure of the composition of the environment surrounding the worker. TLVs are recommended to be used as guidelines rather than absolute boundaries between safe and dangerous concentrations. TLV standards have been developed for industrial work settings and are presently not enforceable for farming operations. The TLVs may provide a useful starting point in determining appropriate standards for confinement house atmospheres (De Boer and Morrison, 1988). Table 1 shows TLVs for dust and microbes. These TLVs have been widely used as guidelines for livestock confinement.

Table 1. Suggested exposure thresholds[a,b] in swine confinement buildings

	Human	Swine
Total dust mg/m^3		
personal sampling	3.8	--
area sampling	2.4	3.7
Respirable dust mg/m^3		
personal sampling	0.28	--
area sampling	0.23	0.23
Endotoxin ug/m^3		
area sampling (total)	0.08	0.15
Total microbes cfu/m^3	$4.3x10^5$	$4.3x10^5$
Bacteria cfu/m^3	$6.3x10^5$	--
Molds cfu/m^3	$1.3x10^5$	--
Total microbes		
microscopic $count/m^3$	$1.5x10^7$	$2.9x10^7$
Respirable microbes		
microscopic $count/m^3$	$2.4x10^7$	$2.4x10^7$

[a]Donham, et al., 1990.
[b]Contaminants in excess of values given in this table were associated with a higher proportion of work related disease or lower production parameters.

Gases

The gases of greatest significance to human and animal health are thought to be hydrogen sulfide (H_2S), ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4). These gases can be produced in relatively high quantities and often possess toxic properties (De Boer and Morrison, 1988). The most recent threshold limit values (TLV) for these gases are listed in Table 2. (Donham et al., 1988).

Table 3. describes the effects of confinement gases on humans (Leonard, 1990). This data was compiled by scientists

at the University of Iowa Institute of Agriculture Medicine. This group has actively investigated the issues of air quality and human health for confinement swine facilities for many years.

Table 2. Threshold limit values for gases considered unhealthful for humans and swine[ab]

Gas	Level (ppm)	
	Human	Swine
CO_2	1,500	1,500
NH_3	7-9	25
H_2S	5	10
CO	50	100
CH_4	No TLV	No TLV

[a]Donham et al., 1988.
[b]Recommended maximum gas levels due to adverse health effects of humans and swine.

Table 3. Effect of confinement gases on humans[a]

Gas Exposure	Effect
Ammonia	
5 ppm	Lowest level detectable by smell
7-10 ppm	Recommended maximum level
6-20+ ppm	Eye irritation, respiratory problems
40 ppm	Headache, nausea, reduced appetite
100 ppm for 1 hr.	Irritation to mucous surfaces
400 ppm for 1 hr.	Irritation to nose and throat
Carbon Dioxide	
2,500 ppm	Recommended maximum level
20,000 ppm	Deep, rapid breathing
40,000-60,000 ppm	Heavy breathing, drowsiness and headaches
100,000+ ppm	Narcotic effect, dizziness, unconsciousness
250,000+ ppm	Death
Carbon Monoxide	
50 ppm	Recommended maximum level
50 ppm for 8 hr.	Fatigue, headaches
500 ppm for 3 hr.	Chronic headaches, nausea and impaired mental ability
1,000 ppm for 1 hr.	Convulsions, coma after prolonged exposure
4,000+ ppm	Death
Hydrogen Sulfide	
5 ppm	Recommended maximum level
10 ppm	Eye irritation
20 ppm more than 20 min	Irritation to the eyes, nose and throat
50-100 ppm	Vomiting, nausea, diarrhea
200 ppm for 1 hr.	Dizziness, nervous system depression, increased susceptibility to pneumonia
500 ppm for 30 min.	Nausea, excitement, unconsciousness
600+ ppm	Rapid death
Methane	
50,000-150,000 ppm	Potentially explosive
500,000 ppm	Asphyxiation

[a]Leonard, 1990.

Swine deaths are often traced to the rapid release (2 to 5 minutes) of lethal H_2S levels from agitated liquid manure. Sudden nausea and unconsciousness are followed by paralysis of the respiratory system and rapid death. Donham, (1989b) has recorded ten separate instances over a three year period in which most (75 to 100%) of the swine in an entire building have died. It is felt that toxic effects of H_2S are related more to the concentration than the time of exposure. However, with adequate ventilation during normal operation, H_2S levels can be maintained well below it's TLV of 5 ppm for human and 10 ppm for swine. (Morrison et al., 1991).

Ammonia is the most common noxious gas in animal quarters. It may reach irritating levels under some conditions, to the point of causing permanent tissue damage in confined animals, however, it is rarely found in lethal concentrations (>3,000 ppm) in animal houses (Morrison et al., 1991). The concerns over NH_3 lie with chronic exposure particularly when NH_3 is combined with other pollutants such as dust. A hydrostatic bond between NH_3 and minute dust particles in the respirable range (less than 5.8 microns in size) enables NH_3 to be inhaled with dust and travel deep into the lungs (Curtis et al., 1975b). Once it has been drawn into the lung on dust particles it may be released and capable of causing an inflammatory reaction. There are several indications that additive and synergistic effects of NH_3 and other pollutants exist. However, the effects of gas and dust mixtures over a long time period are less easily defined. The complex and ever-changing mixture of gases and pollutants often makes it difficult to pinpoint specific cause-effect relationships (Donham et al., 1990a). The level of NH_3 capable of causing harm, following extended exposures, is still being actively debated. The work of Donham (1990a) suggest that safe levels for swine may lie between 9 to 25 ppm. Levels higher than this have been associated with depressed swine performance.

Ammonia is the gas found most consistently above recommended levels (Donham, 1989b). Donham and Popendorf (1985) selected 21 confinement swine operations from a 27 county area in Eastern Iowa. This group of buildings was used to measure ambient levels of NH_3, CO_2, CO, H_2S inside during the winter. Using a grab sample method (detector tubes) on an ambient basis, ammonia appeared to be the most important gas relative to its TLV. Most buildings (17 out of 21 units) exceeded the Threshold Limit Value - Time Weighted Average (TLV-TWA) for ammonia (25 ppm). Furthermore, most farrowing and nursery-grower units exceeded the Threshold Limit Value - Short Term Exposure Limit (TLV-STEL) for ammonia (35 ppm). The fact that ammonia was higher in farrowing and nursery units can be explained in part by higher environmental temperatures and probable lower ventilation rates maintained. Smaller, younger animals require higher environmental temperatures for optimum growth; therefore, winter air temperatures in

farrowing and nursery buildings are kept around 21.1 to 26.7°C. The higher temperatures are maintained in part by minimizing exhaust ventilation to
2 to 15 cfm per animal. This factor seemed to have affected all four gases measured.

Carbon dioxide was observed in excess of the TLV level only once. The particular winter when the measurements were taken was quite mild. However, in a previous pilot study during a very cold winter, they found CO_2 commonly exceeded the TLV-TWA of 5000 ppm. Because the internal temperatures of these buildings are controlled largely by the amount of exhaust ventilation and supplemental heat, the degree of air exchange may have been less during the pilot study. Carbon dioxide appears to provide a good indication of overall air quality in confinement buildings. The authors found NH_3 and CO to be proportional to the amounts of CO_2 in confinement buildings. They reported that correlations between CO_2 and either NH_3 or CO were significant and generally had a r value of greater than 0.5.

In a study comparing the relationship between airborne contaminants and environmental factors in Dutch swine confinement buildings, Atwood et al. (1987) also showed that CO_2 was generally a good indicator of air quality as there was a significant correlation ($P<.05$) with all the airborne contaminants (dust, NH_3, endotoxin) except relative humidity and airborne bacteria levels.

Other surveys suggest that air quality is poor in existing swine facilities, especially in winter weather with ventilation systems operating at minimal rates (Brumm, 1991). Gerber et al. (1988) surveyed 75 farrowing and nursery units in Ohio during the winter of 1987. Ammonia concentrations were determined at both 1.5 meters above the floor (worker level) and 7.7 centimeters above the floor (pig level). The results presented in Table 4 suggest that 64% of the facilities had NH_3 levels of 10 ppm or greater at worker level and 14.6% had greater than 20 ppm at pig level. These levels were suggested (Table 3) to be the point at which human health concerns exist.

Table 4. Percentage of 75 swine facilities with various ammonia concentrations[a]

	Determination Location	
	5 Ft.	3 In.
Ammonia Levels	% Samples[b]	% Samples[b]
0.0 ppm to 6.9 ppm	9.3	10.7
7.0 ppm to 9.9 ppm	26.7	22.6
10.0 ppm to 14.9 ppm	30.7	36.0
15.0 ppm to 19.9 ppm	13.3	16.0
20.0 ppm to 50.0 ppm	20.0	13.3
>50.0 ppm	0	1.3

[a]Gerber et al., 1988.
[b]A total of 87 samples.

Improperly functioning or poorly ventilated fossil fuel burning heating units can release high levels of CO, which can cause abortions and stillbirths (Donham, 1990a). Other possible causes of high CO are cracked heat exchangers, or complete shutdown of ventilation (Donham et al., 1991). High CO concentrations (>500 ppm) often causes sows to abort fetuses or expel normal, but stillborn piglets within a short period of time. Piglets may be born alive but weak, dying shortly thereafter (Donham, 1990a).

Depletion of O_2 along with a critical buildup of CO_2 can occur in as little as seven to eight hours (Morrison et al., 1991). However, under most circumstances, it would be expected that most animals would succumb to heat prostration prior to asphyxiation. Muehling (1970) outlined the following animal responses to atmospheric CO_2 levels. No evidence of distress has been noted in pigs inhaling air at 2% (20,000 ppm) of CO_2 if normal levels of O_2 were present. Levels of 4% (40,000 ppm) to 5% (50,000 ppm) cause an increase in both the rate and depth of respiration. Tolerable limits accompanied by considerable discomfort are between 7 and 9%. Concentrations in excess of 10% may lead to dizziness, anxiety, staggering and even unconsciousness. The degree of distress increases as concentrations increase, but even 20% CO_2 has been survived by adult pigs over 68 kg when exposed for an hour. Pigs then tend to recover completely after they are returned to a normal atmosphere. Although CO_2 is rarely life threatening at above normal levels, it does slow the clearance of foreign materials from the respiratory tract which plays a key role in resistance to disease.

Odors

Waste researchers have identified more than seventy-five specific odorous components of animal manure odor which are end products and intermediates of various biological reactions. Included in the list are a wide range of: (a) volatile organic acids, (b) alcohols, (c) aldehydes, (d) fixed gases, (e) carbonyls, (f) esters, (g) amines, (h) sulfides, (i) mercaptans, and, (j) nitrogen heterocycles.

Odors from fresh livestock manure are normally less objectionable than decomposing manure because handling and storage constraints usually dictate an anaerobic degradation process. Vapors of reduced compounds and gases, which are common products of anaerobic decomposition, characteristically have undesirable odors. Because these compounds result from the anaerobic microbial breakdown of manures, the objectionable nature of manure odors increases with increased temperature, moisture content, and time in storage. As temperature increases, water losses increase also and as water vapor is lost, the emission of objectionable compounds such as amines increases as they distill off with water vapor.

It is unlikely that odor travels exclusively on dust. However, because of the strong affinity of the odor molecule such as amines and heterocyclic nitrogen compounds (normally positively charged) and the dust particle (normally negatively charged), they are likely to disperse together.

Odors from livestock production usually results from manure management practices. The source may be the production unit itself or fields where manure is spread. Manure covered surfaces are a major source of odor. The greater the surface area the greater the potential for odor.

Livestock industries and regulatory agencies are restricted because of a lack of practical odor detection technology either qualitative or quantitative. Odor detection and measurement have commonly relied upon the nose, wet chemistry, and gas chromatography.

Manure odors may be limited by preventing their production or by preventing their emission once they have been produced. Clearly the former is most desirable. Since undesirable odors are a result of anaerobic bacterial activity, reducing odor production requires that conditions be made unfavorable for bacterial growth. Procedures such as reducing moisture content, reducing temperature, altering pH (lowering it), applying bacteriocidal agents, and eliminating the anaerobic environment can be successful in controlling odors.

Today there is a wide variety of products being sold to treat and prevent odors in feedlots, liquid waste storage tanks and lagoons. There are six categories of odor control agents:

(a) masking agents are mixtures of aromatic oils which have a strong particular odor of their own designed to cover up the waste odor with a more desirable one.

(b) counteractants are mixtures of aromatic oils that cancel or neutralize the waste odor so that the intensity of the mixture is less than that of the constituents.

(c) digestive deodorants contain bacteria or enzymes that eliminate odors through a biochemical digestive process.

(d) adsorbents are products with a large surface area that may be used to adorb the odors before they are released to the environment.

(e) feed additives are compounds added to feeds to improve animal performance and reduce odors.

(f) chemical deodorants are strong oxidizing agents or germicides that alter or eliminate bacterial action responsible for odor production, or they chemically oxidize compounds.

(g) enzymes such as urease slow down or stop the release of free ammonia or other reactions that yield strong odor compounds.

The effect of dust and gases on human health

An estimated 300,000 persons are occupationally exposed in swine confinement operations in the United States each year (Donham and Gustafsson, 1982). Swine confinement dust is an organic biologically active material which can cause a biological or chemical reaction with human tissue through sensitization and antibody formation which is part of the natural immune response (Donham et al., 1990). The particulate matter, or aerosols, present in confinement buildings varies in size, shape, characteristics and composition. All influence human respiratory responses. Dust particles have a greater impact than gases on the potential for long-term health effects. In addition, dust is but are also more likely to be overlooked. Donham and Gustaffson (1982) indicated that it takes 10 to 20 years of exposure before acute respiratory problems surface in man. Pigs, on the other hand, are only exposed to the dusty environment for 4 to 5 months before they are slaughtered. This may not be long enough for respiratory problems to surface. Also, swine have a greater ability to more quickly clear their respiratory system than man (Donham and Gustaffson, 1982). The following are ways in which inhaled dust might effect health and productivity: (De Boer and Morrison, 1988).

a) it may exert a direct adverse effect on the respiratory tract, lowering local resistance to disease;

b) it's chemical nature may cause local irritant or systemic reactions (e.g. endotoxin associated with the cell coat of gram-negative bacteria);

c) dust effectively stores, protects and carries pathogens;

d) high dust loads may concentrate non-pathogenic organisms to abnormally high levels which may be harmful;

e) dust is known to absorb potentially harmful gases and transport them deep into the lungs, whereas free gases would normally be absorbed and neutralized on the upper respiratory epithelium.

Recently Donham, (1991) conducted a review of research which looked at the possible relationships of allergy as a cause of pork producer health problems. Results of these studies can be summarized by saying that very few people are allergic in the traditional sense, to the swine confinement air environment. Therefore, the effect on people must be a direct toxic or inflammatory effect of the air environment, not allergies. It is apparent that specific allergic reactions account for only 12% of the stockman's health disorders. The remaining 88% of reactions are caused by direct irritant effects of the air contaminants (Donham et al., 1987).

In view of the complex exposure involving proteins, microbes, gases and other matter in swine confinement buildings, a study on the health consequences to this exposure was undertaken by Donham in 1977. His team of researchers interviewed 11 people working in swine confinement units in the United States. More than half of those interviewed reported symptoms of cough, sputum, chest tightness, wheezing, or a stuffy nose. In addition, 35 veterinarians working in swine confinement buildings were interviewed and 32 of them reported respiratory symptoms in connection with work in the swine units. Subsequent follow-up studies to this research resulted in a total of nearly 2,000 swine confinement workers surveyed, and nearly 70% of these workers report acute respiratory symptoms associated with their work (Haglind and Rylander, 1987). Table 5 lists the prevalence of health symptoms by swine confinement workers.

Table 5. Symptoms of swine confinement workers[a,b]

Symptom	Prevalence
Cough	67%
Sputum or phlegm	56%
Scratchy throat	54%
Runny nose	45%
Burning or watering eyes	39%
Headaches	37%
Tightness of chest	36%
Shortness of breath	30%
Wheezing	27%
Muscle aches and pains	25%

[a]Donham and Gustafsson, 1982.
[b]Percentage of 2000 confinement workers reporting specific symptoms.

Symptoms that swine confinement workers express can be grouped to define a condition. Donham et al., (1991) reported that there are approximately ten different conditions that swine producers experience. Some may experience more than one of these conditions. These 10 conditions include: 1) hydrogen sulfide poisoning, 2) bronchitis, 3) hyperactive airways disease, 4) atopic asthma, 5) acute organic dust toxic syndrome, 6) chronic organic dust toxic syndrome, 7) mucous membrane irritation, 8) increased susceptibility to other chest illnesses, 9) chronic sinusitis, and 10) a byssinosis-like condition (Donham et al., 1991). The following is an explanation of these conditions and their prevalence as reported by Donham's (1989a) survey of Swedish swine confinement workers.

Hydrogen Sulfide Poisoning

There have been occasional incidents where people suddenly collapse, stop breathing and die. This occurs in and around the time when the liquid manure in the pit or storage tank is being agitated and emptied. Hydrogen sulfide is stored in the liquid manure, similar to carbon dioxide in a bottle of soda. Only when it is agitated does it come out rapidly. Exposure of 400 ppm or greater will cause this sudden poisoning. Hydrogen sulfide acts almost as an anesthetic agent. It causes the person to suddenly pass out and stop breathing. It also causes fluid to build up in the lungs. Twenty-four people have died from hydrogen sulfide from manure in the midwest area in the last seven years (1985-1991), (Donham et al., 1991). Many are multiple deaths within a family when the rescuers become victims. It is estimated that fifty percent of all manure pits do have the capacity to produce an acute poisonous situation if the manure is agitated. Lower level (<400 ppm) exposure results in a subacute severe, but survivable disease.

Bronchitis

Cough and coughing up phlegm are perhaps the most common complaints of swine confinement workers. When it occurs for three or more months out of the year for over three years, it is classified as chronic bronchitis. Twenty to 60% of our swine producers have this condition. An additional 30% of the individuals experience acute bronchitis, which occurs in association with working in the hog buildings. Bronchitis is the same disease that cigarette smokers get. Because of long term irritation, the cells lining the airways deteriorate. These cells then produce an extra amount of mucous and the small hairs that normally sweep particles out of the lungs that we breath in, do not work properly. These normal protective mechanisms of the airways becomes less effective. We respond to this airway irritation by coughing up phlegm (Donham et al., 1991).

Hyperactive Airways (Occupational Asthma)

Often associated with chronic bronchitis is a feeling of tightness of the chest and wheezing. Although this may be confused with an allergic-related asthma, it most likely is caused by long-term irritation of the airways from the contaminants in the environment. The muscle cells in the airways become inflamed and enlarged, and will constrict upon almost any irritating substance. When they constrict, it causes the airways to become narrower. This is analogous to trying to get more water through a narrow hose, we hear the air going in and out as wheezing and we feel the constriction as a tightness feeling in the chest. This hyperactive airways disease or occupational asthma is seen in about 20-30% of swine producers (Donham et al., 1991).

Atopic Asthma

Wheezing within a few minutes of exposure to the building is rarely seen in confinement workers. These people are known as asthmatics from other exposures, such as house dust, animal dander or plant pollens. This is the classical allergic (atopic) asthma. It is quite rare in swine producers, probably less than 5% experience this condition (Donham et al., 1990a). Therefore, the bulk of the problems are not allergic in nature as such, but are more directly related to long-term chronic irritation (Donham et al., 1991).

Acute Organic Dust Toxic Syndrome

Thirty to 40% of all farmers have noticed episodes of fever and a flu-like illness with headaches, muscle pains, and chest tightness. Typically, shoveling out moldy grain from a bin or taking off the moldy silage from the top of a silo, induces symptoms that begin in the evening, two to six hours after the exposure. This condition may persist throughout the evening, but may start to progressively get better the next day. It may take 3-4 days or up to a week to fully recover. This condition has been called organic dust toxic syndrome and was first described in 1985. Donham estimates that approximately 25% of swine producers experience these symptoms, particularly after an especially dusty activity such as moving or sorting hogs. It is felt this condition is due to endotoxin in the air. Endotoxin is a component of the cell wall of gram negative bacteria in the air. Endotoxin may be one of the most important toxicants in the swine house air environment (Donham et al., 1991).

Chronic Toxic Organic Dust Syndrome

Another group of symptoms that have been seen in swine producers include chronic tiredness, muscle aches and pains, and chronic shortness of breath. These individuals chest x-rays showed their lungs to be filled with white blood cells (an infiltrate). With proper protection these individuals become better gradually with time. This group of symptoms is related to long-term lower exposures to the confinement environment. It is felt that endotoxin within the environment is the main infectious agent here (Donham et al., 1991).

Mucous Membrane Irritation

Some producers report another group of symptoms that include sore throat, and irritation of the eyes, nose, and sinuses. This condition is called mucous membrane irritation.

Thirty to fifty percent of swine producers experience this condition. Mucous membrane irritation is related to the irritating environment (dust and gases) that irritates those very sensitive mucosal tissues (Donham et al., 1991). The primary irritant here is thought to be ammonia and possibly certain odor causing compounds such as phenols and cresols.

Lowered Resistance to Other Airway Disease

Other producers complain of frequent colds and even pneumonia. Generally this is a condition where people have an increased susceptibility to other chest illnesses. One of the problems is that these chronic exposures damage the normal protective mechanisms of the respiratory tract and make people more susceptible to other lung infections that they may be exposed to. Twenty to thirty percent of swine producers in this Swedish study reported this condition (Donham et al., 1989b; Donham et al., 1991).

Chronic Sinusitis

Additionally, there are a group of producers that report a combination of symptoms, including dizziness, feeling of having a chronic cold, and ears popping. Although not proven, this condition is probably chronic sinusitis. The dizziness and ears popping coming from plugging of the normal air pressure release valve between the outer and middle ears. Chronic sinusitis makes the person feel that their head is constantly stuffed up or their nose is always running just as if they had a real cold. This chronic sinusitis condition was reported by 20-40% of producers (Donham et al., 1991).

Byssinosis-like Condition

In a recent study, Donham (1989b) found that producers report increased symptoms of cough and chest tightness on the first day or two when they return back to work after having several days off. This set of symptoms is very similar to the condition called byssinosis, which is a long recognized condition to people exposed to cotton dust in cotton gins, or mills or cotton textile plants. Whether hog producers experience true byssinosis or not is not known. But because of similarities among agricultural dusts of all types, They very well could be experiencing a condition similar to byssinosis (Donham et al., 1991).

The severity of symptoms regardless of which one of the conditions a producer may have, vary widely amongst individuals from very mild to extremely severe to the point where the worker has to get out of the building. These would be combined symptoms of bronchitis, hyperactive airway disease, and the chronic sinusitis. In some, it is a mere discomfort and in others it forces them out of work. It depends largely on the degree of exposure and the length of exposure, the concentration of hazardous substances in the environment, and the individuals susceptibility (Donham et al., 1991). People working for more than 2 hours a day for 6 or more years are more likely to have serious problems. In general most of these conditions are reversible. Chronic bronchitis may take years to reverse or it could potentially develop into a permanent disease called chronic, obstructive pulmonary disease when tied together with hyperactive airways disease (Donham et al., 1991). This is a chronic situation consisting of air trapped in the lungs which could eventually lead to emphysema. The most dramatic and serious effect is the acute death that may result from hydrogen sulfide poisoning (Donham et al.,1991). The history of working in these buildings has not been long enough yet to truly assess the effects of long term exposure. Many chronic problems take 10 to 20 years or more to develop (Donham et al.,1991).

Personal Protection from Swine Confinement Air

The benefits of personal protective equipment are being considered more frequently as one way to minimize various exposures in farm environments. However, surveys suggest that only 10-15% of confinement workers regularly wear dust masks inside swine facilities. Respirators are used in the workplace to prevent the inhalation of toxic airborne contaminants. A respirator mask that does not adequately fit the wearer will allow penetration of airborne contaminants through the face seal, or the surface of the mask that contacts the wearer's face (Holton et al., 1987). A quantitative respirator fit test can be performed on each respirator wearer to determine which commercially available respirator fits the best. In a fit test, the concentration of an aerosol, gas or vapor in the air surrounding the respirator wearer and the concentration of that same substance inside the mask are measured and compared to determine the leakage into the mask (Holton et al., 1987). A fit factor, defined as the quantitative measure of a fit of a particular respirator to a particular individual, is equal to the concentration of the test agent surrounding the respirator wearer's head divided by the concentration of that same substance inside the mask (Holton et al., 1987).

Respirators should be worn routinely in most livestock buildings until engineering and management controls bring dust and gas concentrations to acceptable levels and until any symptoms of respiratory distress disappear (Popendorf, 1980).

Heggen (1991) outlined a variety of factors that any individual selecting a respirator must consider:

1. Mask fit: For any respirator to be effective, it must provide the correct seal between the skin and face. To achieve this the mask size and shape must be considered. In addition, any facial hair present can compromise the seal.

2. Protection: The respirator type must match the hazard. A person may need protection against dust, chemicals, or both. A mask designed only for dust protection will not provide chemical protection.

3. Cost: Respirators vary in cost. What is the most cost

effective mask for the protection level needed?

4. Maintenance: Maintenance of respirators range from none to moderate. What is the most realistic for your operation? Masks must be well maintained to have maximum effectiveness.

5. National Institute Occupational Safety Hazards approval: This ensures that the respirator is approved for specific hazards (read labeling). Not all masks are government approved, such as the one strap, disposable nuisance mask.

6. Use: Evaluate how the mask will be used and in what situations. The respirator should be convenient to use and store. Perhaps more than one mask is needed so it will be available at the site where it is used. Storage should ensure availability and maintaining the mask in usable condition.

7. Physician approval: Individuals over 40 years of age or with heart/lung problems should have approval for respirator wear. Several types of masks require increased physical exertion which may cause problems for an individual with a compromised health status. Anyone who experiences claustrophobic feelings when using a mask may not be candidates for respirator use.

Respirator types

Disposable: Disposable paper respirators provide protection from dust. These masks should have two straps and fit snugly to the face. The cost range is $1-5. These masks should be changed regularly when breathing becomes difficult or the mask losses it's shape and no longer maintains a good seal (Heggen, 1991).

Quarter and Half Masks: Quarter masks are for dust exposure only while half masks can be used for a variety of exposure including dust, organic vapors, ammonia, pesticides, acid gases, etc. Specific cartridges for these hazards are required for the half mask. Due to the silicone/rubber material face piece a stable seal is easier to achieve. Cost of these masks start at $20 with filter or cartridge replacements ranging from $1-5 each. Filters should be changed regularly when it becomes difficult to breathe or filters become overloaded. Cartridges should be changed immediately when "breakthrough" occurs, this is when the wearer experiences the occurrence of odor, taste, dizziness or irritation (Heggen, 1991).

Powered Air Purifying: The PAP unit is the most expensive respirator, but provides a viable alternative for individuals who cannot wear other masks due to health considerations or individuals who prefer a powered unit. Powered helmets range in cost from $250-$500 depending on the amount of air circulated and battery time capacity. Filter replacement is $2-10. These helmets are for dust only. A hooded unit with cartridges worn on a belt around the waist provides chemical protection, but is cumbersome. None of the PAP units supply oxygen and therefore should not be used in situations immediately dangerous to life and health including oxygen deficient atmospheres (e.g. airtight silo or pit situations) (Heggen, 1991).

Air Supplying Respirators: ASR's provide clean air from a source other than the wearers environment. These require specialized training and are expensive, therefore are not appropriate to be used on the farm except in emergency situations (Heggen, 1991).

Factors that influence dust and air pollutants inside swine confinement housing

The amount of dust and gases that will accumulate in a particular facility is influenced by many variables such as; 1. type of flooring, 2. ventilation, 3. physical form of feed, 4. feeding method, 5. animal activity, 6. cleaning, 7. type of building and production phase, 8. environmental fluctuations.

1. Type of Flooring: There are several types of flooring and many of these are designed for specific phases of swine production. Most settled dust can become airborne when agitated by animal activity and then settle by gravity back to a surface. The amount of surface area that the flooring material provides will influence the quantity of dust that can be held inside a facility. Solid concrete flooring provides the greatest surface area to hold dust and dust generating material (e.g. straw, feed, urine, feces, etc.). Concrete slats are generally 4-8 inches wide and provide an open gap which dust materials can drop through and become trapped in water within the gutter or pit. Although slats are more desirable than solid flooring because they accumulate less dust, they still provide a large surface area when compared to other flooring materials. The least amount of solid area is found on woven wire, coated wire, expanded metal, Tri-Bar, and poly floor. These flooring materials are referred to as self cleaning and are most desirable where dust and gas control is a concern. This is due to the fact that they will hold the least amount of feed, urine, and fecal material, thus providing a more favorable environment (Feddes and Barber, 1990). Ammonia volatilizes and releases from urine instantaneously if urine is deposited on a solid surface such as slats or a solid floor. However, if urine is deposited over wire it enters liquid in the pit and less of it stays on the flooring material limiting the amount of ammonia in the air. Ammonia has a strong affinity for water, therefore, there should always be at least 1 inch of water in the pit or gutter. The more urine that enters the gutter or pit the less ammonia will be released into the animal's and worker's environment. In shallow pits where scrapers or pull plugs are used, adding a thin layer of water back after scraping or draining will help keep ammonia in solution rather than a gaseous state. Frequent flushing of gutter systems with fresh water, instead of recycled liquid waste, will have the same effect (Leonard, 1990c). Bedding also contributes to dust levels inside of swine units. Newer more modern confinement units utilize a variety of semi solid flooring material with manure storage under or outside the building, thus they do not use bedding. However, there are still a lot of older barns around that are used for finishing hogs. Many of these buildings have solid floors and use some form of bedding like straw or wood shavings. When the animal activity is high in these barns the smallest particles and chaff from the bedding is winnowed into the air as airborne dust, while the larger particles of airborne dust settle to surfaces as settled dust. Equipment is now being designed and tested to cut straw, rather than chopping it, to reduce dustiness (Feddes and Barber, 1990).

2. Ventilation: Control of the air movement produced by ventilation seems to be a relatively effective and practical means of dust removal in mild or warm weather. However, it is less effective in cold weather when ventilation rates are lowered, due to excessive losses of thermal energy (Bundy, 1984). Bundy, (1984) reported that the time required to reduce dust levels from 5300 to 1760 particles/cm^3 of air was two and seven times faster at a ventilation rate of 35.8 cm^3/sec and 84 cm^3/sec respectively, compared to no ventilation (Bundy, 1984). Total dust levels under summer ventilation rates are 85% lower when compared with dust levels under winter ventilation rates. Morrison et al., (1991) reported that by increasing the air changes/hour from 2 to 5 to 8, that total

dust also increased from 2.56 to 3.47 and 3.72 mg/m^3 respectively. However, increasing summer rates from 15 to 30 to 60 air changes/hour had no effect on total dust levels (Morrison et al., 1991). The contrast of results has been explained by differing circulation patterns in the different research facilities. Increasing the ventilation rates removes dust from the building, however, it also increases the amount of air entering the room which can exacerbate existing dust and also create more (Morrison et al., 1991). Therefore, the ventilation design (fans, inlets, recirculation tubes etc.) greatly influences how ventilation effects dust levels. The one thing increasing ventilation will consistently do is reduce temperature and gas levels regardless of ventilation design (Morrison et al., 1991). Morrison et al. (1991) tested the effects of filtering recirculated air on total and respirable dust. In one trial total dust appeared to increase somewhat when filters were removed but respirable dust seemed unaffected. He concluded that using filters in a recirculation system does not markedly influence airborne dust.

3. Physical form of feed: The majority of swine house dust emanates from feed particles. Generally as the feed is ground finer there is a larger proportion of smaller particles (15 microns and smaller) which accumulates as dust (Carpenter, 1986). Swine feed rations contain large numbers of fine particles as a result of grinding of whole grains and adding vitamins and minerals (Heber and Martin, 1988). Grain constitutes about 75% of the ration and, thus, has a major influence on dust emissions from feed.

Some feed particles become airborne dust when aerodynamically segregated during feed delivery. Particle segregation is the separation of large and small particles during free flow of the material. This process will occur when material is poured as a steady stream onto a heap (Gast and Bundy, 1986). As a bin is being filled, a core of fine particles develops in the center while the larger particles migrate to the edge of the bin. When the bin is emptied the particles at the center are removed first and the particles at the edge remain stationary until an inverse angle of repose is formed. This results in the separation of large particles from small particles (Van Denburg and Bauer, 1964). Heber and Martin (1988) reported that the moisture content of the grain influences the amount of aerodynamic segregation of feed. The aerodynamic dust segregation of swine feed at 12% moisture content is 22% less than that at 9% moisture content (Heber and Martin, 1988). Furthermore, large geometric median diameter of feed was correlated ($P<.001$) with low aerodynamic dust segregation (Heber and Martin, 1988). Swine producers in states where wheat or grain sorghum are the major crops can expect higher levels of feed dust emissions than in the cornbelt states, if other influencing factors are the same. Corn has inherently more oil in the kernel than wheat or grain sorghum, the oil acts as a natural dust suppressant (Heber and

Martin, 1988). Feed dustiness should be considered in the selection of screen size used to grind the feed. Most feed was ground from 700 to 900 microns with a standard deviation of 50 microns in the studies cited. In a study comparing ground and pelleted feed for floor feeding, Bundy and Hazen reported that dust levels for both ground and pelleted feed dropped within 10 minutes to the level that existed before feeding. For ground feed, the dust level continued to decrease for about 1 hour, reaching a final minimum. The pellet feeding reached it's minimum in 45 minutes. They concluded that the dust level is lower for floor feeding of pellets than for ground feed fed on a concrete floor. However, there was no significant difference in dust levels for pellets and ground feed when fed in self-feeders. This was attributed to the animals grinding the pellets to a fine powder in the bottom of the self-feeders, causing the dust level to be about the same for ground and pelleted feed (Bundy and Hazen, 1975).

When comparing the effects of dry and wet feeding, the concentration of airborne microorganisms in the pens of dry-fed pigs was three times that in the pens of wet-fed pigs (Carpenter, 1986). In addition, the greater the density, moisture, oil content, and size of the feed, the less dust it is likely to produce (Carpenter, 1986).

4. Feeding method: Finishing units use more feed than do the farrowing and nursery buildings. Furthermore, ground feed often may be dropped several feet from an auger to the

feeder resulting in significant dust generation, and feed is more likely to be spilled from the feeders onto the floor (Donham et al., 1986). Finishing units generally incorporate an automated flex auger feed distribution system which drops feed into each feeder in each pen at the same time. A dust cloud is formed as a result of the feed being dropped from the feed tube to the feeder. As the distance from the bottom of the drop tube to the feed pile increases, the size of the dust cloud also increases creating a larger quantity of feed dust. The dust generated during the filling of feeders is a major source of the total amount of dust in buildings (Chiba et al., 1985). Total dust concentrations in growing-finishing buildings with no auger running was measured at 20.2 mg/m^3 (Chiba et al., 1985). A similar trial with the feed auger running resulted in a total aerial dust level of 92.4 mg/m^3 (Stroik and Heber, 1986). Honey and McQuitty (1979) reported that self-feeding resulted in a significantly greater atmospheric dust concentration ($P<.05$) than did floor feeding. In fact, floor-feeding yielded about two-thirds as many dust particles as did self-feeding. The pig whether floor-fed or self-fed consumed approximately the same amount of feed. However, the self-fed pigs appeared to spend a much longer time eating than did the floor-fed pigs. The longer eating time of the self-fed pigs plus the fact that the self-fed pigs played with the excess feed probably contributed to the significantly different effects attributed to the feeding methods. Bundy and Hazen (1975) also concluded that animal activity and atmospheric dust levels were higher when pigs were self-fed than when they were fed twice daily. However, a significantly greater amount of settled dust ($P<.01$) was associated with floor-feeding. This could be due to the intense activity of the pigs during floor-feeding when a great deal of visible dust was observed for a short period of time. The self-fed pigs even while eating were not nearly as active as those being floor-fed.

5. Animal activity: Bundy and Hazen (1975) indicated that dust levels are related to animal activity more so than feeding methods. They conducted a study to compare dust levels as they related to self-feeding vs. hand-feeding. The results showed a higher dust concentration for the self-fed pigs which they attributed to a higher animal activity for the self-fed group. Honey and McQuitty (1979) reported that in a trial comparing different airflows, feeding methods, and stocking densities, that treatments without pigs present could create no differences in dust concentrations. Only pigs caused dust, the treatments simply modified the amount. Further more, the more important factors they considered to be associated with dust concentrations were, in descending order: activity of the pigs, temperature, relative humidity, amount of feed fed, feeding method, pig weight, and air flow rate. They associated a temperature effect with animal activity. Pigs generally become less active with increasing temperature and a

diminished activity is assumed to yield less dust (Anderson et al., 1966).

6. Cleaning: The single, most effective and economical means of controlling dust is to regularly power wash an entire room (Leonard, 1990c). This removes dust from ceilings, walls, rafters, floors, and any other surface where it settles, plus removing some airborne dust. The result is less dust that can become airborne again by fans, animal or person activity, or low humidity. Frequency of washing depends on the type of room. Studies in farrowing rooms have shown that after power washing and introduction of new sows, dust levels climb quite rapidly for about three weeks, then plateau (Leonard, 1990c). Ideally, farrowing rooms should be completely washed before each new group of sows. Because ammonia has an affinity for water, some ammonia is removed from the air and is taken up by the water mist. Rooms should be kept as clean as possible between washing. Special attention should be paid to spilled feed. Sweeping causes dust to become airborne again and puts the sweeper right in the middle of the dust cloud. Therefore it is better to hose down aisles or vacuum. Industrial vacuums with high efficiency filters are used in some European operations to remove settled dust from floors, rafters and other horizontal surfaces (Leonard, 1990c). The most obvious method of controlling dust is to make less of it. Routine house cleaning is a good way to remove dust from a building. If pens are not self cleaning they should be scraped so manure

can be quickly removed before it dries out and becomes dust (Feddes and Barber, 1990). Ammonia production is clearly a function of how much of the floor area is soiled with manure. When pens are cleaner ammonia production is lower (Feddes and Barber, 1990). Because feed and dried manure particles that accumulate on animals eventually fall, break or rub off, livestock that are clean and mange-free will contribute less to total dust levels than dirty animals. Using an oil mist (e.g., mineral oil) helps control hog dander (Leonard, 1990c).

7. Type of building and production phase: Specific building types and production phases accumulate more dust than others due to there specific combination of the above variables. The modified open front (MOF) design seems to accrue the most total airborne and settled dust. This is mainly because of it's design and the nature in which it is used. The MOF building is primarily used as a finishing building and usually employs either solid, slatted, or partially slatted flooring. In addition, it generally utilizes an automated drop feeding system and has a high level of animal activity due to self-feeding. All of these variables combined contribute to a dustier environment than a farrowing house, which usually contains a self cleaning floor such as wire, has low animal activity, and utilizes hand-feeding.

It is interesting to note that dust levels analyzed by the cascade impactor indicate that both the total aerosol concentration and the aerodynamic particles size increased from farrowing to nursery-grower to finishing buildings. Gross examination of aerosolized dust collected in farrowing and nursery grower buildings revealed a fine, dense and blackish-appearing material, while dust in finishing units was a more fluffy, coarse, tannish-appearing material (Donham et al., 1986). Donham speculated that these differences are a result of the relatively greater ratio of feed to fecal components of dust in the finishing vs. farrowing and nursery buildings.

Donham et al., (1986) conducted extensive dust measuring studies in 21 randomly selected swine confinement operations. These environmental studies were carried out during the months of December, January and February. Table 6 shows the results of aerial dust concentrations reported in various production phases and swine confinement buildings. The mean total aerosol concentration for all buildings sampled was 10.2 mg/m^3; however, the total aerosols varied according to the use (type) of building. The farrowing buildings had the lowest mean amounts at 4.1 mg/m^3, followed by grower-nursery units at 10.8 mg/m^3 and finishing units at 15.3 mg/m^3. However, there was a larger percentage of respirable fraction in buildings housing younger animals. Farrowing buildings had 20.1% respirable fraction, followed by nursery-grower buildings (13.4%) and finishing buildings (12.4%).

Table 6. Mass of aerosolized particles in swine confinement[a]

Cascade Impactor	Farrow[b] (n=9)	Nur/gro (n=8)	Finish (n=4)	All Build (n=21)
Mean total mg/m^3	4.1	10.8	15.3	10.1
Mean respirable mg/m^3	2.7	2.0	3.2	2.5
Respirable range (%)	20.1	13.4	12.4	10.2

[a]Donham et al., 1986.
[b]t-test, farrowing vs. nursery/grower and farrowing vs. finish (P<.05)

8. Environmental fluctuations: Curtis et al (1975a) reported that there is an annual or seasonal effect on air pollutants in swine confinement housing. Both aerial bacterial colony forming particle (BCFP) level and aerial dust level were significantly and negatively correlated with median outside temperature. These authors reported an increase of .02 BCFP in a farrowing unit per degree Celsius decrease in median outside temperature. Aerial dust also increased around .01 mg/m^3 per one degree Celsius decrease. Aerial dust and aerial-BCFP in the swine houses tended to be higher during months with cold weather. In general, the lower the outside temperature, the higher the aerial dust and aerial-BCFP in the swine houses. Research indicates that this is mainly from different ventilation rates during periods of cool and warm weather (Curtis et al., 1975c). Curtis et al. (1975a) also noted a tendency for a greater amount of aerial dust and

aerial-BCFP during the day and less at night indicating a diurnal pattern. However, there was too much variation throughout a 24 hour period to show a significant response. Stroik and Heber (1986) described the direct effects influenced by the outside temperature as follows:

1. Ventilation rates are increased at higher temperatures.
2. Animal activity decreases at higher temperatures.
3. Less feed is consumed during higher temperatures.

Bundy, (1984) measured the effect that relative humidity had on total aerial dust. The trial was conducted inside an environmental chamber (1.5 m long, 1.6 m wide, 2.1 m high) with two different relative humidities, 50 and 85% respectively. Bundy, (1984) reported that after dust becomes airborne, the relative humidity has no effect on the change in airborne dust concentration with time. Honey and McQuitty (1979) also reported differing humidities (39.3 and 45.5%) as having no effect on aerial dust concentrations inside four environmentally controlled pig pens. However, they did determine that the lower relative humidity did show a significant increase in settled dust ($P<.05$). Pathogen load was not measured, however, I speculate that the higher relative humidities would support and transport greater levels of molds and bacteria.

Lipids in Swine Rations

Inclusion of supplemental fat not only reduces dustiness of feed, but also makes it somewhat sticky. In fact more than 5 to 6% added fat makes feed susceptible to bridging in bulk bins and self-feeders, causing difficulty in removing the feed. There are special difficulties in handling fat and in mixing it with other ingredients (Pettigrew and Moser, 1989). In bagged feed, similar levels of added fat cause "oiling out" of unlined bags. Pellets made from a high-fat feed are usually soft and susceptible to development of fines. Pigs can efficiently utilize large quantities of supplemental fat in their diets. However, the level of fat which is used is limited by physical problems of mixing and handling and the cost effectiveness of added fat in least-cost formulations.

A temperature of 48.8^{0}C will keep animal fats and blended fats free flowing and easy to apply to feeds. Most vegetable oils would require no heat at temperatures over -6.7^{0}C but the lower cost of fats that require heating should easily pay for a heated system in a short period of time (Pettigrew and Moser, 1989).

A range of animal, vegetable and blended fats are commercially available. Selection among fats for use in swine feeds should be based primarily on price and digestibility, with adequate consideration for handling characteristics and for contaminants. The following is a list of fat types available:

Vegetable oils:

Stimulated by the considerable publicity given research with fats in hog rations, various types of fats, including vegetable oils, have been offered to hog farms. Where heated fat systems were not available to provide ease of handling, low melting point vegetable oils such as soybean and corn have been used to provide energy and dust control. These oils do not require heating at above -12.2 to -6.7^{0}C temperatures. Unfortunately the high cost of these oils has in many cases prohibited their use in full line feeding they are more often used in selective feeding of sows and/or baby pigs (Pettigrew and Moser, 1989).

Tallow:

This high melting point rendered fat is created from mainly beef by-products. It has been used in much hog research with good success. It's fat structure is very saturated and the linoleic essential fatty acid content is approximately 4% (Pettigrew and Moser, 1989).

Grease:

This general category of fats includes restaurant grease, hog by-product fats and other renderer fats. Many feed mills producing high energy hog feeds, use grease as their main source of fat. It is economical and in plentiful supply in most areas. Most greases provide over 10% linoleic essential fatty acid to meet NRC standards (Pettigrew and Moser, 1989).

Blended fats - Animal & Vegetable:

These fats can include combinations of grease, poultry fat, vegetable soapstocks, industrial by-products and other fats. Some fats in this category are used in hog feeds but mainly this category of fats is used in poultry feeds where higher levels of linoleic essential fatty acid (20%) are desirable (Pettigrew and Moser, 1989).

The effect of fats and oils on reducing air pollutants in swine units

The use of fats and oils in swine diets is largely dictated by the differential between the cost of energy from grain and fat. Since fat is considered to have 2.25 times as much energy as grain, It is thought that you can pay only 2.25 times the price of grain for fat. Green (1983) reported that animal fats have many attributes besides being a source of calories. The most important characteristic of fat may be it's ability to reduce feed dust. Dietary fat tends to bind minute particles together, and therefore may play an important role in reducing swine house dust, which might otherwise be a health hazard for both humans and swine (Honey and McQuitty, 1979). Given the increasing size and numbers of confinement units and subsequent longer hours workers spend in them, I believe that the value of lipids as dust suppressants will increase. Most of the work using oil additives for dust control has been done with grain and cotton, and success has been achieved with both materials. Addition of oil has resulted in lowering the amount of dust produced by the material and increasing the average size of dust particles (Gast and Bundy, 1986).

Recently, Chiba et al. (1985) reported that the addition of 2.5% animal fat to a growing-finishing diet resulted in a 21% reduction in aerial dust, whereas there was a 50% reduction with 5% dietary fat. Furthermore, ammonia levels may be reduced when the aerial dust level is reduced, because of their intimate relationships. An experiment was conducted to examine this effect on aerial ammonia concentrations using 7.5% fat (tallow) as the treatment in modified-open-front swine buildings (Chiba et al., 1987). Although the ammonia levels observed in both buildings may not have been high enough to cause adverse effects on respiratory structures (<15 ppm), addition of tallow to the diet resulted in a 60% reduction (10 vs 4 ppm) of aerial ammonia concentration ($P<.001$). Ammonia is very soluble in water, and is readily absorbed by the upper respiratory tract. Therefore, only a small fraction of gaseous ammonia reaches the lower part of the tract. For this reason, ammonia rarely irritates the lungs, even though it may irritate the nasal passages and trachea. However, it is known that aerial dust in swine houses adsorbs and carries ammonia (Donham et al., 1986). Donham et al., (1986) detected levels of ammonia gas adsorbed to aerial dust particles in a range of 2.5-4.0 mg N/g of dust. Dust particles thus may serve as a vehicle to increase the impingement of ammonia in the pulmonary region. Chiba et al., (1987) concluded that the reduction of aerial dust can contribute to the alleviation of adverse effects of ammonia upon pigs and workers where problems exist. The presence of 2.5-4.0 mg adsorbed ammonia per gram of dust carried by these particles into the respiratory system could be an important consideration in evaluating their potential health effects. As particles are inhaled, adsorbed ammonia would be delivered to the deeper, more sensitive portions of the pulmonary system. The irritant effects of ammonia also may increase the inflammatory response from the inhaled aerosol (Donham et al., 1986).

In two other trials adding 5% soybean oil had no effect on ammonia or carbon dioxide in the nursery phase (Gore et al., 1986a; Gore et al., 1986b). It should be noted that in the later two trials gas levels were only minutely detectable and were 50% lower than in Chiba's study. This may help explain why gases showed no response when the dietary soybean oil was added.

Of significance, are the findings of Leonard et al. (1984), who noted a progressive deterioration in air quality over the production cycle in commercial broiler operations in Alberta. Ammonia production increased exponentially, and that of CO_2 production increased as a function of bird age. The levels of both gases peaked in the preslaughter period.

The effect of air quality on pork quality is largely unexplored, except to say that stressful environmental conditions are known to contribute to stress, which in turn is associated with syndromes such as Porcine Stress Syndrome and Pale Soft Excudative pork (Curtis and Backstrom, 1986; De Boer and Morrison, 1988).

Cocke et al., (1978) used a hydrocarbon base oil spray to treat samples of wheat, corn, and soybeans. Aerial dust levels for wheat were reduced 59 percent with an additive level of .04 percent and 92 percent with an additive level of .07 percent. Increasing the additive level further did not significantly reduce the dust levels. Dust levels were reduced in corn and soybean samples as well, but at somewhat lower percentages.

Lai et al., (1981) produced similar results using mineral oil and vegetable oil. Addition of .04 percent vegetable oil reduced total aerial dust levels approximately 93 percent in corn, with similar results found in wheat. Mineral oil added at .06 percent reduced dust levels approximately 95 percent. However, 80 to 90% of the dust that was suppressed was in the nonrespirable range (greater than 5.8 microns) A particle size analysis was also done on the dust samples. The average particle size of oil-treated grain dust was found to be larger than the control grain dust.

Hsieh et al., (1982) used rapeseed oil in tests done on barley, oats, rye, and wheat. Dust level reduction of 80 percent with an additive level of .05 percent were achieved. These tests also showed that the dust reduction level is dependent on initial dust levels. High initial dust levels resulted in a higher percentage reduction in dust than low initial dust levels.

Gast and Bundy, (1986) tested the effects of mineral oil, soybean oil, and lecithin in reducing dust produced by a swine base mix in a laboratory chamber using a drop test procedure. Additives were tested individually at levels of 0.5, 1.0, and 2.0 percent as well as in combinations of lecithin and the oils. Lecithin is a highly-viscous substance produced when soybean oil is degummed. All additives tested resulted in a significant reduction in dust produced by the base mix (P= .001). Table 7. shows the average dust level and the percent reduction from the control for all the additives tested.

Table 7. Effect of additives on the dust level of a swine premix[a].

Additive % Added	Dust Level (mg/m^3)	Reduction in Dust Level (%)
No Additive	331.6	-----------
Soybean oil		
0.5	80.2	75.8
1.0	29.8	91.0
2.0	04.6	98.6
Mineral oil		
0.5	61.8	81.4
1.0	33.5	89.9
2.0	18.7	94.4
Lecithin		
0.5	23.3	93.0
1.0	04.9	98.5
2.0	01.8	99.5
Soy oil + Lecithin		
0.5 + 0.5	04.6	98.6
1.0 + 0.5	05.8	98.2
Min oil + Lecithin		
0.5 + 0.5	06.4	98.1
1.0 + 0.5	09.9	97.0

[a]Gast and Bundy, 1986.

Soybean oil added at 0.5 percent resulted in the least reduction, while lecithin added at 2.0 percent had the highest reduction. Most of the additives resulted in a dust level reduction of at least 90 percent.

There was no significant difference between the dust levels obtained using the combination of soybean oil and lecithin and the combination of mineral oil and lecithin at either level (0.5 or 1.0) of the oil additive. There was also no significant difference between the combination of 0.5 percent oil and 0.5 percent lecithin and the combination of 1.0 percent oil and 0.5 percent lecithin for either type oil. However, combinations of oil (mineral or soybean) and lecithin did show a significant reduction in dust levels over those obtained from mineral oil added at 0.5, 1.0 and 2.0 percent; soybean oil added at 0.5 and 1.0 percent; and lecithin added at 0.5 percent ($P= 0.01$). The difference was not significant between any of the combinations and lecithin added at 1.0 or 2.0 percent, or soybean oil added at 2.0 percent. Gast and Bundy, (1986) reported the results of the Hyac Royco particle counter. Number of particles Less than 0.5 microns with no additive was 36419 and the mean particle count for any additive at any level or combination was 217.3. This represented an overall reduction of over 99 percent for particle count when any type, level or combination of oil was added.

Gore et al., (1986) evaluated the effects of adding 5% soybean oil on air quality inside nurseries. The average reduction in settled dust for nurseries with 5% added dietary soybean oil compared to control nurseries with no added oil was 47% ($P<.05$). Nurseries with and without soybean oil produced .29 and .54 $mg/cm^2/wk$ of dust respectively. An additional trial showed .74 and 1.3 $mg/cm^2/wk$ for nurseries with and without oil, respectively. Settled dust concentrations were highest for positions under the air inlets of each nursery. Positions located opposite the nursery heaters produced the lowest values for the settled dust. Gore et al., (1986) also noted that the level of settled dust increased over time. The mean aerosol bacterial colony forming counts also increased over time for each nursery and were lower in the nursery with added soybean oil for all weeks except week 1 (P<.05, table 8). The average bacterial colony counts for all weeks combined was 27% lower for the nursery with added soybean oil (P<.10). Mean values of 128 and 177 bacterial colonies/m^3 of air were obtained in the nurseries with and without soybean oil. Over all trials, pigs fed diets with added soybean oil tended to consume less feed (4.3%; P<.13) and had 4.1% lower (P<.05) feed per gain, but no difference in average daily gain was observed (Gore et al., 1986).

Table 8. Number of colony forming units per cubic meter of air[ab]

Week	Nursery diet w/o oil	Nursery diet with oil
1	36	38
2	164	75
3	221	181
4	269	179
5	194	170
Mean	177	128

[a]Gore et al., 1986.
[b]5% soybean oil

Chiba et al., (1985) conducted trials in environmentally regulated (ER) and modified open front (MOF) buildings to determine the effect of adding 2.5% and 5.0% animal fat (tallow) on aerial dust with and without a feed auger running, settled dust, and feed particle separation. Overall mean total concentrations of aerial dust were lower in ER buildings than MOF buildings. This was probably due to the automated feed distribution system in the MOF buildings which generally produces more dust during the feeding process.

Addition of 5% tallow to the diet reduced aerial dust concentrations in all size classes. Total dust concentration was 20.21 mg/m^3 for the buildings with no tallow added, and 10.28 mg/m^3 for the buildings with 5% added tallow. This represents a 49% reduction of aerial dust. Adding 2.5% tallow to the diet resulted in a 21% reduction of aerial dust. Overall total dust concentrations with the feed auger running were 17.98 mg/m^3 for the buildings in which the diets contained tallow were fed and 92.35 mg/m^3 for the buildings in which diets did not contain tallow. The dust generated during the filling of feeders is a major source of total amount of dust in buildings.

The addition of 5% tallow to the diet resulted in a 41% reduction (P<.001) of settled dust. However, with no added tallow there was more settled dust in the modified open-front buildings, than the environmentally controlled buildings, 3.55 $g/cm^2/53$ d and $2.33 g/cm^2/53$ d, respectively, this may have been partially due to fact that the MOF building contained more solid flooring area when compared to the ER building. There was an 8.9% reduction of settled dust in the building where a dietary inclusion of 2.5% tallow was fed versus the building that had no tallow added to the diet, .81 $g/cm^2/53d$ versus .89 $g/cm^2/53d$ respectively.

The criteria of response for determining whether any mechanical separation of feed nutrients was affected by adding tallow were crude protein, Ca, P and Cu contents of the diets. There was no difference between the two diets for all criteria except P ($P<.05$). The nutritional significance of this trend was concluded as minor because the difference between the highest and lowest values of P was only .03% (Chiba et al., 1985). It was also reported that the pigs fed the dietary tallow at 5% increased average daily gain (.77 vs .72 kg/d, $P<.002$), consumed less feed (2.36 vs 2.46 kg/d, $P<.002$) and showed a 10.2% improvement in F:G (3.09 vs 3.44, $P<.001$) (Chiba et al., 1985).

Chiba et al., (1987) has examined the effects of a higher percentage of dietary fat (7.5%) on the reduction of aerial dust, settled dust, bacterial colony forming particles, and pig performance in two naturally ventilated MOF buildings. The addition of 7.5% tallow to the swine diet reduced aerial dust concentrations of all size classes ($P<.001$). Total dust concentration was 21.56 mg/m^3 for the building in which the diet without tallow was fed and 10.25 mg/m^3 for the building in which the diet containing the tallow was fed. This was a 53% reduction of dust in the atmosphere of swine house air. The magnitude of aerial dust reduction observed in this study was comparable to the results of the previous study with 5% dietary tallow (approximately 50%; Chiba et al., 1985). Although most of the mass of dust collected was from particles 14 μm or larger, it is conceivable that the number of dust particles with an aerodynamic size of less than 4 μm was greatest.

There was 57% reduction in settled dust in the building in which the diet contained 7.5% tallow ($P<.001$) 1.26 $g/cm^2/53d$ vs 2.96 $g/cm^2/53d$. The settled dust in the building in which the diet contained 7.5% tallow was higher in crude protein content ($P<.001$) 25.88% compared to 22.5%. This indicates that a large proportion of the dust in the building in which a diet without tallow was fed, was feed dust. The reason for this might be differences in the composition of swine house dust. Swine house dust consists of particles of solid matter such as soil, feed, animal hair, skin debris, and dried fecal material. If the feed dust was reduced by the addition of fat to the diets, then the crude protein value should increase because of increased proportion of hair and skin debris (which are high in crude protein content) in the swine house dust (Chiba et al., 1985).

The addition of 7.5% tallow to the diet of growing-finishing swine resulted in a 75% reduction (422,000 vs

104,000/m^3) of aerial BCFP in the MOF building. The reduction of aerial BCFP (75%), by adding tallow to the diet, was greater than the reduction of aerial dust (53%) which is primarily responsible for transporting microorganisms. Larger particles are less likely to become airborne and may settle out quickly once suspended in the air. Thus, the reduction of aerial BCFP might correspond better to the reduction of the number of dust particles rather than mass of dust (Chiba et al., 1987).

Peo and Chiba, (1984) reported very aggressive behavior in unit 2 where pigs which were fed a diet which contained no fat, compared to unit 1 where a more mild behavior was observed in pigs fed a diet containing 5% tallow. In unit 1, only one mild case of tail biting was observed. In unit 2, 27 pigs were bitten either on the tails (19) or above the hocks (8). Eight out of the 19 pigs had no tails left, and most of them were severely bitten.

The reason for this difference in pigs aggressiveness is not clear. Peo and Chiba, (1984) suggest it may have something to do with differences in energy content of the diet, or added tallow in a diet may have created a more comfortable environment by way of reducing dust in the MOF unit. Tail biting can be referred to as "anti-comfort syndrome," and any factors (including dusty conditions) which makes pigs uncomfortable may lead to tail biting (Peo and Chiba, 1984). Other conditions that may lead to tail biting include: over crowding, mycotoxin contaminated feed, hyperactivity, or restlessness.

Electrostatic Precipitation:

Electrostatic precipitation is a recent development in dust removal technique. This system involves placing negatively charged wire electrodes above the pens which ionizes the air in the swine confinement room. Dust particles are then charged by collision with negative gas ions (Curtis et al., 1972a). Particles will continue to collect and retain ions until the particle becomes saturated with charge and repels other ions. Positively charged collector surfaces are located over the pens in the room with respect to the ionizing electrodes to draw the oppositely charged dust particles to them for later removal. Large particles can retain more ions increasing the total particle charge making it easier to attract and collect on the collector surfaces (Veenhuizen and Bundy, 1990). Veenhuizen and Bundy, (1990) have utilized electrostatic precipitation dust removal and reported a 51% reduction of all particles less than 2.0 micron in diameter, the size considered most likely to be retained in the lungs. The researchers also conclude that larger particles are removed at a higher rate than smaller particles. Air movement pattern across the collector surface and ionizing electrode affects the collection efficiency of the ionization system. Ventilation systems must be considered when designing a dust removal system (Veenhuizen and Bundy, 1990).

Morrison et al., (1991) reported that using filters to filter out dust from recirculated room air seemed to decrease nonrespirable range dust but respirable dust seemed unaffected. It seems that using filters in a recirculation situation does not markedly influence airborne dust.

Air Pollutant Control Programs

Environmental control has all to often been looked at with a narrow view. Ventilation improvement and respirators have been the primary emphasis in the literature or scientific presentations. Donham (1989b) stated that control should be thought of as a systems approach, as is exemplified by principles of industrial hygiene. Control of air contaminants should be aimed at three points in the buildings:

1. The source of the contaminants.
2. The contaminants once they are in the air between the source and the person or animal (pathway)
3. Personal protection of the person or pig.

The first consideration must be control of the source of the contaminants, because this may be most effective and inexpensive. Control in the pathway to the recipient is considered secondary, followed by personal protection (Donham, 1989b). Donham's (1989b) pathway to environmental control is illustrated in figure 1. Producer education programs should be initiated to increase awareness of confinement house hazards and available means of control.

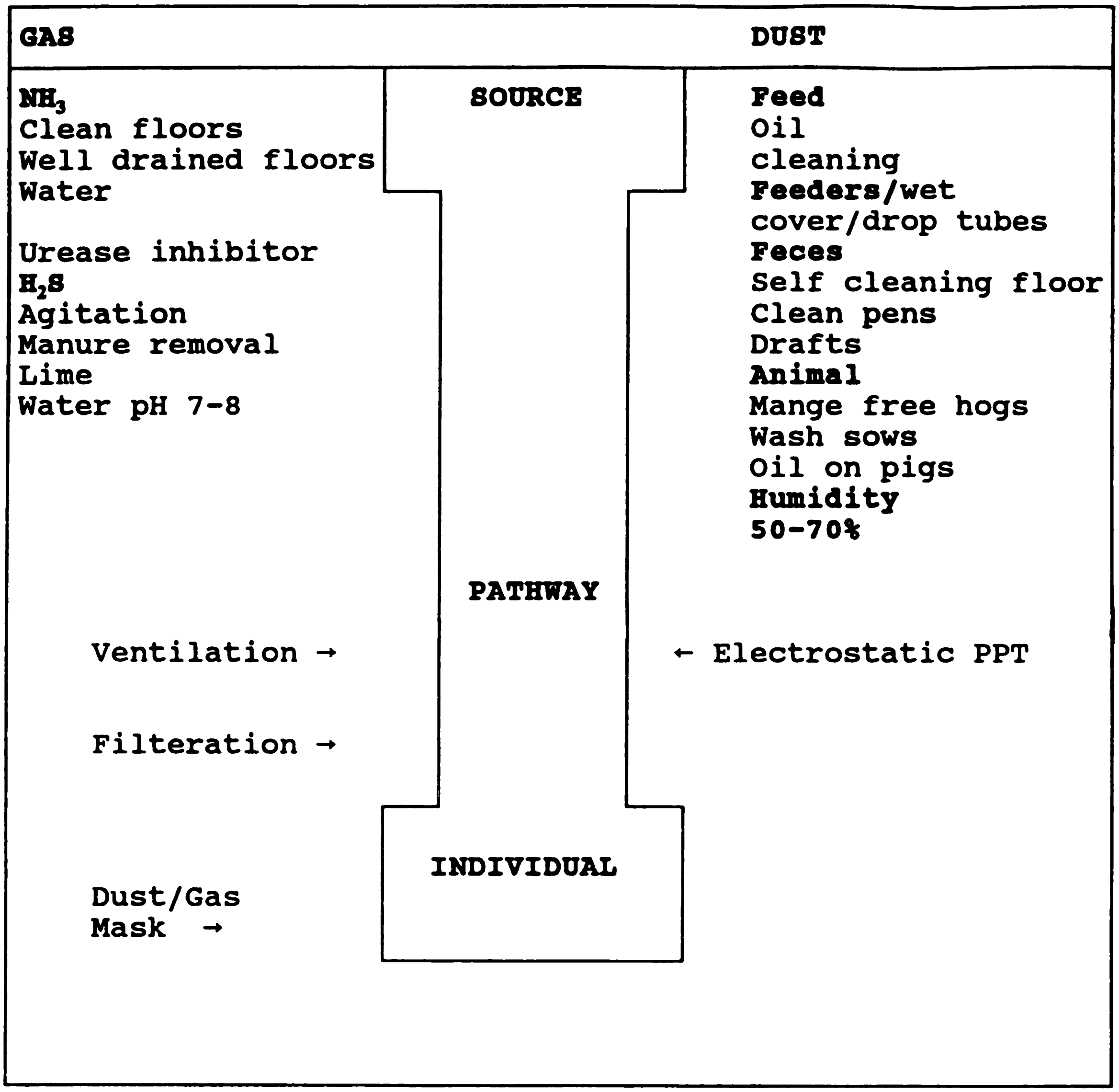

Figure 1. Pathway to environmental control[a]
[a]Donham, 1989b.

Shortcomings of existing research

De Boer and Morrison (1988) have compiled an extensive literature review on air pollutants in the environment of livestock confinement quarters and have outlined the following shortcomings of existing research:

1. Lack of environmental control in many studies is not uncommon. Factors such as temperature, humidity, age and number of animals, type of feed and time of day sampling is done are not specified.
2. Sampling methods vary widely among studies, making comparisons difficult. There are no apparent conversion formulas for different sampling techniques.
3. The number of sampling locations within a building and the frequency of sampling are often inadequate, making study results questionable.
4. Environmental chamber studies often used artificially generated contaminants (e.g. corn starch, corn meal) which were not truly representative of the confinement house atmosphere.
5. Field studies and surveys predominate, while controlled experiments are few.
6. Animal activity is frequently singled out by authors as the most important factor influencing atmospheric dust levels. However, no reports have actually quantified and characterized this activity (i.e. causal factors).
7. There is a lack of comprehensive material addressing

potential health risk associated with hog farming and agriculture in general.

8. In many studies, the cost of the sampling equipment becomes a limiting factor to good methodology. For example, most studies have indicated the use of only one cascade impactor. This does not allow for simultaneous sampling among different rooms or treatments or for multi-point sampling within a room.

EFFECT OF SOYBEAN OIL AND CHOICE WHITE GREASE ON DUST AND MOLD LEVELS INSIDE FARROWING CONFINEMENT ROOMS

Introduction

As intensive livestock housing becomes an ever-growing reality in livestock production, it becomes increasingly evident that the environment within these buildings is a major limiting factor in productivity. Intensive livestock housing with poor environments encourage animal rights activists. If the industry does not address the environmental issues, then perhaps the government will be forced to do so by regulation (Donham, 1989b). The environment within livestock buildings limits human productivity. Additionally, 60% of the workers have one or more respiratory complaints. It is difficult to retain employees under these conditions. Air quality in swine housing is a problem that has grown with the increased use of confinement buildings. Air quality becomes a serious problem when higher than tolerable levels of dust are present. This is particularly a problem for those who spend a majority of their work hours in this environment. The quality of air within total confinement swine buildings can be lowered by the presence of atmospheric contaminants such as dust and molds. While the potentially adverse effects of gaseous contaminants on performance and both pig and human health have been recognized to some degree, dust is still viewed primarily as a nuisance. However, dust in the animal environment is a significant contaminant because of its association with potential pathogenic microorganisms, respiratory diseases, deterioration of buildings and equipment and as a carrier of obnoxious odors (Curtis., 1981).

Farrowing crates, thermostats, fan motors, and other accessories may become less reliable or have to be replaced more frequently due to malfunction caused by dust and gases. Dust is potentially dangerous not only as a carrier of pathogenic microorganisms and harmful gases, but also because of its direct adverse effect on both humans and animals (Honey and McQuitty, 1979). Animal populations in enclosed buildings create quantities of dust that is difficult to remove with standard ventilation systems.

Previous research has shown that the addition of fats and oils will significantly reduce and control dust levels inside swine units. However, little research has been conducted evaluating various dietary inclusion levels of fats and oils in lactation diets to determine an ideal lipid level for dust control in the farrowing house. The farrowing area is the most important area concerning worker health because workers spend the most time here processing litters, hand feeding sows, keeping records on sows etc. Since people have the greatest exposure time in the farrowing area, it should be imperative that we concentrate on controlling dust and gases here first. In addition, since soybean oil and choice white grease are two of the most commonly used fat sources to reduce dust and because of cost differences between animal fats and vegetable oils, and differences in physical form and diet mixing completeness, it is imperative that these sources be evaluated and compared on ability to reduce facility dust levels. This study was conducted to determine the effect of 1, 3, and 5% soybean oil and 1, 3, and 5% choice white grease in lactation diets on dust and mold levels inside the farrowing room.

Materials and Methods

Criteria measured includes: total aerial dust, respirable range dust, nonrespirable range dust, settled dust, and mold colony forming units.

Ninety-six multiparous sows (Yorkshire x Landrace and Purebred Yorkshires) were randomly allotted to two replications of eight treatments (6 sows/treatment) and placed in farrowing rooms on day 108-112 of gestation for a 28 day lactational period. Treatments consisted of a 15.5% crude protein ground basal control diet (0% added lipid), and basal diet supplemented with 1, 3, or 5% soybean oil, or 1, 3, or 5% choice white grease. Corn was replaced with the lipid source on an equal weight basis. Table 9 shows composition and nutrient analysis of diets. Feed samples were sent to the Kansas State University Department of Grain Science for particle sizing. The results showed 56,979 particles/gram of feed, with a mean particle size of 770 microns and a standard deviation of 87.4 for the control diet.

Table 9. Composition and calculated nutrient analysis of diets

	Diets[ab] %lipid			
	0	1	3	5
Ingredient lbs.				
Corn	1480	1460	1420	1380
Mono-Dical	35	35	35	35
Limestone	27	27	27	27
Soybean meal 44%	428	428	428	428
MSU Vit-TM premix	10	10	10	10
Salt	10	10	10	10
Sodium selenite [d]premix	10	10	10	10
Lipid[a]	00	20	60	100
Nutrient Analyses[c]				
ME Kcal/kg	3124	3164	3245	3324
Crude protein, %	15.7	15.6	15.5	15.3
Lysine, %	0.79	0.79	0.79	0.78
Phosphorus, %	0.71	0.71	0.71	0.70
Available Phosphorus, %	0.45	0.45	0.45	0.45
Calcium, %	0.90	0.90	0.90	0.90
Salt, %	0.50	0.50	0.50	0.50
Crude fiber, %	3.19	3.17	3.12	3.08
Selenium ppm	0.55	0.55	0.55	0.55
Vit-E IU/kg	16.80	16.50	16.10	15.6
Fe ppm[e]	111.00	111.00	110.00	109.0
Cu ppm[f]	20.20	20.20	20.10	20.0

[a]Soybean oil or Choice White Grease
[b]AsFed basis
[c]Calculated analysis/Spartan Swine V.2.
[d]Se premix containing 200 ppm Se
[e]Ferrous sulfate/Iron oxide
[f]Copper sulfate

This study was conducted at the Michigan State University Swine Teaching and Research Center. Sows were housed in two similar farrowing rooms that contained 6 crates each. Room dimensions were 8.5 m length, 3.7 m width, and 2.4 m height. The farrowing room environment was regulated using a Fancom® computer system which independently controlled each room's ventilation and heat, while continuously monitoring relative humidity and temperature. A continuous minimum ventilating rate was maintained at 14 cfm/sow and litter which provided 2 air changes per hour, while the maximum ventilating rate was 240 cfm/sow and litter providing 33 air changes per hour. Relative humidity (RH) and temperature was maintained at 62% +/- 3% and 18^{0}C +/- 2^{0}C respectively (additional RH measurements were taken with a Solomat™ RH detector).

The flooring material was uncoated woven wire. The farrowing rooms were cleaned with a power washer between treatments before each new group of sows were brought in. The manure storage was emptied by gravity by pulling the drain plug and allowing the contents to flow out of the shallow-V gutters and into an outside lagoon every 7 days. The feeding method was maintained constant throughout all trials. All sows were hand fed as much as they would eat twice a day at 7:30 am. and at 4:00 pm.

All aerial dust sampling (total, respirable, nonrespirable) was done with an Anderson sampler[a]. The Anderson sampler is a multi-stage, multi-orifice cascade impactor which normally is used in the environmental working areas to measure the size distribution and total concentration levels of all liquid and solid particulate matter. A constant air sample flow of 1 ambient cubic foot per minute (ACFM) is provided by a continuous duty, carbon-vane vacuum pump. Ambient gases enter the inlet cone and cascade through the succeeding orifice stages with successively higher orifice velocities from stage 1 to stage 8. Successively smaller particles are inertially impacted onto the glass fiber filters.

The human respiratory tract is an aerodynamic classifying system for airborne particles. The dust-catching mechanism of the upper respiratory system operates somewhat like the Anderson impactor. Particles larger than 10 microns diameter are almost completely removed in the nasal passage. Removal in the upper respiratory area drops to essentially zero at 1 micron diameter. Dust removal is high in the pulmonary air spaces, being essentially 100% for particles 2 microns or larger (Bundy, 1984). The Anderson impactor device is used as a substitute for the respiratory tract as a dust collector. As

---

[a]Anderson 8 stage non-viable particle sizing sampler.
ANDERSON SAMPLERS, INC. Atlanta, Georgia 30336

such, it should reproduce to a reasonable degree the dust collecting characteristics of the human respiratory system so that lung penetration by airborne particles can be predicted from sampling data. The sampling instrument should therefore classify the particles collected according to the aerodynamic dimension as illustrated in Figure 2, which is the true measure of lung penetrability (Hatch, 1955).

The Anderson impactor collected aerial dust on glass fiber filters that were weighed prior to the dust collection. After the collection was completed the filters were weighed and the tare weight was subtracted to ascertain the mass of dust collected on each filter.

Aerial dust measurements were taken weekly (one sample/week) on day 1, 7, 14, 21, and 28 for all treatments (rooms were sampled consecutively). The Anderson sampler was placed in the center of the farrowing room at worker height 1.5 meters above the floor.

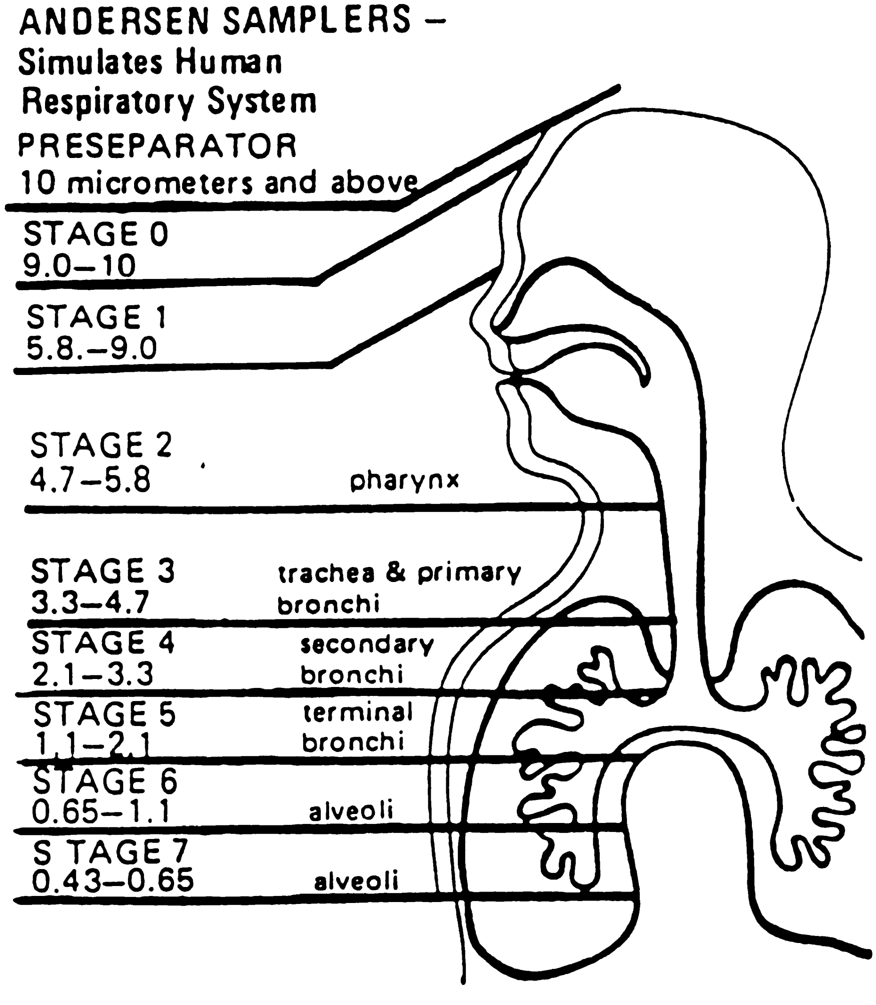

FIGURE 2

ANDERSEN SAMPLER SIMULATES HUMAN RESPIRATORY SYSTEM.

Confinement house contaminants have been shown to follow both a diurnal and an annual pattern. The first is due mainly to daily barn activities, while the second reflects the weather-dependent microclimate adjustments (De Boer and Morrison, 1988). Therefore, standardizing the exact time of sampling is critical.

In order to eliminate any annual effects, all trials were carried out in the cooler months (October to May). Sampling duration was 2 hours in each room, between the hours of 10:00 am. and 2:00 pm. This sampling duration and time should have removed any diurnal effects and the elevated aerial dust levels associated with high animal activity at feeding time. Figure 3 illustrates the effect that high animal activity had on the total aerial dust levels in these trials. The two spiked increases in aerial dust (8.2 mg/m^3 and 9.1 mg/m^3) were measured during a time of high animal activity and were the result of feeding sows in the morning and afternoon. The two spiked increases in aerial dust lasted approximately 30 minutes, the same duration of time it took the sows to finish eating and lie down. Aerial dust levels then decreased to a baseline level of 4.1 mg/m^3. Therefore, sampling time was set to be between the two feeding times (10:00 am to 2:00 pm).

INFLUENCE OF ACTIVITY ON AIRBORNE DUST

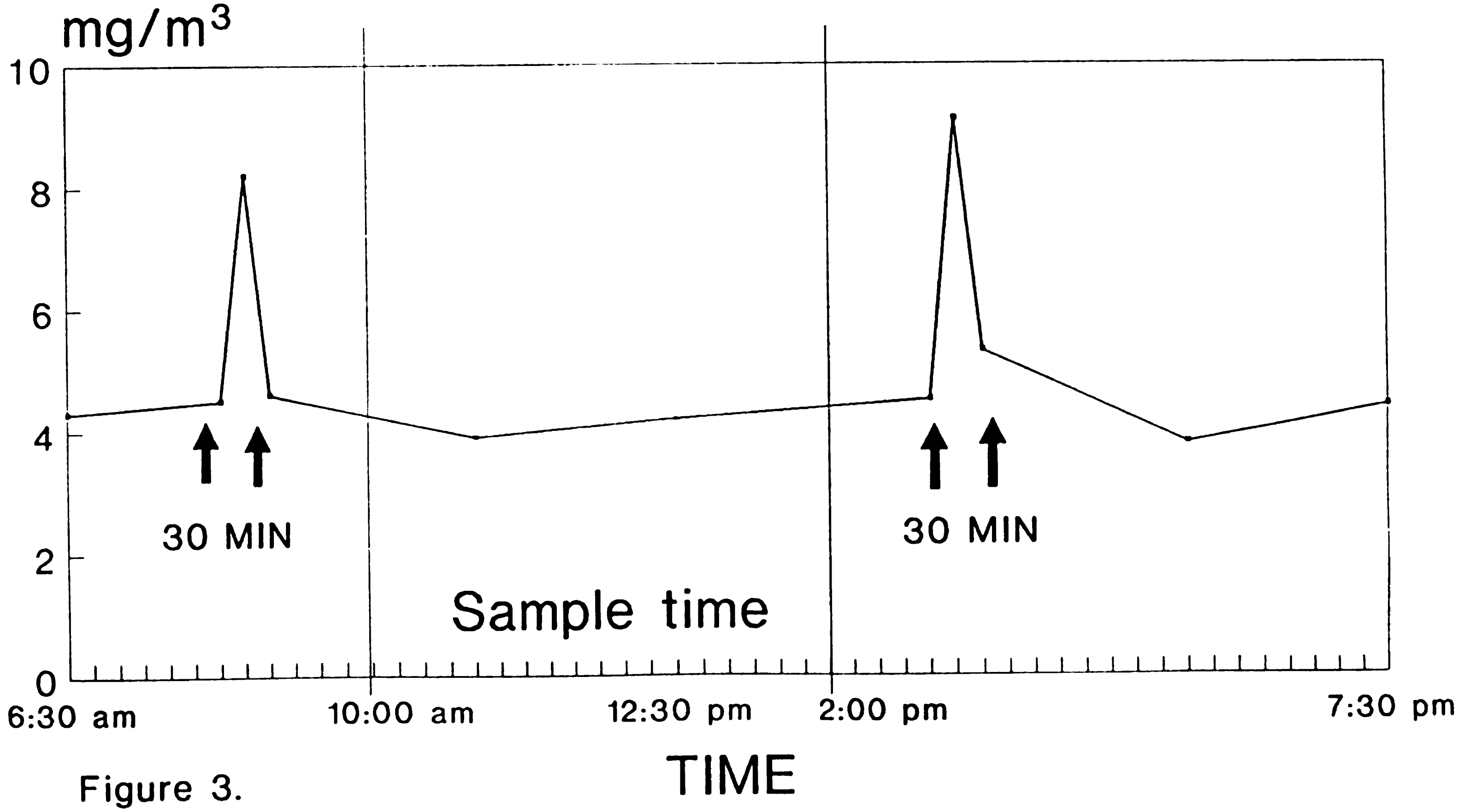

Figure 3.

Settled dust measurements were taken gravimetrically by weighing the dust that settled on a 9 centimeter millipore polyester microweb prefilter which was placed inside a 9 centimeter petri dish. Ten petri dishes were uniformly spaced throughout each room (figure 4.), and were placed approximately 1.5 meters above the floor. The prefilters were weighed after the collection of dust. The settled dust was measured weekly on day 7, 14, 21, and 28. The collection dishes were allowed to collect dust that settled into them for a 7 day period.

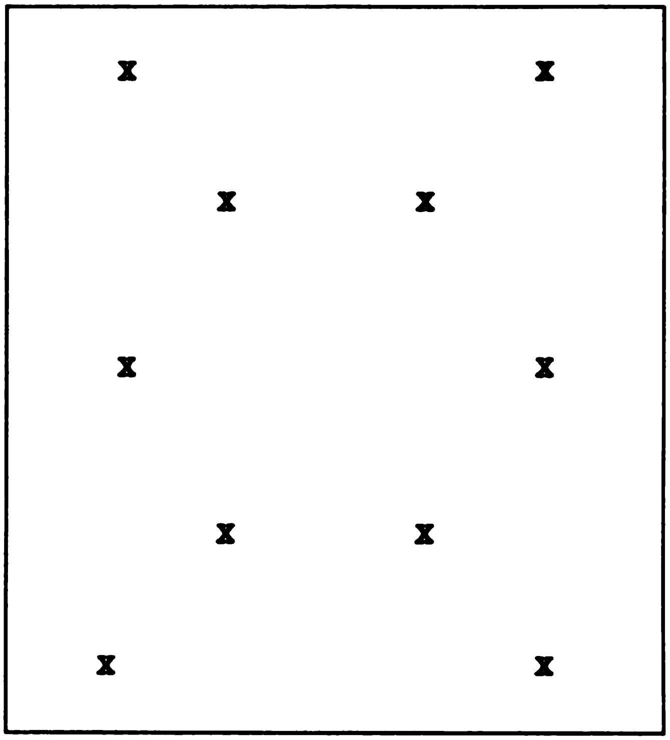

Figure 4. X = settled dust sampling location in farrowing rooms.

Mold colony forming units were enumerated from the settled dust since the aerial dust was collected with a nonviable sampler. After prefilters were measured for settled dust, they were rolled up and placed into 10 ml sterile test tubes. The dust was then harvested by injecting 1.5 ml sterile peptone water (.1%) with .01% Tween 80 into the tubes to moisten the prefilter. Five ml more of the peptone water preparation was added to the tubes. The tubes were stoppered and shaken for 15 minutes. The wash fluid was removed, serially diluted (.5%, .05%, and .005%) and plated onto a malt extract agar using the spread plate method (maltose,12.75g; dextrin,2.75g; glycerol,2.35g; peptone,.78g; agar,15g; 1000 ml distilled water, pH 4.6). After incubation at 36^{0}C for 36 hours colonies were counted. Three replications were done on each dilution to get reasonable consistency. The dilution was used that produced the plate count of 30-300 colonies, as levels below or above this count are inaccurate.

Statistical analysis consisted of analysis of variance with repeated measurements over time using the general linear model of SAS™. Main effects include the source of lipid (soybean oil or choice white grease) and lipid level (0, 1, 3, or 5%).

If all interactions are important (P<.25) then source comparisons are conditional on level and time, and level comparisons are conditional on source and time.

Means of lipid levels were separated using orthogonal polynomials.

If the source by level interaction is nonsignificant ($P>.25$) then means of lipid levels were pooled among sources to test the effect of lipid level on the dependent variable. In addition, the means of lipid sources were pooled among lipid levels to test the effect of lipid source on the dependent variables.

Results and Discussion

The results for total airborne dust, nonrespirable range dust, respirable range dust, settled dust, and mold colony forming units are presented in tables 10 through 20, respectively.

Total airborne dust is defined as the summation of all particles impacting on all 8 stages of the sampler or those particles in the size range of .43 to 10.0 microns. Throughout all trials the mean total airborne dust level for the control was 4.4 mg/m^3. This coincides with Donham's et al. (1986) reported average of 4.1 mg/m^3 of total aerial dust inside 9 farrowing facilities in Iowa. However, the mean concentration of total aerial dust measured in these trials was nearly twice the suggested exposure threshold value considered safe for human health (2.4 mg/m^3) (Donham et al., 1990). The supplementation of soybean oil (SO) and choice white grease (CWG) resulted in an overall linear reduction of total airborne dust from 5.4 mg/m^3 to 1.7 mg/m^3 ($P<.03$) for SO and from 3.4 mg/m^3 to 1.2 mg/m^3 ($P<.09$) for CWG (Tables 10-11). The addition of 1, 3, and 5% CWG showed a 57, 55, and 65% reduction of total airborne dust respectively. Furthermore, adding 1, 3, and 5% SO reduced total airborne dust by 28, 41, and 69% respectively. It appears that total airborne dust can be lowered to a more safe level by the dietary addition of CWG or SO. This is important when looking at the corrosion this dust causes on equipment and the initial nuisance dust load that workers are exposed to.

Dust in the nonrespirable range are those particles impacting on stages 1 and 2 which represent particles in the size range of 5.8 to 10.0 microns. This size range is indicative of those particles that would normally be caught and filtered out in the nasal passages and throat. The mean level of dust found in the nonrespirable range of the control diets was 2.20 mg/m^3. The dust in the nonrespirable range made up approximately 50% of the total airborne dust and was determined to be the summation of all dust collected on stages 1 and 2 of the cascade impactor sampler. The nonrespirable dust seem to increase numerically over time, although not significantly. The dietary addition of SO and CWG resulted in a linear reduction of dust in the nonrespirable range from 2.57 mg/m^3 to 1.02 mg/m^3 ($P<.01$) as increasing levels of SO were added to the diet. Likewise, as the level of CWG increased, the nonrespirable dust was reduced from 1.80 mg/m^3 to .70 mg/m^3 ($P<.002$) (Tables 13-14). This represents a reduction of approximately 60%.

No other source by level interactions existed (P>.25) for remaining criteria measured so data were pooled for main effect analysis. Results are summarized by lipid source, and lipid level.

The respirable range dust is meaningful in that it is indicative of the dust that becomes deposited along the pharynx and trachea, and more importantly drawn into the bronchi and alveoli of the lung. Dust in the respirable range are those particles that have an aerodynamic size of .43 to 5.8 microns. Respirable range dust represents the total mass of all dust collected on stages 3 through 8 of the Anderson sampler and accounted for approximately 50% of the total aerial dust concentration.

The mean level of dust measured in the respirable range was 2.74 mg/m^3, this level is consistent with the mean respirable dust level (2.7 mg/m^3) that Donham et al. (1986) reported in 9 farrowing units. The respirable range dust showed a small numerical increase from week 1-4 for all treatments. However, increasing the dietary lipid level resulted in an overall linear reduction (P<.04) of dust in the respirable range from 2.74 mg/m^3 to 0.7 mg/m^3 (Table 15).

There was no significant treatment effects by lipid source (Table 16). However, the additions of 1, 3, and 5% dietary lipid caused a decrease of 49, 52, and 74% respirable range dust respectively. Although the increasing levels of dietary lipid showed a significant reduction on respirable range dust, it did not reduce this dust to a safe level according to Donham's et al. (1990) suggested threshold exposure level of 0.24 mg/m^3. Donham et al., (1990) stated that respirable range dust in excess of this threshold value has been associated with a higher proportion of work related disease and lower production parameters.

The mean level of settled dust for the control treatment was 10.8g/m^2/wk. Although the amount of settled dust numerically increased over time, there was an overall linear reduction from 10.8 g/m^2/wk to 6.1 g/m^2/wk (P<.09) (Table 17) as the dietary lipid level was increased. The addition of 1, 3, and 5% lipid to the diet resulted in a 31, 24, and 43% reduction of settled dust respectively. Furthermore, the lipid source CWG (7.2 g/m^2/wk) had a tendency to show a greater reduction than SO (9.0 g/m^2/wk) for settled dust (P<.16). This reduction was most notable in week 3 (P<.08) when settled dust for SO treatment was 12.2 g/m^2/wk and the CWG treatment was 8.05 g/m^2/wk (Table 18). Brumm (1991) reported that reducing settled dust within the facility may also mean less dust that can become airborne with pig or human activity, ventilation or low humidity conditions. These trials support this theory as settled dust and aerial dust were reduced simultaneously.

Settled dust that was heat fixed to slides and evaluated under a compound microscope (x100 magnification) for qualitative observation appeared to be heterogeneous in nature with a great diversity of shape and composition. Some of the components identified were: feed particles, epithelial cells, hair or corn silk, and insect parts. Feed components and epithelial cells appeared to make up the majority of dust present.

Mold colony forming units (MCFU) showed a linear reduction ($P<.001$) as a result of increasing the level of lipid in the diet. MCFU displayed a reduction of 40, 73, and 88% by adding 1, 3, and 5% lipid to the diet respectively.

The average MCFU in the control treatments was 14.1×10^4/g of dust which is well below the threshold limit value (1.3×10^5) reported by Donham et al., (1990). MCFU was decreased ($P<.001$) to 1.6×10^4/g of dust as the dietary lipid level increased (Table 19). In addition, the lipid source CWG (6×10^4/g) was more effective than SO ($P<.09$) (8×10^4/g) in reducing MCFU's (Table 20). MCFU's tended to decrease over time. This may be due to the fact that the rooms were power washed at the beginning of each trial and may not have had time to dry completely. The reason for any decrease in MCFU due to dietary additions of lipid is not clear. One reason may be that by reducing dust levels we are also reducing MCFU's because a large number of molds may be attached to dust particles.

Table 10: Effect of soybean oil on total airborne dust levels (mg/m^3)[ab]

	Level of Soybean Oil (%)				
Week	0	1	3	5	P value
1	1.8	1.2	1.6	1.0	NS
2	5.4	2.6	2.7	1.2	NS
3	6.3	3.3	4.1	1.7	NS
4	6.4	5.1	3.6	2.7	NS
5	7.2	7.1	4.1	2.2	.02
1-5	5.4	3.9	3.2	1.7	

[a]Overall linear effect ($p<.03$)
[b]SEM within period =1.0, within treatment =1.7

Table 11: Effect of choice white grease on total airborne dust levels (mg/m^3)[ab]

	Level of Choice White Grease (%)			
Week	0	1	3	5
1	.96	.84	.74	.79
2	5.42	1.04	.97	.90
3	3.10	1.30	1.65	1.25
4	3.45	1.85	1.95	1.40
5	4.10	2.20	2.30	1.70
1-5	3.40	1.45	1.52	1.20

[a]Overall linear effect ($P<.09$).
[b]SEM: within period =2.0, within treatment =1.9

Table 12: Effect of soybean oil on dust in the nonrespirable range (mg/m^3)[abc]

	Level of Soybean Oil (%)			
Week	0	1	3	5
1	.78	.72	1.10	.47
2	1.54	1.13	1.13	.69
3	2.27	2.22	2.10	1.07
4	3.68	3.47	2.06	1.30
5	4.56	4.20	2.91	1.59
1-5	2.57	2.34	1.86	1.02

[a]Overall Linear effect (P<.01).
[b]SEM: within period =.08, within treatment =.06
[c]Particle size range greater than 5.8 microns

Table 13: Effect of choice white grease on dust in the nonrespirable range (mg/m^3)[abc]

	Level of Choice White Grease (%)			
Week	0	1	3	5
1	.70	.42	.49	.36
2	1.45	1.00	.65	.53
3	1.85	.73	1.01	.60
4	2.32	1.28	1.12	.92
5	2.71	1.46	1.52	1.10
1-5	1.81	.98	.95	.70

[a]Overall Linear effect (P<.002).
[b]SEM: within period =.035, within treatment =.033
[c]Particle size greater than 5.8 microns

Table 14: Effect of lipid level on dust in the respirable range (mg/m^3)[c]

	Lipid Level (%)[ab]			
Week	0	1	3	5
1	1.57	.46	.89	.38
2	2.63	1.31	.74	.50
3	3.19	.96	1.36	.58
4	3.20	1.72	1.90	.99
5	3.11	2.53	1.68	1.05
1-5	2.74	1.39	1.31	.70

[a]Source * Level ($P>.25$), Level ($p<.04$), and Time * Level ($p>.25$).
[b]SEM of lipid level =.17.
[c]Particle size less than 5.8 microns

Table 15: Effect of lipid source on dust in the respirable range (mg/m^3)[abc]

	Lipid Source	
Week	Soybean Oil	Choice White Grease
1	2.54	.61
2	1.54	1.05
3	1.76	1.29
4	1.92	1.99
5	1.75	2.44
1-5	1.90	1.40

[a]No significant treatment effects of lipid source.
[b]SEM of lipid source =.22
[c]Particle size less than 5.8 microns

Table 16: Effect of lipid level on settled dust ($g/m^2/wk$)

	Lipid level (%)[ab]			
Week	0	1	3	5
1	4.95	3.65	3.60	3.62
2	8.52	5.50	6.70	4.70
3	13.47	9.15	10.47	7.40
4	16.27	11.30	12.07	8.82
1-4	10.80	7.40	8.21	6.13

[a]Source * level (p>.25), Level (p<.09), and time * level (p>.23).
[b]SEM of lipid level =.27

Table 17: Effect of lipid source on settled dust ($g/m^2/wk$)

	Lipid source[ab]	
Week	Soybean Oil	Choice White Grease
1	4.15	3.76
2	6.91	5.81
3	12.20[c]	8.05[c]
4	12.71	11.52
1-4	9.00	7.20

[c]Means within row with same superscript differ (P<.08).
[a]Source * level (p>.25), source (p<.16), and time * source (p<.05).
[b]SEM of lipid source =.47

Table 18: Effect of lipid level on mold colony forming units (CFU X10^4/g)[ab]

	Lipid Level(%)			
Week	0	1	3	5
1	18.60	9.12	5.85	2.50
2	13.52	12.20	5.42	2.27
3	12.40	5.32	2.35	1.22
4	11.80	7.35	1.60	.67
1-4	14.08	8.50	3.80	1.67

[a]source * level (p>.25), and level (p<.001).
[b]SEM of lipid level =.71

Table 19: Effect of lipid source on mold colony forming units (CFU X 10^4/g)

	Lipid Source[ab]	
Week	Soybean Oil	Choice White Grease
1	10.33	7.70
2	10.60	6.11
3	5.42	5.22
4	5.63	5.07
1-4	8.00	6.00

[a]Source * Level (p>.25), and Source (p<.09).
[b]SEM of Lipid Source =.63

EFFECT OF SOYBEAN OIL AND CHOICE WHITE GREASE ON CARBON DIOXIDE, AMMONIA, AND SOW PERFORMANCE INSIDE FARROWING CONFINEMENT ROOMS

Introduction

The environment within livestock buildings limits human and animal productivity. Furthermore, 60% of the workers have one or more respiratory complaints (Donham et al., 1989a). In the last 7 years, at least 19 workers have died within the premises of swine units due to high gas levels (Donham et al., 1982). Swine exposed to high levels of gases may experience reduced growth rate and feed efficiency (Curtis et al., 1986). Most pork producers are familiar with the need to provide adequate air for ventilation to control heat and moisture within a swine unit. Survey suggest air quality is poor in existing swine facilities, especially in winter weather with ventilation systems operating at minimal rates (Gerber et al., 1989). Gerber et al., (1989) surveyed 75 farrowing units and reported that 64% of the facilities had ammonia concentrations of 10 ppm or greater at people level and 14.6% had greater than 20 ppm at pig level. Aside from the purposes of strict research, Donham (1987) outlined other situations for which gas monitoring is useful. These include: (a) to assure good air quality during everyday operating procedures; (b) to document possible harmful levels where human or animal health problems have been noted; (c) to assure that toxic gas levels are not rapidly rising when undertaking potentially dangerous tasks (e.g. emptying a manure pit); (d) to investigate premises where losses of hogs due to building or ventilation malfunction may lead to suits against manufacturers; and (e) to evaluate the effectiveness of building management procedures or retrofitted environmental control systems.

Manure gases are most effectively controlled by frequent removal of manure from the facility. In general, the gases associated with decomposition of the manure are not released from stored manure until 5-7 days after storage begins. New and remodeled facilities are now being designed for frequent removal of the manure to an outside storage device. This is accomplished with pull-plug manure systems and flush gutter systems.

Several toxic gases may be present in swine confinement units. When liquid manure is stored, the bacteria there release various gases as metabolic by-products (Von Essen, 1991). Gases produced in this way include hydrogen sulfide, methane, ammonia, and carbon dioxide. In addition, carbon dioxide is excreted into the air by the hogs living in the confinement unit. These gases vary greatly in their ability to cause toxicity in humans and swine. Some act as metabolic poisons and/or directly injure the lung, while others replace the oxygen in the air. The amounts of each gas present may vary from one exposure time to the next, such that entering a pit without a protective device may be safe on one occasion, but quite dangerous on another day (Von Essen, 1991).

The objective of this study was to evaluate the levels of ammonia and carbon dioxide in the farrowing unit and measure the impact of adding dietary soybean oil or choice white grease on these gases. In addition, the effect of added dietary soybean oil or choice white grease was evaluated for the following sow performance criteria; lactational weight loss, feed intake, sow postpartum and weaning weight, number of pigs weaned, and adjusted 21 day litter weight.

Materials and Methods

Ninety-six whiteline multiparous sows (Yorkshire x Landrace and purebred Yorkshires) were randomly allotted to two replications of eight treatments (6 sows/treatment) and placed in the farrowing house on day 108-112 of gestation for a 28 day lactational period. All sows were weighed immediately postpartum and again at weaning time (28 days) to ascertain lactational weight loss. In addition, number of pigs weaned, adjusted 21 day litter weights, and sow feed intake were also measured. Treatments consisted of a 15.5% crude protein ground basal control diet (0 added lipid), and control diet supplemented with 1, 3, or 5% soybean oil, or 1, 3, or 5% choice white grease. Corn was replaced with the lipid source on an equal weight basis. Table 9 shows composition and calculated nutrient analysis of diets.

This study was conducted inside the monoslope farrowing-nursery unit at the Michigan State University Swine Teaching and Research Center. Sows were housed in two similar farrowing rooms that contained 6 crates each. Room dimensions were 8.5 m length, 3.7 m width, and 2.4 m height. The farrowing room environment was regulated using a Fancom® computer system which independently controlled each room's ventilation and heat, while continuously monitoring relative humidity and temperature. A continuous minimum ventilating rate was maintained at 14 cfm/sow and litter which provided 2 air changes per hour, while the maximum ventilating rate was 240 cfm/sow and litter providing 33 air changes per hour. Relative humidity and temperature was maintained during sampling at 62% +/- 3% and 18^0 C +/- 2^0 C respectively (backup RH measurements were taken with a Solomat™ RH sensor).

The farrowing rooms were cleaned with a power washer between treatments before each new group of sows were placed in the farrowing rooms. The manure storage was emptied by gravity by pulling the drain plug and allowing the contents to flow out of the shallow V gutters and into an outside lagoon every 7 days.

Confinement house gases have been shown to follow an annual pattern of higher levels in the winter and lower concentrations of gases in the summer months (De Boer and Morrison, 1988). The annual pattern is primarily a function of closing buildings up and lower ventilating rates in the winter compared to more open buildings with higher ventilating rates in the summer (Gerber et al., 1988). In order to eliminate any annual effects, all trials were carried out in the cooler months (October to May).

Ammonia and carbon dioxide measurements were taken simultaneously with aerial dust on day 1, 7, 14, 21, and 28 in each farrowing room. Curtis and Backstrom (1986) reported that environmental factors may vary over space and time, therefore, measurements should be taken where either the pigs or humans encounter the gases. Average gas concentrations were determined by taking samples in replicate at worker level 1.5 meters above the floor. Ammonia and carbon dioxide levels were measured with Kitagawa® precision gas colorimetric detector tubes. Colorimetric tubes have been widely used in routine field sampling and many research studies. The reagent inside the tube is specific for each type of gas being measured. The reagent that detects ammonia and carbon dioxide is phosphoric acid and hydrazine respectively. The colorimetric tubes are used along with a 100 cc capacity syringe to draw an air sample into silica gel that is chemically impregnated with a colorimetric reagent. The gas concentration is determined by the length of the color stain.

Statistical analysis consisted of analysis of variance with repeated measurement over time using the general linear model of SAS™. Main effects include the source of lipid (soybean oil or choice white grease) and lipid level (0, 1, 3, or 5%).

If all interactions are important (P<.25) then source comparisons are conditional on level and time, and level comparisons are conditional on source and time.

Means of lipid levels were separated using orthogonal polynomials.

If the source by level interaction is nonsignificant (P>.25) then means of lipid levels were pooled among sources to test the effect of lipid level on the dependent variable. In addition, the means of lipid sources were pooled among lipid levels to test the effect of lipid source on the dependent variables.

Results and Discussion

The results for ammonia, carbon dioxide, feed intake, sow weight loss, postpartum and weaning weight, adjusted 21 day litter weights, and number of pigs weaned, are presented in tables 21-24. There were no source by level interactions (P>.25) for the criteria measured (except number pigs weaned) so data were pooled for main effect analysis. Results are summarized by lipid source, and lipid level.

Increasing the level of dietary lipid reduced both ammonia (P<.002) and carbon dioxide (P<.003) concentrations by 42% in the farrowing rooms. As the lipid level increased, ammonia was decreased from 1.9 ppm to 1.1 ppm, likewise, carbon dioxide was reduced from 204 ppm to 118 ppm (Table 21). These findings are consistent with those reported by Chiba et al., (1987) when he showed a 60% reduction of ammonia by adding 7.5% tallow to grow-finish diets. However, it should be noted that the level of ammonia measured in these trials was well below those concentrations (7-50 ppm) found in 75 swine units as reported by Gerber et al., (1988). In addition, the gas levels in these trials were well below the threshold limit values for ammonia (7-9 ppm) and carbon dioxide (1500 ppm) as reported by Donham et al., (1988). An explanation for the reduction of gases may lie in the fact that gases become absorbed and attached to aerial dust particles (Donham et al., 1986). Therefore, by reducing aerial dust, we may also be reducing the gases that are bound to the aerial dust. Neither ammonia or carbon dioxide showed a significant source effect for soybean oil or choice white grease (Table 22).

Sow weights measured at postpartum and at weaning, averaged 212 and 195 kg respectively and were not affected by treatments (Table 23-24). In addition, sow feed intake averaged 178 kg/28 day lactation, and was not changed due to dietary treatments (Table 23-24). However, there was a significant reduction (P<.003) in the amount of weight that sows lost over the 28 day lactational period. As the level of lipid increased from 0 to 5%, the sow weight loss was decreased from 21.7 to 7.4 kg/28 day lactation (Table 23). I would expect the difference in sow weaning weights to have an impact on the time to return estrus for sows (longer for light sows than heavy sows) although no post-weaning reproductive data were collected. There was no significant difference due to lipid source (Table 24).

Since feed intake and energy content of feed were not influenced by treatments (Table 9), it is not clear why there was a reduction (P<.003) in the amount of weight that sows lost over the lactation period when higher levels of lipid were fed. One explanation may be that the thoroughness of digestion and absorption of any nutrient is a direct result of the rate at which these processes occur and the time available. Digesta containing a high concentration of fat move through the gastrointestinal tract more slowly than do digesta with lower fat concentrations, allowing more time for digestion and absorption of other nutrients (Pettigrew and Moser, 1989). Thus, adding fat to a swine diet improves the digestion of carbohydrates and proteins in the small intestine (Sauer et al., 1980; Just, 1982). The efficiency of use of proteins and carbohydrates is greater if they are digested in the small intestine than in the large intestine (Sauer et al., 1980; Just, 1982). This causes the total energetic gain from adding fat to be greater than otherwise would be expected.

Adjusted 21 day litter weights were not influenced by the addition of dietary lipids (Table 23-24). The lipid source of choice white grease seemed to reduce (P=.05) the number of pigs weaned per litter over that of soybean oil, 9.8 verses 8.5 pigs weaned per litter respectively (Table 24). However, there was a 1 pig born live advantage for the soy oil group.

Therefore, this decrease in number of pigs weaned is more than likely due to the difference in number of pigs born live than the treatment of lipid sources.

Table 20: Effect of lipid level on gases in the farrowing house

	Lipid Levels (%)			
Week	0	1	3	5
	Carbon Dioxide (ppm)[ab]			
1	137.5	131.2	193.7	100.0
2	187.5	100.0	162.5	125.0
3	218.7	156.2	131.2	150.0
4	275.0	187.5	256.2	100.0
1-4	204.0	143.0	186.0	119.0
	Ammonia (ppm)[cd]			
1	1.12	1.12	1.00	1.00
2	1.45	1.50	1.32	1.20
3	2.07	1.57	1.75	1.52
4	2.95	2.00	2.00	1.00
1-4	1.90	1.54	1.51	1.1

[a]Source * level (p>.25), level (p<.003), time * level (p<.003).
[b]SEM of level =5.3
[c]Source * level (p>.25), level (p<.002), time * level (p<.03).
[d]SEM of level =.04

Table 21: Effect of lipid source on gases in the farrowing house

Week	Soybean Oil	Choice White Grease
	Lipid Source	
	Carbon Dioxide (ppm)[ab]	
1	143.7	137.5
2	143.7	143.7
3	168.7	159.3
4	212.5	196.8
1-4	167.1	159.3
	Ammonia (ppm)[cd]	
1	1.00	1.12
2	1.18	1.55
3	1.81	1.65
4	2.00	1.97
1-4	1.50	1.50

[a]Source * level (p>.25), No significant source effect on carbon dioxide
[b]SEM of source = 4.5
[c]Source * level (p>.25), No significant source effect on ammonia.
[d]SEM of source = .05

Table 22: Effect of lipid level on sow and pig performance

	Level of Lipid (%)					
	0	1	3	5	P Value	SEM
Sow feed intake kg/28 day lactation	191.5	170.5	182.0	171.7	NS	6.38
Sow Wt. (kg) postpartum	211.3	208.4	214.1	215.9	NS	5.05
Sow Wt. (kg) weaning	189.6	189.3	195.7	208.5	NS	5.12
Sow Wt. loss (kg)/28d	21.7	19.1	18.4	7.4	.003	1.2
Adj 21 day litter Wt. (kg)	55.0	56.7	60.8	53.8	NS	1.5
No. pigs weaned	8.8	9.7	9.0	9.2	NS	.45

Table 23: Effect of lipid source on sow and pig performance

	Lipid Source			
	Soybean Oil	Choice White Grease	P Value	SEM
Sow feed intake kg/28 day lactation	178.7	179.2	NS	4.51
Sow Wt. (kg) postpartum	205.5	219.3	NS	5.05
Sow Wt. (kg) weaning	189.5	202.0	NS	5.12
Sow Wt. loss (kg)/28d	16.0	17.3	NS	1.20
Adj. 21 day litter Wt. (kg)	57.3	55.8	NS	1.34
No. pigs weaned	9.4	9.0	NS	.40

Cost comparison

Soybean oil (SO) has been used in swine rations on farms where heated fat systems are not available to provide ease of handling, since SO does not require heating at temperatures above -12.2 to -6.7^{0}C. Unfortunately, the high cost of SO has in many cases prohibited it's use in full line feeding. Table 25 shows the results of the cost analysis for these trials for SO verses choice white grease (CWG) at three different inclusion rates. The cost of SO is 88¢/kg and the cost of CWG is 49¢/kg. Although the cost difference per kg of feed is only a few cents, this difference adds up to $4.20 more for SO than CWG per sow over a 28 day lactation period.

The minimal equipment needed to utilize CWG on farms is a drum heater which would keep a 55 gallon drum of CWG at any desired temperature. Drum heaters are available for approximately $250. This cost comparison indicates that the savings realized from feeding 60 sows 5% CWG verses SO over a 28 day lactation period would pay for a drum heater. On larger farms (200+ sows) where full line fat feeding is used (feeding fat to all swine), a larger fat handling system would be needed. Fat systems costs range from $10,000 (for 200-400 farrow to finish) to $17,000.-$20,000. (for 500-2000 farrow to finish). These fat systems include: insulated storage tank, electric heating system with thermostat controls to maintain any desired temperature (48.8^{0}C normal storage temperature), Fat pump, valves, fill and drain couplings and fat level indicator. Table 26 shows estimated cost of fat for various size operations using full cycle fat feeding at a 5% dietary inclusion rate. The $.20/lb cost would be similar to the expense of CWG, likewise, $.40/lb would simulate the cost of SO. This table indicates a substantial savings ($12,000) for a 100 sow farrow to finish operation when feeding CWG instead of SO. These savings would more than pay for a fat handling system. Given the similar dust and gas suppressing properties between SO and CWG, and the fact that CWG is one-half the cost of SO, it is justifiable to conclude that CWG is the most desirable choice. Adding lipid levels at 1 and 3% resulted in similar dust and gas reductions, while lipid levels at 5% caused the greatest reductions for all the criteria measured. Therefore, it would be more economical to use 1% or 5% lipid level to control dust and gases in farrowing confinement units, realizing that the 5% level would offer greater air pollutant control, but at a higher cost. Since fat contains 2.25 times the energy content of corn it is easy to figure if it is economical to use fat or corn from an energy perspective. However, adding lipids to swine rations also offers the added benefit of reducing dust and other air pollutants. It is difficult to put a monetary value on this added benefit. It is not clear what it is worth to have a cleaner less dusty environment, it may be worth more to one producer and less to others. I would expect that it would be worth a lot more to the owner/owner's of large units that employ several people because of the liability imposed on the owner. If workers can prove poor or impaired health due to poor working conditions in a confinement unit a lawsuit may follow. This could cost owner/owner's of swine confinement units millions of dollars in medical bills, lost time, worker compensation, and personal injury.

Table 24: Cost analysis of diets

TREATMENT	AVG. DAILY FEED INTAKE	FEED COST ¢/kg	$/SOW/DAY	$/28 DAY LACTATION
CONTROL	6.8	13	.88	24.64
1% SO	6.1	14	.85	23.80
1% CWG	6.1	13.5	.82	22.96
3% SO	6.4	16	1.02	28.56
3% CWG	6.4	14.5	.92	25.76
5% SO	6.0	18	1.08	30.24
5% CWG	6.0	15.5	.93	26.04

* Soybean oil (SO) = 88¢/kg
* Choice white grease (CWG) = 49¢/kg (inedible)

Table 25: Estimated fat usage at 5% throughout full cycle feeding

NO. Sows	100	200	500	1000	2000
Hogs/Yr Finished	1600	3200	8000	16,000	32,000
lbs/Yr of Fat	60,000	120,000	300,000	600,000	1.2 mil
cost/yr					
$.20/lb.	$12,000	$24,000	$60,000	$120,000	$240,000
$.40/lb.	$24,000	$48,000	$120,000	$240,000	$480,000

Prepared by Rouse Marketing, Inc. Cincinnati, Ohio.

Conclusion

These data suggest that adding increasing levels of soybean oil (SO) or choice white grease (CWG) has a greater influence than lipid source, on reducing dust, gases, molds, and sow lactational weight loss. CWG is approximately one-half the cost of SO and the savings realized by using CWG instead of SO would easily pay for the extra equipment needed to handle it. Therefore, I would recommend the use of CWG over SO to anyone adding fat to swine rations because of obvious economic advantages and similar dust and air pollutant suppressing qualities. By increasing the level of lipid from 0 to 5% in the diet, there was an approximate 50% reduction of dust and gases in the farrowing house environment. Previous research by Chiba et al. (1987) suggest that adding fat levels over 5% does not reduce dust significantly more than 50-60%. Therefore, it may behoove a producer to add more than 5% fat to swine rations in order to enhance the environment, especially since levels over 5% also have a tendency to bridge in feed bins and feeders. Furthermore, the greater amount of fat there is in the feed the better the chance there is of oxidation of the fat and subsequent rancidity. Fat treated feed is less stable than untreated feed and should be used within two weeks of mixing to prevent oxidative rancidity. The likelihood of feed becoming rancid increases as the fat source becomes more saturated, and is oxidized producing more free fatty acids. CWG is more saturated than SO and contains 18.3% linoleic acid compared to 65.7% in SO.

The addition of fat to swine diets also may reduce hair and skin sloughing by better conditioning the skin and keeping it from becoming dry. However, I would not expect dietary fat to have any influence on the endotoxin in fecal material.

The dust in the respirable range clearly poses the greatest potential to cause adverse human health conditions. Consequently, even though increasing the lipid level from 0 to 5% reduced this dust significantly ($P<.04$) by 74%, this was not a large enough decrease to lower the respirable range dust to a safe level under it's threshold limit value (.23 mg/m^3). Because the treatments did not lower the respirable range dust to a safe level, I conclude that the addition of lipids to the swine ration enhances the farrowing room environment, but does not necessarily create a safe working environment. Therefore, personal protection (e.g. double strap mask, cartridge mask) should be worn for more complete protection against harmful confinement house air pollutants until a better method of environmental control is realized. The human health risk in livestock confinement units is clearly the most important consideration when looking at controlling dust and gases. Wearing personal protection seems to a temporary solution, but in the long run these contaminants must be suppressed at their source. Possible solutions may involve feed additives such as lipids or other new compounds that bind small particles to the larger ones. Feed grinders that grind feed to a very specific size with a small variation may also help in the future. Enzymes that alter the decomposition of waste may eliminate odor problems in the future. This is a serious problem that warrants more research in the formentioned areas.

Extensive respiratory symptoms and dysfunction have been documented among confinement swine workers. Confinement house dusts and gases frequently exceed recommended TLVs. These contaminants can produce a complex set of respiratory responses. The response depends on characteristics of the inhaled components (including composition, particle size, and antigenicity) and on the individual's susceptibility. The latter is affected by pre-existing respiratory conditions (including allergies and asthma), reactivity of the bronchi, and smoking history (Donham and Gustaffson, 1982). People with a history of smoking will probably be more sensitive to swine confinement dust because smoking lowers the lungs natural clearing capacity. The reactions may be due to irritant, toxic or allergic processes, alone or in combination. Since dusts occur in both respirable size and larger, deep lung tissues, small airways, and large airways may all be affected. Gases are suspected of having either an additive or a synergistic effect. Overall, it is difficult to relate responses to a specific contaminant or condition. Evidence suggest that exposed workers become increasingly more reactive to the confinement environment with increasing exposure (greater than 2 hours per day, more than 6 years work, or more swine raised) (Donham, 1987). Therefore, conditions exist which may very well predispose the workers to permanent lung impairment. I strongly advocate longer-term, follow-up studies due to the relatively recent advent of confinement swine production systems. Further work is also needed to determine dose-response relationships which would enable experts to determine exposure limits specific to the swine house atmosphere.

It is now evident that the air inside livestock buildings contains substances that are potentially hazardous to workers. Acute respiratory illness is quite common among exposed workers. However, the presence and nature of chronic and permanent lung damage has not been shown. We may use exposure

limit guidelines in buildings to help insure a safe and healthful work environment. Using these guidelines, buildings might be evaluated on a semiannual basis. This would allow for some guidelines to indicate when there is a need for engineering corrections, work practice changes, or respiratory protection to keep exposure levels within safe limits.

LIST OF REFERENCES

LIST OF REFERENCES

American Conference Governmental Industrial Hygienists. 1986/87. Threshold limit values and biological exposure indices for 1986/87. A.C.G.I.H. Inc., Cincinnati, OH.

Ames, D.R., D.E. Ray. 1983. Environmental manipulation to improve animal productivity. J. Anim. Sci. 57:209.

Anderson, D.P., C.W. Beard, and R.P. Hanson. 1966. Influence of poultry house dust, ammonia and carbon dioxide on the resistance of chickens to Newcastle disease virus. Avian Dis. 10: 177-188.

Attwood, P., R. Brouwer, P. Ruighewaard, P. Versdoot, R. Wii, D. Heederik, J.S.M. Boleij. 1987. A study of the relationship between airborne contaminants and environmental factors in dutch swine confinement buildings. Am. Ind. Hyg. Assoc. J. 48:745.

Barth, C.L., L.F. Elliott, S.W. Melvin. 1984. Using odor control technology to support animal agriculture. Transactions of the ASAE. Amer. Soc. Agr.Eng. (Abstract) 0001-2351:859.

Brumm, M.C. 1991. Water and air - you should care. Techniques for improving profitability seminars for swine producers. Extension seminar. Sept. 12-13. South Sioux City, Nebraska. pp. 25-39.

Bundy, D.S., T.E. Hazen. 1975. Dust levels in swine confinement systems associated with different feeding methods. Transactions of the ASAE. Amer. Soc. Agr. Eng. (Abstract) 75:137.

Bundy, D.S. 1984. Rate of dust decay as affected by relative humidity, ionization and air movement. Transactions of the ASAE. Amer. Soc. Agr. Eng. (Abstract) 0001-2351:865.

Burnett, W.E. 1969. Odor transport by particulate matter in high density poultry houses. Poultry Sci. 48:182.

Carpenter, G.A. 1986. Dust in livestock buildings-review of some aspects. J. agric. Eng. Res. 33:227.

Chiba, L.I., E.R. Peo, Jr., A.J. Lewis, M.C. Brumm, R.D. Fritschen, J.D. Crenshaw. 1985. Effect of dietary fat on pig performance and dust levels in modified-open-front and environmentally regulated confinement buildings. J. Anim. Sci. 61:763.

Chiba, L.I., E.R. Peo, A.J. Lewis. 1979. Use of dietary fat to reduce dust, aerial ammonia and bacterial colony forming particle concentrations in swine confinement buildings. Transactions of the ASAE. Amer. Soc. Agr. Eng. 30:464.

Chiba, L.I., E.R. Peo, Jr., A.J. Lewis. 1987. Use of dietary fat to reduce dust, aerial ammonia and bacterial colony forming particle concentrations in swine confinement buildings. Amer. Soc. Agr. Eng. 8014:464. (Abstr.).

Clark, S., R. Rylander, L. Larsson. 1983. Airborne bacteria, endotoxin and fungi in dust in poultry and swine confinement buildings. Am. Ind. Hyg. Assoc. J. 44:537.

Clark, Scott. 1986. Report on prevention and control. Amer. J. Ind. Med. 10:267.

Cocke, J.B., H.H. Perkins, Jr. and N.F. Getchall. 1978. Controlling dust in agricultural products with additives. Cereal Foods World 23(9):554-556.

Curtis, S.E., J.G. Drummond, K.W. Kelley, D.J. Grunloh, V.J. Meares, H.W. Norton, A.H. Jensen. 1975a. Diurnal and annual fluctuations of aerial bacterial and dust levels in enclosed swine houses. J. Anim. Sci. 41:1502.

Curtis, S.E., C.R. Anderson, J. Simon, A.H. Jensen, D.L. Day, K.W. Kelley. 1975b. Effects of aerial ammonia, hydrogen sulfide and swine-house dust on rate of gain respiratory-tract structure in swine. J. Anim. Sci. 41:735.

Curtis, S.E., J.G. Drummond, D.J. Grunloh, P.B. Lynch, A.H. Jensen. 1975c. Relative and qualitative aspects of aerial bacteria and dust in swine houses. J. Anim. Sci. 14:1512.

Curtis, S.E., D.J. Grunloh, D.L. Day, A.H. Jensen. 1972a. Electrostatic precipitation of airborne swine-house dust and bacteria. J. Anim. Sci. (Abstract) 35:187. No. 84.

Curtis, S.E., D.J. Grunloh, A.H. Jensen, J. Simon, B.G. Harmon. 1972b. Correlation of dust and bacteria in swine-house air. J. Anim. Sci. (Abstract) 35:187. No. 85.

Curtis, S.E., D.J. Grunloh, J. Simon, A.H. Jensen. 1972c. Aerial bactericide in occupied swine houses. J. Anim. Sci. (Abstract) 35:187. No. 86.

Curtis, S.E. and L. Backstrom. 1986. Housing and environmental influences on production. In: A.D. Leman, B. Straw, R.D. Glock, W.L. Mengeling, R.H.C. Penny and E. Scholl (eds.). Diseases of swine. 6th edition. Iowa State University Press, Ames, Iowa.

Day, D.L., E.L. Hansen, S. Anderson. 1965. Gases and odors in confinement swine buildings. Transactions of the ASAE. Amer. Soc. Agr. Eng.(Abstract) 65:118.

De Boer, S., W.D. Morrison. 1988. The effects of the quality of the environment in livestock buildings on the productivity of swine and safety of humans. A Literature Review. University of Guelph. Dept. Anim. and Poultry Science. March:88.

Donham, K.J., P. Haglind, Y. Peterson, R. Rylander, L. Belin. 1989a. Environmental and health studies of farm workers in Swedish swine confinement buildings. Brit. J. Ind. Med. 46:31.

Donham, K.J. 1989b. Relationships of air quality and productivity in intensive swine housing. Agri-Practice. 10:15.

Donham, K.J., W.J. Popendorf. 1985. Ambient levels of selected gases inside swine confinement buildings. Am. Ind. Hyg. Assoc. J. 46:658.

Donham, K.J. 1990a. Protecting your health in swine facilities. Michigan Professional Swine Producers Symposium. Feb:1.

Donham, K.J. 1990b. Your health at risk. In National Hog Farmer. Spring:6.

Donham, K.J., L.J. Scallon, W. Popendorf, M.W. Treuhaft, R.C. Roberts. 1986. Characterization of dusts collected from swine confinement buildings. Am. Ind. Hyg. Assoc. J. 47:404.

Donham, K.J., K.E. Gustaffson. 1982. Human occupational hazards from swine confinement. Annals Am. Conf.

Governmental Ind. Hyg. 2:137-142.

Donham, K.J., W.D. Morrison, D.S. Bundy. National Pork Producers Council. 1991. Making swine buildings a safer place to work. NPPC Symposium Proceedings. 1-219.

Donham, K.J. 1987. Human health and safety for workers in livestock housing. Latest developments in livestock housing. International Commission of Agr. Eng. Urbana-Champaign, Illinois, June 22-26, 1987; pp. 86-95.

Feddes, J., E. Barber. 1990. Deadly air. In National Hog Farmer. Nov:10.

Gast, R.M., D.S. Bundy. 1986. Control of feed dust by adding oils. Amer. Soc. Agr. Eng. (Abstract) 86-4039.

Gerber, D.B., G.C. Shurson and K.M. Mancl. 1988. Ammonia levels in Ohio swine farrowing and nursery facilities Ohio Swine Research and Industry Report, Anim. Sci. Dept. Series 88-1, Ohio State University, Columbus. pp. 44-45.

Gore, A.M., E.T. Kornegay, H.P. Viet, E.R. Collins, Jr. 1986a. Soybean oil effects on nursery air quality and pig performance. Amer. Soc. Agr. Eng. (Abstract) 86-4040.

Gore, A.M., E.T. Kornegay, H.P. Veit. 1986b. The effects of soybean oil on nursery air quality and performance of weanling pigs. J. Anim Sci. 63:1.

Green, J. 1983. Incorrect economic assessment of feed performance. Feedstuffs, Dec. 12:19.

Grunloh, D.J., S.E. Curtis, A.H. Jensen, J. Simon, B.G. Harmon. 1975. Airborne bacterial particles in farrowing rooms. J. Anim. Sci. (Abstract) 11:1139.

Hatch, T.F. 1955. Developments in the sampling of airborne dust. Ind. Hyg. Occup. Med. 11:212-217.

Haglind, P., R. Rylander. 1987. Occupational exposure and lung function measurements among workers in swine confinement buildings. J. Occup. Med. 29:905. No. 11.

Heber, A.J., C.R. Martin. 1988. Effect of additives on aerodynamic segregation of dust from swine feed.

Amer. Soc. Agr. Eng. (Abstract) 86-130:558.

Heggen, M. National Pork Producers Council. 1991. Making swine buildings a safer place to work. NPPC Symposium proceedings. 109-112.

Holton, P.M., D.L. Tackett, K. Willeke. 1987. Particle size-dependent leakage and losses of aerosols in respirators. Am. Ind. Hyg. Assoc. J. 48:848.

Honey, L.F., J.B. McQuitty. 1979. Some physical Factors affecting dust concentrations in a pig facility. Can. Agr. Eng. 21:1:9.

Hsieh,F., J.K. Daun, and K.H. Tipples. 1982. The effect of rapeseed oil added to control grain dust on the quality of wheat. JAOCS 59(1):11-15.

Jones, J.R. 1990. The effect of diet particle size on pig performance. Swine News. North Carolina State University Agricultural Extension Service. Vol.13 No.11.

Just, A. 1982. Livestock Prod. Sci. 9:501.

Kenline, P.A., P.V. Scarpino. 1972. Bacterial air pollution from sewage treatment plants. Ph.D. Dissertation. Univ. Cincinnati. Cincinnati, Ohio.

Lai, F.S., B.S. Miller, C.R. Martin, C.L. Storey, L. Bolte, M. Shogren, K.F. Finney, and J.K. Quinian. 1981. Reducing grain dust with oil additives. Transactions of the ASAE 24(6):1626-1631.

Leonard, J.J., J.J.R. Feddes and J.B. McQuitty. 1984. Air quality in commercial broiler housing. Can. Agr. Eng. 26 (1):65-71.

Leonard, S., K.J. Donham. 1990a. Dusts and gases. In National Hog Farmer. Spring:16.

Leonard, S. 1990b. Evaluating air quality. In National HogFarmer. Spring:24.

Leonard, S. 1990c. Good hog housekeeping. In National Hog Farmer. Spring:32.

Morrison, W.D., L.A. Braithwaite, S. De Boer, J.H. Smith. 1991. Making swine buildings a safer place to work. NPPC Symposium proceedings. 21-40.

Muehling, A.J. 1970. Gases and odors from stored swine wastes. J. Anim. Sci. 30:526-531.

Muirhead, S. 1987. Devices essential to properly monitor swine facility air quality. In Feedstuffs. March, 23:11.

Nordstrom, G.A. and J.B. McQuitty. 1976. Manure gases in the animal environment. Research bulletin 76-1. Dept. of Agricultural Engineering, The University of Alberta. Edmonton, Alberta, T6G 2E1. 80 pp.

Peo, Jr., E.R., L.I. Chiba. 1984. Use of inedible fats to reduce feed dust in swine finishing facilities explored. In Feedstuffs. March,5:38.

Pettigrew, J.E., and R.L. Moser. 1989. Effect of using fat and oil products in swine diets. Michigan Professional Swine Producers Symposium. 1989. pp. 1-22.

Pickrell, J.A., A.J. Heber, J.P. Murphy, F.W. Oehme, D. Schoneweis, J.R. Gillespie, and S.C. Henry. 1992. Ammonia, total and respirable dust and endotoxin in swine confinement buildings. National Pork Producers Council Research Investment Report. 1992. 93-100.

Popendorf, W. 1990. Selecting a respirator. In National Hog Farmer. Spring:38.

Ragnar, R., P. Morey. 1982. Airborne endotoxin in industries processing vegetable fibers. Am. Ind. Hyg. Assoc. J. 43:811.

Rylander, R., and M-C. Snella. 1983. Endotoxins and the lung: Cellular reactions and risk for disease. Prog. Allergy 33:332-344.

Rylander, R., P. Morey. 1982. Airborne endotoxin in industries processing vegetable fibers. AM. Ind. Hyg. Assoc. J. 43:811.

Souer, W.C., A. Just, H.H. Jorgensen, M. Fekadu and B.O. Eggum. 1980. Acta Agr. Scand. 30:449.

Stroik, M., A.J. Heber. 1986. Characteristics of aerial dust in swine finishing houses. Amer. Soc. Agr. Eng. (Abstract) 86-4027.

Tevis, C. 1989. Rural Health. In Successful Farming. Dec:54.

Van Denburg, J.F. and W.C. Bauer. 1964. Segregation of particles in the storage of materials. Chem. Engr. Sept., pp. 135-142.

Veenhuizen, M.A., D.S. Bundy. 1990. Electrostatic precipitation dust removal system for swine housing. Amer. Soc. Agr. Eng. (Abstract) 904066.

Von Essen, S. 1991. Health effects of work in swine confinement units. Techniques for improving profitability seminars for swine producers. Extension seminar. Sept. 12-13. South Sioux City, Nebraska. pp. 51-57.